THE PDF VERSION OF
THE WEB PAGES BY MUTSUMI SUZUKI FOR MAGIC SQUARES

INTRODUCTION

The following pdf document is an effort to provide a free way to know the great work and old site by Mutsumi Suzuki, devoted to the Magic Squares.

Lately, his pages are stored at the Drexel University Math Forum site. Unfortunately, this is not a free access site and whoever wants to read the Mutsumi Suzuki pages is obliged to pay a fee…! In my humble opinion, this is not only a scandal buy a betrayal to the large and generous community working in the several fronts of mathematical recreations. I know for sure and by large that Mr. Suzuki and this community never ask for a payment to read their mathematical work.

It was William Walkington who devised and informed to me a way to access the Mutsumi Suzuki's pages through the free web pages reservoir, http://web.archive.org/web/20060709213003/http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.html

I just made the following step.

From the web.archive.org site, I created a pdf page for each of the 126 web pages from the entire Suzuki's web site.

As you will see, unfortunately 5 from these 126 original pages contain now broken links, so these pages are omitted in this document. These 5 omitted pages are: 41, 67, 103, 114 & 116.

And that's all. Hope you find attractive and useful this pdf document.

Carlos Rivera

May 17, 2019.

Mustsumi Suzuki, Magic Squares web pages
General Index

		Pages	
Section	**Issue**	**Initial**	**Final**
00	**Introduction**	1	1
01	**General Index**	2	6
02	**Main Page**	7	11
A	**DATABASE**		
1	Examples of Magic Squares from 3 x 3 through 20 x 20 (by Tamori's method)	12	18
2	Examples of Magic Squares from 3 x 3 through 10 x 10 (by MATLAB)	19	20
3	The 880 Magic Squares of 4 x 4	21	38
4	The 880 Magic Squares of 4 x 4 (4-adic representation) (Paul Heimbach's web-page)	39	45
5	The 48 Panmagic Squares of 4 x 4	46	48
6	Selfcomplementary Magic Squares of 4 x 4	49	56
7	Fundamental set of Panmagic Squares of 5 x 5 (144)	57	61
8	Fundamental set of Panmagic Squares of 5 x 5 (144) (by Professor Grogono)	62	63
9	Ultra Super Magic Squares of 5 x 5 (Sixteen panmagic and selfcomplementary squares)	64	67
10	6 x 6 Composite but Semi Magic Squares (calculated by Mr. Setsuda)	68	69
11	7 x 7 Self-Complementary Pan-magic Squares (calculated by Mr. Setsuda)	70	71
12	Panmagic and/or special 8 x 8 squares	72	76
13	8 x 8 Semi-magic Squares by a Knight's movement tour	77	77
14	8 x 8 Panmagic square can not be generated by the Knight's movement tour	78	78
15	8 x 8 Composite Magic Squares calculated by Mr. Setsuda	79	85
16	8 x 8 Self-Complementary and/or Pan-magic Squares (calculated by Mr. Setsuda)	86	88
17	9 x 9 Self-Complementary Pan-magic Squares (calculated by Mr. Setsuda)	89	90
18	4 x 4, 5 x 5 and 7 x 7 Sparse Magic Squares (By Toshio Kobayashi)	91	92
19	5 x 5 Sparse Magic Squares (By Hercules Lovell)	93	93
20	6 x 6 Sparse Magic Squares (By Hercules Lovell)	94	94
21	8 x 8 Sparse Magic Squares (By Hercules Lovell)	95	95
22	9 x 9 Sparse Magic Squares (By Hercules Lovell)	96	97
23	8 x 8 Magic Square of Squares (Double squares) (by Mr.Saito and Nakazato)	98	104
24	16 x 16 Magic Square of Squares (Double squares) (by Mr.Saito)	105	106
25	3 x 3 Magic Squares of Prime Numbers	107	110
26	3 x 3 Magic Squares of Prime Numbers (arithmetic series)	111	112

27	3 x 3 Magic Squares of Prime Numbers (arithmetic and/or consecutive series)	113	114
28	3 x 3 Twin Squares with Twin Primes	115	116
29	3 x 3 Twin Squares with Larger Differences	117	118
30	3 x 3 Triplet Prime Squares with Constant Difference	119	119
31	A big family of 3 x 3 Magic Square of Prime Numbers	120	121
32	3 x 3 Prime Squares by Librandi's method	122	127
33	4 x 4 Prime Squares by Librandi's method	128	131
34	4 x 4 Twin Squares with Twin Primes	132	133
35	4 x 4 Magic Squares of Sequential Prime Numbers	134	135
36	Magic Squares of Sequential Prime Numbers from 5x5 through 9x9	136	137
37	7 x 7 Magic Squares of Prime Numbers	138	138
38	Constellation Patterns for PanMagic Squares	139	142
39	Total Number of Magic Squares and Classification	143	144
40	Total Number and Classification of Pan-diagonal hypercubes of prime order(Excellent work by Aale de Winkel)	145	148
41	Total Number of Panmagic Squares (by Prof. Grogono)	Omitted by Broken Link	
42	Nonregular Panmagic Squares (Abe Gakuho's study)	149	153
43	Biggest Magic Square Ever (Ralf Laue's web page on the World Records)	154	155
44	3 x 3 Semi-Magic Squares of Squares (by Randall Rathbun)	156	158
45	4 x 4 Semi-Magic Squares (477 normalized squares)	159	169
46	Old Japanese Nested Magic Squares	170	172
47	Nested Magic Squares (Various nested squares created by Murashin recently)	173	173
48	MATLAB algorithm for the Nested Magic Squares by Srinath Avalchanula	174	179
49	Algebraic form of magic squares	180	182
50	AMBi Magic Square of 3 x 3 (by Lee Sallows; Additive for row and column, multiple for diagonals)	183	183
51	Anti-Magic Square (by John Cormie)	184	185
52	Multiplication Magic Square of 3 x 3 (by Eric W.Weisstein)	186	187
53	Particular Magic Square of 4 x 4 (using only numbers 1 through 9)	188	217
54	Addition Multiplication Magic Square of 8 x 8 (by Eric W.Weisstein; Both for addition and multiplication by single square)	218	218
55	Magic Stars of David (80) (Simple data file)	219	220
56	Magic Stars of David (Beautiful page by Suzanne and Sarah)	221	222
57	More on the Magic Stars (by Suzanne and Sarah)	223	223
58	Special Magic Stars of David (12) (with circular conditions)	224	225
59	Magic Stars of David (with Prime Numbers)	226	227
60	Magic Stars of 7 points (72)	228	229
61	Various Magic Stars by Harvey Heinz	230	234
62	Magic Polygon	235	246

63	Magic cube of 7 x 7 x 7 (by Norio Iriyama)	247	253
64	Magic cube of 8x8x8 (by Charles Hetherington)	254	257
B	**ALGORITHMS**		
65	Elegant C-language program for an odd magic square	258	259
66	C-language program to create all the 4x4 pan magic squares by a simple but a brute force method (Andre Steenveld).	260	272
67	Detailed explanation of his sophisticated recursion method is available (.ps file).	Omitted by Broken Link	
68	Even magic squares	273	274
69	Even magic squares and cubes (Adrian Smith)	275	275
70	Odd, Even(4n type) and Even(4n + 2 type) (Shin, Kwon Young)	276	277
71	A Method of Creating 4P + 2 Magic Squares (by Professor Grogono)	278	279
72	5 x 5 pan-magic squares	280	281
73	An 8 x 8 magic square	282	284
74	9 x 9 pan-magic squares (by Professor Grogono)	285	286
75	Magic Squares by Sequential Primes (by Vincenzo Librandi)	287	288
76	How many 5x5 magic squares are there?	289	291
77	Dr. Kanada's CCM program	292	293
78	Magic cubes, hyper cubes by JAVA program by Charles Kelly	294	295
C	**MATHEMATICAL BACKGROUNG OF MAGIC SQUARES**		
79	Algebraic approach to the magic square (The simplest example by 3x3 square)	296	298
80	Magic Square of Squares (Randall's trial by algebraic considerations)	299	303
81	Lie Algebra and Magic Square (by Tony Smith)	304	312
82	Multiplying Magic Squares (by Allan Adler)	313	313
83	Latin Square, Euler Square and related topics (Eric's page)	314	316
84	Greaco-Latin Square (Professore R. A. Beezer's page)	317	318
85	Analytical Formulae and Algorithms for Constructing Magic Squares from an Arbitrary set of 16 Numbers (large .pdf file)	319	334
86	Prime Magic Squares (pdf file) by C. Price and J. Miller	335	342
87	Production of Arbitrary Large Prime Magic Squares (pdf file) by J. Miller, C. Price, and J. Knox	343	346
88	Mathematical considerations on Magic Cubes (ps file), (pdf file) by Marian Trenkler	347	356
89	Mathematical considerations on Magic Rectangles (pdf file) by Marian Trenkler	357	361
90	Math on Magic Hyper Cube (ps file) by Marian Trenkler	362	366
91	Math on Magic Graphs (ps file) by Marian Trenkler	367	370
92	Characterization of Magic Graphs (ps file) by Marian Trenkler	371	374

93	Magic p-dimensional cubes of order n is not equal to 2 (mod 4) (pdf file) by Marian Trenkler (Published in Acta Arithmetica, 2000)	375	380
94	Magic p-dimensional cubes (pdf file) by Marian Trenkler (Published in Acta Arithmetica, 2001)	381	384
D	**STORY AND HISTORY OF MAGIC SQUARES**		
95	Mark Swaney on the History of Magic Squares (Excellent work by Mark Swaney and Dan Washburn)	385	406
96	Lo Shu, Durer, Franklin, and SATOR (Suzanne's page)	407	409
97	Meaning of SATOR	410	411
98	Lo Shu and Feng Shui (by Geomancy.net in Singapore)	412	412
99	Albrecht Durer's Magic Square (by University of St. Andrews)	413	413
100	History of magic squares (Chinese, Egypt, India, and Europe) (by Chani Welch)	414	418
101	Dudeney, Gardner, Andrews, and others (Professor Grogono's page)	419	420
102	A brief history of magic squares in Japan	421	422
E	**HOME PAGE LINKS TO ALL OVER THE WORLD**		
103	Mr. Kanji SETSUDA's page (Japanese researcher, eager in computation)	Omitted by Broken Link	
104	Eric W. Weisstein's page (Simple but complete explanation)	423	427
105	Suzanne's page (The Math Forum: Various topics on magic squares)	428	430
106	Harvey Heinz page (Excellent!)	431	437
107	Professor Grogono's page (Excellent!)	438	439
108	Kwon Young Shin's page (Algorithms for all odd and even squares)	440	441
109	Arlet's page (Algorithms)	442	443
110	John Knoderer's page (Knoderer's special square)	444	447
111	Robert C. Wilke's page (Nested magic squares)	448	452
112	Letter from Jens Lorenz (Magic hexagon)	453	453
113	Frank Kschischang's page (Magic hexagon)	454	454
114	Eric Weisstein's page (Magic hexagon)	Omitted by Broken Link	
115	Houlton's page (Magic Cube)	455	455
116	J. C. Miller, C. Price and J. Knox (ps files of mathematical theories on Prime Magic Squares)	Omitted by Broken Link	
117	IOI'94 Competition problem and solution (Column of 5-digit prime numbers)	456	457
118	Fabrizio Pivari's Simple Magic Square png maker	458	458
119	Dave Harper's page (Recreational Maths)	459	459
120	Mark Farrar's page (Written by a magician)	460	460
F	**MISCELLANEOUS RELATED TOPICS**		
121	Magic Square on a Jigsaw puzzle by Dubi Kaufmann	461	461
G	**PHOTOGRAPHS OF MAGIC SQUARES**		

122	The famous "Melancholia" by Albrecht Durer (University of St. Andrews)	462	462
123	A Magic Square in Gaudi's Cathedral in Barcelona (Mark Farrar's collection of photos)	463	464
124	A Magic Square in Gaudi's Cathedral in Barcelona (Harvey Heinz's web page)	465	473
125	**Mails Come From All Over The World**	474	483
126	**Literatures On Magic Squares**	484	489

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.html Go JUN JUL NOV
46 captures 09
9 Jul 2006 - 4 Apr 2019 2005 2006 2008 About this capture

Magic Squares

These pages were written by Mutsumi Suzuki and until his retirement in 2001, were available through his site in Japan. It is the Math Forum's pleasure to host these pages so that the mathematical community can continue to enjoy all of the information presented by Mr. Suzuki on the topic of magic squares.

- **Data Base**
  - Examples of Magic Squares from 3 x 3 through 20 x 20 (by Tamori's method)
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  - The 880 Magic Squares of 4 x 4
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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.html Go JUN JUL NOV
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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.html Go JUN JUL NOV
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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.html Go
JUN JUL NOV
09
2005 2006 2008
46 captures
9 Jul 2006 - 4 Apr 2019
About this capture

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- **Literatures on Magic Squares**

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9 Jul 2006 - 4 Apr 2019
JUN JUL NOV
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2005 2006 2008
About this capture

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8 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009
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Mutsumi Suzuki
Magic Squares

Examples of Magic Squares from 3 x 3 through 20 x 20 (by Tamori's method)

(Caution! Errors were found in 4n + 2 type squares by Martin Henz)
(Michel Eric kindly corrected the errors in 10x10, 14x14 and 18x18, Feb. 2001)

```
      ---   3   ---

   4   3   8
   9   5   1
   2   7   6

-----------------------------------------------


      ---   4   ---

   1  14  15   4
   8  11  10   5
  12   7   6   9
  13   2   3  16

-----------------------------------------------


      ---   5   ---

  11  10   4  23  17
  18  12   6   5  24
  25  19  13   7   1
   2  21  20  14   8
   9   3  22  16  15

-----------------------------------------------


      ---   6   ---

   1  32   3  34  35   6
  12  29   9  10  26  25
  13  14  22  21  23  18
  24  20  16  15  17  19
  30  11  28  27   8   7
  31   5  33   4   2  36

-----------------------------------------------


      ---   7   ---

  22  21  13   5  46  38  30
  31  23  15  14   6  47  39
```

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8 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009
About this capture

20	12	4	45	37	29	28

--- 8 ---

1	58	3	60	61	6	63	8
16	55	14	53	52	11	50	9
17	42	19	44	45	22	47	24
32	39	30	37	36	27	34	25
40	31	38	29	28	35	26	33
41	18	43	20	21	46	23	48
56	15	54	13	12	51	10	49
57	2	59	4	5	62	7	64

--- 9 ---

37	36	26	16	6	77	67	57	47
48	38	28	27	17	7	78	68	58
59	49	39	29	19	18	8	79	69
70	60	50	40	30	20	10	9	80
81	71	61	51	41	31	21	11	1
2	73	72	62	52	42	32	22	12
13	3	74	64	63	53	43	33	23
24	14	4	75	65	55	54	44	34
35	25	15	5	76	66	56	46	45

--- 10 ---

1	92	3	94	5	6	97	98	99	10
20	89	18	87	16	15	84	13	82	81
21	72	23	74	25	76	77	28	79	30
40	69	38	67	35	36	64	33	62	31
41	52	43	44	56	55	57	48	59	50
51	42	58	54	46	45	47	53	49	60
70	39	68	37	66	65	34	63	32	61
80	22	73	24	75	26	27	78	29	71
90	19	88	17	86	85	14	83	12	11
91	9	93	4	95	96	7	8	2	100

Michel Eric pointed out errors in the square.
The following is his revised version; (Feb. 2001)

1	92	3	94	5	6	97	98	99	10
20	89	18	87	16	15	84	13	82	81
21	72	23	74	25	76	77	28	79	30
40	69	38	67	35	36	64	33	62	61
41	52	43	44	56	55	57	48	59	50
51	42	58	54	46	45	47	53	49	60
70	39	68	37	66	65	34	63	32	31
80	22	73	24	75	26	27	78	29	71
90	19	88	17	86	85	14	83	12	11
91	9	93	7	95	96	4	8	2	100

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.byTAMORI.html Go DEC JAN JUL
8 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009
About this capture

--- 11 ---

56	55	43	31	19	7	116	104	92	80	68
69	57	45	44	32	20	8	117	105	93	81
82	70	58	46	34	33	21	9	118	106	94
95	83	71	59	47	35	23	22	10	119	107
108	96	84	72	60	48	36	24	12	11	120
121	109	97	85	73	61	49	37	25	13	1
2	111	110	98	86	74	62	50	38	26	14
15	3	112	100	99	87	75	63	51	39	27
28	16	4	113	101	89	88	76	64	52	40
41	29	17	5	114	102	90	78	77	65	53
54	42	30	18	6	115	103	91	79	67	66

--- 12 ---

1	134	3	136	5	138	139	8	141	10	143	12
24	131	22	129	20	127	126	17	124	15	122	13
25	110	27	112	29	114	115	32	117	34	119	36
48	107	46	105	44	103	102	41	100	39	98	37
49	86	51	88	53	90	91	56	93	58	95	60
72	83	70	81	68	79	78	65	76	63	74	61
84	71	82	69	80	67	66	77	64	75	62	73
85	50	87	52	89	54	55	92	57	94	59	96
108	47	106	45	104	43	42	101	40	99	38	97
109	26	111	28	113	30	31	116	33	118	35	120
132	23	130	21	128	19	18	125	16	123	14	121
133	2	135	4	137	6	7	140	9	142	11	144

--- 13 ---

79	78	64	50	36	22	8	163	149	135	121	107	93
94	80	66	65	51	37	23	9	164	150	136	122	108
109	95	81	67	53	52	38	24	10	165	151	137	123
124	110	96	82	68	54	40	39	25	11	166	152	138
139	125	111	97	83	69	55	41	27	26	12	167	153
154	140	126	112	98	84	70	56	42	28	14	13	168
169	155	141	127	113	99	85	71	57	43	29	15	1
2	157	156	142	128	114	100	86	72	58	44	30	16
17	3	158	144	143	129	115	101	87	73	59	45	31
32	18	4	159	145	131	130	116	102	88	74	60	46
47	33	19	5	160	146	132	118	117	103	89	75	61
62	48	34	20	6	161	147	133	119	105	104	90	76
77	63	49	35	21	7	162	148	134	120	106	92	91

--- 14 ---

1	184	3	186	5	188	7	8	191	10	193	194	195	14
28	181	26	179	24	177	22	21	174	19	172	17	170	169
29	156	31	158	33	160	35	36	163	164	165	40	167	42
56	153	54	151	52	149	50	49	146	47	144	45	142	43
57	128	59	130	61	132	63	64	135	66	137	68	139	70

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.byTAMORI.html Go DEC JAN JUL
8 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009
About this capture

127	58	138	60	131	62	133	134	65	136	67	129	69	140
154	55	152	53	150	51	148	147	48	145	46	143	44	141
168	30	157	32	159	34	161	162	37	38	39	166	41	155
182	27	180	25	178	23	176	175	20	173	18	171	16	15
183	13	185	4	187	6	189	190	9	192	11	12	2	196

Eric's revised square;

1	184	3	186	5	188	7	8	191	10	193	194	195	14
28	181	26	179	24	177	22	21	174	19	172	17	170	169
29	156	31	158	33	160	35	36	163	164	165	40	167	42
56	153	54	151	52	149	50	49	146	47	144	45	142	141
57	128	59	130	61	132	63	64	135	66	137	68	139	140
84	125	82	123	80	121	77	78	118	75	116	73	114	113
85	100	87	102	89	90	106	105	107	94	109	96	111	98
99	86	101	88	103	104	92	91	93	108	95	110	97	112
126	83	124	81	122	79	120	119	76	117	74	115	72	71
127	58	138	60	131	62	133	134	65	136	67	129	69	70
154	55	152	53	150	51	148	147	48	145	46	143	44	43
168	30	157	32	159	34	161	162	37	38	39	166	41	155
182	27	180	25	178	23	176	175	20	173	18	171	16	15
183	13	185	11	192	9	189	190	6	187	4	12	2	196

--- 15 ---

106	105	89	73	57	41	25	9	218	202	186	170	154	138	122
123	107	91	90	74	58	42	26	10	219	203	187	171	155	139
140	124	108	92	76	75	59	43	27	11	220	204	188	172	156
157	141	125	109	93	77	61	60	44	28	12	221	205	189	173
174	158	142	126	110	94	78	62	46	45	29	13	222	206	190
191	175	159	143	127	111	95	79	63	47	31	30	14	223	207
208	192	176	160	144	128	112	96	80	64	48	32	16	15	224
225	209	193	177	161	145	129	113	97	81	65	49	33	17	1
2	211	210	194	178	162	146	130	114	98	82	66	50	34	18
19	3	212	196	195	179	163	147	131	115	99	83	67	51	35
36	20	4	213	197	181	180	164	148	132	116	100	84	68	52
53	37	21	5	214	198	182	166	165	149	133	117	101	85	69
70	54	38	22	6	215	199	183	167	151	150	134	118	102	86
87	71	55	39	23	7	216	200	184	168	152	136	135	119	103
104	88	72	56	40	24	8	217	201	185	169	153	137	121	120

--- 16 ---

1	242	3	244	5	246	7	248	249	10	251	12	253	14	255	16
32	239	30	237	28	235	26	233	232	23	230	21	228	19	226	17
33	210	35	212	37	214	39	216	217	42	219	44	221	46	223	48
64	207	62	205	60	203	58	201	200	55	198	53	196	51	194	49
65	178	67	180	69	182	71	184	185	74	187	76	189	78	191	80
96	175	94	173	92	171	90	169	168	87	166	85	164	83	162	81
97	146	99	148	101	150	103	152	153	106	155	108	157	110	159	112
128	143	126	141	124	139	122	137	136	119	134	117	132	115	130	113
144	127	142	125	140	123	138	121	120	135	118	133	116	131	114	129
145	98	147	100	149	102	151	104	105	154	107	156	109	158	111	160
176	95	174	93	172	91	170	89	88	167	86	165	84	163	82	161
177	66	179	68	181	70	183	72	73	186	75	188	77	190	79	192

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.byTAMORI.html Go DEC JAN JUL
8 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009
About this capture

--- 17 ---

137	136	118	100	82	64	46	28	10	281	263	245	227	209	191	173	155
156	138	120	119	101	83	65	47	29	11	282	264	246	228	210	192	174
175	157	139	121	103	102	84	66	48	30	12	283	265	247	229	211	193
194	176	158	140	122	104	86	85	67	49	31	13	284	266	248	230	212
213	195	177	159	141	123	105	87	69	68	50	32	14	285	267	249	231
232	214	196	178	160	142	124	106	88	70	52	51	33	15	286	268	250
251	233	215	197	179	161	143	125	107	89	71	53	35	34	16	287	269
270	252	234	216	198	180	162	144	126	108	90	72	54	36	18	17	288
289	271	253	235	217	199	181	163	145	127	109	91	73	55	37	19	1
2	273	272	254	236	218	200	182	164	146	128	110	92	74	56	38	20
21	3	274	256	255	237	219	201	183	165	147	129	111	93	75	57	39
40	22	4	275	257	239	238	220	202	184	166	148	130	112	94	76	58
59	41	23	5	276	258	240	222	221	203	185	167	149	131	113	95	77
78	60	42	24	6	277	259	241	223	205	204	186	168	150	132	114	96
97	79	61	43	25	7	278	260	242	224	206	188	187	169	151	133	115
116	98	80	62	44	26	8	279	261	243	225	207	189	171	170	152	134
135	117	99	81	63	45	27	9	280	262	244	226	208	190	172	154	153

--- 18 ---

1	308	3	310	5	312	7	314	9	10	317	12	319	14	321	322	323	18
36	305	34	303	32	301	30	299	28	27	296	25	294	23	292	21	290	289
37	272	39	274	41	276	43	278	45	46	281	48	283	284	285	52	287	54
72	269	70	267	68	265	66	263	64	63	260	61	258	59	256	57	254	55
73	236	75	238	77	240	79	242	81	82	245	84	247	86	249	88	251	90
108	233	106	231	104	229	102	227	100	99	224	97	222	95	220	93	218	91
109	200	111	202	113	204	115	206	117	118	209	120	211	122	213	124	215	126
144	197	142	195	140	193	138	191	135	136	188	133	186	131	184	129	182	127
145	164	147	166	149	168	151	152	172	171	173	156	175	158	177	160	179	162
163	146	165	148	167	150	169	170	154	153	155	174	157	176	159	178	161	180
198	143	196	141	194	139	192	137	190	189	134	187	132	185	130	183	128	181
199	110	201	112	203	114	205	116	207	208	119	210	121	212	123	214	125	216
234	107	232	105	230	103	228	101	226	225	98	223	96	221	94	219	92	217
235	74	250	76	239	78	241	80	243	244	83	246	85	248	87	237	89	252
270	71	268	69	266	67	264	65	262	261	62	259	60	257	58	255	56	253
288	38	273	40	275	42	277	44	279	280	47	282	49	50	51	286	53	271
306	35	304	33	302	31	300	29	298	297	26	295	24	293	22	291	20	19
307	17	309	4	311	6	313	8	315	316	11	318	13	320	15	16	2	324

Eric's revised square;

1	308	3	310	5	312	7	314	9	10	317	12	319	14	321	322	323	18
36	305	34	303	32	301	30	299	28	27	296	25	294	23	292	21	290	289
37	272	39	274	41	276	43	278	45	46	281	48	283	284	285	52	287	54
72	269	70	267	68	265	66	263	64	63	260	61	258	59	256	57	254	253
73	236	75	238	77	240	79	242	81	82	245	84	247	86	249	88	251	252
108	233	106	231	104	229	102	227	100	99	224	97	222	95	220	93	218	217
109	200	111	202	113	204	115	206	117	118	209	120	211	122	213	124	215	216
144	197	142	195	140	193	138	191	135	136	188	133	186	131	184	129	182	181
145	164	147	166	149	168	151	152	172	171	173	156	175	158	177	160	179	162
163	146	165	148	167	150	169	170	154	153	155	174	157	176	159	178	161	180
198	143	196	141	194	139	192	137	190	189	134	187	132	185	130	183	128	127

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.byTAMORI.html Go DEC JAN JUL
8 captures 17 2006 2007 2009
17 Jan 2007 - 21 Jul 2016 About this capture

288	38	273	40	275	42	277	44	279	280	47	282	49	50	51	286	53	271
306	35	304	33	302	31	300	29	298	297	26	295	24	293	22	291	20	19
307	17	309	15	320	13	318	11	315	316	8	313	6	311	4	16	2	324

--- 19 ---

172	171	151	131	111	91	71	51	31	11	352	332	312	292	272	252	232	212	192
193	173	153	152	132	112	92	72	52	32	12	353	333	313	293	273	253	233	213
214	194	174	154	134	133	113	93	73	53	33	13	354	334	314	294	274	254	234
235	215	195	175	155	135	115	114	94	74	54	34	14	355	335	315	295	275	255
256	236	216	196	176	156	136	116	96	95	75	55	35	15	356	336	316	296	276
277	257	237	217	197	177	157	137	117	97	77	76	56	36	16	357	337	317	297
298	278	258	238	218	198	178	158	138	118	98	78	58	57	37	17	358	338	318
319	299	279	259	239	219	199	179	159	139	119	99	79	59	39	38	18	359	339
340	320	300	280	260	240	220	200	180	160	140	120	100	80	60	40	20	19	360
361	341	321	301	281	261	241	221	201	181	161	141	121	101	81	61	41	21	1
2	343	342	322	302	282	262	242	222	202	182	162	142	122	102	82	62	42	22
23	3	344	324	323	303	283	263	243	223	203	183	163	143	123	103	83	63	43
44	24	4	345	325	305	304	284	264	244	224	204	184	164	144	124	104	84	64
65	45	25	5	346	326	306	286	285	265	245	225	205	185	165	145	125	105	85
86	66	46	26	6	347	327	307	287	267	266	246	226	206	186	166	146	126	106
107	87	67	47	27	7	348	328	308	288	268	248	247	227	207	187	167	147	127
128	108	88	68	48	28	8	349	329	309	289	269	249	229	228	208	188	168	148
149	129	109	89	69	49	29	9	350	330	310	290	270	250	230	210	209	189	169
170	150	130	110	90	70	50	30	10	351	331	311	291	271	251	231	211	191	190

--- 20 ---

1	382	3	384	5	386	7	388	9	390	391	12	393	14	395	16	397	18	399	20
40	379	38	377	36	375	34	373	32	371	370	29	368	27	366	25	364	23	362	21
41	342	43	344	45	346	47	348	49	350	351	52	353	54	355	56	357	58	359	60
80	339	78	337	76	335	74	333	72	331	330	69	328	67	326	65	324	63	322	61
81	302	83	304	85	306	87	308	89	310	311	92	313	94	315	96	317	98	319	100
120	299	118	297	116	295	114	293	112	291	290	109	288	107	286	105	284	103	282	101
121	262	123	264	125	266	127	268	129	270	271	132	273	134	275	136	277	138	279	140
160	259	158	257	156	255	154	253	152	251	250	149	248	147	246	145	244	143	242	141
161	222	163	224	165	226	167	228	169	230	231	172	233	174	235	176	237	178	239	180
200	219	198	217	196	215	194	213	192	211	210	189	208	187	206	185	204	183	202	181
220	199	218	197	216	195	214	193	212	191	190	209	188	207	186	205	184	203	182	201
221	162	223	164	225	166	227	168	229	170	171	232	173	234	175	236	177	238	179	240
260	159	258	157	256	155	254	153	252	151	150	249	148	247	146	245	144	243	142	241
261	122	263	124	265	126	267	128	269	130	131	272	133	274	135	276	137	278	139	280
300	119	298	117	296	115	294	113	292	111	110	289	108	287	106	285	104	283	102	281
301	82	303	84	305	86	307	88	309	90	91	312	93	314	95	316	97	318	99	320
340	79	338	77	336	75	334	73	332	71	70	329	68	327	66	325	64	323	62	321
341	42	343	44	345	46	347	48	349	50	51	352	53	354	55	356	57	358	59	360
380	39	378	37	376	35	374	33	372	31	30	369	28	367	26	365	24	363	22	361
381	2	383	4	385	6	387	8	389	10	11	392	13	394	15	396	17	398	19	400

Back to Suzuki's Magic Squares

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.byTAMORI.html Go DEC JAN JUL
8 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009 About this capture

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.byMATLAB.html Go DEC JAN JUL
8 captures 17 2006 2007 2009
17 Jan 2007 - 21 Jul 2016 About this capture

Mutsumi Suzuki
[Magic Squares]

Examples of Magic Squares from 3 x 3 through 10 x 10 (generated by MATLAB)

The matrix computation program MATLAB (Math Works Inc.) includes a function called "magic," such that magic(n) returns an n by n magic square. According to the manual, three different alogorithms are used: one for odd n, one for doubly n (= 4 m), and one for singly even n (= 4 m + 2). The following exapmles shows that the algorithm for odd n and even n (= 4m) yield the same results as the Tamori's method.

8	3	4
1	5	9
6	7	2

16	5	9	4
2	11	7	14
3	10	6	15
13	8	12	1

17	23	4	10	11
24	5	6	12	18
1	7	13	19	25
8	14	20	21	2
15	16	22	3	9

35	3	31	8	30	4
1	32	9	28	5	36
6	7	2	33	34	29
26	21	22	17	12	13
19	23	27	10	14	18
24	25	20	15	16	11

30	38	46	5	13	21	22
39	47	6	14	15	23	31
48	7	8	16	24	32	40
1	9	17	25	33	41	49
10	18	26	34	42	43	2
19	27	35	36	44	3	11
28	29	37	45	4	12	20

64	9	17	40	32	41	49	8
2	55	47	26	34	23	15	58
3	54	46	27	35	22	14	59
61	12	20	37	29	44	52	5
60	13	21	36	28	45	53	4
6	51	43	30	38	19	11	62
7	50	42	31	39	18	10	63
57	16	24	33	25	48	56	1

47	57	67	77	6	16	26	36	37
58	68	78	7	17	27	28	38	48
69	79	8	18	19	29	39	49	59
80	9	10	20	30	40	50	60	70
1	11	21	31	41	51	61	71	81
12	22	32	42	52	62	72	73	2

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8 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009
About this capture

92	98	4	85	86	17	23	79	10	11
99	80	81	87	93	24	5	6	12	18
1	7	88	19	25	76	82	13	94	100
8	14	20	21	2	83	89	95	96	77
15	16	22	3	9	90	91	97	78	84
67	73	54	60	61	42	48	29	35	36
74	55	56	62	68	49	30	31	37	43
51	57	63	69	75	26	32	38	44	50
58	64	70	71	52	33	39	45	46	27
40	41	47	28	34	65	66	72	53	59

68	80	92	104	116	7	19	31	43	55	56
81	93	105	117	8	20	32	44	45	57	69
94	106	118	9	21	33	34	46	58	70	82
107	119	10	22	23	35	47	59	71	83	95
120	11	12	24	36	48	60	72	84	96	108
1	13	25	37	49	61	73	85	97	109	121
14	26	38	50	62	74	86	98	110	111	2
27	39	51	63	75	87	99	100	112	3	15
40	52	64	76	88	89	101	113	4	16	28
53	65	77	78	90	102	114	5	17	29	41
66	67	79	91	103	115	6	18	30	42	54

Back to **Suzuki's Magic Squares**

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.total.html Go JUN JUL SEP
22 captures 08
8 Jul 2006 - 7 Apr 2016 2005 2006 2007
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Mutsumi Suzuki
Magic Squares

The 880 Magic Square of 4 x 4

The complete set of 880 magic squares is derivable from a fundamental set of 220 squares. Four different squares can be produced from each fundamental square by means of the following transformations.

The 1-4 exchange:
Switch first column with fourth column, then switch first row with fourth row. (Alternatively, the 2nd and 3rd rows/columns can be switched, the result being a rotation or reflection of the square produced by the first method.)

The 1-2-3-4 exchange:
Switch first and second columns, third and fourth columns, then repeat same with the rows.

```
              Exchange rules;


                1-4 exchange
          (A)  <-------------->  (B)

           ^                      ^
           |                      |
           |1-2-3-4 exchange      |1-2-3-4 exchange
           |                      |
           v                      v

          (D)  <-------------->  (C)
                1-4 exchange
```

880 (= 220 x 4) squares

```
      (A)            (B)            (C)            (D)

   1  2 15 16     9 11  6  8    14  4 13  3    10  5 12  7
  13 14  3  4     4 14  3 13    11  9  8  6     6  9  8 11
  12  7 10  5     5  7 10 12     2 16  1 15    15 16  1  2
   8 11  6  9    16  2 15  1     7  5 12 10     3  4 13 14
------------------------------------------------------------   4
   2  1 16 15    10 12  5  7    13  3 14  4     9  6 11  8
  14 13  4  3     3 13  4 14    12 10  7  5     5 10  7 12
  11  8  9  6     6  8  9 11     1 15  2 16    16 15  2  1
   7 12  5 10    15  1 16  2     8  6 11  9     4  3 14 13
------------------------------------------------------------   8
   1  2 16 15    10 11  5  8    14  3 13  4     9  6 12  7
  13 14  4  3     3 14  4 13    11 10  8  5     5 10  8 11
  12  7  9  6     6  7  9 12     2 15  1 16    16 15  1  2
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.total.html Go
JUN JUL SEP
08
2005 2006 2007
22 captures
8 Jul 2006 - 7 Apr 2016
About this capture

```
 11  8 10  5     5  8 10 11     1 16  2 15    15 16  2  1
  7 12  6  9    16  1 15  2     8  5 11 10     3  4 14 13
------------------------------------------------------------- 16
  1  2 15 16     9 11  6  8    14  5 12  3    10  4 13  7
 12 14  3  5     5 14  3 12    11  9  8  6     6  9  8 11
 13  7 10  4     4  7 10 13     2 16  1 15    15 16  1  2
  8 11  6  9    16  2 15  1     7  4 13 10     3  5 12 14
------------------------------------------------------------- 20
  2 16  1 15    10  5 12  7     9  3 14  8    13  6 11  4
 14  9  8  3     3  9  8 14     5 10  7 12    12 10  7  5
 11  4 13  6     6  4 13 11    16 15  2  1     1 15  2 16
  7  5 12 10    15 16  1  2     4  6 11 13     8  3 14  9
------------------------------------------------------------- 24
 16 14  1  3    10  7 12  5     2 13  4 15     6  8  9 11
  4  2 15 13    13  2 15  4     7 10  5 12    12 10  5  7
  9 11  6  8     8 11  6  9    14  3 16  1     1  3 16 14
  5  7 12 10     3 14  1 16    11  8  9  6    15 13  4  2
------------------------------------------------------------- 28
  3  1 16 14     7 12  5 10    15  2 13  4     9 11  8  6
 13 15  4  2     2 15  4 13    12  7 10  5     5  7 10 12
  8  6  9 11    11  6  9  8     1 14  3 16    16 14  3  1
 10 12  5  7    14  1 16  3     6 11  8  9     4  2 13 15
------------------------------------------------------------- 32
 16 14  1  3     6 11  8  9     2 13  4 15    10 12  5  7
  4  2 15 13    13  2 15  4    11  6  9  8     8  6  9 11
  5  7 10 12    12  7 10  5    14  3 16  1     1  3 16 14
  9 11  8  6     3 14  1 16     7 12  5 10    15 13  4  2
------------------------------------------------------------- 36
  3  1 16 14    11  8  9  6    15  2 13  4     5  7 12 10
 13 15  4  2     2 15  4 13     8 11  6  9     9 11  6  8
 12 10  5  7     7 10  5 12     1 14  3 16    16 14  3  1
  6  8  9 11    14  1 16  3    10  7 12  5     4  2 13 15
------------------------------------------------------------- 40
  1  3 16 14     7 10  5 12    15  4 13  2    11  9  8  6
 13 15  2  4     4 15  2 13    10  7 12  5     5  7 12 10
  8  6 11  9     9  6 11  8     3 14  1 16    16 14  1  3
 12 10  5  7    14  3 16  1     6  9  8 11     2  4 13 15
------------------------------------------------------------- 44
 14 16  1  3    10  5 12  7     2 15  4 13     8  6  9 11
  4  2 13 15    15  2 13  4     5 10  7 12    12 10  7  5
  9 11  8  6     6 11  8  9    16  3 14  1     1  3 14 16
  7  5 12 10     3 16  1 14    11  6  9  8    13 15  4  2
------------------------------------------------------------- 48
  1  3 16 14    11  6  9  8    15  4 13  2     7  5 12 10
 13 15  2  4     4 15  2 13     6 11  8  9     9 11  8  6
 12 10  7  5     5 10  7 12     3 14  1 16    16 14  1  3
  8  6  9 11    14  3 16  1    10  5 12  7     2  4 13 15
------------------------------------------------------------- 52
 14 16  1  3     6  9  8 11     2 15  4 13    12 10  5  7
  4  2 13 15    15  2 13  4     9  6 11  8     8  6 11  9
  5  7 12 10    10  7 12  5    16  3 14  1     1  3 14 16
 11  9  8  6     3 16  1 14     7 10  5 12    13 15  4  2
------------------------------------------------------------- 56
  1  3 14 16    11 10  7  6    13  2 15  4     9  5 12  8
 15 13  4  2     2 13  4 15    10 11  6  7     7 11  6 10
 12  8  9  5     5  8  9 12     3 16  1 14    14 16  1  3
  6 10  7 11    16  3 14  1     8  5 12  9     4  2 15 13
------------------------------------------------------------- 60
  1  3 14 16     9 12  5  8    13  2 15  4    11  7 10  6
 15 13  4  2     2 13  4 15    12  9  8  5     5  9  8 12
 10  6 11  7     7  6 11 10     3 16  1 14    14 16  1  3
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.total.html Go
JUN JUL SEP
08
2005 2006 2007
22 captures
8 Jul 2006 - 7 Apr 2016
About this capture

```
   4  7 10 13     13  7 10  4     14  3 16  1      1  3 16 14
   9 11  8  6      3 14  1 16      7 13  4 10     15 12  5  2
----------------------------------------------------------------- 68
   1  3 16 14     11  6  9  8     15  5 12  2      7  4 13 10
  12 15  2  5      5 15  2 12      6 11  8  9      9 11  8  6
  13 10  7  4      4 10  7 13      3 14  1 16     16 14  1  3
   8  6  9 11     14  3 16  1     10  4 13  7      2  5 12 15
----------------------------------------------------------------- 72
   1 14  3 16      9  5 12  8     11  2 15  6     13  7 10  4
  15 11  6  2      2 11  6 15      5  9  8 12     12  9  8  5
  10  4 13  7      7  4 13 10     14 16  1  3      3 16  1 14
   8  5 12  9     16 14  3  1      4  7 10 13      6  2 15 11
----------------------------------------------------------------- 76
   1 14  3 16     11  7 10  6      9  2 15  8     13  5 12  4
  15  9  8  2      2  9  8 15      7 11  6 10     10 11  6  7
  12  4 13  5      5  4 13 12     14 16  1  3      3 16  1 14
   6  7 10 11     16 14  3  1      4  5 12 13      8  2 15  9
----------------------------------------------------------------- 80
  16 14  1  3     10  7 12  5      2  8  9 15      6 13  4 11
   9  2 15  8      8  2 15  9      7 10  5 12     12 10  5  7
   4 11  6 13     13 11  6  4     14  3 16  1      1  3 16 14
   5  7 12 10      3 14  1 16     11 13  4  6     15  8  9  2
----------------------------------------------------------------- 84
   1  3 16 14      7 10  5 12     15  9  8  2     11  4 13  6
   8 15  2  9      9 15  2  8     10  7 12  5      5  7 12 10
  13  6 11  4      4  6 11 13      3 14  1 16     16 14  1  3
  12 10  5  7     14  3 16  1      6  4 13 11      2  9  8 15
----------------------------------------------------------------- 88
   1 16 13  4     14  2  3 15      9 11  6  8     10  5 12  7
   6  9  8 11     11  9  8  6      2 14 15  3      3 14 15  2
  12  7 10  5      5  7 10 12     16  4  1 13     13  4  1 16
  15  2  3 14      4 16 13  1      7  5 12 10      8 11  6  9
----------------------------------------------------------------- 92
  13  4  1 16      2 14 15  3      9 11  6  8     10  5 12  7
   6  9  8 11     11  9  8  6     14  2  3 15     15  2  3 14
  12  7 10  5      5  7 10 12      4 16 13  1      1 16 13  4
   3 14 15  2     16  4  1 13      7  5 12 10      8 11  6  9
----------------------------------------------------------------- 96
   1  4 16 13      8  9  5 12     14  3 15  2     11 10  6  7
  15 14  2  3      3 14  2 15      9  8 12  5      5  8 12  9
   6  7 11 10     10  7 11  6      4 13  1 16     16 13  1  4
  12  9  5  8     13  4 16  1      7 10  6 11      2  3 15 14
-----------------------------------------------------------------100
   1  4 13 16     11  7 10  6     14  2 15  3      8  5 12  9
  15 14  3  2      2 14  3 15      7 11  6 10     10 11  6  7
  12  9  8  5      5  9  8 12      4 16  1 13     13 16  1  4
   6  7 10 11     16  4 13  1      9  5 12  8      3  2 15 14
-----------------------------------------------------------------104
   1 16 13  4     14  2  3 15     11  7  6 10      8  9 12  5
   6 11 10  7      7 11 10  6      2 14 15  3      3 14 15  2
  12  5  8  9      9  5  8 12     16  4  1 13     13  4  1 16
  15  2  3 14      4 16 13  1      5  9 12  8     10  7  6 11
-----------------------------------------------------------------108
  13  4  1 16      2 14 15  3      7 11 10  6     12  5  8  9
  10  7  6 11     11  7  6 10     14  2  3 15     15  2  3 14
   8  9 12  5      5  9 12  8      4 16 13  1      1 16 13  4
   3 14 15  2     16  4  1 13      9  5  8 12      6 11 10  7
-----------------------------------------------------------------112
  13 16  1  4      7 11  6 10      2 14  3 15     12  9  8  5
   3  2 15 14     14  2 15  3     11  7 10  6      6  7 10 11
   8  5 12  9      9  5 12  8     16  4 13  1      1  4 13 16
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.total.html Go JUN JUL SEP
22 captures 08
8 Jul 2006 - 7 Apr 2016 2005 2006 2007
About this capture

```
 11 10  6  7     7 10  6 11    13  4 16  1     1  4 16 13
  5  8 12  9     4 13  1 16    10  7 11  6    15 14  2  3
-------------------------------------------------------------120
  1 13 16  4    14  3  2 15    10 11  6  7     9  5 12  8
  6 10  7 11    11 10  7  6     3 14 15  2     2 14 15  3
 12  8  9  5     5  8  9 12    13  4  1 16    16  4  1 13
 15  3  2 14     4 13 16  1     8  5 12  9     7 11  6 10
-------------------------------------------------------------124
  1  4 13 16    10  6 11  7    15  3 14  2     8  5 12  9
 14 15  2  3     3 15  2 14     6 10  7 11    11 10  7  6
 12  9  8  5     5  9  8 12     4 16  1 13    13 16  1  4
  7  6 11 10    16  4 13  1     9  5 12  8     2  3 14 15
-------------------------------------------------------------128
  1  4 16 13     8  9  5 12    15  2 14  3    10 11  7  6
 14 15  3  2     2 15  3 14     9  8 12  5     5  8 12  9
  7  6 10 11    11  6 10  7     4 13  1 16    16 13  1  4
 12  9  5  8    13  4 16  1     6 11  7 10     3  2 14 15
-------------------------------------------------------------132
  1 16 13  4    15  3  2 14    10  6  7 11     8  9 12  5
  7 10 11  6     6 10 11  7     3 15 14  2     2 15 14  3
 12  5  8  9     9  5  8 12    16  4  1 13    13  4  1 16
 14  3  2 15     4 16 13  1     5  9 12  8    11  6  7 10
-------------------------------------------------------------136
 16  1  4 13     2 14 15  3     7 11 10  6     9  8  5 12
 10  7  6 11    11  7  6 10    14  2  3 15    15  2  3 14
  5 12  9  8     8 12  9  5     1 13 16  4     4 13 16  1
  3 14 15  2    13  1  4 16    12  8  5  9     6 11 10  7
-------------------------------------------------------------140
 16 13  1  4     9  8 12  5     2 15  3 14     7  6 10 11
  3  2 14 15    15  2 14  3     8  9  5 12    12  9  5  8
 10 11  7  6     6 11  7 10    13  4 16  1     1  4 16 13
  5  8 12  9     4 13  1 16    11  6 10  7    14 15  3  2
-------------------------------------------------------------144
 13 16  1  4     6 10  7 11     3 15  2 14    12  9  8  5
  2  3 14 15    15  3 14  2    10  6 11  7     7  6 11 10
  8  5 12  9     9  5 12  8    16  4 13  1     1  4 13 16
 11 10  7  6     4 16  1 13     5  9  8 12    14 15  2  3
-------------------------------------------------------------148
 13  1  4 16     2 15 14  3    10 11  6  7     9  5 12  8
  6 10  7 11    11 10  7  6    15  2  3 14    14  2  3 15
 12  8  9  5     5  8  9 12     1 16 13  4     4 16 13  1
  3 15 14  2    16  1  4 13     8  5 12  9     7 11  6 10
-------------------------------------------------------------152
  1  4 16 13    12  5  9  8    14  3 15  2     7  6 10 11
 15 14  2  3     3 14  2 15     5 12  8  9     9 12  8  5
 10 11  7  6     6 11  7 10     4 13  1 16    16 13  1  4
  8  5  9 12    13  4 16  1    11  6 10  7     2  3 15 14
-------------------------------------------------------------156
  1  4 13 16     7 11  6 10    14  2 15  3    12  9  8  5
 15 14  3  2     2 14  3 15    11  7 10  6     6  7 10 11
  8  5 12  9     9  5 12  8     4 16  1 13    13 16  1  4
 10 11  6  7    16  4 13  1     5  9  8 12     3  2 15 14
-------------------------------------------------------------160
  1 16 13  4    14  2  3 15     7 11 10  6    12  5  8  9
 10  7  6 11    11  7  6 10     2 14 15  3     3 14 15  2
  8  9 12  5     5  9 12  8    16  4  1 13    13  4  1 16
 15  2  3 14     4 16 13  1     9  5  8 12     6 11 10  7
-------------------------------------------------------------164
 13  4  1 16     2 14 15  3    11  7  6 10     8  9 12  5
  6 11 10  7     7 11 10  6    14  2  3 15    15  2  3 14
 12  5  8  9     9  5  8 12     4 16 13  1     1 16 13  4
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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.total.html Go JUN JUL SEP
22 captures 08
8 Jul 2006 - 7 Apr 2016 2005 2006 2007 About this capture

```
  12  9  8  5     5  9  8 12    16  4 13  1     1  4 13 16
   6  7 10 11     4 16  1 13     9  5 12  8    15 14  3  2
-----------------------------------------------------------------172
  16 13  1  4     5 12  8  9     3 14  2 15    10 11  7  6
   2  3 15 14    14  3 15  2    12  5  9  8     8  5  9 12
   7  6 10 11    11  6 10  7    13  4 16  1     1  4 16 13
   9 12  8  5     4 13  1 16     6 11  7 10    15 14  2  3
-----------------------------------------------------------------176
   1  4 13 16     6 10  7 11    15  3 14  2    12  9  8  5
  14 15  2  3     3 15  2 14    10  6 11  7     7  6 11 10
   8  5 12  9     9  5 12  8     4 16  1 13    13 16  1  4
  11 10  7  6    16  4 13  1     5  9  8 12     2  3 14 15
-----------------------------------------------------------------180
   1  4 16 13    12  5  9  8    15  2 14  3     6  7 11 10
  14 15  3  2     2 15  3 14     5 12  8  9     9 12  8  5
  11 10  6  7     7 10  6 11     4 13  1 16    16 13  1  4
   8  5  9 12    13  4 16  1    10  7 11  6     3  2 14 15
-----------------------------------------------------------------184
   1 16 13  4    15  3  2 14     6 10 11  7    12  5  8  9
  11  6  7 10    10  6  7 11     3 15 14  2     2 15 14  3
   8  9 12  5     5  9 12  8    16  4  1 13    13  4  1 16
  14  3  2 15     4 16 13  1     9  5  8 12     7 10 11  6
-----------------------------------------------------------------188
  16  1  4 13     2 14 15  3    11  7  6 10     5 12  9  8
   6 11 10  7     7 11 10  6    14  2  3 15    15  2  3 14
   9  8  5 12    12  8  5  9     1 13 16  4     4 13 16  1
   3 14 15  2    13  1  4 16     8 12  9  5    10  7  6 11
-----------------------------------------------------------------192
  16 13  1  4     5 12  8  9     2 15  3 14    11 10  6  7
   3  2 14 15    15  2 14  3    12  5  9  8     8  5  9 12
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   9 12  8  5     4 13  1 16     7 10  6 11    14 15  3  2
-----------------------------------------------------------------196
  13 16  1  4    10  6 11  7     3 15  2 14     8  5 12  9
   2  3 14 15    15  3 14  2     6 10  7 11    11 10  7  6
  12  9  8  5     5  9  8 12    16  4 13  1     1  4 13 16
   7  6 11 10     4 16  1 13     9  5 12  8    14 15  2  3
-----------------------------------------------------------------200
   1  4 13 16    10  6 11  7    15  5 12  2     8  3 14  9
  12 15  2  5     5 15  2 12     6 10  7 11    11 10  7  6
  14  9  8  3     3  9  8 14     4 16  1 13    13 16  1  4
   7  6 11 10    16  4 13  1     9  3 14  8     2  5 12 15
-----------------------------------------------------------------204
  13  1 16  4     6  7 10 11    12 15  2  5     3  9  8 14
   2 12  5 15    15 12  5  2     7  6 11 10    10  6 11  7
   8 14  3  9     9 14  3  8     1  4 13 16    16  4 13  1
  11  7 10  6     4  1 16 13    14  9  8  3     5 15  2 12
-----------------------------------------------------------------208
   4  1 16 13     8 14  3  9    12  2 15  5    10 11  6  7
  15 12  5  2     2 12  5 15    14  8  9  3     3  8  9 14
   6  7 10 11    11  7 10  6     1 13  4 16    16 13  4  1
   9 14  3  8    13  1 16  4     7 11  6 10     5  2 15 12
-----------------------------------------------------------------212
   1 13  4 16     7  6 11 10    12  2 15  5    14  9  8  3
  15 12  5  2     2 12  5 15     6  7 10 11    11  7 10  6
   8  3 14  9     9  3 14  8    13 16  1  4     4 16  1 13
  10  6 11  7    16 13  4  1     3  9  8 14     5  2 15 12
-----------------------------------------------------------------216
  13 16  1  4    11  7 10  6     2  5 12 15     8 14  3  9
  12  2 15  5     5  2 15 12     7 11  6 10    10 11  6  7
   3  9  8 14    14  9  8  3    16  4 13  1     1  4 13 16
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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.total.html Go JUN JUL SEP
22 captures 08
8 Jul 2006 - 7 Apr 2016 2005 2006 2007 About this capture

```
 14 10  3  7     7 10  3 14     1 13  4 16    16 13  4  1
  5  8  9 12    13  1 16  4    10  7 14  3     6  2 11 15
-------------------------------------------------------------224
 13 16  1  4     5  9  8 12     2 15  6 11    14 10  3  7
  6  2 11 15    15  2 11  6     9  5 12  8     8  5 12  9
  3  7 14 10    10  7 14  3    16  4 13  1     1  4 13 16
 12  9  8  5     4 16  1 13     7 10  3 14    11 15  6  2
-------------------------------------------------------------228
  4 16  1 13     8  3 14  9    10  2 15  7    12 11  6  5
 15 10  7  2     2 10  7 15     3  8  9 14    14  8  9  3
  6  5 12 11    11  5 12  6    16 13  4  1     1 13  4 16
  9  3 14  8    13 16  1  4     5 11  6 12     7  2 15 10
-------------------------------------------------------------232
  1 13  4 16    11 10  7  6     8  2 15  9    14  5 12  3
 15  8  9  2     2  8  9 15    10 11  6  7     7 11  6 10
 12  3 14  5     5  3 14 12    13 16  1  4     4 16  1 13
  6 10  7 11    16 13  4  1     3  5 12 14     9  2 15  8
-------------------------------------------------------------236
 13 16  1  4     7 11  6 10     2  9  8 15    12 14  3  5
  8  2 15  9     9  2 15  8    11  7 10  6     6  7 10 11
  3  5 12 14    14  5 12  3    16  4 13  1     1  4 13 16
 10 11  6  7     4 16  1 13     5 14  3 12    15  9  8  2
-------------------------------------------------------------240
  1  4 13 16     6 10  7 11    15  9  8  2    12  3 14  5
  8 15  2  9     9 15  2  8    10  6 11  7     7  6 11 10
 14  5 12  3     3  5 12 14     4 16  1 13    13 16  1  4
 11 10  7  6    16  4 13  1     5  3 14 12     2  9  8 15
-------------------------------------------------------------244
 13  1 16  4    10 11  6  7     8 15  2  9     3  5 12 14
  2  8  9 15    15  8  9  2    11 10  7  6     6 10  7 11
 12 14  3  5     5 14  3 12     1  4 13 16    16  4 13  1
  7 11  6 10     4  1 16 13    14  5 12  3     9 15  2  8
-------------------------------------------------------------248
  1 14 15  4    13  3  2 16     9  7 12  6    11 10  5  8
 12  9  6  7     7  9  6 12     3 13 16  2     2 13 16  3
  5  8 11 10    10  8 11  5    14  4  1 15    15  4  1 14
 16  3  2 13     4 14 15  1     8 10  5 11     6  7 12  9
-------------------------------------------------------------252
  1 15 14  4    13  2  3 16     9  7 12  6    11 10  5  8
 12  9  6  7     7  9  6 12     2 13 16  3     3 13 16  2
  5  8 11 10    10  8 11  5    15  4  1 14    14  4  1 15
 16  2  3 13     4 15 14  1     8 10  5 11     6  7 12  9
-------------------------------------------------------------256
  1  4 15 14     8 10  5 11    13  3 16  2    12  9  6  7
 16 13  2  3     3 13  2 16    10  8 11  5     5  8 11 10
  6  7 12  9     9  7 12  6     4 14  1 15    15 14  1  4
 11 10  5  8    14  4 15  1     7  9  6 12     2  3 16 13
-------------------------------------------------------------260
  1  4 14 15    12  7  9  6    13  2 16  3     8  5 11 10
 16 13  3  2     2 13  3 16     7 12  6  9     9 12  6  7
 11 10  8  5     5 10  8 11     4 15  1 14    14 15  1  4
  6  7  9 12    15  4 14  1    10  5 11  8     3  2 16 13
-------------------------------------------------------------264
  1 15 14  4    13  2  3 16    12  7  6  9     8 10 11  5
  6 12  9  7     7 12  9  6     2 13 16  3     3 13 16  2
 11  5  8 10    10  5  8 11    15  4  1 14    14  4  1 15
 16  2  3 13     4 15 14  1     5 10 11  8     9  7  6 12
-------------------------------------------------------------268
 14  4  1 15     2 13 16  3     7 12  9  6    11  5  8 10
  9  7  6 12    12  7  6  9    13  2  3 16    16  2  3 13
  8 10 11  5     5 10 11  8     4 15 14  1     1 15 14  4
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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.total.html Go JUN JUL SEP
22 captures 08
8 Jul 2006 - 7 Apr 2016 2005 2006 2007 About this capture

```
  8  5 11 10    10  5 11  8    15  4 14  1     1  4 14 15
  9 12  6  7     4 15  1 14     5 10  8 11    16 13  3  2
-----------------------------------------------------------276
 15 14  1  4    10  8 11  5     3 13  2 16     6  7 12  9
  2  3 16 13    13  3 16  2     8 10  5 11    11 10  5  8
 12  9  6  7     7  9  6 12    14  4 15  1     1  4 15 14
  5  8 11 10     4 14  1 15     9  7 12  6    16 13  2  3
-----------------------------------------------------------280
  1 14 15  4    13  3  2 16    12  7  6  9     8 10 11  5
  6 12  9  7     7 12  9  6     3 13 16  2     2 13 16  3
 11  5  8 10    10  5  8 11    14  4  1 15    15  4  1 14
 16  3  2 13     4 14 15  1     5 10 11  8     9  7  6 12
-----------------------------------------------------------284
 14  4  1 15     2 13 16  3     7  9 12  6    11  8  5 10
 12  7  6  9     9  7  6 12    13  2  3 16    16  2  3 13
  5 10 11  8     8 10 11  5     4 15 14  1     1 15 14  4
  3 13 16  2    15  4  1 14    10  8  5 11     6  9 12  7
-----------------------------------------------------------288
  1 15 14  4    13  2  3 16    12  6  7  9     8 11 10  5
  7 12  9  6     6 12  9  7     2 13 16  3     3 13 16  2
 10  5  8 11    11  5  8 10    15  4  1 14    14  4  1 15
 16  2  3 13     4 15 14  1     5 11 10  8     9  6  7 12
-----------------------------------------------------------292
 14  1  4 15     2 16 13  3     7 12  9  6    11  5  8 10
  9  7  6 12    12  7  6  9    16  2  3 13    13  2  3 16
  8 10 11  5     5 10 11  8     1 15 14  4     4 15 14  1
  3 16 13  2    15  1  4 14    10  5  8 11     6 12  9  7
-----------------------------------------------------------296
  1 14 15  4    13  3  2 16     9 12  7  6    11  5 10  8
  7  9  6 12    12  9  6  7     3 13 16  2     2 13 16  3
 10  8 11  5     5  8 11 10    14  4  1 15    15  4  1 14
 16  3  2 13     4 14 15  1     8  5 10 11     6 12  7  9
-----------------------------------------------------------300
  1  4 15 14    12  6  9  7    13  3 16  2     8  5 10 11
 16 13  2  3     3 13  2 16     6 12  7  9     9 12  7  6
 10 11  8  5     5 11  8 10     4 14  1 15    15 14  1  4
  7  6  9 12    14  4 15  1    11  5 10  8     2  3 16 13
-----------------------------------------------------------304
  1  4 14 15     8 11  5 10    13  2 16  3    12  9  7  6
 16 13  3  2     2 13  3 16    11  8 10  5     5  8 10 11
  7  6 12  9     9  6 12  7     4 15  1 14    14 15  1  4
 10 11  5  8    15  4 14  1     6  9  7 12     3  2 16 13
-----------------------------------------------------------308
  1 14 15  4    13  3  2 16    12  6  7  9     8 11 10  5
  7 12  9  6     6 12  9  7     3 13 16  2     2 13 16  3
 10  5  8 11    11  5  8 10    14  4  1 15    15  4  1 14
 16  3  2 13     4 14 15  1     5 11 10  8     9  6  7 12
-----------------------------------------------------------312
 14  1  4 15     2 16 13  3     7  9 12  6    11  8  5 10
 12  7  6  9     9  7  6 12    16  2  3 13    13  2  3 16
  5 10 11  8     8 10 11  5     1 15 14  4     4 15 14  1
  3 16 13  2    15  1  4 14    10  8  5 11     6  9 12  7
-----------------------------------------------------------316
 14 15  1  4    11  8 10  5     2 13  3 16     7  6 12  9
  3  2 16 13    13  2 16  3     8 11  5 10    10 11  5  8
 12  9  7  6     6  9  7 12    15  4 14  1     1  4 14 15
  5  8 10 11     4 15  1 14     9  6 12  7    16 13  3  2
-----------------------------------------------------------320
 15 14  1  4     6 12  7  9     3 13  2 16    10 11  8  5
  2  3 16 13    13  3 16  2    12  6  9  7     7  6  9 12
  8  5 10 11    11  5 10  8    14  4 15  1     1  4 15 14
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.total.html Go
JUN JUL SEP
08
2005 2006 2007
22 captures
8 Jul 2006 - 7 Apr 2016
About this capture

```
 10  8 11  5     5  8 11 10    15  4  1 14    14  4  1 15
 16  2  3 13     4 15 14  1     8  5 10 11     6 12  7  9
-----------------------------------------------------------328
  1  4 14 15     6  9  7 12    16  3 13  2    11 10  8  5
 13 16  2  3     3 16  2 13     9  6 12  7     7  6 12  9
  8  5 11 10    10  5 11  8     4 15  1 14    14 15  1  4
 12  9  7  6    15  4 14  1     5 10  8 11     2  3 13 16
-----------------------------------------------------------332
  1  4 15 14    11  5 10  8    16  2 13  3     6  7 12  9
 13 16  3  2     2 16  3 13     5 11  8 10    10 11  8  5
 12  9  6  7     7  9  6 12     4 14  1 15    15 14  1  4
  8  5 10 11    14  4 15  1     9  7 12  6     3  2 13 16
-----------------------------------------------------------336
  1 15 14  4    16  3  2 13     6  9 12  7    11  5  8 10
 12  6  7  9     9  6  7 12     3 16 13  2     2 16 13  3
  8 10 11  5     5 10 11  8    15  4  1 14    14  4  1 15
 13  3  2 16     4 15 14  1    10  5  8 11     7  9 12  6
-----------------------------------------------------------340
  1  4 14 15    10  5 11  8    16  3 13  2     7  6 12  9
 13 16  2  3     3 16  2 13     5 10  8 11    11 10  8  5
 12  9  7  6     6  9  7 12     4 15  1 14    14 15  1  4
  8  5 11 10    15  4 14  1     9  6 12  7     2  3 13 16
-----------------------------------------------------------344
  1  4 15 14     7  9  6 12    16  2 13  3    10 11  8  5
 13 16  3  2     2 16  3 13     9  7 12  6     6  7 12  9
  8  5 10 11    11  5 10  8     4 14  1 15    15 14  1  4
 12  9  6  7    14  4 15  1     5 11  8 10     3  2 13 16
-----------------------------------------------------------348
  1 14 15  4    16  2  3 13     7  9 12  6    10  5  8 11
 12  7  6  9     9  7  6 12     2 16 13  3     3 16 13  2
  8 11 10  5     5 11 10  8    14  4  1 15    15  4  1 14
 13  2  3 16     4 14 15  1    11  5  8 10     6  9 12  7
-----------------------------------------------------------352
 15  1  4 14     2 13 16  3    12  7  6  9     5 11 10  8
  6 12  9  7     7 12  9  6    13  2  3 16    16  2  3 13
 10  8  5 11    11  8  5 10     1 14 15  4     4 14 15  1
  3 13 16  2    14  1  4 15     8 11 10  5     9  7  6 12
-----------------------------------------------------------356
 15 14  1  4     5 11  8 10     2 16  3 13    12  9  6  7
  3  2 13 16    16  2 13  3    11  5 10  8     8  5 10 11
  6  7 12  9     9  7 12  6    14  4 15  1     1  4 15 14
 10 11  8  5     4 14  1 15     7  9  6 12    13 16  3  2
-----------------------------------------------------------360
 15  4  1 14     2 16 13  3     9  7  6 12     8 11 10  5
  6  9 12  7     7  9 12  6    16  2  3 13    13  2  3 16
 10  5  8 11    11  5  8 10     4 14 15  1     1 14 15  4
  3 16 13  2    14  4  1 15     5 11 10  8    12  7  6  9
-----------------------------------------------------------364
 15 14  1  4     9  7 12  6     2 16  3 13     8  5 10 11
  3  2 13 16    16  2 13  3     7  9  6 12    12  9  6  7
 10 11  8  5     5 11  8 10    14  4 15  1     1  4 15 14
  6  7 12  9     4 14  1 15    11  5 10  8    13 16  3  2
-----------------------------------------------------------368
 14 15  1  4     5 10  8 11     3 16  2 13    12  9  7  6
  2  3 13 16    16  3 13  2    10  5 11  8     8  5 11 10
  7  6 12  9     9  6 12  7    15  4 14  1     1  4 14 15
 11 10  8  5     4 15  1 14     6  9  7 12    13 16  2  3
-----------------------------------------------------------372
 14 15  1  4     9  6 12  7     3 16  2 13     8  5 11 10
  2  3 13 16    16  3 13  2     6  9  7 12    12  9  7  6
 11 10  8  5     5 10  8 11    15  4 14  1     1  4 14 15
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.total.html Go
JUN JUL SEP
08
2005 2006 2007
22 captures
8 Jul 2006 - 7 Apr 2016
About this capture

```
 13  8 10  3     3  8 10 13    15 14  4  1     1 14  4 15
  5  2 16 11    14 15  1  4     8  3 13 10     7  6 12  9
------------------------------------------------------------380
  1  4 14 15    10 13  3  8    11  2 16  5    12  7  9  6
 16 11  5  2     2 11  5 16    13 10  8  3     3 10  8 13
  9  6 12  7     7  6 12  9     4 15  1 14    14 15  1  4
  8 13  3 10    15  4 14  1     6  7  9 12     5  2 16 11
------------------------------------------------------------384
  1 14  4 15    10  3 13  8    11  2 16  5    12  7  9  6
 16 11  5  2     2 11  5 16     3 10  8 13    13 10  8  3
  9  6 12  7     7  6 12  9    14 15  1  4     4 15  1 14
  8  3 13 10    15 14  4  1     6  7  9 12     5  2 16 11
------------------------------------------------------------388
  4  1 15 14    11 16  2  5     9  6 12  7    10  3 13  8
 12  9  7  6     6  9  7 12    16 11  5  2     2 11  5 16
 13  8 10  3     3  8 10 13     1 14  4 15    15 14  4  1
  5 16  2 11    14  1 15  4     8  3 13 10     7  6 12  9
------------------------------------------------------------392
 14 15  1  4    13  6 12  3     2  9  7 16     5  8 10 11
  7  2 16  9     9  2 16  7     6 13  3 12    12 13  3  6
 10 11  5  8     8 11  5 10    15  4 14  1     1  4 14 15
  3  6 12 13     4 15  1 14    11  8 10  5    16  9  7  2
------------------------------------------------------------396
  4 15  1 14     7  2 16  9    11 10  8  5    12  3 13  6
  8 11  5 10    10 11  5  8     2  7  9 16    16  7  9  2
 13  6 12  3     3  6 12 13    15 14  4  1     1 14  4 15
  9  2 16  7    14 15  1  4     6  3 13 12     5 10  8 11
------------------------------------------------------------400
 14 15  1  4    13  6 12  3     2  7  9 16     5 10  8 11
  9  2 16  7     7  2 16  9     6 13  3 12    12 13  3  6
  8 11  5 10    10 11  5  8    15  4 14  1     1  4 14 15
  3  6 12 13     4 15  1 14    11 10  8  5    16  7  9  2
------------------------------------------------------------404
  4  1 15 14     7 16  2  9    11 10  8  5    12  3 13  6
  8 11  5 10    10 11  5  8    16  7  9  2     2  7  9 16
 13  6 12  3     3  6 12 13     1 14  4 15    15 14  4  1
  9 16  2  7    14  1 15  4     6  3 13 12     5 10  8 11
------------------------------------------------------------408
  4  1 14 15    10 16  3  5    11  2 13  8     9  7 12  6
 13 11  8  2     2 11  8 13    16 10  5  3     3 10  5 16
 12  6  9  7     7  6  9 12     1 15  4 14    14 15  4  1
  5 16  3 10    15  1 14  4     6  7 12  9     8  2 13 11
------------------------------------------------------------412
  1 15  4 14    11  2 13  8    12  6  9  7    10  3 16  5
  9 12  7  6     6 12  7  9     2 11  8 13    13 11  8  2
 16  5 10  3     3  5 10 16    15 14  1  4     4 14  1 15
  8  2 13 11    14 15  4  1     5  3 16 10     7  6  9 12
------------------------------------------------------------416
  1  4 15 14    11 13  2  8    12  6  9  7    10  3 16  5
  9 12  7  6     6 12  7  9    13 11  8  2     2 11  8 13
 16  5 10  3     3  5 10 16     4 14  1 15    15 14  1  4
  8 13  2 11    14  4 15  1     5  3 16 10     7  6  9 12
------------------------------------------------------------420
  4 14  1 15    10  3 16  5    11  2 13  8     9  7 12  6
 13 11  8  2     2 11  8 13     3 10  5 16    16 10  5  3
 12  6  9  7     7  6  9 12    14 15  4  1     1 15  4 14
  5  3 16 10    15 14  1  4     6  7 12  9     8  2 13 11
------------------------------------------------------------424
  1  5 16 12    13  4  9  8    14  2 15  3     6  7 10 11
 15 14  3  2     2 14  3 15     4 13  8  9     9 13  8  4
 10 11  6  7     7 11  6 10     5 12  1 16    16 12  1  5
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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.total.html Go
JUN JUL SEP
08
2005 2006 2007
22 captures
8 Jul 2006 - 7 Apr 2016
About this capture

```
  7  6 11 10     10  6 11  7     12  5 16  1      1  5 16 12
  9 13  8  4      5 12  1 16      6 10  7 11     14 15  2  3
-----------------------------------------------------------------432
  1 12  5 16      9  3 14  8     13  2 15  4     11  7 10  6
 15 13  4  2      2 13  4 15      3  9  8 14     14  9  8  3
 10  6 11  7      7  6 11 10     12 16  1  5      5 16  1 12
  8  3 14  9     16 12  5  1      6  7 10 11      4  2 15 13
-----------------------------------------------------------------436
  1 16  5 12      6  2 11 15     13  9  8  4     14  7 10  3
  8 13  4  9      9 13  4  8      2  6 15 11     11  6 15  2
 10  3 14  7      7  3 14 10     16 12  1  5      5 12  1 16
 15  2 11  6     12 16  5  1      3  7 10 14      4  9  8 13
-----------------------------------------------------------------440
 12  1 16  5     11 15  2  6      8  4  9 13      3 14  7 10
  9  8 13  4      4  8 13  9     15 11  6  2      2 11  6 15
  7 10  3 14     14 10  3  7      1  5 12 16     16  5 12  1
  6 15  2 11      5  1 16 12     10 14  7  3     13  4  9  8
-----------------------------------------------------------------444
  1 16  5 12     13  9  4  8      6  2 15 11     14  7 10  3
 15  6 11  2      2  6 11 15      9 13  8  4      4 13  8  9
 10  3 14  7      7  3 14 10     16 12  1  5      5 12  1 16
  8  9  4 13     12 16  5  1      3  7 10 14     11  2 15  6
-----------------------------------------------------------------448
 12  1 16  5      4  8  9 13     15 11  2  6      3 14  7 10
  2 15  6 11     11 15  6  2      8  4 13  9      9  4 13  8
  7 10  3 14     14 10  3  7      1  5 12 16     16  5 12  1
 13  8  9  4      5  1 16 12     10 14  7  3      6 11  2 15
-----------------------------------------------------------------452
  5 16  1 12     13  9  8  4      2  6 15 11     14  3 10  7
 15  2 11  6      6  2 11 15      9 13  4  8      8 13  4  9
 10  7 14  3      3  7 14 10     16 12  5  1      1 12  5 16
  4  9  8 13     12 16  1  5      7  3 10 14     11  6 15  2
-----------------------------------------------------------------456
 16  1 12  5      4  8 13  9     11 15  2  6      3 10  7 14
  2 11  6 15     15 11  6  2      8  4  9 13     13  4  9  8
  7 14  3 10     10 14  3  7      1  5 16 12     12  5 16  1
  9  8 13  4      5  1 12 16     14 10  7  3      6 15  2 11
-----------------------------------------------------------------460
  1 16  5 12      6  2 11 15     13  7 10  4     14  9  8  3
 10 13  4  7      7 13  4 10      2  6 15 11     11  6 15  2
  8  3 14  9      9  3 14  8     16 12  1  5      5 12  1 16
 15  2 11  6     12 16  5  1      3  9  8 14      4  7 10 13
-----------------------------------------------------------------464
  1  5 12 16      9 14  3  8     11  2 15  6     13  7 10  4
 15 11  6  2      2 11  6 15     14  9  8  3      3  9  8 14
 10  4 13  7      7  4 13 10      5 16  1 12     12 16  1  5
  8 14  3  9     16  5 12  1      4  7 10 13      6  2 15 11
-----------------------------------------------------------------468
  1  6 11 16      5  9  8 12     15  3 14  2     13 10  7  4
 14 15  2  3      3 15  2 14      9  5 12  8      8  5 12  9
  7  4 13 10     10  4 13  7      6 16  1 11     11 16  1  6
 12  9  8  5     16  6 11  1      4 10  7 13      2  3 14 15
-----------------------------------------------------------------472
  1  6 11 16     10  4 13  7     15  3 14  2      8  5 12  9
 14 15  2  3      3 15  2 14      4 10  7 13     13 10  7  4
 12  9  8  5      5  9  8 12      6 16  1 11     11 16  1  6
  7  4 13 10     16  6 11  1      9  5 12  8      2  3 14 15
-----------------------------------------------------------------476
  6 16  1 11     13 10  7  4      3  2 15 14     12  8  9  5
 15  3 14  2      2  3 14 15     10 13  4  7      7 13  4 10
  9  5 12  8      8  5 12  9     16 11  6  1      1 11  6 16
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.total.html Go JUN JUL SEP
08
2005 2006 2007
22 captures
8 Jul 2006 - 7 Apr 2016
About this capture

```
  8  5 12  9     9  5 12  8     11 16  1  6      6 16  1 11
 10  4 13  7    16 11  6  1      5  9  8 12      3  2 15 14
-----------------------------------------------------------484
 11 16  1  6    13  7 10  4      2  3 14 15      8 12  5  9
 14  2 15  3     3  2 15 14      7 13  4 10     10 13  4  7
  5  9  8 12    12  9  8  5     16  6 11  1      1  6 11 16
  4  7 10 13     6 16  1 11      9 12  5  8     15  3 14  2
-----------------------------------------------------------488
 11  1 16  6     3  8  9 14     15 13  2  4      5 12  7 10
  2 15  4 13    13 15  4  2      8  3 14  9      9  3 14  8
  7 10  5 12    12 10  5  7      1  6 11 16     16  6 11  1
 14  8  9  3     6  1 16 11     10 12  7  5      4 13  2 15
-----------------------------------------------------------492
  6 16  1 11    14  9  8  3      2  4 15 13     12  5 10  7
 15  2 13  4     4  2 13 15      9 14  3  8      8 14  3  9
 10  7 12  5     5  7 12 10     16 11  6  1      1 11  6 16
  3  9  8 14    11 16  1  6      7  5 10 12     13  4 15  2
-----------------------------------------------------------496
 11  1 16  6    12 15  2  5      8  9  4 13      3  7 14 10
  4  8 13  9     9  8 13  4     15 12  5  2      2 12  5 15
 14 10  3  7     7 10  3 14      1  6 11 16     16  6 11  1
  5 15  2 12     6  1 16 11     10  7 14  3     13  9  4  8
-----------------------------------------------------------500
  1  6 11 16    10  4 13  7     15  5 12  2      8  3 14  9
 12 15  2  5     5 15  2 12      4 10  7 13     13 10  7  4
 14  9  8  3     3  9  8 14      6 16  1 11     11 16  1  6
  7  4 13 10    16  6 11  1      9  3 14  8      2  5 12 15
-----------------------------------------------------------504
  1 16 11  6    15  5  2 12     10  4  7 13      8  9 14  3
  7 10 13  4     4 10 13  7      5 15 12  2      2 15 12  5
 14  3  8  9     9  3  8 14     16  6  1 11     11  6  1 16
 12  5  2 15     6 16 11  1      3  9 14  8     13  4  7 10
-----------------------------------------------------------508
  1  6 16 11     8  9  3 14     15  2 12  5     10 13  7  4
 12 15  5  2     2 15  5 12      9  8 14  3      3  8 14  9
  7  4 10 13    13  4 10  7      6 11  1 16     16 11  1  6
 14  9  3  8    11  6 16  1      4 13  7 10      5  2 12 15
-----------------------------------------------------------512
 16 11  1  6     9  8 14  3      2 15  5 12      7  4 10 13
  5  2 12 15    15  2 12  5      8  9  3 14     14  9  3  8
 10 13  7  4     4 13  7 10     11  6 16  1      1  6 16 11
  3  8 14  9     6 11  1 16     13  4 10  7     12 15  5  2
-----------------------------------------------------------516
 16  1  6 11     2 12 15  5      7 13 10  4      9  8  3 14
 10  7  4 13    13  7  4 10     12  2  5 15     15  2  5 12
  3 14  9  8     8 14  9  3      1 11 16  6      6 11 16  1
  5 12 15  2    11  1  6 16     14  8  3  9      4 13 10  7
-----------------------------------------------------------520
  6  1 16 11    13  7 10  4     12  2 15  5      3  8  9 14
 15 12  5  2     2 12  5 15      7 13  4 10     10 13  4  7
  9 14  3  8     8 14  3  9      1 11  6 16     16 11  6  1
  4  7 10 13    11  1 16  6     14  8  9  3      5  2 15 12
-----------------------------------------------------------524
  1  6 16 11    14  3  9  8     12  5 15  2      7  4 10 13
 15 12  2  5     5 12  2 15      3 14  8  9      9 14  8  3
 10 13  7  4     4 13  7 10      6 11  1 16     16 11  1  6
  8  3  9 14    11  6 16  1     13  4 10  7      2  5 15 12
-----------------------------------------------------------528
  1  6 11 16     7 13  4 10     12  2 15  5     14  9  8  3
 15 12  5  2     2 12  5 15     13  7 10  4      4  7 10 13
  8  3 14  9     9  3 14  8      6 16  1 11     11 16  1  6
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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.total.html Go
JUN JUL SEP
08
2005 2006 2007
22 captures
8 Jul 2006 - 7 Apr 2016
About this capture

```
  8  9 14  3      3  9 14  8     16  6  1 11     11  6  1 16
 15  2  5 12      6 16 11  1      9  3  8 14      4 13 10  7
-----------------------------------------------------------------536
 11  6  1 16      2 12 15  5     13  7  4 10      8  9 14  3
  4 13 10  7      7 13 10  4     12  2  5 15     15  2  5 12
 14  3  8  9      9  3  8 14      6 16 11  1      1 16 11  6
  5 12 15  2     16  6  1 11      3  9 14  8     10  7  4 13
-----------------------------------------------------------------540
 11 16  1  6     13  7 10  4      2 12  5 15      8  3 14  9
  5  2 15 12     12  2 15  5      7 13  4 10     10 13  4  7
 14  9  8  3      3  9  8 14     16  6 11  1      1  6 11 16
  4  7 10 13      6 16  1 11      9  3 14  8     15 12  5  2
-----------------------------------------------------------------544
 16 11  1  6      3 14  8  9      5 12  2 15     10 13  7  4
  2  5 15 12     12  5 15  2     14  3  9  8      8  3  9 14
  7  4 10 13     13  4 10  7     11  6 16  1      1  6 16 11
  9 14  8  3      6 11  1 16      4 13  7 10     15 12  2  5
-----------------------------------------------------------------548
  1  6 11 16      4 10  7 13     15  5 12  2     14  9  8  3
 12 15  2  5      5 15  2 12     10  4 13  7      7  4 13 10
  8  3 14  9      9  3 14  8      6 16  1 11     11 16  1  6
 13 10  7  4     16  6 11  1      3  9  8 14      2  5 12 15
-----------------------------------------------------------------552
  1  6 16 11     14  3  9  8     15  2 12  5      4  7 13 10
 12 15  5  2      2 15  5 12      3 14  8  9      9 14  8  3
 13 10  4  7      7 10  4 13      6 11  1 16     16 11  1  6
  8  3  9 14     11  6 16  1     10  7 13  4      5  2 12 15
-----------------------------------------------------------------556
  1 16 11  6     15  5  2 12      4 10 13  7     14  3  8  9
 13  4  7 10     10  4  7 13      5 15 12  2      2 15 12  5
  8  9 14  3      3  9 14  8     16  6  1 11     11  6  1 16
 12  5  2 15      6 16 11  1      9  3  8 14      7 10 13  4
-----------------------------------------------------------------560
 16  1  6 11      2 12 15  5     13  7  4 10      3 14  9  8
  4 13 10  7      7 13 10  4     12  2  5 15     15  2  5 12
  9  8  3 14     14  8  3  9      1 11 16  6      6 11 16  1
  5 12 15  2     11  1  6 16      8 14  9  3     10  7  4 13
-----------------------------------------------------------------564
 16 11  1  6      3 14  8  9      2 15  5 12     13 10  4  7
  5  2 12 15     15  2 12  5     14  3  9  8      8  3  9 14
  4  7 13 10     10  7 13  4     11  6 16  1      1  6 16 11
  9 14  8  3      6 11  1 16      7 10  4 13     12 15  5  2
-----------------------------------------------------------------568
 11 16  1  6     10  4 13  7      5 15  2 12      8  3 14  9
  2  5 12 15     15  5 12  2      4 10  7 13     13 10  7  4
 14  9  8  3      3  9  8 14     16  6 11  1      1  6 11 16
  7  4 13 10      6 16  1 11      9  3 14  8     12 15  2  5
-----------------------------------------------------------------572
  1  6 11 16      5  9  8 12     15 10  7  2     13  3 14  4
  7 15  2 10     10 15  2  7      9  5 12  8      8  5 12  9
 14  4 13  3      3  4 13 14      6 16  1 11     11 16  1  6
 12  9  8  5     16  6 11  1      4  3 14 13      2 10  7 15
-----------------------------------------------------------------576
 11 16  1  6      9  3 14  8      2 15 10  7     12  4  5 13
 10  2  7 15     15  2  7 10      3  9  8 14     14  9  8  3
  5 13 12  4      4 13 12  5     16  6 11  1      1  6 11 16
  8  3 14  9      6 16  1 11     13  4  5 12      7 15 10  2
-----------------------------------------------------------------580
  1  6 11 16      9 15  2  8     10  5 12  7     14  4 13  3
 12 10  7  5      5 10  7 12     15  9  8  2      2  9  8 15
 13  3 14  4      4  3 14 13      6 16  1 11     11 16  1  6
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.total.html Go JUN JUL SEP
22 captures 08
8 Jul 2006 - 7 Apr 2016 2005 2006 2007 About this capture

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 12  3 14  5     5  3 14 12     6 16  1 11    11 16  1  6
 13 10  7  4    16  6 11  1     3  5 12 14     2  9  8 15
---------------------------------------------------------------588
  1  6 11 16     9 15  2  8    10  4 13  7    14  5 12  3
 13 10  7  4     4 10  7 13    15  9  8  2     2  9  8 15
 12  3 14  5     5  3 14 12     6 16  1 11    11 16  1  6
  8 15  2  9    16  6 11  1     3  5 12 14     7  4 13 10
---------------------------------------------------------------592
 11  1 16  6    10 13  4  7     8 15  2  9     5  3 14 12
  2  8  9 15    15  8  9  2    13 10  7  4     4 10  7 13
 14 12  5  3     3 12  5 14     1  6 11 16    16  6 11  1
  7 13  4 10     6  1 16 11    12  3 14  5     9 15  2  8
---------------------------------------------------------------596
 12  1 15  6     3 16  2 13    10 11  5  8     9 14  4  7
  5 10  8 11    11 10  8  5    16  3 13  2     2  3 13 16
  4  7  9 14    14  7  9  4     1  6 12 15    15  6 12  1
 13 16  2  3     6  1 15 12     7 14  4  9     8 11  5 10
---------------------------------------------------------------600
 12 15  1  6    11 10  8  5     2 13  3 16     9  4 14  7
  3  2 16 13    13  2 16  3    10 11  5  8     8 11  5 10
 14  7  9  4     4  7  9 14    15  6 12  1     1  6 12 15
  5 10  8 11     6 15  1 12     7  4 14  9    16 13  3  2
---------------------------------------------------------------604
 12 15  1  6    11 10  8  5     2  3 13 16     9 14  4  7
 13  2 16  3     3  2 16 13    10 11  5  8     8 11  5 10
  4  7  9 14    14  7  9  4    15  6 12  1     1  6 12 15
  5 10  8 11     6 15  1 12     7 14  4  9    16  3 13  2
---------------------------------------------------------------608
 12 15  1  6     3  2 16 13    10 11  5  8     9 14  4  7
  5 10  8 11    11 10  8  5     2  3 13 16    16  3 13  2
  4  7  9 14    14  7  9  4    15  6 12  1     1  6 12 15
 13  2 16  3     6 15  1 12     7 14  4  9     8 11  5 10
---------------------------------------------------------------612
  1 15 12  6    11  2  5 16    14  4  7  9     8 13 10  3
  7 14  9  4     4 14  9  7     2 11 16  5     5 11 16  2
 10  3  8 13    13  3  8 10    15  6  1 12    12  6  1 15
 16  2  5 11     6 15 12  1     3 13 10  8     9  4  7 14
---------------------------------------------------------------616
 12  1  6 15     2 16 11  5     7 14  9  4    13  3  8 10
  9  7  4 14    14  7  4  9    16  2  5 11    11  2  5 16
  8 10 13  3     3 10 13  8     1 15 12  6     6 15 12  1
  5 16 11  2    15  1  6 12    10  3  8 13     4 14  9  7
---------------------------------------------------------------620
  1 12 15  6    11  5  2 16     9 14  7  4    13  3 10  8
  7  9  4 14    14  9  4  7     5 11 16  2     2 11 16  5
 10  8 13  3     3  8 13 10    12  6  1 15    15  6  1 12
 16  5  2 11     6 12 15  1     8  3 10 13     4 14  7  9
---------------------------------------------------------------624
  1  6 15 12    14  4  9  7    11  5 16  2     8  3 10 13
 16 11  2  5     5 11  2 16     4 14  7  9     9 14  7  4
 10 13  8  3     3 13  8 10     6 12  1 15    15 12  1  6
  7  4  9 14    12  6 15  1    13  3 10  8     2  5 16 11
---------------------------------------------------------------628
  1 12 15  6    11  5  2 16    14  4  7  9     8 13 10  3
  7 14  9  4     4 14  9  7     5 11 16  2     2 11 16  5
 10  3  8 13    13  3  8 10    12  6  1 15    15  6  1 12
 16  5  2 11     6 12 15  1     3 13 10  8     9  4  7 14
---------------------------------------------------------------632
  1  6 12 15     8 13  3 10    11  2 16  5    14  9  7  4
 16 11  5  2     2 11  5 16    13  8 10  3     3  8 10 13
  7  4 14  9     9  4 14  7     6 15  1 12    12 15  1  6
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.total.html Go JUN JUL SEP
08
2005 2006 2007
22 captures
8 Jul 2006 - 7 Apr 2016
About this capture

```
 14  9  7  4     4  9  7 14    15  6 12  1     1  6 12 15
  3  8 10 13     6 15  1 12     9  4 14  7    16 11  5  2
-----------------------------------------------------------640
 12  1  6 15     2 16 11  5     7  9 14  4    13  8  3 10
 14  7  4  9     9  7  4 14    16  2  5 11    11  2  5 16
  3 10 13  8     8 10 13  3     1 15 12  6     6 15 12  1
  5 16 11  2    15  1  6 12    10  8  3 13     4  9 14  7
-----------------------------------------------------------644
  6  1 12 15     9  7 14  4    16  2 11  5     3  8 13 10
 11 16  5  2     2 16  5 11     7  9  4 14    14  9  4  7
 13 10  3  8     8 10  3 13     1 15  6 12    12 15  6  1
  4  7 14  9    15  1 12  6    10  8 13  3     5  2 11 16
-----------------------------------------------------------648
  1 15 12  6    11  2  5 16     9 14  7  4    13  3 10  8
  7  9  4 14    14  9  4  7     2 11 16  5     5 11 16  2
 10  8 13  3     3  8 13 10    15  6  1 12    12  6  1 15
 16  2  5 11     6 15 12  1     8  3 10 13     4 14  7  9
-----------------------------------------------------------652
  1  6 12 15     4  9  7 14    16  5 11  2    13 10  8  3
 11 16  2  5     5 16  2 11     9  4 14  7     7  4 14  9
  8  3 13 10    10  3 13  8     6 15  1 12    12 15  1  6
 14  9  7  4    15  6 12  1     3 10  8 13     2  5 11 16
-----------------------------------------------------------656
  1  6 15 12    13  3 10  8    16  2 11  5     4  7 14  9
 11 16  5  2     2 16  5 11     3 13  8 10    10 13  8  3
 14  9  4  7     7  9  4 14     6 12  1 15    15 12  1  6
  8  3 10 13    12  6 15  1     9  7 14  4     5  2 11 16
-----------------------------------------------------------660
  1 15 12  6    16  5  2 11     4  9 14  7    13  3  8 10
 14  4  7  9     9  4  7 14     5 16 11  2     2 16 11  5
  8 10 13  3     3 10 13  8    15  6  1 12    12  6  1 15
 11  5  2 16     6 15 12  1    10  3  8 13     7  9 14  4
-----------------------------------------------------------664
  1  6 12 15    10  3 13  8    16  5 11  2     7  4 14  9
 11 16  2  5     5 16  2 11     3 10  8 13    13 10  8  3
 14  9  7  4     4  9  7 14     6 15  1 12    12 15  1  6
  8  3 13 10    15  6 12  1     9  4 14  7     2  5 11 16
-----------------------------------------------------------668
  1  6 15 12     7  9  4 14    16  2 11  5    10 13  8  3
 11 16  5  2     2 16  5 11     9  7 14  4     4  7 14  9
  8  3 10 13    13  3 10  8     6 12  1 15    15 12  1  6
 14  9  4  7    12  6 15  1     3 13  8 10     5  2 11 16
-----------------------------------------------------------672
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 14  7  4  9     9  7  4 14     2 16 11  5     5 16 11  2
  8 13 10  3     3 13 10  8    12  6  1 15    15  6  1 12
 11  2  5 16     6 12 15  1    13  3  8 10     4  9 14  7
-----------------------------------------------------------676
 15  1  6 12     2 11 16  5    14  7  4  9     3 13 10  8
  4 14  9  7     7 14  9  4    11  2  5 16    16  2  5 11
 10  8  3 13    13  8  3 10     1 12 15  6     6 12 15  1
  5 11 16  2    12  1  6 15     8 13 10  3     9  7  4 14
-----------------------------------------------------------680
 15 12  1  6     3 13  8 10     2 16  5 11    14  9  4  7
  5  2 11 16    16  2 11  5    13  3 10  8     8  3 10 13
  4  7 14  9     9  7 14  4    12  6 15  1     1  6 15 12
 10 13  8  3     6 12  1 15     7  9  4 14    11 16  5  2
-----------------------------------------------------------684
 15  6  1 12     2 16 11  5     9  7  4 14     8 13 10  3
  4  9 14  7     7  9 14  4    16  2  5 11    11  2  5 16
 10  3  8 13    13  3  8 10     6 12 15  1     1 12 15  6
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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.total.html Go JUN JUL SEP
22 captures 08
8 Jul 2006 - 7 Apr 2016 2005 2006 2007 About this capture

```
  10 13  8  3     3 13  8 10     12  6 15  1      1  6 15 12
   4  7 14  9     6 12  1 15     13  3 10  8     11 16  5  2
---------------------------------------------------------------692
  12 15  1  6     3 10  8 13      5 16  2 11     14  9  7  4
   2  5 11 16    16  5 11  2     10  3 13  8      8  3 13 10
   7  4 14  9     9  4 14  7     15  6 12  1      1  6 12 15
  13 10  8  3     6 15  1 12      4  9  7 14     11 16  2  5
---------------------------------------------------------------696
  12 15  1  6     9  4 14  7      5 16  2 11      8  3 13 10
   2  5 11 16    16  5 11  2      4  9  7 14     14  9  7  4
  13 10  8  3     3 10  8 13     15  6 12  1      1  6 12 15
   7  4 14  9     6 15  1 12     10  3 13  8     11 16  2  5
---------------------------------------------------------------700
  15  1 12  6     9 16  5  4      7 11  2 14      3  8 13 10
   2  7 14 11    11  7 14  2     16  9  4  5      5  9  4 16
  13 10  3  8     8 10  3 13      1  6 15 12     12  6 15  1
   4 16  5  9     6  1 12 15     10  8 13  3     14 11  2  7
---------------------------------------------------------------704
   1 10  7 16     6  4 13 11     15  3 14  2     12  9  8  5
  14 15  2  3     3 15  2 14      4  6 11 13     13  6 11  4
   8  5 12  9     9  5 12  8     10 16  1  7      7 16  1 10
  11  4 13  6    16 10  7  1      5  9  8 12      2  3 14 15
---------------------------------------------------------------708
  10 16  1  7    13  6 11  4      3  2 15 14      8 12  5  9
  15  3 14  2     2  3 14 15      6 13  4 11     11 13  4  6
   5  9  8 12    12  9  8  5     16  7 10  1      1  7 10 16
   4  6 11 13     7 16  1 10      9 12  5  8     14  2 15  3
---------------------------------------------------------------712
  10 16  1  7    14  5 12  3      2  4 15 13      8  9  6 11
  15  2 13  4     4  2 13 15      5 14  3 12     12 14  3  5
   6 11  8  9     9 11  8  6     16  7 10  1      1  7 10 16
   3  5 12 14     7 16  1 10     11  9  6  8     13  4 15  2
---------------------------------------------------------------716
  10 16  1  7     2  5 12 15      9 11  6  8     13 14  3  4
   6  9  8 11    11  9  8  6      5  2 15 12     12  2 15  5
   3  4 13 14    14  4 13  3     16  7 10  1      1  7 10 16
  15  5 12  2     7 16  1 10      4 14  3 13      8 11  6  9
---------------------------------------------------------------720
   1 10  7 16     4  6 11 13     15  5 12  2     14  9  8  3
  12 15  2  5     5 15  2 12      6  4 13 11     11  4 13  6
   8  3 14  9     9  3 14  8     10 16  1  7      7 16  1 10
  13  6 11  4    16 10  7  1      3  9  8 14      2  5 12 15
---------------------------------------------------------------724
  10  1 16  7     2 12  5 15     13 11  6  4      9 14  3  8
   6 13  4 11    11 13  4  6     12  2 15  5      5  2 15 12
   3  8  9 14    14  8  9  3      1  7 10 16     16  7 10  1
  15 12  5  2     7  1 16 10      8 14  3  9      4 11  6 13
---------------------------------------------------------------728
  10 16  1  7    11  4 13  6      5  2 15 12      8 14  3  9
  15  5 12  2     2  5 12 15      4 11  6 13     13 11  6  4
   3  9  8 14    14  9  8  3     16  7 10  1      1  7 10 16
   6  4 13 11     7 16  1 10      9 14  3  8     12  2 15  5
---------------------------------------------------------------732
   1 16  7 10    15  9  2  8      5  6 11 12     13  3 14  4
  11  5 12  6     6  5 12 11      9 15  8  2      2 15  8  9
  14  4 13  3     3  4 13 14     16 10  1  7      7 10  1 16
   8  9  2 15    10 16  7  1      4  3 14 13     12  6 11  5
---------------------------------------------------------------736
  16  1 10  7     2  8 15  9     12 11  6  5      4 14  3 13
   6 12  5 11    11 12  5  6      8  2  9 15     15  2  9  8
   3 13  4 14    14 13  4  3      1  7 16 10     10  7 16  1
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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.total.html Go
JUN JUL SEP
08
2005 2006 2007
22 captures
8 Jul 2006 - 7 Apr 2016
About this capture

```
 14  5 12  3     3  5 12 14    10 16  1  7     7 16  1 10
 11  4 13  6    16 10  7  1     5  3 14 12     2  9  8 15
---------------------------------------------------------------744
  1 16  7 10    15  9  2  8     6  4 11 13    12  5 14  3
 11  6 13  4     4  6 13 11     9 15  8  2     2 15  8  9
 14  3 12  5     5  3 12 14    16 10  1  7     7 10  1 16
  8  9  2 15    10 16  7  1     3  5 14 12    13  4 11  6
---------------------------------------------------------------748
  1 10 16  7    12  5  3 14    15  2  8  9     6 13 11  4
  8 15  9  2     2 15  9  8     5 12 14  3     3 12 14  5
 11  4  6 13    13  4  6 11    10  7  1 16    16  7  1 10
 14  5  3 12     7 10 16  1     4 13 11  6     9  2  8 15
---------------------------------------------------------------752
 16  7  1 10     5 12 14  3     2 15  9  8    11  4  6 13
  9  2  8 15    15  2  8  9    12  5  3 14    14  5  3 12
  6 13 11  4     4 13 11  6     7 10 16  1     1 10 16  7
  3 12 14  5    10  7  1 16    13  4  6 11     8 15  9  2
---------------------------------------------------------------756
 16  1 10  7     2  8 15  9    11 13  6  4     5 12  3 14
  6 11  4 13    13 11  4  6     8  2  9 15    15  2  9  8
  3 14  5 12    12 14  5  3     1  7 16 10    10  7 16  1
  9  8 15  2     7  1 10 16    14 12  3  5     4 13  6 11
---------------------------------------------------------------760
 10  1 16  7    13 11  6  4     8  2 15  9     3 12  5 14
 15  8  9  2     2  8  9 15    11 13  4  6     6 13  4 11
  5 14  3 12    12 14  3  5     1  7 10 16    16  7 10  1
  4 11  6 13     7  1 16 10    14 12  5  3     9  2 15  8
---------------------------------------------------------------764
  1  7 16 10    15  2  9  8    13  6 11  4     5  3 14 12
 11 13  4  6     6 13  4 11     2 15  8  9     9 15  8  2
 14 12  5  3     3 12  5 14     7 10  1 16    16 10  1  7
  8  2  9 15    10  7 16  1    12  3 14  5     4  6 11 13
---------------------------------------------------------------768
 16 10  1  7     2 15  8  9     4 11  6 13    12 14  3  5
  6  4 13 11    11  4 13  6    15  2  9  8     8  2  9 15
  3  5 12 14    14  5 12  3    10  7 16  1     1  7 16 10
  9 15  8  2     7 10  1 16     5 14  3 12    13 11  6  4
---------------------------------------------------------------772
  1 10  7 16     4  6 11 13    15  9  8  2    14  5 12  3
  8 15  2  9     9 15  2  8     6  4 13 11    11  4 13  6
 12  3 14  5     5  3 14 12    10 16  1  7     7 16  1 10
 13  6 11  4    16 10  7  1     3  5 12 14     2  9  8 15
---------------------------------------------------------------776
  1 16  7 10    15  9  2  8     4  6 13 11    14  3 12  5
 13  4 11  6     6  4 11 13     9 15  8  2     2 15  8  9
 12  5 14  3     3  5 14 12    16 10  1  7     7 10  1 16
  8  9  2 15    10 16  7  1     5  3 12 14    11  6 13  4
---------------------------------------------------------------780
  1 10 16  7    14  3  5 12    15  2  8  9     4 11 13  6
  8 15  9  2     2 15  9  8     3 14 12  5     5 14 12  3
 13  6  4 11    11  6  4 13    10  7  1 16    16  7  1 10
 12  3  5 14     7 10 16  1     6 11 13  4     9  2  8 15
---------------------------------------------------------------784
 16  7  1 10     3 14 12  5     2 15  9  8    13  6  4 11
  9  2  8 15    15  2  8  9    14  3  5 12    12  3  5 14
  4 11 13  6     6 11 13  4     7 10 16  1     1 10 16  7
  5 14 12  3    10  7  1 16    11  6  4 13     8 15  9  2
---------------------------------------------------------------788
 16  1 10  7     2  8 15  9    13 11  4  6     3 14  5 12
  4 13  6 11    11 13  6  4     8  2  9 15    15  2  9  8
  5 12  3 14    14 12  3  5     1  7 16 10    10  7 16  1
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.total.html Go JUN JUL SEP
08
22 captures
8 Jul 2006 - 7 Apr 2016 2005 2006 2007
About this capture

```
  3 12  5 14     14 12  5  3      1  7 10 16     16  7 10  1
  6 13  4 11      7  1 16 10     12 14  3  5      9  2 15  8
-----------------------------------------------------------------796
 12 14  1  7     10 11  8  5      3 13  2 16      9  4 15  6
  2  3 16 13     13  3 16  2     11 10  5  8      8 10  5 11
 15  6  9  4      4  6  9 15     14  7 12  1      1  7 12 14
  5 11  8 10      7 14  1 12      6  4 15  9     16 13  2  3
-----------------------------------------------------------------800
 12 14  1  7      2  3 16 13     11 10  5  8      9 15  4  6
  5 11  8 10     10 11  8  5      3  2 13 16     16  2 13  3
  4  6  9 15     15  6  9  4     14  7 12  1      1  7 12 14
 13  3 16  2      7 14  1 12      6 15  4  9      8 10  5 11
-----------------------------------------------------------------804
 12 14  1  7     10 11  8  5      3  2 13 16      9 15  4  6
 13  3 16  2      2  3 16 13     11 10  5  8      8 10  5 11
  4  6  9 15     15  6  9  4     14  7 12  1      1  7 12 14
  5 11  8 10      7 14  1 12      6 15  4  9     16  2 13  3
-----------------------------------------------------------------808
  1  7 14 12      5 10  3 16     13 11  8  2     15  6  9  4
  8 13  2 11     11 13  2  8     10  5 16  3      3  5 16 10
  9  4 15  6      6  4 15  9      7 12  1 14     14 12  1  7
 16 10  3  5     12  7 14  1      4  6  9 15      2 11  8 13
-----------------------------------------------------------------812
 12  1 14  7     10 16  3  5      8 11  2 13      4  6 15  9
  2  8 13 11     11  8 13  2     16 10  5  3      3 10  5 16
 15  9  4  6      6  9  4 15      1  7 12 14     14  7 12  1
  5 16  3 10      7  1 14 12      9  6 15  4     13 11  2  8
-----------------------------------------------------------------816
  1 14  7 12      5  3 10 16     13 11  8  2     15  6  9  4
  8 13  2 11     11 13  2  8      3  5 16 10     10  5 16  3
  9  4 15  6      6  4 15  9     14 12  1  7      7 12  1 14
 16  3 10  5     12 14  7  1      4  6  9 15      2 11  8 13
-----------------------------------------------------------------820
 12  1 14  7     10 16  3  5      8  2 11 13      4 15  6  9
 11  8 13  2      2  8 13 11     16 10  5  3      3 10  5 16
  6  9  4 15     15  9  4  6      1  7 12 14     14  7 12  1
  5 16  3 10      7  1 14 12      9 15  6  4     13  2 11  8
-----------------------------------------------------------------824
  1  7 14 12     13  2 11  8     15  6  9  4      5  3 16 10
  9 15  4  6      6 15  4  9      2 13  8 11     11 13  8  2
 16 10  5  3      3 10  5 16      7 12  1 14     14 12  1  7
  8  2 11 13     12  7 14  1     10  3 16  5      4  6  9 15
-----------------------------------------------------------------828
 12 14  1  7      2 11  8 13      4 15  6  9     16 10  3  5
  6  4  9 15     15  4  9  6     11  2 13  8      8  2 13 11
  3  5 16 10     10  5 16  3     14  7 12  1      1  7 12 14
 13 11  8  2      7 14  1 12      5 10  3 16      9 15  6  4
-----------------------------------------------------------------832
  1 12  7 14      4  6  9 15     13 11  8  2     16  5 10  3
  8 13  2 11     11 13  2  8      6  4 15  9      9  4 15  6
 10  3 16  5      5  3 16 10     12 14  1  7      7 14  1 12
 15  6  9  4     14 12  7  1      3  5 10 16      2 11  8 13
-----------------------------------------------------------------836
  1 14  7 12     13 11  2  8      4  6 15  9     16  3 10  5
 15  4  9  6      6  4  9 15     11 13  8  2      2 13  8 11
 10  5 16  3      3  5 16 10     14 12  1  7      7 12  1 14
  8 11  2 13     12 14  7  1      5  3 10 16      9  6 15  4
-----------------------------------------------------------------840
  1 12 14  7     16  3  5 10     13  2  8 11      4  9 15  6
  8 13 11  2      2 13 11  8      3 16 10  5      5 16 10  3
 15  6  4  9      9  6  4 15     12  7  1 14     14  7  1 12
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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.total.html Go JUN JUL SEP
22 captures 08
8 Jul 2006 - 7 Apr 2016 2005 2006 2007
About this capture

```
 10  5 16  3     3  5 16 10    14 12  1  7     7 12  1 14
 15  4  9  6    12 14  7  1     5  3 10 16     2 13  8 11
------------------------------------------------------------848
  1 12  7 14    11 13  2  8     6  4 15  9    16  5 10  3
 15  6  9  4     4  6  9 15    13 11  8  2     2 11  8 13
 10  3 16  5     5  3 16 10    12 14  1  7     7 14  1 12
  8 13  2 11    14 12  7  1     3  5 10 16     9  4 15  6
------------------------------------------------------------852
  1 14 12  7    16  5  3 10    11  2  8 13     6  9 15  4
  8 11 13  2     2 11 13  8     5 16 10  3     3 16 10  5
 15  4  6  9     9  4  6 15    14  7  1 12    12  7  1 14
 10  5  3 16     7 14 12  1     4  9 15  6    13  2  8 11
------------------------------------------------------------856
 14  7  1 12     3 16 10  5     2 13 11  8    15  6  4  9
 11  2  8 13    13  2  8 11    16  3  5 10    10  3  5 16
  4  9 15  6     6  9 15  4     7 12 14  1     1 12 14  7
  5 16 10  3    12  7  1 14     9  6  4 15     8 13 11  2
------------------------------------------------------------860
 14  1 12  7     2  8 13 11    15  9  4  6     3 16  5 10
  4 15  6  9     9 15  6  4     8  2 11 13    13  2 11  8
  5 10  3 16    16 10  3  5     1  7 14 12    12  7 14  1
 11  8 13  2     7  1 12 14    10 16  5  3     6  9  4 15
------------------------------------------------------------864
 12  7  1 14     5 16 10  3     2 11 13  8    15  4  6  9
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Back to Suzuki's Magic Squares

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http://www.aks.de/heimbach/quadrate/jupiter/880.htm Go
AUG DEC JUN
25 captures 03
9 Jan 2001 - 22 Oct 2010 2000 2001 2002
About this capture

880 Jupiter-Quadrate

00 01 14 15	00 01 14 15	00 01 15 14	00 02 13 15	00 02 13 15	00 02 13 15	00 02 13 15	00 02 15 13
12 13 02 03	11 13 02 04	12 13 03 02	14 12 03 01	09 12 03 06	11 12 03 04	14 12 03 01	12 14 01 03
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http://www.aks.de/heimbach/quadrate/jupiter/880.htm Go
AUG DEC JUN
03
2000 2001 2002
25 captures
9 Jan 2001 - 22 Oct 2010
About this capture

00 09 06 15	00 09 06 15	00 09 06 15	00 09 06 15	00 09 06 15	00 09 06 15	00 09 06 15	00 09 07 14
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http://www.aks.de/heimbach/quadrate/jupiter/880.htm Go AUG DEC JUN
25 captures 03
9 Jan 2001 - 22 Oct 2010 2000 2001 2002
About this capture

12 09 02 07	06 03 08 13	13 08 03 06	07 02 09 12	12 11 00 07	15 11 00 04	15 11 00 04	06 02 09 13
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http://www.aks.de/heimbach/quadrate/jupiter/880.htm Go AUG DEC JUN
03
2000 2001 2002
25 captures
9 Jan 2001 - 22 Oct 2010
About this capture

07 05 08 10	11 09 04 06	10 04 09 07	05 06 11 08	09 10 07 04	07 04 09 10	11 08 05 06	04 07 11 08
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http://www.aks.de/heimbach/quadrate/jupiter/880.htm Go AUG DEC JUN
25 captures 03
9 Jan 2001 - 22 Oct 2010 2000 2001 2002
About this capture

15 01 04 10	14 05 00 11	13 06 01 10	14 03 04 09	15 01 06 08	14 01 08 07	15 03 12 00	15 10 05 00
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http://www.aks.de/heimbach/quadrate/jupiter/880.htm Go AUG DEC JUN 03 2000 2001 2002
25 captures
9 Jan 2001 - 22 Oct 2010
About this capture

03 09 04 14	03 09 06 12	03 09 06 12	03 09 06 12	03 09 12 06	03 09 12 06	03 09 14 04	03 09 14 04
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08 05 06 11	11 06 05 08	11 06 05 08	09 01 14 06	11 13 00 06	08 06 05 11	11 05 06 08	11 05 06 08
04 11 08 07	04 11 08 07	04 12 03 11	04 12 03 11	04 13 02 11	04 13 03 10	04 14 01 11	04 14 01 11
14 01 02 13	13 02 01 14	15 07 00 08	15 07 00 08	15 10 05 00	14 09 07 00	15 09 06 00	15 08 07 00
03 12 15 00	03 12 15 00	01 09 14 06	02 10 13 05	03 06 09 12	01 02 12 15	03 05 10 12	02 03 12 13
09 06 05 10	10 05 06 09	10 02 13 05	09 01 14 06	08 01 14 07	11 06 08 05	08 02 13 07	09 05 10 06
05 00 14 11	05 00 14 11	05 00 15 10	05 00 15 10	05 00 15 10	05 00 15 10	05 00 15 10	05 00 15 10
15 10 04 01	10 15 01 04	06 14 09 01	14 11 04 01	11 14 01 04	02 11 04 13	08 14 01 07	14 06 01 09
02 07 09 12	09 12 02 07	11 03 04 12	02 07 08 13	08 13 02 07	14 07 08 01	11 13 02 04	03 11 12 04
08 13 03 06	06 03 13 08	08 13 02 07	09 12 03 06	06 03 12 09	09 12 03 06	06 03 12 09	08 13 02 07
05 01 14 10	05 01 14 10	05 02 12 11	05 02 12 11	05 02 13 10	05 02 13 10	05 02 13 10	05 02 13 10
11 15 00 04	06 15 00 09	14 09 07 00	09 14 00 07	11 04 03 12	03 12 11 04	11 15 00 04	06 15 00 09
06 12 03 09	11 12 03 04	03 04 10 13	10 13 03 04	06 09 14 01	14 01 06 09	06 12 03 09	11 12 03 04
08 02 13 07	08 02 13 07	08 15 01 06	06 01 15 08	08 15 00 07	08 15 00 07	08 01 14 07	08 01 14 07
05 02 14 09	05 02 14 09	05 02 14 09	05 02 14 09	05 02 14 09	05 02 15 08	05 02 15 08	05 03 12 10
08 15 03 04	11 12 00 07	12 11 07 00	15 08 04 03	03 08 04 15	14 09 04 03	09 14 03 04	14 08 07 01
11 12 00 07	08 15 03 04	03 04 08 15	00 07 11 12	12 07 11 00	00 07 10 13	10 13 00 07	02 04 11 13

http://www.aks.de/heimbach/quadrate/jupiter/880.htm Go AUG DEC JUN
25 captures 03
9 Jan 2001 - 22 Oct 2010 2000 2001 2002 About this capture

05 06 11 08 13 03 00 14 02 12 15 01 10 09 04 07	05 08 11 06 14 03 00 13 02 15 12 01 09 04 07 10	05 08 11 06 15 02 01 12 00 13 14 03 10 07 04 09	05 08 11 06 12 02 01 15 03 13 14 00 10 07 04 09	05 09 10 06 14 02 01 13 00 12 15 03 11 07 04 08	05 09 10 06 14 02 01 13 03 15 12 00 08 04 07 11	05 10 09 06 15 00 03 12 02 13 14 01 08 07 04 11	05 10 09 06 12 03 00 15 02 13 14 01 11 04 07 08
05 11 06 08 15 04 09 02 00 03 14 13 10 12 01 07	05 11 06 08 14 03 00 13 01 12 15 02 10 04 09 07	05 11 06 08 13 03 00 14 02 12 15 01 10 04 09 07	05 11 08 06 14 00 03 13 02 12 15 01 09 07 04 10	05 11 08 06 12 02 01 15 03 13 14 00 10 04 07 09	05 11 08 06 15 02 01 12 00 13 14 03 10 04 07 09	05 12 03 10 14 11 04 01 02 07 08 13 09 00 15 06	05 13 02 10 14 06 01 09 03 11 12 04 08 00 15 07
05 13 10 02 14 06 09 01 03 11 04 12 08 00 07 15	05 14 02 09 15 08 04 03 00 07 11 12 10 01 13 06	06 00 15 09 05 13 10 02 11 03 04 12 08 14 01 07	06 00 15 09 13 05 02 10 03 11 12 04 08 14 01 07	06 01 14 09 11 04 03 12 05 10 13 02 08 15 00 07	06 01 14 09 03 12 11 04 13 02 05 10 08 15 00 07	06 01 15 08 11 14 00 05 04 13 03 10 09 02 12 07	06 01 15 08 05 14 00 11 10 13 03 04 09 02 12 07
06 03 13 08 14 05 11 00 09 10 04 07 01 12 02 15	06 03 13 08 04 15 01 10 11 12 02 05 09 00 14 07	06 03 13 08 10 15 01 04 05 12 02 11 09 00 14 07	06 03 13 08 15 12 02 01 00 11 05 14 09 04 10 07	06 04 11 09 15 03 00 12 01 13 14 02 08 10 05 07	06 05 10 09 13 02 01 14 03 12 15 00 08 11 04 07	06 05 11 08 14 13 03 00 01 10 04 15 09 02 12 07	06 10 05 09 15 03 00 12 01 13 14 02 08 04 11 07
06 11 04 09 13 02 01 14 03 12 15 00 08 05 10 07	06 11 05 08 15 04 10 01 00 03 13 14 09 12 02 07	06 13 03 08 14 05 11 00 09 10 04 07 01 02 12 15	06 13 03 08 14 05 11 00 01 02 12 15 09 10 04 07	07 01 12 10 15 04 09 02 08 11 06 05 00 14 03 13	07 02 12 09 15 04 10 01 08 11 05 06 00 13 03 14	07 12 01 10 15 04 09 02 08 11 06 05 00 03 14 13	07 12 02 09 15 04 10 01 08 11 05 06 00 03 13 14

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.complete.htm Go DEC JAN JUL
9 captures 17
17 Jan 2007 - 20 Jul 2016 2006 2007 2009 About this capture

Mutsumi Suzuki
[Magic Squares]

Panmagic square of 4 x 4 (48 = 3 X 16)

In 4 X 4 panmagic squares, the rows, columns, and every diagonal, including the so-called 'broken' diagonals, sum to 34.

```
  A * * *
  * B * *
  * * C *
  * * * D     A + B + C + D = 34

  * A * *
  * * B *
  * * * C
  D * * *     A + B + C + D = 34

  * * A *
  * * * B
  C * * *
  * D * *     A + B + C + D = 34
...
...
and so on.
```

The following 48 squares are all panmagic.

The squares are classified into three groups.
The 16 squares belonging to each group can be derived from each other by means of column and/or row shift transformations.
For this reason we may say that there are only three fundamental panmagic squares.

```
(Group A)

  1 14  4 15    15  1 14  4     4 15  1 14    14  4 15  1
  8 11  5 10    10  8 11  5     5 10  8 11    11  5 10  8
 13  2 16  3     3 13  2 16    16  3 13  2     2 16  3 13
 12  7  9  6     6 12  7  9     9  6 12  7     7  9  6 12
---------------------------------------------------------------  4
 12  7  9  6     6 12  7  9     9  6 12  7     7  9  6 12
  1 14  4 15    15  1 14  4     4 15  1 14    14  4 15  1
  8 11  5 10    10  8 11  5     5 10  8 11    11  5 10  8
 13  2 16  3     3 13  2 16    16  3 13  2     2 16  3 13
---------------------------------------------------------------  8
 13  2 16  3     3 13  2 16    16  3 13  2     2 16  3 13
 12  7  9  6     6 12  7  9     9  6 12  7     7  9  6 12
  1 14  4 15    15  1 14  4     4 15  1 14    14  4 15  1
  8 11  5 10    10  8 11  5     5 10  8 11    11  5 10  8
--------------------------------------------------------------- 12
  8 11  5 10    10  8 11  5     5 10  8 11    11  5 10  8
 13  2 16  3     3 13  2 16    16  3 13  2     2 16  3 13
 12  7  9  6     6 12  7  9     9  6 12  7     7  9  6 12
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.complete.htm Go DEC JAN JUL
9 captures 17
17 Jan 2007 - 20 Jul 2016 2006 2007 2009
About this capture

```
  1 12  6 15    15  1 12  6     6 15  1 12    12  6 15  1
  8 13  3 10    10  8 13  3     3 10  8 13    13  3 10  8
 11  2 16  5     5 11  2 16    16  5 11  2     2 16  5 11
 14  7  9  4     4 14  7  9     9  4 14  7     7  9  4 14
--------------------------------------------------------------- 20
 14  7  9  4     4 14  7  9     9  4 14  7     7  9  4 14
  1 12  6 15    15  1 12  6     6 15  1 12    12  6 15  1
  8 13  3 10    10  8 13  3     3 10  8 13    13  3 10  8
 11  2 16  5     5 11  2 16    16  5 11  2     2 16  5 11
--------------------------------------------------------------- 24
 11  2 16  5     5 11  2 16    16  5 11  2     2 16  5 11
 14  7  9  4     4 14  7  9     9  4 14  7     7  9  4 14
  1 12  6 15    15  1 12  6     6 15  1 12    12  6 15  1
  8 13  3 10    10  8 13  3     3 10  8 13    13  3 10  8
--------------------------------------------------------------- 28
  8 13  3 10    10  8 13  3     3 10  8 13    13  3 10  8
 11  2 16  5     5 11  2 16    16  5 11  2     2 16  5 11
 14  7  9  4     4 14  7  9     9  4 14  7     7  9  4 14
  1 12  6 15    15  1 12  6     6 15  1 12    12  6 15  1
--------------------------------------------------------------- 32

(Group C)

  1 12  7 14    14  1 12  7     7 14  1 12    12  7 14  1
  8 13  2 11    11  8 13  2     2 11  8 13    13  2 11  8
 10  3 16  5     5 10  3 16    16  5 10  3     3 16  5 10
 15  6  9  4     4 15  6  9     9  4 15  6     6  9  4 15
--------------------------------------------------------------- 36
 15  6  9  4     4 15  6  9     9  4 15  6     6  9  4 15
  1 12  7 14    14  1 12  7     7 14  1 12    12  7 14  1
  8 13  2 11    11  8 13  2     2 11  8 13    13  2 11  8
 10  3 16  5     5 10  3 16    16  5 10  3     3 16  5 10
--------------------------------------------------------------- 40
 10  3 16  5     5 10  3 16    16  5 10  3     3 16  5 10
 15  6  9  4     4 15  6  9     9  4 15  6     6  9  4 15
  1 12  7 14    14  1 12  7     7 14  1 12    12  7 14  1
  8 13  2 11    11  8 13  2     2 11  8 13    13  2 11  8
--------------------------------------------------------------- 44
  8 13  2 11    11  8 13  2     2 11  8 13    13  2 11  8
 10  3 16  5     5 10  3 16    16  5 10  3     3 16  5 10
 15  6  9  4     4 15  6  9     9  4 15  6     6  9  4 15
  1 12  7 14    14  1 12  7     7 14  1 12    12  7 14  1
--------------------------------------------------------------- 48


          48             0
```

Back to **[Suzuki's Magic Squares]**

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.complete.htm Go
9 captures
17 Jan 2007 - 20 Jul 2016
DEC JAN JUL
17
2006 2007 2009
About this capture

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.selfcompl.htm Go DEC JAN MAY
7 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2011
About this capture

Mutsumi Suzuki
Magic Squares

Selfcomplementary magic squares of 4 x 4

Complementary squares have the property that a new magic square results when every entry, n, is replaced by 17 - n. The two squares are said to be complementary to each other.

```
Example;

      1  2 16 15           16 15  1  2
     13 14  4  3            4  3 13 14
     12  7  9  6   <----->  5 10  8 11
      8 11  5 10            9  6 12  7
```

If the complement square is itself, it is called self-complementary.

There are 352 self-conplementary magic squares of 4x4.
(No panmagic squares are found in this set.)

```
(Group A) 48 axi-symmetric squares;

  1 15 14  4    16  3  2 13     6  9 12  7    11  5  8 10
 12  6  7  9     9  6  7 12     3 16 13  2     2 16 13  3
  8 10 11  5     5 10 11  8    15  4  1 14    14  4  1 15
 13  3  2 16     4 15 14  1    10  5  8 11     7  9 12  6
-------------------------------------------------------------  4
  1 14 15  4    16  2  3 13     7  9 12  6    10  5  8 11
 12  7  6  9     9  7  6 12     2 16 13  3     3 16 13  2
  8 11 10  5     5 11 10  8    14  4  1 15    15  4  1 14
 13  2  3 16     4 14 15  1    11  5  8 10     6  9 12  7
-------------------------------------------------------------  8
 15  1  4 14     2 13 16  3    12  7  6  9     5 11 10  8
  6 12  9  7     7 12  9  6    13  2  3 16    16  2  3 13
 10  8  5 11    11  8  5 10     1 14 15  4     4 14 15  1
  3 13 16  2    14  1  4 15     8 11 10  5     9  7  6 12
------------------------------------------------------------- 12
 15  4  1 14     2 16 13  3     9  7  6 12     8 11 10  5
  6  9 12  7     7  9 12  6    16  2  3 13    13  2  3 16
 10  5  8 11    11  5  8 10     4 14 15  1     1 14 15  4
  3 16 13  2    14  4  1 15     5 11 10  8    12  7  6  9
------------------------------------------------------------- 16
  1 15 12  6    16  5  2 11     4  9 14  7    13  3  8 10
 14  4  7  9     9  4  7 14     5 16 11  2     2 16 11  5
  8 10 13  3     3 10 13  8    15  6  1 12    12  6  1 15
 11  5  2 16     6 15 12  1    10  3  8 13     7  9 14  4
------------------------------------------------------------- 20
  1 12 15  6    16  2  5 11     7  9 14  4    10  3  8 13
 14  7  4  9     9  7  4 14     2 16 11  5     5 16 11  2
  8 13 10  3     3 13 10  8    12  6  1 15    15  6  1 12
 11  2  5 16     6 12 15  1    13  3  8 10     4  9 14  7
------------------------------------------------------------- 24
 15  1  6 12     2 11 16  5    14  7  4  9     3 13 10  8
  4 14  9  7     7 14  9  4    11  2  5 16    16  2  5 11
 10  8  3 13    13  8  3 10     1 12 15  6     6 12 15  1
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.selfcompl.htm Go DEC JAN MAY
7 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2011
About this capture

```
 10  3  8 13    13  3  8 10     6 12 15  1     1 12 15  6
  5 16 11  2    12  6  1 15     3 13 10  8    14  7  4  9
-------------------------------------------------------------- 32
  1 12 14  7    16  3  5 10    13  2  8 11     4  9 15  6
  8 13 11  2     2 13 11  8     3 16 10  5     5 16 10  3
 15  6  4  9     9  6  4 15    12  7  1 14    14  7  1 12
 10  3  5 16     7 12 14  1     6  9 15  4    11  2  8 13
-------------------------------------------------------------- 36
  1 14 12  7    16  5  3 10    11  2  8 13     6  9 15  4
  8 11 13  2     2 11 13  8     5 16 10  3     3 16 10  5
 15  4  6  9     9  4  6 15    14  7  1 12    12  7  1 14
 10  5  3 16     7 14 12  1     4  9 15  6    13  2  8 11
-------------------------------------------------------------- 40
 14  7  1 12     3 16 10  5     2 13 11  8    15  6  4  9
 11  2  8 13    13  2  8 11    16  3  5 10    10  3  5 16
  4  9 15  6     6  9 15  4     7 12 14  1     1 12 14  7
  5 16 10  3    12  7  1 14     9  6  4 15     8 13 11  2
-------------------------------------------------------------- 44
 12  7  1 14     5 16 10  3     2 11 13  8    15  4  6  9
 13  2  8 11    11  2  8 13    16  5  3 10    10  5  3 16
  6  9 15  4     4  9 15  6     7 14 12  1     1 14 12  7
  3 16 10  5    14  7  1 12     9  4  6 15     8 11 13  2
-------------------------------------------------------------- 48


(Group B)  304 symmetrical squares;

 16  4  5  9     8 13 12  1     3  6 15 10     7 11  2 14
 15  3 10  6     6  3 10 15    13  8  1 12    12  8  1 13
  2 14  7 11    11 14  7  2     4  9 16  5     5  9 16  4
  1 13 12  8     9  4  5 16    14 11  2  7    10  6 15  3
--------------------------------------------------------------  4
 15  3  6 10     7 14 11  2     4  5 16  9     8 12  1 13
 16  4  9  5     5  4  9 16    14  7  2 11    11  7  2 14
  1 13  8 12    12 13  8  1     3 10 15  6     6 10 15  3
  2 14 11  7    10  3  6 15    13 12  1  8     9  5 16  4
--------------------------------------------------------------  8
 16  5  4  9     8 12 13  1     3  6 15 10     7 11  2 14
 15  3 10  6     6  3 10 15    12  8  1 13    13  8  1 12
  2 14  7 11    11 14  7  2     5  9 16  4     4  9 16  5
  1 12 13  8     9  5  4 16    14 11  2  7    10  6 15  3
-------------------------------------------------------------- 12
 15  3  6 10     7 14 11  2     8 12  1 13     4  5 16  9
  1  8 13 12    12  8 13  1    14  7  2 11    11  7  2 14
 16  9  4  5     5  9  4 16     3 10 15  6     6 10 15  3
  2 14 11  7    10  3  6 15     9  5 16  4    13 12  1  8
-------------------------------------------------------------- 16
 16  2  5 11     6 15 12  1     4  7 14  9     8 10  3 13
 14  4  9  7     7  4  9 14    15  6  1 12    12  6  1 15
  3 13  8 10    10 13  8  3     2 11 16  5     5 11 16  2
  1 15 12  6    11  2  5 16    13 10  3  8     9  7 14  4
-------------------------------------------------------------- 20
 16  2  7  9     8 15 10  1     4  5 14 11     6 12  3 13
 14  4 11  5     5  4 11 14    15  8  1 10    10  8  1 15
  3 13  6 12    12 13  6  3     2  9 16  7     7  9 16  2
  1 15 10  8     9  2  7 16    13 12  3  6    11  5 14  4
-------------------------------------------------------------- 24
 16  2  7  9     8 15 10  1     6 12  3 13     4  5 14 11
  3  6 13 12    12  6 13  3    15  8  1 10    10  8  1 15
 14 11  4  5     5 11  4 14     2  9 16  7     7  9 16  2
  1 15 10  8     9  2  7 16    11  5 14  4    13 12  3  6
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.selfcompl.htm Go DEC JAN MAY
7 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2011
About this capture

```
  1 15 12  6    11  2  5 16     9  7 14  4    13 10  3  8
------------------------------------------------------------- 32
 16  2  5 11     6 15 12  1     3 10 13  8     9  7  4 14
 13  3  8 10    10  3  8 13    15  6  1 12    12  6  1 15
  4 14  9  7     7 14  9  4     2 11 16  5     5 11 16  2
  1 15 12  6    11  2  5 16    14  7  4  9     8 10 13  3
------------------------------------------------------------- 36
  4 14  9  7    10  3  8 13    15  6  1 12     5 11 16  2
  1 15 12  6     6 15 12  1     3 10 13  8     8 10 13  3
 16  2  5 11    11  2  5 16    14  7  4  9     9  7  4 14
 13  3  8 10     7 14  9  4     2 11 16  5    12  6  1 15
------------------------------------------------------------- 40
 16  3  5 10     7 14 12  1     2 11 13  8     9  6  4 15
 13  2  8 11    11  2  8 13    14  7  1 12    12  7  1 14
  4 15  9  6     6 15  9  4     3 10 16  5     5 10 16  3
  1 14 12  7    10  3  5 16    15  6  4  9     8 11 13  2
------------------------------------------------------------- 44
  4 15  9  6    11  2  8 13    14  7  1 12     5 10 16  3
  1 14 12  7     7 14 12  1     2 11 13  8     8 11 13  2
 16  3  5 10    10  3  5 16    15  6  4  9     9  6  4 15
 13  2  8 11     6 15  9  4     3 10 16  5    12  7  1 14
------------------------------------------------------------- 48
 16  2  9  7    10 15  8  1     3  6 13 12     5 11  4 14
 13  3 12  6     6  3 12 13    15 10  1  8     8 10  1 15
  4 14  5 11    11 14  5  4     2  7 16  9     9  7 16  2
  1 15  8 10     7  2  9 16    14 11  4  5    12  6 13  3
------------------------------------------------------------- 52
  4 14  5 11     6  3 12 13    15 10  1  8     9  7 16  2
  1 15  8 10    10 15  8  1     3  6 13 12    12  6 13  3
 16  2  9  7     7  2  9 16    14 11  4  5     5 11  4 14
 13  3 12  6    11 14  5  4     2  7 16  9     8 10  1 15
------------------------------------------------------------- 56
 16  3  9  6    11 14  8  1     2  7 13 12     5 10  4 15
 13  2 12  7     7  2 12 13    14 11  1  8     8 11  1 14
  4 15  5 10    10 15  5  4     3  6 16  9     9  6 16  3
  1 14  8 11     6  3  9 16    15 10  4  5    12  7 13  2
------------------------------------------------------------- 60
  4 15  5 10     7  2 12 13    14 11  1  8     9  6 16  3
  1 14  8 11    11 14  8  1     2  7 13 12    12  7 13  2
 16  3  9  6     6  3  9 16    15 10  4  5     5 10  4 15
 13  2 12  7    10 15  5  4     3  6 16  9     8 11  1 14
------------------------------------------------------------- 64
 16  5  3 10     7 12 14  1     2 11 13  8     9  6  4 15
 13  2  8 11    11  2  8 13    12  7  1 14    14  7  1 12
  4 15  9  6     6 15  9  4     5 10 16  3     3 10 16  5
  1 12 14  7    10  5  3 16    15  6  4  9     8 11 13  2
------------------------------------------------------------- 68
  4 15  9  6    11  2  8 13     5 10 16  3    14  7  1 12
 16  5  3 10    10  5  3 16     2 11 13  8     8 11 13  2
  1 12 14  7     7 12 14  1    15  6  4  9     9  6  4 15
 13  2  8 11     6 15  9  4    12  7  1 14     3 10 16  5
------------------------------------------------------------- 72
 13  2 11  8     9 15  6  4     5  3 16 10     7 14  1 12
 16  5 10  3     3  5 10 16    15  9  4  6     6  9  4 15
  1 12  7 14    14 12  7  1     2  8 13 11    11  8 13  2
  4 15  6  9     8  2 11 13    12 14  1  7    10  3 16  5
------------------------------------------------------------- 76
 16  2  9  7    10 15  8  1     5 11  4 14     3  6 13 12
  4  5 14 11    11  5 14  4    15 10  1  8     8 10  1 15
 13 12  3  6     6 12  3 13     2  7 16  9     9  7 16  2
  1 15  8 10     7  2  9 16    12  6 13  3    14 11  4  5
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.selfcompl.htm Go DEC JAN MAY
7 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2011
About this capture

```
 13 12  3  6    11  5 14  4     2  7 16  9     8 10  1 15
---------------------------------------------------------------- 84
 13  2 11  8     9 15  6  4     7 14  1 12     5  3 16 10
  1  7 12 14    14  7 12  1    15  9  4  6     6  9  4 15
 16 10  5  3     3 10  5 16     2  8 13 11    11  8 13  2
  4 15  6  9     8  2 11 13    10  3 16  5    12 14  1  7
---------------------------------------------------------------- 88
 16  2  5 11     6 15 12  1     9  7  4 14     3 10 13  8
  4  9 14  7     7  9 14  4    15  6  1 12    12  6  1 15
 13  8  3 10    10  8  3 13     2 11 16  5     5 11 16  2
  1 15 12  6    11  2  5 16     8 10 13  3    14  7  4  9
---------------------------------------------------------------- 92
  4  9 14  7    10  8  3 13    15  6  1 12     5 11 16  2
  1 15 12  6     6 15 12  1     8 10 13  3     3 10 13  8
 16  2  5 11    11  2  5 16     9  7  4 14    14  7  4  9
 13  8  3 10     7  9 14  4     2 11 16  5    12  6  1 15
---------------------------------------------------------------- 96
 16  9  3  6    11  8 14  1     2  7 13 12     5 10  4 15
 13  2 12  7     7  2 12 13     8 11  1 14    14 11  1  8
  4 15  5 10    10 15  5  4     9  6 16  3     3  6 16  9
  1  8 14 11     6  9  3 16    15 10  4  5    12  7 13  2
----------------------------------------------------------------100
  4 15  5 10     7  2 12 13     9  6 16  3    14 11  1  8
 16  9  3  6     6  9  3 16     2  7 13 12    12  7 13  2
  1  8 14 11    11  8 14  1    15 10  4  5     5 10  4 15
 13  2 12  7    10 15  5  4     8 11  1 14     3  6 16  9
----------------------------------------------------------------104
  1 14 15  4    13  3  2 16     9  7 12  6    11 10  5  8
 12  9  6  7     7  9  6 12     3 13 16  2     2 13 16  3
  5  8 11 10    10  8 11  5    14  4  1 15    15  4  1 14
 16  3  2 13     4 14 15  1     8 10  5 11     6  7 12  9
----------------------------------------------------------------108
  1 15 14  4    13  2  3 16     9  7 12  6    11 10  5  8
 12  9  6  7     7  9  6 12     2 13 16  3     3 13 16  2
  5  8 11 10    10  8 11  5    15  4  1 14    14  4  1 15
 16  2  3 13     4 15 14  1     8 10  5 11     6  7 12  9
----------------------------------------------------------------112
  1 15 14  4    13  2  3 16    12  7  6  9     8 10 11  5
  6 12  9  7     7 12  9  6     2 13 16  3     3 13 16  2
 11  5  8 10    10  5  8 11    15  4  1 14    14  4  1 15
 16  2  3 13     4 15 14  1     5 10 11  8     9  7  6 12
----------------------------------------------------------------116
 14  4  1 15     2 13 16  3     7 12  9  6    11  5  8 10
  9  7  6 12    12  7  6  9    13  2  3 16    16  2  3 13
  8 10 11  5     5 10 11  8     4 15 14  1     1 15 14  4
  3 13 16  2    15  4  1 14    10  5  8 11     6 12  9  7
----------------------------------------------------------------120
  1 14 15  4    13  3  2 16    12  7  6  9     8 10 11  5
  6 12  9  7     7 12  9  6     3 13 16  2     2 13 16  3
 11  5  8 10    10  5  8 11    14  4  1 15    15  4  1 14
 16  3  2 13     4 14 15  1     5 10 11  8     9  7  6 12
----------------------------------------------------------------124
 14  4  1 15     2 13 16  3     7  9 12  6    11  8  5 10
 12  7  6  9     9  7  6 12    13  2  3 16    16  2  3 13
  5 10 11  8     8 10 11  5     4 15 14  1     1 15 14  4
  3 13 16  2    15  4  1 14    10  8  5 11     6  9 12  7
----------------------------------------------------------------128
  1 15 14  4    13  2  3 16    12  6  7  9     8 11 10  5
  7 12  9  6     6 12  9  7     2 13 16  3     3 13 16  2
 10  5  8 11    11  5  8 10    15  4  1 14    14  4  1 15
 16  2  3 13     4 15 14  1     5 11 10  8     9  6  7 12
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.selfcompl.htm Go DEC JAN MAY
7 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2011
About this capture

```
  3 16 13  2    15  1  4 14    10  5  8 11     6 12  9  7
-------------------------------------------------------------136
  1 14 15  4    13  3  2 16     9 12  7  6    11  5 10  8
  7  9  6 12    12  9  6  7     3 13 16  2     2 13 16  3
 10  8 11  5     5  8 11 10    14  4  1 15    15  4  1 14
 16  3  2 13     4 14 15  1     8  5 10 11     6 12  7  9
-------------------------------------------------------------140
  1 14 15  4    13  3  2 16    12  6  7  9     8 11 10  5
  7 12  9  6     6 12  9  7     3 13 16  2     2 13 16  3
 10  5  8 11    11  5  8 10    14  4  1 15    15  4  1 14
 16  3  2 13     4 14 15  1     5 11 10  8     9  6  7 12
-------------------------------------------------------------144
 14  1  4 15     2 16 13  3     7  9 12  6    11  8  5 10
 12  7  6  9     9  7  6 12    16  2  3 13    13  2  3 16
  5 10 11  8     8 10 11  5     1 15 14  4     4 15 14  1
  3 16 13  2    15  1  4 14    10  8  5 11     6  9 12  7
-------------------------------------------------------------148
  1 15 14  4    13  2  3 16     9 12  7  6    11  5 10  8
  7  9  6 12    12  9  6  7     2 13 16  3     3 13 16  2
 10  8 11  5     5  8 11 10    15  4  1 14    14  4  1 15
 16  2  3 13     4 15 14  1     8  5 10 11     6 12  7  9
-------------------------------------------------------------152
 16  2  7  9     8 15 10  1     4 14  5 11     6  3 12 13
  5  4 11 14    14  4 11  5    15  8  1 10    10  8  1 15
 12 13  6  3     3 13  6 12     2  9 16  7     7  9 16  2
  1 15 10  8     9  2  7 16    13  3 12  6    11 14  5  4
-------------------------------------------------------------156
 16  2  7  9     8 15 10  1     6  3 12 13     4 14  5 11
 12  6 13  3     3  6 13 12    15  8  1 10    10  8  1 15
  5 11  4 14    14 11  4  5     2  9 16  7     7  9 16  2
  1 15 10  8     9  2  7 16    11 14  5  4    13  3 12  6
-------------------------------------------------------------160
 16  3 10  5    12 14  7  1     2  8 11 13     4  9  6 15
 11  2 13  8     8  2 13 11    14 12  1  7     7 12  1 14
  6 15  4  9     9 15  4  6     3  5 16 10    10  5 16  3
  1 14  7 12     5  3 10 16    15  9  6  4    13  8 11  2
-------------------------------------------------------------164
 16  3  5 10     7 14 12  1     2 13 11  8     9  4  6 15
 11  2  8 13    13  2  8 11    14  7  1 12    12  7  1 14
  6 15  9  4     4 15  9  6     3 10 16  5     5 10 16  3
  1 14 12  7    10  3  5 16    15  4  6  9     8 13 11  2
-------------------------------------------------------------168
 11  2  8 13     4 15  9  6    14  7  1 12     5 10 16  3
  1 14 12  7     7 14 12  1    15  4  6  9     9  4  6 15
 16  3  5 10    10  3  5 16     2 13 11  8     8 13 11  2
  6 15  9  4    13  2  8 11     3 10 16  5    12  7  1 14
-------------------------------------------------------------172
 16  2  9  7    10 15  8  1     3 13  6 12     5  4 11 14
  6  3 12 13    13  3 12  6    15 10  1  8     8 10  1 15
 11 14  5  4     4 14  5 11     2  7 16  9     9  7 16  2
  1 15  8 10     7  2  9 16    14  4 11  5    12 13  6  3
-------------------------------------------------------------176
  6  3 12 13     4 14  5 11    15 10  1  8     9  7 16  2
  1 15  8 10    10 15  8  1    14  4 11  5     5  4 11 14
 16  2  9  7     7  2  9 16     3 13  6 12    12 13  6  3
 11 14  5  4    13  3 12  6     2  7 16  9     8 10  1 15
-------------------------------------------------------------180
 16  5  3 10     7 12 14  1     2 13 11  8     9  4  6 15
 11  2  8 13    13  2  8 11    12  7  1 14    14  7  1 12
  6 15  9  4     4 15  9  6     5 10 16  3     3 10 16  5
  1 12 14  7    10  5  3 16    15  4  6  9     8 13 11  2
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.selfcompl.htm Go DEC JAN MAY
7 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2011 About this capture

```
  6 15  9  4    13  2  8 11    12  7  1 14     3 10 16  5
----------------------------------------------------------------188
 16  2  9  7    10 15  8  1     5  4 11 14     3 13  6 12
 11  5 14  4     4  5 14 11    15 10  1  8     8 10  1 15
  6 12  3 13    13 12  3  6     2  7 16  9     9  7 16  2
  1 15  8 10     7  2  9 16    12 13  6  3    14  4 11  5
----------------------------------------------------------------192
  6 12  3 13     4  5 14 11    15 10  1  8     9  7 16  2
  1 15  8 10    10 15  8  1     5  4 11 14    14  4 11  5
 16  2  9  7     7  2  9 16    12 13  6  3     3 13  6 12
 11  5 14  4    13 12  3  6     2  7 16  9     8 10  1 15
----------------------------------------------------------------196
 16  5  9  4    13 12  8  1     2  7 11 14     3 10  6 15
 11  2 14  7     7  2 14 11    12 13  1  8     8 13  1 12
  6 15  3 10    10 15  3  6     5  4 16  9     9  4 16  5
  1 12  8 13     4  5  9 16    15 10  6  3    14  7 11  2
----------------------------------------------------------------200
  6 15  3 10     7  2 14 11    12 13  1  8     9  4 16  5
  1 12  8 13    13 12  8  1     2  7 11 14    14  7 11  2
 16  5  9  4     4  5  9 16    15 10  6  3     3 10  6 15
 11  2 14  7    10 15  3  6     5  4 16  9     8 13  1 12
----------------------------------------------------------------204
 16 10  3  5    12  7 14  1     2  8 11 13     4  9  6 15
 11  2 13  8     8  2 13 11     7 12  1 14    14 12  1  7
  6 15  4  9     9 15  4  6    10  5 16  3     3  5 16 10
  1  7 14 12     5 10  3 16    15  9  6  4    13  8 11  2
----------------------------------------------------------------208
 16  5  4  9     8 12 13  1     7  2 11 14     3 15  6 10
 11  7 14  2     2  7 14 11    12  8  1 13    13  8  1 12
  6 10  3 15    15 10  3  6     5  9 16  4     4  9 16  5
  1 12 13  8     9  5  4 16    10 15  6  3    14  2 11  7
----------------------------------------------------------------212
 16  9  5  4    13  8 12  1     2  7 11 14     3 10  6 15
 11  2 14  7     7  2 14 11     8 13  1 12    12 13  1  8
  6 15  3 10    10 15  3  6     9  4 16  5     5  4 16  9
  1  8 12 13     4  9  5 16    15 10  6  3    14  7 11  2
----------------------------------------------------------------216
 16  4  5  9     8 13 12  1     7  2 11 14     3 15  6 10
 11  7 14  2     2  7 14 11    13  8  1 12    12  8  1 13
  6 10  3 15    15 10  3  6     4  9 16  5     5  9 16  4
  1 13 12  8     9  4  5 16    10 15  6  3    14  2 11  7
----------------------------------------------------------------220
  6 15  3 10     7  2 14 11     9  4 16  5    12 13  1  8
 16  9  5  4     4  9  5 16     2  7 11 14    14  7 11  2
  1  8 12 13    13  8 12  1    15 10  6  3     3 10  6 15
 11  2 14  7    10 15  3  6     8 13  1 12     5  4 16  9
----------------------------------------------------------------224
  1 15 12  6    11  2  5 16    14  4  7  9     8 13 10  3
  7 14  9  4     4 14  9  7     2 11 16  5     5 11 16  2
 10  3  8 13    13  3  8 10    15  6  1 12    12  6  1 15
 16  2  5 11     6 15 12  1     3 13 10  8     9  4  7 14
----------------------------------------------------------------228
 12  1  6 15     2 16 11  5     7 14  9  4    13  3  8 10
  9  7  4 14    14  7  4  9    16  2  5 11    11  2  5 16
  8 10 13  3     3 10 13  8     1 15 12  6     6 15 12  1
  5 16 11  2    15  1  6 12    10  3  8 13     4 14  9  7
----------------------------------------------------------------232
  1 12 15  6    11  5  2 16     9 14  7  4    13  3 10  8
  7  9  4 14    14  9  4  7     5 11 16  2     2 11 16  5
 10  8 13  3     3  8 13 10    12  6  1 15    15  6  1 12
 16  5  2 11     6 12 15  1     8  3 10 13     4 14  7  9
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.selfcompl.htm Go DEC JAN MAY
7 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2011
About this capture

```
16  5  2 11     6 12 15  1     3 13 10  8     9  4  7 14
------------------------------------------------------------240
12  1  6 15     2 16 11  5     7  9 14  4    13  8  3 10
14  7  4  9     9  7  4 14    16  2  5 11    11  2  5 16
 3 10 13  8     8 10 13  3     1 15 12  6     6 15 12  1
 5 16 11  2    15  1  6 12    10  8  3 13     4  9 14  7
------------------------------------------------------------244
 1 15 12  6    11  2  5 16     9 14  7  4    13  3 10  8
 7  9  4 14    14  9  4  7     2 11 16  5     5 11 16  2
10  8 13  3     3  8 13 10    15  6  1 12    12  6  1 15
16  2  5 11     6 15 12  1     8  3 10 13     4 14  7  9
------------------------------------------------------------248
16  3  9  6    11 14  8  1     2 13  7 12     5  4 10 15
 7  2 12 13    13  2 12  7    14 11  1  8     8 11  1 14
10 15  5  4     4 15  5 10     3  6 16  9     9  6 16  3
 1 14  8 11     6  3  9 16    15  4 10  5    12 13  7  2
------------------------------------------------------------252
 7  2 12 13     4 15  5 10    14 11  1  8     9  6 16  3
 1 14  8 11    11 14  8  1    15  4 10  5     5  4 10 15
16  3  9  6     6  3  9 16     2 13  7 12    12 13  7  2
10 15  5  4    13  2 12  7     3  6 16  9     8 11  1 14
------------------------------------------------------------256
 7 11 14  2    15  6  3 10     8 12  1 13     4  5 16  9
 1  8 13 12    12  8 13  1     6 15 10  3     3 15 10  6
16  9  4  5     5  9  4 16    11  2  7 14    14  2  7 11
10  6  3 15     2 11 14  7     9  5 16  4    13 12  1  8
------------------------------------------------------------260
16  5  9  4    13 12  8  1     2 11  7 14     3  6 10 15
 7  2 14 11    11  2 14  7    12 13  1  8     8 13  1 12
10 15  3  6     6 15  3 10     5  4 16  9     9  4 16  5
 1 12  8 13     4  5  9 16    15  6 10  3    14 11  7  2
------------------------------------------------------------264
 7 11 14  2    15  6  3 10     4  5 16  9     8 12  1 13
16  4  9  5     5  4  9 16     6 15 10  3     3 15 10  6
 1 13  8 12    12 13  8  1    11  2  7 14    14  2  7 11
10  6  3 15     2 11 14  7    13 12  1  8     9  5 16  4
------------------------------------------------------------268
 7  2 14 11     6 15  3 10    12 13  1  8     9  4 16  5
 1 12  8 13    13 12  8  1    15  6 10  3     3  6 10 15
16  5  9  4     4  5  9 16     2 11  7 14    14 11  7  2
10 15  3  6    11  2 14  7     5  4 16  9     8 13  1 12
------------------------------------------------------------272
16  9  3  6    11  8 14  1     2 13  7 12     5  4 10 15
 7  2 12 13    13  2 12  7     8 11  1 14    14 11  1  8
10 15  5  4     4 15  5 10     9  6 16  3     3  6 16  9
 1  8 14 11     6  9  3 16    15  4 10  5    12 13  7  2
------------------------------------------------------------276
 7  2 12 13     4 15  5 10     9  6 16  3    14 11  1  8
16  9  3  6     6  9  3 16    15  4 10  5     5  4 10 15
 1  8 14 11    11  8 14  1     2 13  7 12    12 13  7  2
10 15  5  4    13  2 12  7     8 11  1 14     3  6 16  9
------------------------------------------------------------280
16  9  5  4    13  8 12  1     2 11  7 14     3  6 10 15
 7  2 14 11    11  2 14  7     8 13  1 12    12 13  1  8
10 15  3  6     6 15  3 10     9  4 16  5     5  4 16  9
 1  8 12 13     4  9  5 16    15  6 10  3    14 11  7  2
------------------------------------------------------------284
 7  2 14 11     6 15  3 10     9  4 16  5    12 13  1  8
16  9  5  4     4  9  5 16    15  6 10  3     3  6 10 15
 1  8 12 13    13  8 12  1     2 11  7 14    14 11  7  2
10 15  3  6    11  2 14  7     8 13  1 12     5  4 16  9
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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.selfcompl.htm Go DEC JAN MAY
17
2006 2007 2011
7 captures
17 Jan 2007 - 21 Jul 2016
About this capture

```
 16 10  3  5    12  7 14  1     4  6  9 15     2 11  8 13
-------------------------------------------------------------292
 12  1 14  7    10 16  3  5     8 11  2 13     4  6 15  9
  2  8 13 11    11  8 13  2    16 10  5  3     3 10  5 16
 15  9  4  6     6  9  4 15     1  7 12 14    14  7 12  1
  5 16  3 10     7  1 14 12     9  6 15  4    13 11  2  8
-------------------------------------------------------------296
  1 14  7 12     5  3 10 16    13 11  8  2    15  6  9  4
  8 13  2 11    11 13  2  8     3  5 16 10    10  5 16  3
  9  4 15  6     6  4 15  9    14 12  1  7     7 12  1 14
 16  3 10  5    12 14  7  1     4  6  9 15     2 11  8 13
-------------------------------------------------------------300
 12  1 14  7    10 16  3  5     8  2 11 13     4 15  6  9
 11  8 13  2     2  8 13 11    16 10  5  3     3 10  5 16
  6  9  4 15    15  9  4  6     1  7 12 14    14  7 12  1
  5 16  3 10     7  1 14 12     9 15  6  4    13  2 11  8
-------------------------------------------------------------304
```

Back to **Suzuki's Magic Squares**

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Please mail comments and suggestions to Suzanne Alejandre.

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.5x5.pan.html Go DEC JAN MAY
8 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2011
About this capture

Mutsumi Suzuki
Magic Squares

The 144 Panmagic Squares of 5 x 5

Fundamental magic squares

Following 144 fundamental panmagic squares are found.
Each square yields 25 squares by row and/or column shift.

```
  1  7 24 20 13     1  7 20 24 13     1  7 25 19 13     1  7 19 25 13
 19 15  3  6 22    19 23 11  2 10    20 14  3  6 22    20 23 11  2  9
  8 21 17 14  5    12  5  9 18 21     8 21 17 15  4    12  4 10 18 21
 12  4 10 23 16     8 16 22 15  4    12  5  9 23 16     8 16 22 14  5
 25 18 11  2  9    25 14  3  6 17    24 18 11  2 10    24 15  3  6 17
-----------------------------------------------------------------------    4

  1  7 23 20 14     1  7 20 23 14     1  7 25 18 14     1  7 18 25 14
 18 15  4  6 22    18 24 11  2 10    20 13  4  6 22    20 24 11  2  8
  9 21 17 13  5    12  5  8 19 21     9 21 17 15  3    12  3 10 19 21
 12  3 10 24 16     9 16 22 15  3    12  5  8 24 16     9 16 22 13  5
 25 19 11  2  8    25 13  4  6 17    23 19 11  2 10    23 15  4  6 17
-----------------------------------------------------------------------    8

  1  7 23 19 15     1  7 19 23 15     1  7 24 18 15     1  7 18 24 15
 18 14  5  6 22    18 25 11  2  9    19 13  5  6 22    19 25 11  2  8
 10 21 17 13  4    12  4  8 20 21    10 21 17 14  3    12  3  9 20 21
 12  3  9 25 16    10 16 22 14  3    12  4  8 25 16    10 16 22 13  4
 24 20 11  2  8    24 13  5  6 17    23 20 11  2  9    23 14  5  6 17
-----------------------------------------------------------------------   12

  1  7 24 15 18     1  7 15 24 18     1  7 25 14 18     1  7 14 25 18
 14 20  3  6 22    14 23 16  2 10    15 19  3  6 22    15 23 16  2  9
  8 21 12 19  5    17  5  9 13 21     8 21 12 20  4    17  4 10 13 21
 17  4 10 23 11     8 11 22 20  4    17  5  9 23 11     8 11 22 19  5
 25 13 16  2  9    25 19  3  6 12    24 13 16  2 10    24 20  3  6 12
-----------------------------------------------------------------------   16

  1  7 23 15 19     1  7 15 23 19     1  7 25 13 19     1  7 13 25 19
 13 20  4  6 22    13 24 16  2 10    15 18  4  6 22    15 24 16  2  8
  9 21 12 18  5    17  5  8 14 21     9 21 12 20  3    17  3 10 14 21
 17  3 10 24 11     9 11 22 20  3    17  5  8 24 11     9 11 22 18  5
 25 14 16  2  8    25 18  4  6 12    23 14 16  2 10    23 20  4  6 12
-----------------------------------------------------------------------   20

  1  7 23 14 20     1  7 14 23 20     1  7 24 13 20     1  7 13 24 20
 13 19  5  6 22    13 25 16  2  9    14 18  5  6 22    14 25 16  2  8
 10 21 12 18  4    17  4  8 15 21    10 21 12 19  3    17  3  9 15 21
 17  3  9 25 11    10 11 22 19  3    17  4  8 25 11    10 11 22 18  4
 24 15 16  2  8    24 18  5  6 12    23 15 16  2  9    23 19  5  6 12
-----------------------------------------------------------------------   24

  1  7 15 19 23     1  7 19 15 23     1  7 14 20 23     1  7 20 14 23
 14 18 21  2 10    14 25  3  6 17    15 18 21  2  9    15 24  3  6 17
 22  5  9 13 16     8 16 12 24  5    22  4 10 13 16     8 16 12 25  4
  8 11 17 25  4    22  4 10 18 11     8 11 17 24  5    22  5  9 18 11
 20 24  3  6 12    20 13 21  2  9    19 25  3  6 12    19 13 21  2 10
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.5x5.pan.html Go DEC JAN MAY
8 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2011 About this capture

```
 22  5  8 14 16     9 16 12 25  5    22  3 10 14 16     9 16 12 25  3
  9 11 17 25  3    22  3 10 19 11     9 11 17 23  5    22  5  8 19 11
 20 23  4  6 12    20 14 21  2  8    18 25  4  6 12    18 14 21  2 10
---------------------------------------------------------------------- 32

  1  7 14 18 25     1  7 18 14 25     1  7 13 19 25     1  7 19 13 25
 13 20 21  2  9    13 24  5  6 17    14 20 21  2  8    14 23  5  6 17
 22  4  8 15 16    10 16 12 23  4    22  3  9 15 16    10 16 12 24  3
 10 11 17 24  3    22  3  9 20 11    10 11 17 23  4    22  4  8 20 11
 19 23  5  6 12    19 15 21  2  8    18 24  5  6 12    18 15 21  2  9
---------------------------------------------------------------------- 36

  1  8 24 20 12     1  8 20 24 12     1  8 25 19 12     1  8 19 25 12
 19 15  2  6 23    19 22 11  3 10    20 14  2  6 23    20 22 11  3  9
  7 21 18 14  5    13  5  9 17 21     7 21 18 15  4    13  4 10 17 21
 13  4 10 22 16     7 16 23 15  4    13  5  9 22 16     7 16 23 14  5
 25 17 11  3  9    25 14  2  6 18    24 17 11  3 10    24 15  2  6 18
---------------------------------------------------------------------- 40

  1  8 22 20 14     1  8 20 22 14     1  8 25 17 14     1  8 17 25 14
 17 15  4  6 23    17 24 11  3 10    20 12  4  6 23    20 24 11  3  7
  9 21 18 12  5    13  5  7 19 21     9 21 18 15  2    13  2 10 19 21
 13  2 10 24 16     9 16 23 15  2    13  5  7 24 16     9 16 23 12  5
 25 19 11  3  7    25 12  4  6 18    22 19 11  3 10    22 15  4  6 18
---------------------------------------------------------------------- 44

  1  8 22 19 15     1  8 19 22 15     1  8 24 17 15     1  8 17 24 15
 17 14  5  6 23    17 25 11  3  9    19 12  5  6 23    19 25 11  3  7
 10 21 18 12  4    13  4  7 20 21    10 21 18 14  2    13  2  9 20 21
 13  2  9 25 16    10 16 23 14  2    13  4  7 25 16    10 16 23 12  4
 24 20 11  3  7    24 12  5  6 18    22 20 11  3  9    22 14  5  6 18
---------------------------------------------------------------------- 48

  1  8 24 15 17     1  8 15 24 17     1  8 25 14 17     1  8 14 25 17
 14 20  2  6 23    14 22 16  3 10    15 19  2  6 23    15 22 16  3  9
  7 21 13 19  5    18  5  9 12 21     7 21 13 20  4    18  4 10 12 21
 18  4 10 22 11     7 11 23 20  4    18  5  9 22 11     7 11 23 19  5
 25 12 16  3  9    25 19  2  6 13    24 12 16  3 10    24 20  2  6 13
---------------------------------------------------------------------- 52

  1  8 22 15 19     1  8 15 22 19     1  8 25 12 19     1  8 12 25 19
 12 20  4  6 23    12 24 16  3 10    15 17  4  6 23    15 24 16  3  7
  9 21 13 17  5    18  5  7 14 21     9 21 13 20  2    18  2 10 14 21
 18  2 10 24 11     9 11 23 20  2    18  5  7 24 11     9 11 23 17  5
 25 14 16  3  7    25 17  4  6 13    22 14 16  3 10    22 20  4  6 13
---------------------------------------------------------------------- 56

  1  8 22 14 20     1  8 14 22 20     1  8 24 12 20     1  8 12 24 20
 12 19  5  6 23    12 25 16  3  9    14 17  5  6 23    14 25 16  3  7
 10 21 13 17  4    18  4  7 15 21    10 21 13 19  2    18  2  9 15 21
 18  2  9 25 11    10 11 23 19  2    18  4  7 25 11    10 11 23 17  4
 24 15 16  3  7    24 17  5  6 13    22 15 16  3  9    22 19  5  6 13
---------------------------------------------------------------------- 60

  1  8 15 19 22     1  8 19 15 22     1  8 14 20 22     1  8 20 14 22
 14 17 21  3 10    14 25  2  6 18    15 17 21  3  9    15 24  2  6 18
 23  5  9 12 16     7 16 13 24  5    23  4 10 12 16     7 16 13 25  4
  7 11 18 25  4    23  4 10 17 11     7 11 18 24  5    23  5  9 17 11
 20 24  2  6 13    20 12 21  3  9    19 25  2  6 13    19 12 21  3 10
---------------------------------------------------------------------- 64
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.5x5.pan.html Go DEC JAN MAY
8 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2011
About this capture

```
 20 22  4  6 13    20 14 21  3  7    17 25  4  6 13    17 14 21  3 10
---------------------------------------------------------------------  68

  1  8 14 17 25     1  8 17 14 25     1  8 12 19 25     1  8 19 12 25
 12 20 21  3  9    12 24  5  6 18    14 20 21  3  7    14 22  5  6 18
 23  4  7 15 16    10 16 13 22  4    23  2  9 15 16    10 16 13 24  2
 10 11 18 24  2    23  2  9 20 11    10 11 18 22  4    23  4  7 20 11
 19 22  5  6 13    19 15 21  3  7    17 24  5  6 13    17 15 21  3  9
---------------------------------------------------------------------  72

  1  9 23 20 12     1  9 20 23 12     1  9 25 18 12     1  9 18 25 12
 18 15  2  6 24    18 22 11  4 10    20 13  2  6 24    20 22 11  4  8
  7 21 19 13  5    14  5  8 17 21     7 21 19 15  3    14  3 10 17 21
 14  3 10 22 16     7 16 24 15  3    14  5  8 22 16     7 16 24 13  5
 25 17 11  4  8    25 13  2  6 19    23 17 11  4 10    23 15  2  6 19
---------------------------------------------------------------------  76

  1  9 22 20 13     1  9 20 22 13     1  9 25 17 13     1  9 17 25 13
 17 15  3  6 24    17 23 11  4 10    20 12  3  6 24    20 23 11  4  7
  8 21 19 12  5    14  5  7 18 21     8 21 19 15  2    14  2 10 18 21
 14  2 10 23 16     8 16 24 15  2    14  5  7 23 16     8 16 24 12  5
 25 18 11  4  7    25 12  3  6 19    22 18 11  4 10    22 15  3  6 19
---------------------------------------------------------------------  80

  1  9 22 18 15     1  9 18 22 15     1  9 23 17 15     1  9 17 23 15
 17 13  5  6 24    17 25 11  4  8    18 12  5  6 24    18 25 11  4  7
 10 21 19 12  3    14  3  7 20 21    10 21 19 13  2    14  2  8 20 21
 14  2  8 25 16    10 16 24 13  2    14  3  7 25 16    10 16 24 12  3
 23 20 11  4  7    23 12  5  6 19    22 20 11  4  8    22 13  5  6 19
---------------------------------------------------------------------  84

  1  9 23 15 17     1  9 15 23 17     1  9 25 13 17     1  9 13 25 17
 13 20  2  6 24    13 22 16  4 10    15 18  2  6 24    15 22 16  4  8
  7 21 14 18  5    19  5  8 12 21     7 21 14 20  3    19  3 10 12 21
 19  3 10 22 11     7 11 24 20  3    19  5  8 22 11     7 11 24 18  5
 25 12 16  4  8    25 18  2  6 14    23 12 16  4 10    23 20  2  6 14
---------------------------------------------------------------------  88

  1  9 22 15 18     1  9 15 22 18     1  9 25 12 18     1  9 12 25 18
 12 20  3  6 24    12 23 16  4 10    15 17  3  6 24    15 23 16  4  7
  8 21 14 17  5    19  5  7 13 21     8 21 14 20  2    19  2 10 13 21
 19  2 10 23 11     8 11 24 20  2    19  5  7 23 11     8 11 24 17  5
 25 13 16  4  7    25 17  3  6 14    22 13 16  4 10    22 20  3  6 14
---------------------------------------------------------------------  92

  1  9 22 13 20     1  9 13 22 20     1  9 23 12 20     1  9 12 23 20
 12 18  5  6 24    12 25 16  4  8    13 17  5  6 24    13 25 16  4  7
 10 21 14 17  3    19  3  7 15 21    10 21 14 18  2    19  2  8 15 21
 19  2  8 25 11    10 11 24 18  2    19  3  7 25 11    10 11 24 17  3
 23 15 16  4  7    23 17  5  6 14    22 15 16  4  8    22 18  5  6 14
---------------------------------------------------------------------  96

  1  9 15 18 22     1  9 18 15 22     1  9 13 20 22     1  9 20 13 22
 13 17 21  4 10    13 25  2  6 19    15 17 21  4  8    15 23  2  6 19
 24  5  8 12 16     7 16 14 23  5    24  3 10 12 16     7 16 14 25  3
  7 11 19 25  3    24  3 10 17 11     7 11 19 23  5    24  5  8 17 11
 20 23  2  6 14    20 12 21  4  8    18 25  2  6 14    18 12 21  4 10
--------------------------------------------------------------------- 100

  1  9 15 17 23     1  9 17 15 23     1  9 12 20 23     1  9 20 12 23
 12 18 21  4 10    12 25  3  6 19    15 18 21  4  7    15 22  3  6 19
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.5x5.pan.html Go DEC JAN MAY
8 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2011
About this capture

```
  1  9 13 17 25     1  9 17 13 25     1  9 12 18 25     1  9 18 12 25
 12 20 21  4  8    12 23  5  6 19    13 20 21  4  7    13 22  5  6 19
 24  3  7 15 16    10 16 14 22  3    24  2  8 15 16    10 16 14 23  2
 10 11 19 23  2    24  2  8 20 11    10 11 19 22  3    24  3  7 20 11
 18 22  5  6 14    18 15 21  4  7    17 23  5  6 14    17 15 21  4  8
--------------------------------------------------------------------- 108

  1 10 23 19 12     1 10 19 23 12     1 10 24 18 12     1 10 18 24 12
 18 14  2  6 25    18 22 11  5  9    19 13  2  6 25    19 22 11  5  8
  7 21 20 13  4    15  4  8 17 21     7 21 20 14  3    15  3  9 17 21
 15  3  9 22 16     7 16 25 14  3    15  4  8 22 16     7 16 25 13  4
 24 17 11  5  8    24 13  2  6 20    23 17 11  5  9    23 14  2  6 20
--------------------------------------------------------------------- 112

  1 10 22 19 13     1 10 19 22 13     1 10 24 17 13     1 10 17 24 13
 17 14  3  6 25    17 23 11  5  9    19 12  3  6 25    19 23 11  5  7
  8 21 20 12  4    15  4  7 18 21     8 21 20 14  2    15  2  9 18 21
 15  2  9 23 16     8 16 25 14  2    15  4  7 23 16     8 16 25 12  4
 24 18 11  5  7    24 12  3  6 20    22 18 11  5  9    22 14  3  6 20
--------------------------------------------------------------------- 116

  1 10 22 18 14     1 10 18 22 14     1 10 23 17 14     1 10 17 23 14
 17 13  4  6 25    17 24 11  5  8    18 12  4  6 25    18 24 11  5  7
  9 21 20 12  3    15  3  7 19 21     9 21 20 13  2    15  2  8 19 21
 15  2  8 24 16     9 16 25 13  2    15  3  7 24 16     9 16 25 12  3
 23 19 11  5  7    23 12  4  6 20    22 19 11  5  8    22 13  4  6 20
--------------------------------------------------------------------- 120

  1 10 23 14 17     1 10 14 23 17     1 10 24 13 17     1 10 13 24 17
 13 19  2  6 25    13 22 16  5  9    14 18  2  6 25    14 22 16  5  8
  7 21 15 18  4    20  4  8 12 21     7 21 15 19  3    20  3  9 12 21
 20  3  9 22 11     7 11 25 19  3    20  4  8 22 11     7 11 25 18  4
 24 12 16  5  8    24 18  2  6 15    23 12 16  5  9    23 19  2  6 15
--------------------------------------------------------------------- 124

  1 10 22 14 18     1 10 14 22 18     1 10 24 12 18     1 10 12 24 18
 12 19  3  6 25    12 23 16  5  9    14 17  3  6 25    14 23 16  5  7
  8 21 15 17  4    20  4  7 13 21     8 21 15 19  2    20  2  9 13 21
 20  2  9 23 11     8 11 25 19  2    20  4  7 23 11     8 11 25 17  4
 24 13 16  5  7    24 17  3  6 15    22 13 16  5  9    22 19  3  6 15
--------------------------------------------------------------------- 128

  1 10 22 13 19     1 10 13 22 19     1 10 23 12 19     1 10 12 23 19
 12 18  4  6 25    12 24 16  5  8    13 17  4  6 25    13 24 16  5  7
  9 21 15 17  3    20  3  7 14 21     9 21 15 18  2    20  2  8 14 21
 20  2  8 24 11     9 11 25 18  2    20  3  7 24 11     9 11 25 17  3
 23 14 16  5  7    23 17  4  6 15    22 14 16  5  8    22 18  4  6 15
--------------------------------------------------------------------- 132

  1 10 14 18 22     1 10 18 14 22     1 10 13 19 22     1 10 19 13 22
 13 17 21  5  9    13 24  2  6 20    14 17 21  5  8    14 23  2  6 20
 25  4  8 12 16     7 16 15 23  4    25  3  9 12 16     7 16 15 24  3
  7 11 20 24  3    25  3  9 17 11     7 11 20 23  4    25  4  8 17 11
 19 23  2  6 15    19 12 21  5  8    18 24  2  6 15    18 12 21  5  9
--------------------------------------------------------------------- 136

  1 10 14 17 23     1 10 17 14 23     1 10 12 19 23     1 10 19 12 23
 12 18 21  5  9    12 24  3  6 20    14 18 21  5  7    14 22  3  6 20
 25  4  7 13 16     8 16 15 22  4    25  2  9 13 16     8 16 15 24  2
  8 11 20 24  2    25  2  9 18 11     8 11 20 22  4    25  4  7 18 11
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.5x5.pan.html Go DEC JAN MAY
8 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2011
About this capture

```
 12 19 21  5  8    12 23  4  6 20    13 19 21  5  7    13 22  4  6 20
 25  3  7 14 16     9 16 15 22  3    25  2  8 14 16     9 16 15 23  2
  9 11 20 23  2    25  2  8 19 11     9 11 20 22  3    25  3  7 19 11
 18 22  4  6 15    18 14 21  5  7    17 23  4  6 15    17 14 21  5  8
---------------------------------------------------------------------- 144
```

Back to **Suzuki's Magic Squares**

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Please mail comments and suggestions to Suzanne Alejandre.

http://www.grogono.com/magic/index.php Go
171 captures
25 Jul 2003 - 2 May 2019
JAN FEB APR
15
2004 2005 2006
About this capture

Grogono Magic Squares Home Page

Revision: Features in Recent Revisions

Same Author: Acid-Base, Animated Knots, Stereo Art

Home Page
Make Your Own
Choose by Size
How Many?
The Formula
Magic Carpets
Analysis
Magic Cubes
History
References
Contact
Downloads
Links
Glossary
Grogono Home

Introduction.

A Magic square is intriguing; its complexity challenges the mind. For order 4 and above the number of different magic squares is astonishing - and the number remains large even if we limit consideration to Pan-Magic squares. This website reflects my own fascination with these large numbers and presents techniques aimed at explaining and reducing the huge numbers by showing how this abundance can be reduced to a small number of underlying patterns or Magic Carpets.

Recent Addition

Do it yourself! Make your own magic square of any size up to 97x97.

Discoveries.

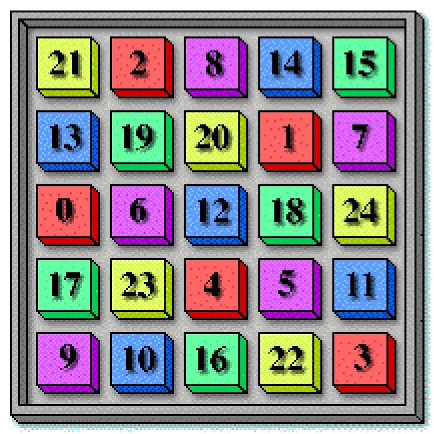
The development of this website was associated with several intriguing discoveries. Please look at the pages for the Order 4, Order 5, Order 6 magic squares.

Dedication.

This Magic Square website is dedicated to my father E.B. Grogono (1909 - 1999) and was originally created at his bedside during his last illness. My fondest memories of him, from my earliest childhood to the final days of his life, center on his ability to transmit his love for, and fascination with, mathematics and science.

Revision

This revision uses up to date technology to make the website easier to manage and the material has been re-arranged to make it more accessible. A glossary has been added and the index system has been revised.



Now, Belatedly, Welcome!

Visit, play, learn about Magic Squares and Magic Carpets, make your Own Magic squares, and explore the techniques devised to understand pan-magic squares.

Glossary

If you want to check on the meaning of the terms used on this website, please review the Glossary

Pan-Magic Squares.

The Main focus of this website is Pan-Magic squares where even the broken diagonals add up to the Magic Sum, e.g., 60 in the square above 60 (diagonal 13, 2, 16, 5, 24). Pan-magic squares have also been called Pan-Diagonal and Nasik.

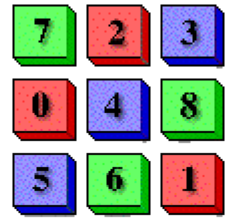
Why start Magic Squares using zero?

A glib answer might be because I like to and this is my site. A mathematical answer is that analysis (and construction) of magic squares is more logical, and the results easier to analyze, when the smallest number is 0. This is particularly true when the Magic Carpet approach is used to analyze or construct a magic square, e.g., to construct an order four magic square, four magic carpets would be required using: 8 & 0; 4 & 0; 2 & 0; and 1 & 0.

- **Traditional Magic Squares**, start at one, probably because magic squares were discovered first and analyzed later. Early counting systems didn't include either zero or negative numbers, so number one must have seemed a pretty good starting place.

http://www.grogono.com/magic/index.php Go JAN FEB APR
171 captures 15
25 Jul 2003 - 2 May 2019 2004 2005 2006
About this capture

I am frequently asked to provide the Formula for Magic Squares. At the risk of spoiling some teacher's classwork assignments I have worked out a satisfactory answer and have devoted a page to this topic. (Thank you Danny Lawrence for making me do this and for sitting with me while I worked it out.) Two formulae are included, one for the prime-number orders, e.g., 5, 7, 11, 13, etc., and one for an order 4 square.



How Many Squares?

My fascination with magic squares grew from experimental attempts to count the total number of possible squares when squares which, apparently different, were really identical when appropriately reflected or rotated. A separate page lists the Number of Pan-Magic Squares for the Prime Number Order squares.

Unique Identifiers.

The process of counting and comparing regular panmagic squares generated a need to identify squares to facilitate ranking and comparison. Out of this grew a scoring system to uniquely identify any order 4 or order 5 pan-magic square.

The method I developed assigns a Unique Identifier to each square and is applicable to regular panmagic squares of orders 4 and 5. It depends on summing defined cells which have been multiplied by successively higher powers of the square's order. Although the technique could be extended to larger squares, the length of the expression, and the resulting magnitude of the numbers, makes it too unwieldy.

By the Same Author

If you have found this website useful, you are invited to visit my one of my other teaching sites.

Two of these other sites are mounted on my main website but all three are treated as an independent website:

- **Acid-Base Tutorial**

  This website is aimed at physicians, physiologists, medical students, nurses, and other health care professionals. The Tutorial includes interactive diagrams and equations to make the material more interesting and more readily understood.

- **Animated Knots**

  This website is aimed at yachtsmen, scouts, climbers, fishermen and anyone else who needs to know how to tie Practical Safe Knots. Each animated knot "ties itself" automatically and can also be "tied" and "untied" slowly to reveal its structure.

- **Stereo Art**

  This website demonstrates how a vivid three-dimensional stereo image is created from a repeated stereo image pair. A collection of Stereo Art Images illustrates the technique.

Size: Index | 3x3 | 4x4 | 5x5 | 6x6 | 7x7 | 8x8 | 9x9 | 10x10 | 11x11 | 12x12 | 13x13

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.5x5.selfsim.html Go DEC JAN FEB
10 captures 17 2006 2007 2009
17 Jan 2007 - 21 Jul 2016 About this capture

Mutsumi Suzuki
Magic Squares

Ultra Super Magic Squares of 5 x 5

What is ultra super magic square?

These squares are panmagic and self-similar square and have special constellation patterns all at a time!

(1) panmagic property;
Not only the major but olso the minor diagonals add up to the same number 65.
For examples;

```
  A * * * *
  * B * * *
  * * C * *
  * * * D *     A + B + C + D + E = 65    (Major diagonal)
  * * * * E

  * A * * *
  * * B * *
  * * * C *
  * * * * D     A + B + C + D + E = 65
  E * * * *

  * * A * *
  * * * B *
  * * * * C
  D * * * *     A + B + C + D + E = 65
  * E * * *

...
...   and so on.
```

(2) Self complementary property;
The square is invariant for the complemental transform.
If you change all the number "n" of the square by "26-n" , you get the same square rotated.
You can say that it is axisymmetry or self-simillar, in another word.

(3) five-star constellation patterns;
Five numbers of all small squares and the centers sum up to the same number 65.

```
  1  *  *  *  9     1  * 22  *  *     * 15  * 18  *     *  * 22  *  9
  *  *  *  *  *     * 19  *  *  *     *  *  6  *  *     *  *  *  5  *
  *  * 13  *  *    10  * 13  *  *     *  2  * 24  *     *  * 13  * 16
  *  *  *  *  *     *  *  *  *  *     *  *  *  *  *     *  *  *  *  *
 17  *  *  * 25     *  *  *  *  *     *  *  *  *  *     *  *  *  *  *

  ....
  ....
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.5x5.selfsim.html Go DEC JAN FEB
10 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009
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```
Rhonbohedral patterns;
Furthermore, five numbers of all small rhonbohedrons add up to
the same number 65.

  * 15  *  *  *     *  * 22  *  *
 23 19  6  *  *     * 19  6  5  *
  *  2  *  *  *     *  * 13  *  *
  *  *  *  *  *     *  *  *  *  *
  *  *  *  *  *     *  *  *  *  *   ......

  ......
  ......

  *  *  *  *  *     *  * 22  *  *
  *  *  *  *  *     *  *  *  *  *
  *  *  * 24  *    10  * 13  * 16
  *  * 20  7  3     *  *  *  *  *
  *  *  * 11  *     *  *  4  *  *
```

The following sixteen squares are found

```
( 1)
  1 15 22 18  9
 23 19  6  5 12
 10  2 13 24 16
 14 21 20  7  3
 17  8  4 11 25

( 2)
  1 15 24 18  7
 23 17  6  5 14
 10  4 13 22 16
 12 21 20  9  3
 19  8  2 11 25

( 3)
  1 23 20 12  9
 15  7  4 21 18
 24 16 13 10  2
  8  5 22 19 11
 17 14  6  3 25

( 4)
  1 23 20 14  7
 15  9  2 21 18
 22 16 13 10  4
  8  5 24 17 11
 19 12  6  3 25

( 5)
  2 14 21 18 10
 23 20  7  4 11
  9  1 13 25 17
 15 22 19  6  3
 16  8  5 12 24
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.5x5.selfsim.html Go DEC JAN FEB
10 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009
About this capture

```
  9  5 13 21 17
 11 22 19 10  3
 20  8  1 12 24

( 7)
  2 23 19 11 10
 14  6  5 22 18
 25 17 13  9  1
  8  4 21 20 12
 16 15  7  3 24

( 8)
  2 23 19 15  6
 14 10  1 22 18
 21 17 13  9  5
  8  4 25 16 12
 20 11  7  3 24

( 9)
  4 12 21 18 10
 23 20  9  2 11
  7  1 13 25 19
 15 24 17  6  3
 16  8  5 14 22

(10)
  4 12 25 18  6
 23 16  9  2 15
  7  5 13 21 19
 11 24 17 10  3
 20  8  1 14 22

(11)
  4 23 17 11 10
 12  6  5 24 18
 25 19 13  7  1
  8  2 21 20 14
 16 15  9  3 22

(12)
  4 23 17 15  6
 12 10  1 24 18
 21 19 13  7  5
  8  2 25 16 14
 20 11  9  3 22

(13)
  5 11 22 18  9
 23 19 10  1 12
  6  2 13 24 20
 14 25 16  7  3
 17  8  4 15 21

(14)
  5 11 24 18  7
 23 17 10  1 14
  6  4 13 22 20
 12 25 16  9  3
 19  8  2 15 21

(15)
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.5x5.selfsim.html Go DEC JAN FEB
10 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009
About this capture

```
 17 14 10  3 21

(16)
  5 23 16 14  7
 11  9  2 25 18
 22 20 13  6  4
  8  1 24 17 15
 19 12 10  3 21
```

It's a really ultra super magic squares!
If I were a mathematician born in the Greek era, these squares would be engraved on my tombstone. Ha! Ha!

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Mutsumi Suzuki
[Magic Squares](#)

Composite Semi Magic Squares of 6 x 6 by Mr. Setsuda

Composite magic square is a square constructed by many small 2 x 2 sub-squares of the same sum.

According to Mr. Setsuda's analysis, a composite magic square is always pan-magic, but the pan-magic square is not always composite. More detailed discussions can be seen on the page of the 8x8 composite squares .

There is no composite square for the half-even (4n + 2 type) order. The followings are composite but semi-magic squares of 6 x 6 in which the diagonal conditions are not satisfied. Mr. Setsuda confirmed the total 1476 semi-magic squares in September, 2000.

```
(  1)
 1 36  4 33  7 30
35  2 32  5 29  8
 3 34  6 31  9 28
25 12 22 15 19 18
20 17 23 14 26 11
27 10 24 13 21 16

(305)
 1 36  2 35  3 34
33  4 32  5 31  6
 7 30  8 29  9 28
21 16 20 17 19 18
22 15 23 14 24 13
27 10 26 11 25 12

(545)
 1 36 13 24 25 12
32  5 20 17  8 29
 3 34 15 22 27 10
33  4 21 16  9 28
11 26 23 14 35  2
31  6 19 18  7 30

(593)
 1 36 13 24 25 12
31  6 19 18  7 30
 8 29 20 17 32  5
33  4 21 16  9 28
11 26 23 14 35  2
27 10 15 22  3 34

(617)
 1 36  2 35  3 34
27 10 26 11 25 12
 7 30  8 29  9 28
21 16 20 17 19 18
31  6 32  5 33  4
24 13 23 14 22 15

(761)
 1 36  4 33  7 30
26 11 23 14 20 17
 3 34  6 31  9 28
27 10 24 13 21 16
29  8 32  5 35  2
25 12 22 15 19 18

(809)
 1 36  4 33  7 30
25 12 22 15 19 18
20 17 23 14 26 11
27 10 24 13 21 16
29  8 32  5 35  2
 9 28  6 31  3 34

(841)
 1 36  2 35  3 34
24 13 23 14 22 15
 7 30  8 29  9 28
27 10 26 11 25 12
31  6 32  5 33  4
21 16 20 17 19 18

(937)
 1 36  5 32  9 28
23 14 19 18 15 22
16 21 20 17 24 13
33  4 29  8 25 12
27 10 31  6 35  2
11 26  7 30  3 34

(961)
 1 36  2 35  3 34
21 16 20 17 19 18
22 15 23 14 24 13
27 10 26 11 25 12
31  6 32  5 33  4
 9 28  8 29  7 30

(985)
 1 35  2 36  3 34
33  5 32  4 31  6
 7 29  8 30  9 28
21 17 20 16 19 18
22 14 23 15 24 13
27 11 26 10 25 12

(1089)
 1 35  3 33 15 24
32  6 30  8 18 17
 5 31  7 29 19 20
36  2 34  4 22 13
 9 27 11 25 23 16
28 10 26 12 14 21

(1137)
 1 35  2 36  3 34
27 11 26 10 25 12
 7 29  8 30  9 28
21 17 20 16 19 18
31  5 32  6 33  4
24 14 23 13 22 15

(1173)
 1 35  2 36  3 34
24 14 23 13 22 15
 7 29  8 30  9 28
27 11 26 10 25 12
31  5 32  6 33  4
21 17 20 16 19 18

(1245)
 1 35  2 36  3 34
21 17 20 16 19 18
22 14 23 15 24 13
27 11 26 10 25 12
31  5 32  6 33  4
 9 29  8 28  7 30

(1257)
 1 33  3 35 15 24
32  8 30  6 18 17
 5 29  7 31 19 20
36  4 34  2 22 13
 9 25 11 27 23 16
28 12 26 10 14 21

(1293)
 1 33  4 36  7 30
27 13 24 10 21 16
 3 31  6 34  9 28
25 15 22 12 19 18
29  5 32  8 35  2
26 14 23 11 20 17

(1329)
 1 33  4 36  7 30
26 14 23 11 20 17
 3 31  6 34  9 28
27 13 24 10 21 16
29  5 32  8 35  2
25 15 22 12 19 18

(1353)
 1 33  4 36  7 30
25 15 22 12 19 18
20 14 23 17 26 11
27 13 24 10 21 16
29  5 32  8 35  2
 9 31  6 28  3 34

(1369)
 1 33  3 35  7 32
24 16 22 14 18 17
13 21 15 23 19 20
36  4 34  2 30  5
25  9 27 11 31  8
12 28 10 26  6 29

(1405)

(1453)

(1465)
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSq.6x6.composite.semi.h Go DEC JAN JUL 17 2006 2007 2009
9 captures
17 Jan 2007 - 20 Jul 2016
About this capture

```
25  8 27 11 33  7    27  6 31 10 35  2    25  7 32 11 33  5
12 29 10 26  4 30    11 30  7 26  3 34    12 30  5 26  4 34
```

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17 Jan 2007 - 21 Jul 2016 2006 2007 2011 About this capture

Mutsumi Suzuki
Magic Squares

Self-complementary Pan Magic Square of 7x7

These squares are pan-magic and also self-similar.

(1) pan-magic property:
In the squares, not only the major but also the minor diagonals add up to the same sum 175.
For example:

```
  A * * * * * *
  * B * * * * *
  * * C * * * *
  * * * D * * *    A + B + C + D + E + F + G  = 175    (Major diagonal)
  * * * * E * *
  * * * * * F *
  * * * * * * G

  * A * * * * *
  * * B * * * *
  * * * C * * *
  * * * * D * *    A + B + C + D + E + F + G  = 175   (Pan-diagonal)
  * * * * * E *
  * * * * * * F
  G * * * * * *
...
...   and so on.
```

(2) Self complementary property:
The square is invariant for the complementary transformations. If you change all the number "n" of the square by "50 - n," you get the rotated same square.
You can say that it is axisymmetry or self-simillar, in another word.

There are only few such squares are known for the 5 x 5 systems, but there are too many 7 x 7 squares to determine the total number. The following are some examples calculated by Mr. Setsuda.

```
 1 48  5 19 40 42 20     1 48  3 18 43 38 24     1 48  3 28 41 37 17
47 38 28 27  4 16 15    46 37 29 28  6  9 20    45 38 19 40  7 20  6
11 14 44  9 37 43 17    15 10 45 11 36 42 16    15 18 42 11 14 46 29
18 26 29 25 21 24 32    23 19 33 25 17 31 27    16 24 23 25 27 26 34
33  7 13 41  6 36 39    34  8 14 39  5 40 35    21  4 36 39  8 32 35
35 34 46 23 22 12  3    30 41 44 22 21 13  4    44 30 43 10 31 12  5
30  8 10 31 45  2 49    26 12  7 32 47  2 49    33 13  9 22 47  2 49

 1 48  3 42 43 26 12     1 48  3 34 46 23 20     1 48  3 37 39 26 21
44 40 11 29  5 31 15    43 40  9 33  8 18 24    42 41  7 38 10 18 19
14 13 46 18 20 41 23    15 11 44 28 13 45 19    15  6 45 22 14 46 27
16 22 33 25 17 28 34    29 12 36 25 14 38 21    34 20 33 25 17 30 16
27  9 30 32  4 37 36    31  5 37 22  6 39 35    23  4 36 28  5 44 35
35 19 45 21 39 10  6    26 32 42 17 41 10  7    31 32 40 12 43  9  8
38 24  7  8 47  2 49    30 27  4 16 47  2 49    29 24 11 13 47  2 49

48  4 47  1 13 44 18    48  4 47  1  5 44 26    48  4 47  1 11 42 22
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSq.7x7.selfsim.pan.html Go DEC JAN MAY
8 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2011 About this capture

```
15 41  7 34 12 21 45     12 36 11 34 18 21 43     15 34  6 45 12 20 43
32  6 37 49  3 46  2     24  6 45 49  3 46  2     28  8 39 49  3 46  2
```

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.html Go
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09
2005 2006 2008
46 captures
9 Jul 2006 - 4 Apr 2019
About this capture

Magic Squares

These pages were written by Mutsumi Suzuki and until his retirement in 2001, were available through his site in Japan. It is the Math Forum's pleasure to host these pages so that the mathematical community can continue to enjoy all of the information presented by Mr. Suzuki on the topic of magic squares.

- **Data Base**
  - Examples of Magic Squares from 3 x 3 through 20 x 20 (by Tamori's method)
  - Examples of Magic Squares from 3 x 3 through 10 x 10 (by MATLAB)
  - The 880 Magic Squares of 4 x 4
  - The 880 Magic Squares of 4 x 4 (4-adic representation) (Paul Heimbach's web-page)
  - The 48 Panmagic Squares of 4 x 4
  - Selfcomplementary Magic Squares of 4 x 4
  - Fundamental set of Panmagic Squares of 5 x 5 (144)
  - Fundamental set of Panmagic Squares of 5 x 5 (144) (by Professor Grogono)
  - Ultra Super Magic Squares of 5 x 5 (Sixteen panmagic and selfcomplementary squares)
  - 6 x 6 Composite but Semi Magic Squares (calculated by Mr. Setsuda)
  - 7 x 7 Self-Complementary Pan-magic Squares (calculated by Mr. Setsuda)
  - Panmagic and/or special 8 x 8 squares
  - 8 x 8 Semi-magic Squares by a Knight's movement tour
  - 8 x 8 Panmagic square can not be generated by the Knight's movement tour
  - 8 x 8 Composite Magic Squares calculated by Mr. Setsuda
  - 8 x 8 Self-Complementary and/or Pan-magic Squares (calculated by Mr. Setsuda)
  - 9 x 9 Self-Complementary Pan-magic Squares (calculated by Mr. Setsuda)

  - 4 x 4, 5 x 5 and 7 x 7 Sparse Magic Squares (By Toshio Kobayashi)
  - 5 x 5 Sparse Magic Squares (By Hercules Lovell)
  - 6 x 6 Sparse Magic Squares (By Hercules Lovell)
  - 8 x 8 Sparse Magic Squares (By Hercules Lovell)
  - 9 x 9 Sparse Magic Squares (By Hercules Lovell)

  - 8 x 8 Magic Square of Squares (Double squares) (by Mr.Saito and Nakazato)
  - 16 x 16 Magic Square of Squares (Double squares) (by Mr.Saito)

  - 3 x 3 Magic Squares of Prime Numbers
  - 3 x 3 Magic Squares of Prime Numbers (arithmetic series)
  - 3 x 3 Magic Squares of Prime Numbers (arithmetic and/or consecutive series)
  - 3 x 3 Twin Squares with Twin Primes
  - 3 x 3 Twin Squares with Larger Differences
  - 3 x 3 Triplet Prime Squares with Constant Difference

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.html Go JUN JUL NOV
46 captures 09
9 Jul 2006 - 4 Apr 2019 2005 2006 2008 About this capture

- 4 x 4 Magic Squares of Sequential Prime Numbers
- Magic Squares of Sequential Prime Numbers from 5x5 through 9x9
- 7 x 7 Magic Squares of Prime Numbers

- Constellation Patterns for PanMagic Squares
- Total Number of Magic Squares and Classification
- Total Number and Classification of Pan-diagonal hypercubes of prime order (Excellent work by Aale de Winkel)
- Total Number of Panmagic Squares (by Prof. Grogono)
- Nonregular Panmagic Squares (Abe Gakuho's study)
- Biggest Magic Square Ever (Ralf Laue's web page on the World Records)

- 3 x 3 Semi-Magic Squares of Squares (by Randall Rathbun)
- 4 x 4 Semi-Magic Squares (477 normalized squares)

- Old Japanese Nested Magic Squares
- Nested Magic Squares (Various nested squares created by Murashin recently)
- MATLAB algorithm for the Nested Magic Squares by Srinath Avalchanula

- Algebraic form of magic squares

- AMBi Magic Square of 3 x 3 (by Lee Sallows; Additive for row and column, multiple for diagonals)
- Anti-Magic Square (by John Cormie)
- Multiplication Magic Square of 3 x 3 (by Eric W.Weisstein)
- Particular Magic Square of 4 x 4 (using only numbers 1 through 9)
- Addition Multiplication Magic Square of 8 x 8 (by Eric W.Weisstein; Both for addition and multiplication by single square)

- Magic Stars of David (80) (Simple data file)
- Magic Stars of David (Beautiful page by Suzanne and Sarah)
- More on the Magic Stars (by Suzanne and Sarah)
- Special Magic Stars of David (12) (with circular conditions)
- Magic Stars of David (with Prime Numbers)
- Magic Stars of 7 points (72)
- Various Magic Stars by Harvey Heinz

- Magic Polygon

- Magic cube of 7 x 7 x 7 (by Norio Iriyama)
- Magic cube of 8x8x8 (by Charles Hetherington)

- **Algorithms**
  - Elegant C-language program for an odd magic square
  - C-language program to create all the 4x4 pan magic squares by a simple but a brute force method (Andre Steenveld).
    Detailed explanation of his sophisticated recursion method is available (.ps file).

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.html Go JUN JUL NOV
46 captures 09
9 Jul 2006 - 4 Apr 2019 2005 2006 2008 About this capture

- Odd, Even(4n type) and Even(4n + 2 type) (Shin, Kwon Young)
- A Method of Creating 4P + 2 Magic Squares (by Professor Grogono)

- 5 x 5 pan-magic squares
- An 8 x 8 magic square
- 9 x 9 pan-magic squares (by Professor Grogono)

- Magic Squares by Sequential Primes (by Vincenzo Librandi)

- How many 5x5 magic squares are there?

- Dr. Kanada's CCM program

- Magic cubes, hyper cubes by JAVA program by Charles Kelly

- **Mathematical Background of Magic Squares**
  - Algebraic approach to the magic square (The simplest example by 3x3 square)
  - Magic Square of Squares (Randall's trial by algebraic considerations)

  - Lie Algebra and Magic Square (by Tony Smith)

  - Multiplying Magic Squares (by Allan Adler)

  - Latin Square, Euler Square and related topics (Eric's page)
  - Greaco-Latin Square (Professore R. A. Beezer's page)

  - Analytical Formulae and Algorithms for Constructing Magic Squares from an Arbitrary set of 16 Numbers (large .pdf file)
    (Yuriy Chebrakov's paper)

  - Prime Magic Squares (pdf file) by C. Price and J. Miller
  - Production of Arbitrary Large Prime Magic Squares (pdf file) by J. Miller, C. Price, and J. Knox

  - Mathematical considerations on Magic Cubes (ps file), (pdf file) by Marian Trenkler
  - Mathematical considerations on Magic Rectangles (pdf file) by Marian Trenkler
  - Math on Magic Hyper Cube (ps file) by Marian Trenkler
  - Math on Magic Graphs (ps file) by Marian Trenkler
  - Characterization of Magic Graphs (ps file) by Marian Trenkler
  - Magic p-dimensional cubes of order n is not equal to 2 (mod 4) (pdf file) by Marian Trenkler (Published in Acta Arithmetica, 2000)
  - Magic p-dimensional cubes (pdf file) by Marian Trenkler (Published in Acta Arithmetica, 2001)

- **Story and/or History of Magic Squares**
  - Mark Swaney on the History of Magic Squares (Excellent work by Mark Swaney and Dan Washburn)

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.html Go JUN JUL NOV
46 captures 09
9 Jul 2006 - 4 Apr 2019 2005 2006 2008 About this capture

- History of magic squares (Chinese, Egypt, India, and Europe) (by Chani Welch)
- Dudeney, Gardner, Andrews, and others (Professor Grogono's page)
- A brief history of magic squares in Japan

- **Home page links to all over the world**
  - Mr. Kanji SETSUDA's page (Japanese researcher, eager in computation)
  - Eric W. Weisstein's page (Simple but complete explanation)
  - Suzanne's page (The Math Forum: Various topics on magic squares)
  - Harvey Heinz page (Excellent!)
  - Professor Grogono's page (Excellent!)
  - Kwon Young Shin's page (Algorithms for all odd and even squares)
  - Arlet's page (Algorithms)
  - John Knoderer's page (Knoderer's special square)
  - Robert C. Wilke's page (Nested magic squares)
  - Letter from Jens Lorenz (Magic hexagon)
  - Frank Kschischang's page (Magic hexagon)
  - Eric Weisstein's page (Magic hexagon)
  - Houlton's page (Magic Cube)
  - J. C. Miller, C. Price and J. Knox (ps files of mathematical theories on Prime Magic Squares)
  - IOI'94 Competition problem and solution (Column of 5-digit prime numbers)
  - Fabrizio Pivari's Simple Magic Square png maker
  - Dave Harper's page (Recreational Maths)
  - Mark Farrar's page (Written by a magician)

- **Miscellaneous: Related Topics**
  - Magic Square on a Jigsaw puzzle by Dubi Kaufmann

- **Photographs of Magic Squares**
  - The famous "Melancholia" by Albrecht Durer (University of St. Andrews)
  - A Magic Square in Gaudi's Cathedral in Barcelona (Mark Farrar's collection of photos)
  - A Magic Square in Gaudi's Cathedral in Barcelona (Harvey Heinz's web page)

- **Mails come from all over the world**
- **Literatures on Magic Squares**

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46 captures
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JUN JUL NOV
09
2005 2006 2008
About this capture

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.8x8.knight.html Go DEC NOV JUL
9 captures 17
17 Jan 2007 - 21 Jul 2016 2006 1996 2009 About this capture

Mutsumi Suzuki
Magic Squares

8 x 8 semi-magic square by a Knight's movement tour

Schuber's 8x8 square was made by the knight's tour. This is a semi-magic square (the diagonal sums are not constant).

```
47 10 23 64 49  2 59  6
22 63 48  9 60  5 50  3
11 46 61 24  1 52  7 58
62 21 12 45  8 57  4 51
19 36 25 40 13 44 53 30
26 39 20 33 56 29 14 43
35 18 37 28 41 16 31 54
38 27 34 17 32 55 42 15
```

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17
2006 2007 2011
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Mutsumi Suzuki
Magic Squares

It is impossible to make any 8x8 panmagic square by the Knight's move tour

Proof

1. The constant sum for the 8x8 magic square is 260.

2. If the knight's movement starts from black cell on a chessboard, the next step is on a white cell.
   So, the all black cells are occupied by odd numbers, and the all white cells are even.

3. Thus, each diagonal (major- and pan-) is constructed by the same type of number, odd or even.

4. The sum of odd numbers 1+3+5+...+63 = 1024 < 260 x 4
   The sum of even numbers 2+4+6+...+64 = 1056 > 260 x 4

5. Therefore the panmagic condition (sums are constant for all pan- and major-diagonals) can not be satisfied.

Back to Suzuki's Magic Squares

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Mutsumi Suzuki
Magic Squares

Composite magic squares of 8 x 8 by Mr. Setsuda

Composite magic square is a square constructed by many small 2 x 2 sub-squares of the same sum. The following is an example of 8 x 8 composite square:

1	63	9	60	14	52	6	55
62	4	54	7	49	15	57	12
33	31	41	28	46	20	38	23
48	18	40	21	35	29	43	26
51	13	59	10	64	2	56	5
16	50	8	53	3	61	11	58
19	45	27	42	32	34	24	37
30	36	22	39	17	47	25	44

The sum of the all small sub-square is 130.

For the above example;
1 + 63 + 62 + 4 = 130;
7 + 49 + 28 + 46 = 130;
13 + 59 + 50 + 8 = 130;
61 + 11 + 34 + 24 = 130;
.... and so on.

Composite magic square looks like the composite flowers.

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.8x8.composite.htm Go DEC JAN JUL
10 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009
About this capture

get another squares by the following row- or column-exchange rules.

1	63	9	60	14	52	6	55
62	4	54	7	49	15	57	12
35	29	43	26	48	18	40	21
46	20	38	23	33	31	41	28
51	13	59	10	64	2	56	5
16	50	8	53	3	61	11	58
17	47	25	44	30	36	22	39
32	34	24	37	19	45	27	42

<---- Half row exchange ---->

1	63	9	60	14	52	6	55
62	4	54	7	49	15	57	12
33	31	41	28	46	20	38	23
48	18	40	21	35	29	43	26
51	13	59	10	64	2	56	5
16	50	8	53	3	61	11	58
19	45	27	42	32	34	24	37
30	36	22	39	17	47	25	44

About the same manner you can create another squares by the half column exchage rule
So, you can create another three from one by these row- or column-exchange rules;

The followings are fundamental 90 composite squares by Mr. Setsuda (Sept. 2000).
You can create 360 squares from the data and the exchange rules.
You can also create 64 (=8x8) squares from single square by row and/or column shift, because the squares are pan-magic.

```
(  1)
 1 63  9 60 14 52  6 55
62  4 54  7 49 15 57 12
33 31 41 28 46 20 38 23
48 18 40 21 35 29 43 26
51 13 59 10 64  2 56  5
16 50  8 53  3 61 11 58
19 45 27 42 32 34 24 37
30 36 22 39 17 47 25 44
```

```
(  5)
 1 63 17 60 22 44  6 47
62  4 46  7 41 23 57 20
33 31 49 28 54 12 38 15
56 10 40 13 35 29 51 26
43 21 59 18 64  2 48  5
24 42  8 45  3 61 19 58
11 53 27 50 32 34 16 37
30 36 14 39  9 55 25 52
```

```
(  9)
 1 63 17 56 26 40 10 47
62  4 46 11 37 27 53 20
33 31 49 24 58  8 42 15
60  6 44 13 35 29 51 22
39 25 55 18 64  2 48  9
28 38 12 45  3 61 19 54
 7 57 23 50 32 34 16 41
30 36 14 43  5 59 21 52
```

```
( 13)
 1 63 33 60 38 28  6 31
62  4 30  7 25 39 57 36
17 47 49 44 54 12 22 15
56 10 24 13 19 45 51 42
27 37 59 34 64  2 32  5
40 26  8 29  3 61 35 58
11 53 43 50 48 18 16 21
46 20 14 23  9 55 41 52
```

```
( 17)
 1 63 33 56 42 24 10 31
62  4 30 11 21 43 53 36
17 47 49 40 58  8 26 15
60  6 28 13 19 45 51 38
23 41 55 34 64  2 32  9
44 22 12 29  3 61 35 54
 7 57 39 50 48 18 16 25
46 20 14 27  5 59 37 52
```

```
( 21)
 1 63 33 48 50 16 18 31
62  4 30 19 13 51 45 36
 9 55 41 40 58  8 26 23
60  6 28 21 11 53 43 38
15 49 47 34 64  2 32 17
52 14 20 29  3 61 35 46
 7 57 39 42 56 10 24 25
54 12 22 27  5 59 37 44
```

```
( 25)
 1 63  9 62 12 54  4 55
60  6 52  7 49 15 57 14
33 31 41 30 44 22 36 23
48 18 40 19 37 27 45 26
53 11 61 10 64  2 56  3
16 50  8 51  5 59 13 58
21 43 29 42 32 34 24 35
28 38 20 39 17 47 25 46
```

```
( 29)
 1 63 17 62 20 46  4 47
60  6 44  7 41 23 57 22
33 31 49 30 52 14 36 15
56 10 40 11 37 27 53 26
45 19 61 18 64  2 48  3
24 42  8 43  5 59 21 58
13 51 29 50 32 34 16 35
28 38 12 39  9 55 25 54
```

```
( 33)
 1 63 17 56 26 40 10 47
60  6 44 13 35 29 51 22
33 31 49 24 58  8 42 15
62  4 46 11 37 27 53 20
39 25 55 18 64  2 48  9
30 36 14 43  5 59 21 52
 7 57 23 50 32 34 16 41
28 38 12 45  3 61 19 54
```

```
( 37)
 1 63 33 62 36 30  4 31
60  6 28  7 25 39 57 38
17 47 49 46 52 14 20 15
56 10 24 11 21 43 53 42
```

```
( 41)
 1 63 33 56 42 24 10 31
60  6 28 13 19 45 51 38
17 47 49 40 58  8 26 15
62  4 30 11 21 43 53 36
```

```
( 45)
 1 63 33 48 50 16 18 31
60  6 28 21 11 53 43 38
 9 55 41 40 58  8 26 23
62  4 30 19 13 51 45 36
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.8x8.composite.htm Go DEC JAN JUL 17 2006 2007 2009
10 captures
17 Jan 2007 - 21 Jul 2016
About this capture

(49)

1	63	17	56	26	40	10	47
58	8	42	15	33	31	49	24
35	29	51	22	60	6	44	13
62	4	46	11	37	27	53	20
39	25	55	18	64	2	48	9
32	34	16	41	7	57	23	50
5	59	21	52	30	36	14	43
28	38	12	45	3	61	19	54

(53)

1	63	33	56	42	24	10	31
58	8	26	15	17	47	49	40
19	45	51	38	60	6	28	13
62	4	30	11	21	43	53	36
23	41	55	34	64	2	32	9
48	18	16	25	7	57	39	50
5	59	37	52	46	20	14	27
44	22	12	29	3	61	35	54

(57)

1	63	33	48	50	16	18	31
58	8	26	23	9	55	41	40
11	53	43	38	60	6	28	21
62	4	30	19	13	51	45	36
15	49	47	34	64	2	32	17
56	10	24	25	7	57	39	42
5	59	37	44	54	12	22	27
52	14	20	29	3	61	35	46

(61)

1	63	5	62	8	58	4	59
56	10	52	11	49	15	53	14
33	31	37	30	40	26	36	27
48	18	44	19	41	23	45	22
57	7	61	6	64	2	60	3
16	50	12	51	9	55	13	54
25	39	29	38	32	34	28	35
24	42	20	43	17	47	21	46

(65)

1	63	17	62	20	46	4	47
56	10	40	11	37	27	53	26
33	31	49	30	52	14	36	15
60	6	44	7	41	23	57	22
45	19	61	18	64	2	48	3
28	38	12	39	9	55	25	54
13	51	29	50	32	34	16	35
24	42	8	43	5	59	21	58

(69)

1	63	17	60	22	44	6	47
56	10	40	13	35	29	51	26
33	31	49	28	54	12	38	15
62	4	46	7	41	23	57	20
43	21	59	18	64	2	48	5
30	36	14	39	9	55	25	52
11	53	27	50	32	34	16	37
24	42	8	45	3	61	19	58

(73)

1	63	33	62	36	30	4	31
56	10	24	11	21	43	53	42
17	47	49	46	52	14	20	15
60	6	28	7	25	39	57	38
29	35	61	34	64	2	32	3
44	22	12	23	9	55	41	54
13	51	45	50	48	18	16	19
40	26	8	27	5	59	37	58

(77)

1	63	33	60	38	28	6	31
56	10	24	13	19	45	51	42
17	47	49	44	54	12	22	15
62	4	30	7	25	39	57	36
27	37	59	34	64	2	32	5
46	20	14	23	9	55	41	52
11	53	43	50	48	18	16	21
40	26	8	29	3	61	35	58

(81)

1	63	17	60	22	44	6	47
54	12	38	15	33	31	49	28
35	29	51	26	56	10	40	13
62	4	46	7	41	23	57	20
43	21	59	18	64	2	48	5
32	34	16	37	11	53	27	50
9	55	25	52	30	36	14	39
24	42	8	45	3	61	19	58

(85)

1	63	33	60	38	28	6	31
54	12	22	15	17	47	49	44
19	45	51	42	56	10	24	13
62	4	30	7	25	39	57	36
27	37	59	34	64	2	32	5
48	18	16	21	11	53	43	50
9	55	41	52	46	20	14	23
40	26	8	29	3	61	35	58

(89)

1	63	17	62	20	46	4	47
52	14	36	15	33	31	49	30
37	27	53	26	56	10	40	11
60	6	44	7	41	23	57	22
45	19	61	18	64	2	48	3
32	34	16	35	13	51	29	50
9	55	25	54	28	38	12	39
24	42	8	43	5	59	21	58

(93)

1	63	33	62	36	30	4	31
52	14	20	15	17	47	49	46
21	43	53	42	56	10	24	11
60	6	28	7	25	39	57	38
29	35	61	34	64	2	32	3
48	18	16	19	13	51	45	50
9	55	41	54	44	22	12	23
40	26	8	27	5	59	37	58

(97)

1	63	5	62	8	58	4	59
48	18	44	19	41	23	45	22
33	31	37	30	40	26	36	27
56	10	52	11	49	15	53	14
57	7	61	6	64	2	60	3
24	42	20	43	17	47	21	46
25	39	29	38	32	34	28	35
16	50	12	51	9	55	13	54

(101)

1	63	9	62	12	54	4	55
48	18	40	19	37	27	45	26
33	31	41	30	44	22	36	23
60	6	52	7	49	15	57	14
53	11	61	10	64	2	56	3
28	38	20	39	17	47	25	46
21	43	29	42	32	34	24	35
16	50	8	51	5	59	13	58

(105)

1	63	9	60	14	52	6	55
48	18	40	21	35	29	43	26
33	31	41	28	46	20	38	23
62	4	54	7	49	15	57	12
51	13	59	10	64	2	56	5
30	36	22	39	17	47	25	44
19	45	27	42	32	34	24	37
16	50	8	53	3	61	11	58

(109)

1	63	9	60	14	52	6	55
46	20	38	23	33	31	41	28
35	29	43	26	48	18	40	21
62	4	54	7	49	15	57	12
51	13	59	10	64	2	56	5
32	34	24	37	19	45	27	42
17	47	25	44	30	36	22	39
16	50	8	53	3	61	11	58

(113)

1	63	9	62	12	54	4	55
44	22	36	23	33	31	41	30
37	27	45	26	48	18	40	19
60	6	52	7	49	15	57	14
53	11	61	10	64	2	56	3
32	34	24	35	21	43	29	42
17	47	25	46	28	38	20	39
16	50	8	51	5	59	13	58

(117)

1	63	5	62	8	58	4	59
40	26	36	27	33	31	37	30
41	23	45	22	48	18	44	19
56	10	52	11	49	15	53	14
57	7	61	6	64	2	60	3
32	34	28	35	25	39	29	38
17	47	21	46	24	42	20	43
16	50	12	51	9	55	13	54

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.8x8.composite.htm Go DEC JAN JUL
10 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009 About this capture

48	19	40	18	37	26	45	27
53	10	61	11	64	3	56	2
16	51	8	50	5	58	13	59
21	42	29	43	32	35	24	34
28	39	20	38	17	46	25	47

56	11	40	10	37	26	53	27
45	18	61	19	64	3	48	2
24	43	8	42	5	58	21	59
13	50	29	51	32	35	16	34
28	39	12	38	9	54	25	55

63	4	47	10	37	26	53	20
38	25	54	19	64	3	48	9
31	36	15	42	5	58	21	52
6	57	22	51	32	35	16	41
28	39	12	45	2	61	18	55

(133)

1	62	33	63	36	31	4	30
60	7	28	6	25	38	57	39
17	46	49	47	52	15	20	14
56	11	24	10	21	42	53	43
29	34	61	35	64	3	32	2
40	27	8	26	5	58	37	59
13	50	45	51	48	19	16	18
44	23	12	22	9	54	41	55

(137)

1	62	33	56	43	24	11	30
60	7	28	13	18	45	50	39
17	46	49	40	59	8	27	14
63	4	31	10	21	42	53	36
22	41	54	35	64	3	32	9
47	20	15	26	5	58	37	52
6	57	38	51	48	19	16	25
44	23	12	29	2	61	34	55

(141)

1	62	33	48	51	16	19	30
60	7	28	21	10	53	42	39
9	54	41	40	59	8	27	22
63	4	31	18	13	50	45	36
14	49	46	35	64	3	32	17
55	12	23	26	5	58	37	44
6	57	38	43	56	11	24	25
52	15	20	29	2	61	34	47

(145)

1	62	17	56	27	40	11	46
59	8	43	14	33	30	49	24
34	29	50	23	60	7	44	13
63	4	47	10	37	26	53	20
38	25	54	19	64	3	48	9
32	35	16	41	6	57	22	51
5	58	21	52	31	36	15	42
28	39	12	45	2	61	18	55

(149)

1	62	33	56	43	24	11	30
59	8	27	14	17	46	49	40
18	45	50	39	60	7	28	13
63	4	31	10	21	42	53	36
22	41	54	35	64	3	32	9
48	19	16	25	6	57	38	51
5	58	37	52	47	20	15	26
44	23	12	29	2	61	34	55

(153)

1	62	33	48	51	16	19	30
59	8	27	22	9	54	41	40
10	53	42	39	60	7	28	21
63	4	31	18	13	50	45	36
14	49	46	35	64	3	32	17
56	11	24	25	6	57	38	43
5	58	37	44	55	12	23	26
52	15	20	29	2	61	34	47

(157)

1	62	5	63	8	59	4	58
56	11	52	10	49	14	53	15
33	30	37	31	40	27	36	26
48	19	44	18	41	22	45	23
57	6	61	7	64	3	60	2
16	51	12	50	9	54	13	55
25	38	29	39	32	35	28	34
24	43	20	42	17	46	21	47

(161)

1	62	17	63	20	47	4	46
56	11	40	10	37	26	53	27
33	30	49	31	52	15	36	14
60	7	44	6	41	22	57	23
45	18	61	19	64	3	48	2
28	39	12	38	9	54	25	55
13	50	29	51	32	35	16	34
24	43	8	42	5	58	21	59

(165)

1	62	17	60	23	44	7	46
56	11	40	13	34	29	50	27
33	30	49	28	55	12	39	14
63	4	47	6	41	22	57	20
42	21	58	19	64	3	48	5
31	36	15	38	9	54	25	52
10	53	26	51	32	35	16	37
24	43	8	45	2	61	18	59

(169)

1	62	33	63	36	31	4	30
56	11	24	10	21	42	53	43
17	46	49	47	52	15	20	14
60	7	28	6	25	38	57	39
29	34	61	35	64	3	32	2
44	23	12	22	9	54	41	55
13	50	45	51	48	19	16	18
40	27	8	26	5	58	37	59

(173)

1	62	33	60	39	28	7	30
56	11	24	13	18	45	50	43
17	46	49	44	55	12	23	14
63	4	31	6	25	38	57	36
26	37	58	35	64	3	32	5
47	20	15	22	9	54	41	52
10	53	42	51	48	19	16	21
40	27	8	29	2	61	34	59

(177)

1	62	17	60	23	44	7	46
55	12	39	14	33	30	49	28
34	29	50	27	56	11	40	13
63	4	47	6	41	22	57	20
42	21	58	19	64	3	48	5
32	35	16	37	10	53	26	51
9	54	25	52	31	36	15	38
24	43	8	45	2	61	18	59

(181)

1	62	33	60	39	28	7	30
55	12	23	14	17	46	49	44
18	45	50	43	56	11	24	13
63	4	31	6	25	38	57	36
26	37	58	35	64	3	32	5
48	19	16	21	10	53	42	51
9	54	41	52	47	20	15	22
40	27	8	29	2	61	34	59

(185)

1	62	17	63	20	47	4	46
52	15	36	14	33	30	49	31
37	26	53	27	56	11	40	10
60	7	44	6	41	22	57	23
45	18	61	19	64	3	48	2
32	35	16	34	13	50	29	51
9	54	25	55	28	39	12	38
24	43	8	42	5	58	21	59

(189)

1	62	33	63	36	31	4	30
52	15	20	14	17	46	49	47
21	42	53	43	56	11	24	10
60	7	28	6	25	38	57	39
29	34	61	35	64	3	32	2
48	19	16	18	13	50	45	51
9	54	41	55	44	23	12	22
40	27	8	26	5	58	37	59

(193)

1	62	5	63	8	59	4	58
48	19	44	18	41	22	45	23
33	30	37	31	40	27	36	26
56	11	52	10	49	14	53	15

(197)

1	62	9	63	12	55	4	54
48	19	40	18	37	26	45	27
33	30	41	31	44	23	36	22
60	7	52	6	49	14	57	15

(201)

1	62	9	60	15	52	7	54
48	19	40	21	34	29	42	27
33	30	41	28	47	20	39	22
63	4	55	6	49	14	57	12

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.8x8.composite.htm Go DEC JAN JUL
10 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009
About this capture

(205)

1	62	9	60	15	52	7	54
47	20	39	22	33	30	41	28
34	29	42	27	48	19	40	21
63	4	55	6	49	14	57	12
50	13	58	11	64	3	56	5
32	35	24	37	18	45	26	43
17	46	25	44	31	36	23	38
16	51	8	53	2	61	10	59

(209)

1	62	9	63	12	55	4	54
44	23	36	22	33	30	41	31
37	26	45	27	48	19	40	18
60	7	52	6	49	14	57	15
53	10	61	11	64	3	56	2
32	35	24	34	21	42	29	43
17	46	25	47	28	39	20	38
16	51	8	50	5	58	13	59

(213)

1	62	5	63	8	59	4	58
40	27	36	26	33	30	37	31
41	22	45	23	48	19	44	18
56	11	52	10	49	14	53	15
57	6	61	7	64	3	60	2
32	35	28	34	25	38	29	39
17	46	21	47	24	43	20	42
16	51	12	50	9	54	13	55

(217)

1	61	10	63	12	56	3	54
60	8	51	6	49	13	58	15
33	29	42	31	44	24	35	22
48	20	39	18	37	25	46	27
53	9	62	11	64	4	55	2
16	52	7	50	5	57	14	59
21	41	30	43	32	36	23	34
28	40	19	38	17	45	26	47

(221)

1	61	18	63	20	48	3	46
60	8	43	6	41	21	58	23
33	29	50	31	52	16	35	14
56	12	39	10	37	25	54	27
45	17	62	19	64	4	47	2
24	44	7	42	5	57	22	59
13	49	30	51	32	36	15	34
28	40	11	38	9	53	26	55

(225)

1	61	34	63	36	32	3	30
60	8	27	6	25	37	58	39
17	45	50	47	52	16	19	14
56	12	23	10	21	41	54	43
29	33	62	35	64	4	31	2
40	28	7	26	5	57	38	59
13	49	46	51	48	20	15	18
44	24	11	22	9	53	42	55

(229)

1	61	6	63	8	60	3	58
56	12	51	10	49	13	54	15
33	29	38	31	40	28	35	26
48	20	43	18	41	21	46	23
57	5	62	7	64	4	59	2
16	52	11	50	9	53	14	55
25	37	30	39	32	36	27	34
24	44	19	42	17	45	22	47

(233)

1	61	18	63	20	48	3	46
56	12	39	10	37	25	54	27
33	29	50	31	52	16	35	14
60	8	43	6	41	21	58	23
45	17	62	19	64	4	47	2
28	40	11	38	9	53	26	55
13	49	30	51	32	36	15	34
24	44	7	42	5	57	22	59

(237)

1	61	34	63	36	32	3	30
56	12	23	10	21	41	54	43
17	45	50	47	52	16	19	14
60	8	27	6	25	37	58	39
29	33	62	35	64	4	31	2
44	24	11	22	9	53	42	55
13	49	46	51	48	20	15	18
40	28	7	26	5	57	38	59

(241)

1	61	18	63	20	48	3	46
52	16	35	14	33	29	50	31
37	25	54	27	56	12	39	10
60	8	43	6	41	21	58	23
45	17	62	19	64	4	47	2
32	36	15	34	13	49	30	51
9	53	26	55	28	40	11	38
24	44	7	42	5	57	22	59

(245)

1	61	34	63	36	32	3	30
52	16	19	14	17	45	50	47
21	41	54	43	56	12	23	10
60	8	27	6	25	37	58	39
29	33	62	35	64	4	31	2
48	20	15	18	13	49	46	51
9	53	42	55	44	24	11	22
40	28	7	26	5	57	38	59

(249)

1	61	6	63	8	60	3	58
48	20	43	18	41	21	46	23
33	29	38	31	40	28	35	26
56	12	51	10	49	13	54	15
57	5	62	7	64	4	59	2
24	44	19	42	17	45	22	47
25	37	30	39	32	36	27	34
16	52	11	50	9	53	14	55

(253)

1	61	10	63	12	56	3	54
48	20	39	18	37	25	46	27
33	29	42	31	44	24	35	22
60	8	51	6	49	13	58	15
53	9	62	11	64	4	55	2
28	40	19	38	17	45	26	47
21	41	30	43	32	36	23	34
16	52	7	50	5	57	14	59

(257)

1	61	10	63	12	56	3	54
44	24	35	22	33	29	42	31
37	25	46	27	48	20	39	18
60	8	51	6	49	13	58	15
53	9	62	11	64	4	55	2
32	36	23	34	21	41	30	43
17	45	26	47	28	40	19	38
16	52	7	50	5	57	14	59

(261)

1	61	6	63	8	60	3	58
40	28	35	26	33	29	38	31
41	21	46	23	48	20	43	18
56	12	51	10	49	13	54	15
57	5	62	7	64	4	59	2
32	36	27	34	25	37	30	39
17	45	22	47	24	44	19	42
16	52	11	50	9	53	14	55

(265)

1	60	17	63	22	47	6	44
56	13	40	10	35	26	51	29
33	28	49	31	54	15	38	12
62	7	46	4	41	20	57	23
43	18	59	21	64	5	48	2
30	39	14	36	9	52	25	55
11	50	27	53	32	37	16	34
24	45	8	42	3	58	19	61

(269)

1	60	17	62	23	46	7	44
56	13	40	11	34	27	50	29
33	28	49	30	55	14	39	12
63	6	47	4	41	20	57	22
42	19	58	21	64	5	48	3
31	38	15	36	9	52	25	54
10	51	26	53	32	37	16	35
24	45	8	43	2	59	18	61

(273)

1	60	33	63	38	31	6	28
56	13	24	10	19	42	51	45
17	44	49	47	54	15	22	12
62	7	30	4	25	36	57	39
27	34	59	37	64	5	32	2
46	23	14	20	9	52	41	55
11	50	43	53	48	21	16	18
40	29	8	26	3	58	35	61

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.8x8.composite.html Go DEC JAN JUL
10 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009 About this capture

```
63  6 31  4 25 36 57 38
26 35 58 37 64  5 32  3
47 22 15 20  9 52 41 54
10 51 42 53 48 21 16 19
40 29  8 27  2 59 34 61
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63  6 47  4 41 20 57 22
42 19 58 21 64  5 48  3
32 37 16 35 10 51 26 53
 9 52 25 54 31 38 15 36
24 45  8 43  2 59 18 61
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63  6 31  4 25 36 57 38
26 35 58 37 64  5 32  3
48 21 16 19 10 51 42 53
 9 52 41 54 47 22 15 20
40 29  8 27  2 59 34 61
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(289)
 1 60 17 63 22 47  6 44
54 15 38 12 33 28 49 31
35 26 51 29 56 13 40 10
62  7 46  4 41 20 57 23
43 18 59 21 64  5 48  2
32 37 16 34 11 50 27 53
 9 52 25 55 30 39 14 36
24 45  8 42  3 58 19 61
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(293)
 1 60 33 63 38 31  6 28
54 15 22 12 17 44 49 47
19 42 51 45 56 13 24 10
62  7 30  4 25 36 57 39
27 34 59 37 64  5 32  2
48 21 16 18 11 50 43 53
 9 52 41 55 46 23 14 20
40 29  8 26  3 58 35 61
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(297)
 1 60  9 63 14 55  6 52
48 21 40 18 35 26 43 29
33 28 41 31 46 23 38 20
62  7 54  4 49 12 57 15
51 10 59 13 64  5 56  2
30 39 22 36 17 44 25 47
19 42 27 45 32 37 24 34
16 53  8 50  3 58 11 61
```

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(301)
 1 60  9 62 15 54  7 52
48 21 40 19 34 27 42 29
33 28 41 30 47 22 39 20
63  6 55  4 49 12 57 14
50 11 58 13 64  5 56  3
31 38 23 36 17 44 25 46
18 43 26 45 32 37 24 35
16 53  8 51  2 59 10 61
```

```
(305)
 1 60  9 62 15 54  7 52
47 22 39 20 33 28 41 30
34 27 42 29 48 21 40 19
63  6 55  4 49 12 57 14
50 11 58 13 64  5 56  3
32 37 24 35 18 43 26 45
17 44 25 46 31 38 23 36
16 53  8 51  2 59 10 61
```

```
(309)
 1 60  9 63 14 55  6 52
46 23 38 20 33 28 41 31
35 26 43 29 48 21 40 18
62  7 54  4 49 12 57 15
51 10 59 13 64  5 56  2
32 37 24 34 19 42 27 45
17 44 25 47 30 39 22 36
16 53  8 50  3 58 11 61
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(313)
 1 59 18 63 22 48  5 44
56 14 39 10 35 25 52 29
33 27 50 31 54 16 37 12
62  8 45  4 41 19 58 23
43 17 60 21 64  6 47  2
30 40 13 36  9 51 26 55
11 49 28 53 32 38 15 34
24 46  7 42  3 57 20 61
```

```
(317)
 1 59 34 63 38 32  5 28
56 14 23 10 19 41 52 45
17 43 50 47 54 16 21 12
62  8 29  4 25 35 58 39
27 33 60 37 64  6 31  2
46 24 13 20  9 51 42 55
11 49 44 53 48 22 15 18
40 30  7 26  3 57 36 61
```

```
(321)
 1 59 18 63 22 48  5 44
54 16 37 12 33 27 50 31
35 25 52 29 56 14 39 10
62  8 45  4 41 19 58 23
43 17 60 21 64  6 47  2
32 38 15 34 11 49 28 53
 9 51 26 55 30 40 13 36
24 46  7 42  3 57 20 61
```

```
(325)
 1 59 34 63 38 32  5 28
54 16 21 12 17 43 50 47
19 41 52 45 56 14 23 10
62  8 29  4 25 35 58 39
27 33 60 37 64  6 31  2
48 22 15 18 11 49 44 53
 9 51 42 55 46 24 13 20
40 30  7 26  3 57 36 61
```

```
(329)
 1 59 10 63 14 56  5 52
48 22 39 18 35 25 44 29
33 27 42 31 46 24 37 20
62  8 53  4 49 11 58 15
51  9 60 13 64  6 55  2
30 40 21 36 17 43 26 47
19 41 28 45 32 38 23 34
16 54  7 50  3 57 12 61
```

```
(333)
 1 59 10 63 14 56  5 52
46 24 37 20 33 27 42 31
35 25 44 29 48 22 39 18
62  8 53  4 49 11 58 15
51  9 60 13 64  6 55  2
32 38 23 34 19 41 28 45
17 43 26 47 30 40 21 36
16 54  7 50  3 57 12 61
```

```
(337)
 1 58 19 62 23 48  5 44
56 15 38 11 34 25 52 29
33 26 51 30 55 16 37 12
63  8 45  4 41 18 59 22
42 17 60 21 64  7 46  3
31 40 13 36  9 50 27 54
10 49 28 53 32 39 14 35
24 47  6 43  2 57 20 61
```

```
(341)
 1 58 35 62 39 32  5 28
56 15 22 11 18 41 52 45
17 42 51 46 55 16 21 12
63  8 29  4 25 34 59 38
26 33 60 37 64  7 30  3
47 24 13 20  9 50 43 54
10 49 44 53 48 23 14 19
40 31  6 27  2 57 36 61
```

```
(345)
 1 58 19 62 23 48  5 44
55 16 37 12 33 26 51 30
34 25 52 29 56 15 38 11
63  8 45  4 41 18 59 22
42 17 60 21 64  7 46  3
32 39 14 35 10 49 28 53
 9 50 27 54 31 40 13 36
24 47  6 43  2 57 20 61
```

```
(349)
 1 58 35 62 39 32  5 28
55 16 21 12 17 42 51 46
18 41 52 45 56 15 22 11
63  8 29  4 25 34 59 38
```

```
(353)
 1 58 11 62 15 56  5 52
48 23 38 19 34 25 44 29
33 26 43 30 47 24 37 20
63  8 53  4 49 10 59 14
```

```
(357)
 1 58 11 62 15 56  5 52
47 24 37 20 33 26 43 30
34 25 44 29 48 23 38 19
63  8 53  4 49 10 59 14
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.8x8.composite.html Go DEC JAN JUL
10 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009
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Mutsumi Suzuki
Magic Squares

8 x 8 Symmetrical and/or Pan-Magic Squares by Mr. Setsuda

The self complementary square is invariant for the complementary transformations. If you change all the number "n" of the 8x8 square by "65 - n," you get the rotated same square. You can say that it is axisymmetry or self-similar, in another word. The pan-magic square is the square in which the pan diagonals add up to the same sum.

If the both conditions are satisfied, the square is called a self-complementary pan-magic square. There is, however, no such a square in the 8x8 magic squares.

Mr. Setsuda found that every symmetrical square can be transformed into a pan-magic square. There are one to one correspondence. You can see the relations in the following figures.

(Self Complementary Square)

1	62	5	59	58	12	61	2
57	14	50	48	19	45	18	9
10	27	34	25	41	36	33	54
49	30	26	23	37	22	21	52
13	44	43	28	42	39	35	16
11	32	29	24	40	31	38	55
56	47	20	46	17	15	51	8
63	4	53	7	6	60	3	64

<--one by one correspondence-->

(Pan-Magic Square)

1	62	5	59	2	61	12	58
57	14	50	48	9	18	45	19
10	27	34	25	54	33	36	41
49	30	26	23	52	21	22	37
63	4	53	7	64	3	60	6
56	47	20	46	8	51	15	17
11	32	29	24	55	38	31	40
13	44	43	28	16	35	39	42

The following examples are by Mr. Setsuda (Sept. 2000).

```
 (Self Complementary Square)           (Pan-Magic Square)
 1 62  5 59 58 12 61  2           1 62  5 59  2 61 12 58
57 14 50 48 19 45 18  9          57 14 50 48  9 18 45 19
10 27 34 25 41 36 33 54          10 27 34 25 54 33 36 41
49 30 26 23 37 22 21 52  <----->  49 30 26 23 52 21 22 37
13 44 43 28 42 39 35 16          63  4 53  7 64  3 60  6
11 32 29 24 40 31 38 55          56 47 20 46  8 51 15 17
56 47 20 46 17 15 51  8          11 32 29 24 55 38 31 40
63  4 53  7  6 60  3 64          13 44 43 28 16 35 39 42

 1 62  5 59 58 12 61  2           1 62  5 59  2 61 12 58
57 14 50 48 18 45 19  9          57 14 50 48  9 19 45 18
10 27 37 23 43 36 30 54          10 27 37 23 54 30 36 43
49 31 26 21 32 25 24 52  <----->  49 31 26 21 52 24 25 32
13 41 40 33 44 39 34 16          63  4 53  7 64  3 60  6
11 35 29 22 42 28 38 55          56 46 20 47  8 51 15 17
56 46 20 47 17 15 51  8          11 35 29 22 55 38 28 42
63  4 53  7  6 60  3 64          13 41 40 33 16 34 39 44
```

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8 captures 17
17 Jan 2007 - 20 Jul 2016 2006 2007 2011
About this capture

```
49 33 26 19 34 25 24 52   <----->   49 33 26 19 52 24 25 34
13 41 42 31 46 39 32 16             63  4 53  7 64  3 60  6
11 36 28 22 38 30 40 55             56 45 21 47  8 51 15 17
56 45 21 47 17 15 51  8             11 36 28 22 55 40 30 38
63  4 53  7  6 60  3 64             13 41 42 31 16 32 39 46

 1 62  5 59 58 12 61  2              1 62  5 59  2 61 12 58
57 14 50 48 18 43 21  9             57 14 50 48  9 21 43 18
10 25 35 28 45 36 27 54             10 25 35 28 54 27 36 45
49 34 24 19 33 23 26 52   <----->   49 34 24 19 52 26 23 33
13 39 42 32 46 41 31 16             63  4 53  7 64  3 60  6
11 38 29 20 37 30 40 55             56 44 22 47  8 51 15 17
56 44 22 47 17 15 51  8             11 38 29 20 55 40 30 37
63  4 53  7  6 60  3 64             13 39 42 32 16 31 41 46

 1 62  5 59 58 12 61  2              1 62  5 59  2 61 12 58
57 14 50 48 18 42 22  9             57 14 50 48  9 22 42 18
10 24 39 25 44 36 28 54             10 24 39 25 54 28 36 44
49 30 27 20 32 31 19 52   <----->   49 30 27 20 52 19 31 32
13 46 34 33 45 38 35 16             63  4 53  7 64  3 60  6
11 37 29 21 40 26 41 55             56 43 23 47  8 51 15 17
56 43 23 47 17 15 51  8             11 37 29 21 55 41 26 40
63  4 53  7  6 60  3 64             13 46 34 33 16 35 38 45

 1 62  5 59 58 12 61  2              1 62  5 59  2 61 12 58
57 14 50 48 18 41 23  9             57 14 50 48  9 23 41 18
10 25 29 26 45 38 33 54             10 25 29 26 54 33 38 45
49 35 28 22 34 21 19 52   <----->   49 35 28 22 52 19 21 34
13 46 44 31 43 37 30 16             63  4 53  7 64  3 60  6
11 32 27 20 39 36 40 55             56 42 24 47  8 51 15 17
56 42 24 47 17 15 51  8             11 32 27 20 55 40 36 39
63  4 53  7  6 60  3 64             13 46 44 31 16 30 37 43

 1 62  5 59 58 12 61  2              1 62  5 59  2 61 12 58
57 14 50 48 18 40 24  9             57 14 50 48  9 24 40 18
10 23 36 28 45 34 30 54             10 23 36 28 54 30 34 45
49 38 21 19 33 26 22 52   <----->   49 38 21 19 52 22 26 33
13 43 39 32 46 44 27 16             63  4 53  7 64  3 60  6
11 35 31 20 37 29 42 55             56 41 25 47  8 51 15 17
56 41 25 47 17 15 51  8             11 35 31 20 55 42 29 37
63  4 53  7  6 60  3 64             13 43 39 32 16 27 44 46

 1 62  5 59 58 12 61  2              1 62  5 59  2 61 12 58
57 14 50 48 18 39 25  9             57 14 50 48  9 25 39 18
10 23 34 29 43 35 32 54             10 23 34 29 54 32 35 43
49 38 21 20 37 24 19 52   <----->   49 38 21 20 52 19 24 37
13 46 41 28 45 44 27 16             63  4 53  7 64  3 60  6
11 33 30 22 36 31 42 55             56 40 26 47  8 51 15 17
56 40 26 47 17 15 51  8             11 33 30 22 55 42 31 36
63  4 53  7  6 60  3 64             13 46 41 28 16 27 44 45

 1 62  5 59 58 12 61  2              1 62  5 59  2 61 12 58
57 14 50 48 18 38 26  9             57 14 50 48  9 26 38 18
10 23 34 28 45 36 30 54             10 23 34 28 54 30 36 45
49 40 21 19 33 24 22 52   <----->   49 40 21 19 52 22 24 33
13 43 41 32 46 44 25 16             63  4 53  7 64  3 60  6
11 35 29 20 37 31 42 55             56 39 27 47  8 51 15 17
56 39 27 47 17 15 51  8             11 35 29 20 55 42 31 37
63  4 53  7  6 60  3 64             13 43 41 32 16 25 44 46

 1 62  5 59 58 12 61  2              1 62  5 59  2 61 12 58
```

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DEC JAN MAY
17
2006 2007 2011
8 captures
17 Jan 2007 - 20 Jul 2016
About this capture

```
11 40 21 20 39 33 41 55              56 38 28 47  8 51 15 17
56 38 28 47 17 15 51  8              11 40 21 20 55 41 33 39
63  4 53  7  6 60  3 64              13 43 42 34 16 30 36 46

 1 62  5 59 58 12 61  2               1 62  5 59  2 61 12 58
57 14 50 48 18 36 28  9              57 14 50 48  9 28 36 18
10 23 34 32 43 38 26 54              10 23 34 32 54 26 38 43
49 35 21 20 40 24 19 52    <----->   49 35 21 20 52 19 24 40
13 46 41 25 45 44 30 16              63  4 53  7 64  3 60  6
11 39 27 22 33 31 42 55              56 37 29 47  8 51 15 17
56 37 29 47 17 15 51  8              11 39 27 22 55 42 31 33
63  4 53  7  6 60  3 64              13 46 41 25 16 30 44 45

 1 62  5 59 58 12 61  2               1 62  5 59  2 61 12 58
57 14 50 48 18 35 29  9              57 14 50 48  9 29 35 18
10 23 34 25 43 44 27 54              10 23 34 25 54 27 44 43
49 37 26 20 33 24 19 52    <----->   49 37 26 20 52 19 24 33
13 46 41 32 45 39 28 16              63  4 53  7 64  3 60  6
11 38 21 22 40 31 42 55              56 36 30 47  8 51 15 17
56 36 30 47 17 15 51  8              11 38 21 22 55 42 31 40
63  4 53  7  6 60  3 64              13 46 41 32 16 28 39 45
```

Back to **Suzuki's Magic Squares**

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17 Jan 2007 - 24 Oct 2018
About this capture

Mutsumi Suzuki
Magic Squares

Self-complementary Pan Magic Square of 9x9

These squares are pan-magic and also self-similar. In the pan-magic squares, not only the major but also the minor diagonals add up to the same sum. The self complementary square is invariant for the complementary transformations. If you change all the number "n" of the square by "82 - n," you get the rotated same square. You can say that it is axisymmetry or self-simillar, in another word.

If the both conditions are satisfied, the square is called a self-complementary pan-magic square. There are only few such squares are known for the 5 x 5 systems, but there are too many 9 x 9 squares to determine the total number. The followings are some examples calculated by Mr. Setsuda.

1	44	14	65	62	78	64	26	15	1	44	14	65	62	78	64	26	15
31	2	77	75	37	71	16	57	3	31	2	77	69	60	53	42	24	11
61	63	59	22	27	35	24	32	46	61	63	70	6	49	9	27	47	37
52	69	42	28	10	8	53	34	73	52	72	8	23	3	36	34	75	66
33	12	6	43	41	39	76	70	49	25	32	39	54	41	28	43	50	57
9	48	29	74	72	54	40	13	30	16	7	48	46	79	59	74	10	30
36	50	58	47	55	60	23	19	21	45	35	55	73	33	76	12	19	21
79	25	66	11	45	7	5	80	51	71	58	40	29	22	13	5	80	51
67	56	18	4	20	17	68	38	81	67	56	18	4	20	17	68	38	81

1	44	14	65	62	78	64	26	15	1	44	14	65	62	78	64	26	15
31	12	80	76	43	71	37	16	3	31	12	80	72	42	59	33	37	3
61	50	49	19	34	5	53	58	40	61	50	69	29	11	6	66	22	55
52	74	54	10	13	22	25	46	73	52	39	47	8	7	48	63	28	77
27	7	23	47	41	35	59	75	55	46	9	57	58	41	24	25	73	36
9	36	57	60	69	72	28	8	30	5	54	19	34	75	74	35	43	30
42	24	29	77	48	63	33	32	21	27	60	16	76	71	53	13	32	21
79	66	45	11	39	6	2	70	51	79	45	49	23	40	10	2	70	51
67	56	18	4	20	17	68	38	81	67	56	18	4	20	17	68	38	81

1	44	14	65	62	78	64	26	15	1	44	14	65	62	78	64	26	15
31	12	80	77	33	60	46	27	3	31	12	80	76	47	57	40	23	3
61	50	76	13	11	9	37	40	72	61	50	71	8	24	9	45	29	72
52	48	35	23	16	53	75	28	39	52	33	27	16	13	43	77	48	60
25	8	58	63	41	19	24	74	57	46	28	75	63	41	19	7	54	36
43	54	7	29	66	59	47	34	30	22	34	5	39	69	66	55	49	30
10	42	45	73	71	69	6	32	21	10	53	37	73	58	74	11	32	21
79	55	36	22	49	5	2	70	51	79	59	42	25	35	6	2	70	51
67	56	18	4	20	17	68	38	81	67	56	18	4	20	17	68	38	81

1	44	14	65	62	78	64	26	15	1	44	14	65	62	78	64	26	15
31	22	70	57	77	34	23	53	2	31	22	70	73	75	45	27	24	2
61	50	74	3	40	13	37	16	75	61	50	57	3	11	16	43	54	74
52	39	10	27	11	49	76	47	58	52	53	5	48	6	72	40	47	46
46	28	73	63	41	19	9	54	36	33	23	69	63	41	19	13	59	49
24	35	6	33	71	55	72	43	30	36	35	42	10	76	34	77	29	30
7	66	45	69	42	79	8	32	21	8	28	39	66	71	79	25	32	21
80	29	59	48	5	25	12	60	51	80	58	55	37	7	9	12	60	51
67	56	18	4	20	17	68	38	81	67	56	18	4	20	17	68	38	81

1	44	14	65	62	78	64	26	15	1	44	14	65	62	78	64	26	15

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14 captures
17 Jan 2007 - 24 Oct 2018
DEC JAN MAY
17
2006 2007 2011
About this capture

```
13 35 36 57 49 72 54 23 30     27 74 13 40 36 77 43 29 30
 9 29 48 79 37 71 43 32 21     16 35 33 73 63 72 24 32 21
80 58 76  5  8 19 12 60 51     80 28 79 25 23 11 12 60 51
67 56 18  4 20 17 68 38 81     67 56 18  4 20 17 68 38 81
```

Back to **Suzuki's Magic Squares**

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Mutsumi Suzuki
Magic Squares

Sparse Magic Squares by Mr. Toshio Kobayashi

Mr. Hercules Lovell created new magic squares of

- 9x9
- 8x8
- 5x5

in which many blank holes are scattered in a special pattern (Dec. 2000). Recently I got an information that a Japanese Mr. Kobayashi created many such squares in 1999. The following are his squares published in a local circular "Puzzle Research" in Oct. 1999.

```
 6 # 4 2
 5 1 6 #
 # 3 2 7
 1 8 # 3


 # 5 2 4
 3 2 6 #
 7 # 3 1
 1 4 # 6


  #  1 10 13  #
  8 14  #  #  2
  #  #  3  6 15
  4  9 11  #  #
 12  #  #  5  7


  2  # 10 12  #
  7 14  #  3  #
  #  4  #  9 11
  #  6 13  #  5
 15  #  1  #  8


  #  #  1 10 13
  7 12  #  #  5
  #  4  9 11  #
 15  #  #  3  6
  2  8 14  #  #


  1 14 19  #  8
  # 16  4  9 13
 20  5  #  6 11
  3  7 17 15  #
 18  #  2 12 10


  #  #  # 40 10 13 37
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSq.kobayashi.sparse.htm Go
9 captures
17 Jan 2007 - 20 Jul 2016
DEC JAN JUL
17
2006 2007 2009
About this capture

```
49  #  #  #  3 47  1
11 39 42  8  #  #  #
```

The following square compensates the last square above,

```
15 31 29  #  #  #  #
 #  #  # 20 32 23  #
34 17  #  #  #  # 24
 #  # 28 25 22  #  #
26  #  #  #  # 33 16
 # 27 18 30  #  #  #
 #  #  #  # 21 19 35    by Mr. ABE, (Jan. 2001)
```

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11 captures
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2006 17 2007 2009
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Mutsumi Suzuki
Magic Squares

5x5 Sparse Magic Squares

Mr. Hercules Lovell created new magic squares of 9x9 and 8x8 in which many blank holes are scattered in a special pattern (Dec. 2000).

Here is his third sparse square of 5x5;

```
17  ##  13  11  01

14  02  08  18  ##

07  09  ##  10  16

##  19  15  03  05

04  12  06  ##  20
```

The pattern of the blank holes is symmetrical.

The name "Sparce Magic Square" is tentative.

Back to **Suzuki's Magic Squares**

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18
2006 2007 2009
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Mutsumi Suzuki
Magic Squares

6x6 Sparse Magic Squares

Mr. Hercules Lovell created new magic squares of 9x9 , 8x8 (Dec.2000) and 5x5 (Jan.2001), in which many blank holes are scattered in a special pattern.

Here is his fourth sparse square of 6 x 6 (Jan.2001);

```
## 21 02 03 24 ##

17 06 ## ## 07 20

16 ## 11 10 ## 13

12 ## 14 15 ## 09

05 19 ## ## 18 08

## 04 23 22 01 ##
```

The pattern of the blank holes is symmetrical.

The name "Sparce Magic Square" is tentative.

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7 captures 2006 19 2007 2011
19 Jan 2007 - 21 Jul 2016 About this capture

Mutsumi Suzuki
Magic Squares

8x8 Sparse Magic Squares

Mr. Hercules Lovell created new magic squares of 9x9 in which many blank holes are scattered in a special pattern (Dec. 2000).

Here is his second sparse square of 8x8;

```
## ## 04 29 ## ## 20 13

04 19 ## ## 30 03 ## ##

## ## 05 12 ## ## 21 28

11 06 ## ## 27 22 ## ##

## ## 26 10 ## ## 07 23

25 09 ## ## 08 24 ## ##

## ## 31 15 ## ## 18 02

16 32 ## ## 01 17 ## ##

Each row, column, and diagonal sums to 66.
```

The pattern of the blank holes is symmetrical. The mirror image of the same square compensates the holes and creates a new magic square.

The name "Sparce Magic Square" is tentative.

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7 captures 18
18 Jan 2007 - 21 Jul 2016 2006 2007 2009 About this capture

Mutsumi Suzuki
Magic Squares

9x9 Sparse Magic Squares

Mr. Hercules Lovell created new magic squares in which many blank holes are scattered in a special pattern (Dec. 2000).

```
17   #  46  35  24   #   #  42  01
30  25   #   #  43  05  12   #  50
 #  36  02  22   #  47  40  18   #
19   #  53  33  15   #   #  37  08
32  21   #   #  39  07  14   #  52
 #  29  04  11   #  49  45  27   #
26   #  51  44  10   #   #  28  06
41  23   #   #  34  03  16   #  48
 #  31  09  20   #  54  38  13   #
```

He opened a door to the new category of magic square problems. He is challenging to the 7x7 squares now. He wrote "Can a magic square of 49 boxes be created with only one box on each line blank in such a way hat the numbers 1 to 42 can be arranged so that each row, column, and diagonal totals 129?

I was very impressed by his new idea. So, I tried to make another such squares and found the following square which compensates the blank boxes of the Lovell's square.

```
 #  70   #   #   #  77  57   #   #
 #   #  59  73   #   #   #  72   #
61   #   #   #  78   #   #   #  65
 #  60   #   #   #  64  80   #   #
 #   #  66  62   #   #   #  76   #
75   #   #   #  71   #   #   #  58
 #  74   #   #   #  63  67   #   #
 #   #  79  69   #   #   #  56   #
68   #   #   #  55   #   #   #  81
```

Single magic square of 9x9 can be created by combining the tow squares. Two squares compensate each other to form single magic square.

The name "Sparce Magic Square" is tentative.

Back to **Suzuki's Magic Squares**

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.9x9.sparse.html Go DEC JAN JUL
7 captures 18
18 Jan 2007 - 21 Jul 2016 2006 2007 2009
About this capture

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.8x8.square.html Go DEC JAN JUL
9 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009 About this capture

Mutsumi Suzuki
Magic Squares

8x8 Magic Square of Squares (double magic square)

Mr. Matsugoro SAITO, a 90 year old magic square mania, is very eager to create magic squares even now. His son H.Saito wrote that he created five double magic squares during his long period of study of the magic squares. He does not use any computer. Tools he used were pencils, sheets of paper and his brain.

The followings are his results;

(No.1) (May 30,1989)

Original square;

38	26	49	13	44	24	63	3
43	23	64	4	37	25	50	14
29	33	10	54	19	47	8	60
20	48	7	59	30	34	9	53
58	6	45	17	56	12	35	31
55	11	36	32	57	5	46	18
1	61	22	42	15	51	28	40
16	52	27	39	2	62	21	41

Squared square;

1444	676	2401	169	1936	576	3969	9
1849	529	4096	16	1369	625	2500	196
841	1089	100	2916	361	2209	64	3600
400	2304	49	3481	900	1156	81	2809
3364	36	2025	289	3136	144	1225	961
3025	121	1296	1024	3249	25	2116	324
1	3721	484	1764	225	2601	784	1600
256	2704	729	1521	4	3844	441	1681

(No.2) (Mar.24 1990)

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.8x8.square.html Go DEC JAN JUL
9 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009
About this capture

21	41	28	40	14	50	3	63
58	6	55	11	33	29	48	20
56	12	57	5	47	19	34	30
35	31	46	18	60	8	53	9
45	17	36	32	54	10	59	7
2	62	15	51	25	37	24	44
16	52	1	61	23	43	26	38

Squared square;

729	1521	484	1764	16	4096	169	2401
441	1681	784	1600	196	2500	9	3969
3364	36	3025	121	1089	841	2304	400
3136	144	3249	25	2209	361	1156	900
1225	961	2116	324	3600	64	2809	81
2025	289	1296	1024	2916	100	3481	49
4	3844	225	2601	625	1369	576	1936
256	2704	1	3721	529	1849	676	1444

(No.3) (May 3,1991)

20	55	25	62	44	15	33	6
29	58	24	51	37	2	48	11
39	4	9	46	60	31	22	49
42	13	8	35	53	18	27	64
1	38	47	12	30	57	52	23
16	43	34	5	19	56	61	26
54	17	63	28	14	41	7	36
59	32	50	21	3	40	10	45

400	3025	625	3844	1936	225	1089	36
841	3364	576	2601	1369	4	2304	121
1521	16	81	2116	3600	961	484	2401

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.8x8.square.html Go DEC JAN JUL 17 2006 2007 2009
9 captures
17 Jan 2007 - 21 Jul 2016
About this capture

256	1849	1156	25	361	3136	3721	676
2916	289	3969	784	196	1681	49	1296
3481	1024	2500	441	9	1600	100	2025

(No.4) (May 3,1991)

47	25	4	54	23	33	60	14
24	34	59	13	48	26	3	53
38	20	9	63	30	44	49	7
29	43	50	8	37	19	10	64
1	55	46	28	57	15	22	36
58	16	21	35	2	56	45	27
12	62	39	17	52	6	31	41
51	5	32	42	11	61	40	18

2209	625	16	2816	529	1089	3600	196
576	1156	3481	169	2304	676	9	2809
1444	400	81	3969	900	1936	2401	49
841	1849	2500	64	1369	361	100	4096
1	3025	2116	784	3249	225	484	1296
3364	256	441	1225	4	3136	2025	729
144	3844	1521	289	2704	36	961	1681
2601	25	1024	1764	121	3721	1600	324

(No.5) (May 1 , 1994)

5	54	26	41	31	48	4	51
40	23	59	12	62	13	33	18
43	28	56	7	49	2	46	29
10	57	21	38	20	35	15	64
50	1	45	30	44	27	55	8
19	36	16	63	9	58	22	37

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.8x8.square.html Go DEC JAN JUL
9 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009 About this capture

```
  25 2916  676 1681  961 2304   16 2601

1600  529 3481  144 3844  169 1089  324

1849  784 3136   49 2401    4 2116  841

 100 3249  441 1444  400 1225  225 4096

2500    1 2025  900 1936  729 3025   64

 361 1296  256 3969   81 3364  484 1369

1024 2209    9 2704   36 2809  625 1764

3721  196 1156  289 1521  576 3600  121
```

The following squares are created by Mr. Nakazato.
You can see more informations in Nakazato's page (written in Japanese)

```
Original magic square;


 2 13 24 27 35 48 53 58

23 28  1 14 54 57 36 47

37 42 51 64  8 11 18 29

52 63 38 41 17 30  7 12

16  3 26 21 45 34 59 56

25 22 15  4 60 55 46 33

43 40 61 50 10  5 32 19

62 49 44 39 31 20  9  6

Squared result; The Magic Square of Squares


   4  169  576  729 1225 2304 2809 3364

 529  784    1  196 2916 3249 1296 2209

1369 1764 2601 4096   64  121  324  841

2704 3969 1444 1681  289  900   49  144

 256    9  676  441 2025 1156 3481 3136

 625  484  225   16 3600 3025 2116 1089

1849 1600 3721 2500  100   25 1024  361
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.8x8.square.html Go DEC JAN JUL
9 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009
About this capture

Frolow's 8x8 square (1892);

45	23	1	59	26	36	54	16
40	30	12	50	19	41	63	5
22	48	58	4	33	27	13	55
31	37	51	9	44	18	8	62
3	57	47	21	56	14	28	34
10	52	38	32	61	7	17	43
60	2	24	46	15	53	35	25
49	11	29	39	6	64	42	20

Frolow's 9x9 square (1892);

4	77	35	11	46	57	42	27	70
63	52	1	32	24	67	17	74	39
68	33	18	75	2	37	22	61	53
73	38	23	62	16	54	3	69	31
26	72	48	76	41	6	34	10	56
51	13	79	28	66	20	59	44	9
29	21	60	45	80	7	64	49	14
43	8	65	15	58	50	81	30	19
12	55	40	25	36	71	47	5	78

Coccoz's 8x8 square (1897);

5	31	35	60	57	34	8	30
19	9	53	46	47	56	18	12
16	22	42	39	52	61	27	1
63	37	25	24	3	14	44	50
26	4	64	49	38	43	13	23
41	51	15	2	21	28	62	40

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.8x8.square.html Go DEC JAN JUL
9 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009
About this capture

Fittings 8x8 squares (1941);
Rows and columns do not give the constant sum, but every pan-diagonals are constant.

1	2	60	59	7	8	62	61
15	40	32	49	9	34	26	55
18	42	45	21	24	48	43	19
54	27	35	12	52	29	37	14
64	63	5	6	58	57	3	4
50	25	33	16	56	31	39	10
47	23	20	44	41	17	22	46
11	38	30	53	13	36	28	51

1	17	63	47	4	20	62	46
8	28	56	41	5	25	53	44
49	29	14	34	52	32	15	35
58	39	11	23	59	38	10	22
64	48	2	18	61	45	3	19
57	37	9	24	60	40	12	21
16	36	51	31	13	33	50	30
7	26	54	42	6	27	55	43

The followings are from Omori's book.

6	15	17	28	36	41	55	62
19	26	8	13	53	64	34	43
39	46	52	57	1	12	22	31
50	59	37	48	24	29	3	10
9	4	30	23	47	38	60	49
32	21	11	2	58	51	45	40
44	33	63	54	14	7	25	20

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9 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009 About this capture

squares. If you exchange each number n of the above square to 65-n the result is also double square;

```
59 50 48 37 29 24 10  3

46 39 57 52 12  1 31 22

26 19 13  8 64 53 43 34

15  6 28 17 41 36 62 55

56 61 35 42 18 27  5 16

33 44 54 63  7 14 20 25

21 32  2 11 51 58 40 45

 4  9 23 30 38 47 49 60
```

Back to **Suzuki's Magic Squares**

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.16x16.square.htm Go
9 captures
17 Jan 2007 - 21 Jul 2016
DEC JAN JUL
17
2006 2007 2009
About this capture

Mutsumi Suzuki
[Magic Squares]

16x16 Magic Square of Squares (Double magic square) by Mr.Saito

Mr. Matsugoro Saito, a 90 year old boy, created a 16x16 double magic square recently (Dec. 2000). He did not use a computer. According to his son's mail, he will show us how to make such a big double magic square.

16x16 original square (magic sum = 2056);

48	69	194	171	152	253	122	19	29	120	243	154	165	208	75	34
202	163	40	77	114	27	160	245	251	146	21	128	67	42	173	200
96	53	178	219	232	141	10	99	109	8	131	234	213	192	59	82
186	211	88	61	2	107	240	133	139	226	101	16	51	90	221	184
115	26	157	248	203	162	37	80	66	43	176	197	250	147	24	125
149	256	123	18	45	72	195	170	168	205	74	35	32	117	242	155
3	106	237	136	187	210	85	64	50	91	224	181	138	227	104	13
229	144	11	98	93	56	179	218	216	189	58	83	112	5	130	235
41	68	199	174	145	252	127	22	28	113	246	159	164	201	78	39
207	166	33	76	119	30	153	244	254	151	20	121	70	47	172	193
89	52	183	222	225	140	15	102	108	1	134	239	212	185	62	87
191	214	81	60	7	110	233	132	142	231	100	9	54	95	220	177
118	31	156	241	206	167	36	73	71	46	169	196	255	150	17	124
148	249	126	23	44	65	198	175	161	204	79	38	25	116	247	158
6	111	236	129	190	215	84	57	55	94	217	180	143	230	97	12
228	137	14	103	92	49	182	223	209	188	63	86	105	4	135	238

squared square (magic sum = 351576);

2304	4761	37636	29241	23104	64009	14884	361	841	14400	59049	23716	27225	43264	5625	1156
40804	26569	1600	5929	12996	729	25600	60025	63001	21316	441	16384	4489	1764	29929	40000
9216	2809	31684	47961	53824	19881	100	9801	11881	64	17161	54756	45369	36864	3481	6724
34596	44521	7744	3721	4	11449	57600	17689	19321	51076	10201	256	2601	8100	48841	33856
13225	676	24649	61504	41209	26244	1369	6400	4356	1849	30976	38809	62500	21609	576	15625
22201	65536	15129	324	2025	5184	38025	28900	28224	42025	5476	1225	1024	13689	58564	24025
9	11236	56169	19496	34969	44100	7225	4096	2500	8281	50176	32761	19044	51529	10816	169
52441	20736	121	9604	8649	3136	32041	47524	46656	35721	3364	6889	12544	25	16900	55225
1681	4624	39601	30276	21025	63504	16129	484	784	12769	60516	25281	26896	40401	6084	1521
42849	27556	1089	5776	14161	900	23409	59536	64516	22801	400	14641	4900	2209	29584	37249
7921	2704	33489	49284	50625	19600	225	10404	11664	1	17956	57121	44944	34225	3844	7569
36481	45796	6561	3600	49	12100	54289	17424	20164	53361	10000	81	2916	9025	48400	31329
13924	961	24336	58081	42436	27889	1296	5329	5041	2116	28561	38416	65025	22500	289	15376
21904	62001	15876	529	1936	4225	39204	30625	25921	41616	6241	1444	625	13456	61009	24964
36	12321	55696	16641	36100	46225	7056	3249	3025	8836	47089	32400	20449	52900	9409	144
51984	18769	196	10609	8464	2401	33124	49729	43681	35344	3969	7369	11025	16	18225	56644

Back to [Suzuki's Magic Squares]

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.16x16.square.htm Go
9 captures
17 Jan 2007 - 21 Jul 2016
DEC JAN JUL
17
2006 2007 2009
About this capture

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.3x3.prime.html Go DEC JAN SEP
10 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2008
About this capture

Mutsumi Suzuki
Magic Squares

3x3 Magic Square of Prime Numbers

164 squares are constructed by using prime numbers.
You can see two patterns of arrangement.

Let the primes be
a < b < c < d < e < f < g < h < i

then the ordinary pattern is

```
f a h
g e c
b i d
```

However, you can find some squares have the folloing pattern.

```
g a h
d e f
b i c
```

Few mistakes were pointed out by Carlos B. Rivera F. (May.1999) He wrote to me that;
a) The matrix 1, 56, 73 & 128 contain a non-prime number each ("1")
b) The matrix 106 contain two numbers repeated (607 twice, and 307 twice)

```
  1              2              3              4
   7  61  43      17  89  71      41  89  83      37  79 103
  73  37   1     113  59   5     113  71  29     139  73   7
  31  13  67      47  29 101      59  53 101      43  67 109
--------------------------------------------------------------
  5              6              7              8
  29 131 107      43 127 139      37 151 139      43 181 157
 167  89  11     199 103   7     211 109   7     241 127  13
  71  47 149      67  79 163      79  67 181      97  73 211
--------------------------------------------------------------
  9              10             11             12
  73 151 157      71 149 173      47 191 173      67 151 199
 211 127  43     233 131  29     263 137  11     271 139   7
  97 103 181      89 113 191     101  83 227      79 127 211
--------------------------------------------------------------
 13              14             15             16
  59 197 191      61 199 193      37 271 163      53 251 197
 281 149  17     283 151  19     283 157  31     311 167  23
 107 101 239     109 103 241     151  43 277     137  83 281
--------------------------------------------------------------
 17              18             19             20
  71 233 197      89 197 233      89 191 257      71 269 233
 293 167  41     317 173  29     347 179  11     353 191  29
 137 101 263     113 149 257     101 167 269     149 113 311
--------------------------------------------------------------
 21              22             23             24
  89 233 251      73 277 229      43 349 241     101 263 317
 353 191  29     349 193  37     409 211  13     443 227  11
 131 149 293     157 109 313     181  73 379     137 191 353
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.3x3.prime.html Go DEC JAN SEP
10 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2008
About this capture

```
191 173 317      197 131 389      199 103 421      151 199 373
-------------------------------------------------------------
29               30               31               32
 73 379 271       41 443 269       71 419 263       71 383 317
439 241  43      479 251  23      443 251  59      503 257  11
211 103 409      233  59 461      239  83 431      197 131 443
-------------------------------------------------------------
33               34               35               36
 47 443 281      137 359 293      173 347 269      137 281 389
491 257  23      419 263 107      359 263 167      521 269  17
233  71 467      233 167 389      257 179 353      149 257 401
-------------------------------------------------------------
37               38               39               40
 59 467 281      137 311 359      149 311 347      149 347 311
491 269  47      491 269  47      467 269  71      431 269 107
257  71 479      179 227 401      191 227 389      227 191 389
-------------------------------------------------------------
41               42               43               44
103 379 331       71 461 311       83 449 311       71 479 293
499 271  43      521 281  41      509 281  53      503 281  59
211 163 439      251 101 491      251 113 479      269  83 491
-------------------------------------------------------------
45               46               47               48
101 431 311      109 367 373       83 449 347      167 359 353
491 281  71      547 283  19      557 293  29      479 293 107
251 131 461      193 199 457      239 137 503      233 227 419
-------------------------------------------------------------
49               50               51               52
 37 547 337       43 541 337      127 373 421       53 521 359
607 307   7      601 307  13      601 307  13      617 311   5
277  67 577      277  73 571      193 241 487      263 101 569
-------------------------------------------------------------
53               54               55               56
101 443 389      101 449 383      191 353 389       31 613 367
599 311  23      593 311  29      509 311 113      673 337   1
233 179 521      239 173 521      233 269 431      307  61 643
-------------------------------------------------------------
57               58               59               60
 43 601 367       73 571 367       97 547 367      131 443 467
661 337  13      631 337  43      607 337  67      683 347  11
307  73 631      307 103 601      307 127 577      227 251 563
-------------------------------------------------------------
61               62               63               64
137 461 443      173 401 467      137 521 383      227 431 383
653 347  41      641 347  53      593 347 101      503 347 191
251 233 557      227 293 521      311 173 557      311 263 467
-------------------------------------------------------------
65               66               67               68
 79 547 421       53 647 359      137 479 443      149 467 443
691 349   7      659 353  47      659 353  47      647 353  59
277 151 619      347  59 653      263 227 569      263 239 557
-------------------------------------------------------------
69               70               71               72
227 389 443       59 617 401      149 461 467      149 479 449
569 353 137      701 359  17      677 359  41      659 359  59
263 317 479      317 101 659      251 257 569      269 239 569
-------------------------------------------------------------
73               74               75               76
157 421 523       73 631 397      157 523 421       13 727 379
733 367   1      691 367  43      631 367 103      739 373   7
211 313 577      337 103 661      313 211 577      367  19 733
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.3x3.prime.html Go DEC JAN SEP
10 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2008
About this capture

```
 307 139 673      349 127 661      349 157 631      337 181 619
--------------------------------------------------------------
 81               82               83               84
 181 547 409      113 587 449      137 509 521       59 677 431
 607 379 151      719 383  47      773 389   5      761 389  17
 349 211 577      317 179 653      257 269 641      347 101 719
--------------------------------------------------------------
 85               86               87               88
 137 521 509      179 521 467      269 431 467      103 631 457
 761 389  17      677 389 101      587 389 191      751 397  43
 269 257 641      311 257 599      311 347 509      337 163 691
--------------------------------------------------------------
 89               90               91               92
 163 571 457      149 563 491      199 487 541      241 547 439
 691 397 103      743 401  59      751 409  67      607 409 211
 337 223 631      311 239 653      277 331 619      379 271 577
--------------------------------------------------------------
 93               94               95               96
 179 491 587      179 521 557      211 433 619      199 463 601
 827 419  11      797 419  41      829 421  13      823 421  19
 251 347 659      281 317 659      223 409 631      241 379 643
--------------------------------------------------------------
 97               98               99              100
 211 619 433       53 761 479      101 683 509      293 467 569
 643 421 199      857 431   5      839 431  23      719 443 167
 409 223 631      383 101 809      353 179 761      317 419 593
--------------------------------------------------------------
101              102              103              104
 293 569 467       41 827 479       71 797 479      197 641 509
 617 443 269      887 449  11      857 449  41      761 449 137
 419 317 593      419  71 857      419 101 827      389 257 701
--------------------------------------------------------------
105              106              107              108
 281 587 479      157 607 607      239 503 641      263 479 641
 647 449 251      907 457   7      863 461  59      839 461  83
 419 311 617      307 307 757      281 419 683      281 443 659
--------------------------------------------------------------
109              110              111              112
 401 479 503      157 619 613       43 859 487      199 547 643
 563 461 359      919 463   7      907 463  19      907 463  19
 419 443 521      313 307 769      439  67 883      283 379 727
--------------------------------------------------------------
113              114              115              116
  47 863 491      233 491 677      173 641 587      257 491 653
 911 467  23      911 467  23      881 467  53      863 467  71
 443  71 887      257 443 701      347 293 761      281 443 677
--------------------------------------------------------------
117              118              119              120
 257 653 491       17 929 491      137 701 599      101 827 509
 701 467 233      953 479   5      941 479  17      887 479  71
 443 281 677      467  29 941      359 257 821      449 131 857
--------------------------------------------------------------
121              122              123              124
 389 491 557      241 643 577       41 911 521       41 929 503
 647 479 311      823 487 151      971 491  11      953 491  29
 401 467 569      397 331 733      461  71 941      479  53 941
--------------------------------------------------------------
125              126              127              128
 101 809 563       71 881 521      281 593 599      229 541 727
 953 491  29      941 491  41      809 491 173      997 499   1
 419 173 881      461 101 911      383 389 701      271 457 769
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.3x3.prime.html Go DEC JAN SEP
10 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2008
About this capture

367 271 839	457 421 619	419 347 743	461 137 929
133	134	135	136
131 827 569	197 761 569	257 701 569	401 599 563
947 509 71	881 509 137	821 509 197	683 521 359
449 191 887	449 257 821	449 317 761	479 443 641
137	138	139	140
193 769 607	313 547 709	223 739 607	331 619 673
937 523 109	919 523 127	907 523 139	883 541 199
439 277 853	337 499 733	439 307 823	409 463 751
141	142	143	144
283 631 727	307 607 727	337 631 673	227 797 647
991 547 103	967 547 127	883 547 211	977 557 137
367 463 811	367 487 787	421 463 757	467 317 887
145	146	147	148
353 659 677	263 881 617	269 887 641	359 797 641
887 563 239	941 587 233	971 599 227	881 599 317
449 467 773	557 293 911	557 311 929	557 401 839
149	150	151	152
479 641 677	409 823 661	521 683 719	379 877 673
797 599 401	883 631 379	839 641 443	937 643 349
521 557 719	601 439 853	563 599 761	613 409 907
153	154	155	156
433 787 709	389 887 701	599 677 701	467 863 701
919 643 367	971 659 347	761 659 557	911 677 443
577 499 853	617 431 929	617 641 719	653 491 887
157	158	159	160
479 797 773	599 797 761	547 823 811	571 877 769
977 683 389	881 719 557	991 727 463	937 739 541
593 569 887	677 641 839	643 631 907	709 601 907
161	162	163	164
577 907 787	661 823 787	601 877 829	739 937 883
967 757 547	883 757 631	997 769 541	997 853 709
727 607 937	727 691 853	709 661 937	823 769 967

Back to **Suzuki's Magic Squares**

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8 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009 About this capture

Mutsumi Suzuki
Magic Squares

Magic Square of 3 x 3 Prime number (with arithmetic series)

```
Arithmetic series is defined by;

     a, a+d, a+2d, a+3d, ,,,

Examples;

(a = d = 1)
     1     2     3     4     5     6     7     8     9


series of prime numbers;

(d = 210)
   199   409   619   829  1039  1249  1459  1669  1879  2089
  3499  3709  3919  4129  4339  4549  4759  4969  5179
 10859 11069 11279 11489 11699 11909 12119 12329 12539

(d = 840)
  6043  6883  7723  8563  9403 10243 11083 11923 12763
 10861 11701 12541 13381 14221 15061 15901 16741 17581

d=3150;{  433,  3583,  6733,  9883, 13033, 16183, 19333, 22483, 25633}
d=3990;{ 1699,  5689,  9679, 13669, 17659, 21649, 25639, 29629, 33619}
d=1260;{ 2063,  3323,  4583,  5843,  7103,  8363,  9623, 10883, 12143}
d=2310;{ 3823,  6133,  8443, 10753, 13063, 15373, 17683, 19993, 22303}
d=2730;{ 4721,  7451, 10181, 12911, 15641, 18371, 21101, 23831, 26561}
d=2940;{11927, 14867, 17807, 20747, 23687, 26627, 29567, 32507, 35447}
d=1890;{15607, 17497, 19387, 21277, 23167, 25057, 26947, 28837, 30727}
d=2520;{19141, 21661, 24181, 26701, 29221, 31741, 34261, 36781, 39301}
d=2520;{23509, 26029, 28549, 31069, 33589, 36109, 38629, 41149, 43669}
d=1680;{31333, 33013, 34693, 36373, 38053, 39733, 41413, 43093, 44773}

--------------------------------------------------------
You can construct magic squares by these series.

Examples;

Square by natural integer (d=1)

     2    9    4

     7    5    3

     6    1    8


Square by a prime number series (d=210)

   409 1879  829

  1459 1039  619
```

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9 captures
18 Jul 2007 - 20 Jul 2016
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18
2006 2007 2008
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Mutsumi Suzuki
Magic Squares

Magic Square of 3 x 3 Prime numbers (arithmetic and/or consecutive series)

Magic square with a consecutive primes is reported in Eric's home page.

His primes and square are;

```
p1=1480028129
p2=.......141
p3=.......153
p4=.......159
p5=.......171
p6=.......183
p7=.......189
p8=.......201
p9=.......213

     p4 p3 p8
     p9 p5 p1
     p2 p7 p6
```

The series is consecutive. No primes exist in between these 9 primes. However, it is not arithmetic series, the differnces are not constant;
p4 - p3 = p7 - p6 = 6 while the other differences are 12.

Arithmetic and consecutive series of primes were found by Mr. Dennis Kluk who is a member of a group to find a sequence of 9 consecutive primes in arithmetic progression. (Feb. 1998)

According to his mail, the primes can be created by using the following three integers N , m and x ;

N = 500996388736659 = 3 * 166998796245553.

m = the product of the 44 primes p such that 2 <= p <= 193.
m =
1989623763916909816404152515452851536027344027218210582122039760954139
10572270.

x =
6240141611007307622465889025426185177074468140120944390087327315890659
848721 = 1117 * 326941 * 33408059 * 51408341 *
99491746076651361273664201816977007093548834782204447.

Now take

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9 captures
18 Jul 2007 - 20 Jul 2016
JUN JUL SEP
18
2006 2007 2008
About this capture

```
p4 = p3 + 210,
p5 = p4 + 210,
p6 = p5 + 210,
p7 = p6 + 210,
p8 = p7 + 210, and
p9 = p8 + 210.

p1 =
9967943206670108648449065369585356163898236408099161839577404858552907
1475461114799677694651 which has 92 decimal places.
```

He has verified that p1 through p9 are indeed prime, and that every number between p1 and p9 is composite except p2, p3, p4, p5, p6, p7 and p8 which are prime.

Back to **Suzuki's Magic Squares**

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18
2006 2007 2009
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Mutsumi Suzuki
Magic Squares

Twin squares with twin primes

Twin primes are a pair of primes with differnce two. For example, (3,5), (5,7), (11,13), 17,19),... are such pairs.

If magic squares are constructed by the twin primes, the squares become twin squares in which each coressponding cells differs by two.

This property can be seen in the following smallest example, which is constructed by Lee Sallows.

```
Lee's square
 191   17  239     2 2 2      193   19  241
 197  149  101  +  2 2 2  =   199  151  103
  59  281  107     2 2 2       61  283  109

Another example;
3371   17 4799     2 2 2     3373   19 4801
4157 2729 1301  +  2 2 2  =  4159 2731 1303
 659 5441 2087     2 2 2      661 5443 2089
```

The following prime set yield such squares;

```
                    F A H
                    G E C
                    B I D
```

A	B	C	D	E	F	G	H	I
227	857	1487	3527	4157	4787	6827	7457	8087
229	859	1489	3529	4159	4789	6829	7459	8089
821	1481	2141	5639	6299	6959	10457	11117	11777
823	1483	2143	5641	6301	6961	10459	11119	11779
3461	3851	4241	6569	6959	7349	9677	10067	10457
3463	3853	4243	6571	6961	7351	9679	10069	10459
1697	1787	1877	9677	9767	9857	17657	17747	17837
1699	1789	1879	9679	9769	9859	17659	17749	17839
4127	6779	9431	11057	13709	16361	17987	20639	23291
4129	6781	9433	11059	13711	16363	17989	20641	23293
3821	6551	9281	11831	14561	17291	19841	22571	25301
3823	6553	9283	11833	14563	17293	19843	22573	25303
191	809	1427	16361	16979	17597	32531	33149	33767
193	811	1429	16363	16981	17599	32533	33151	33769

```
--------------  (unusual pattern)  ---------------

                    G A H
```

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8 captures
18 Jul 2007 - 21 Jul 2016
JUN JUL JUL
18
2006 2007 2009
About this capture

2143	3331	3823	4519	5011	5503	6199	6691	7879
29	4229	6869	8429	11069	13709	15269	17909	22109
31	4231	6871	8431	11071	13711	15271	17911	22111

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18
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Mutsumi Suzuki
Magic Squares

Twin squares with larger differences

In the following twin squares, the differences between corresponding cells are the same four.

```
 487  19 883      4 4 4     491  23 887
 859 463  67  +   4 4 4  =  863 467  71
  43 907 439      4 4 4      47 911 443
```

Data set;

```
        Usual pattern of the 3x3 square;

                       F A H
                       G E C
                       B I D

    with a condition; A < B < C < D < E < F < G < H < I

------------------------------------------------------
  A      B      C      D      E      F      G      H      I
------------------------------------------------------
(delta = 4)
  19     43     67    439    463    487    859    883    907
  23     47     71    443    467    491    863    887    911

  97    163    229   5347   5413   5479  10597  10663  10729
 101    167    233   5351   5417   5483  10601  10667  10733


(delta = 6)
  53    353    653    677    977   1277   1301   1601   1901
  59    359    659    683    983   1283   1307   1607   1907

1423   1753   2083   2137   2467   2797   2851   3181   3511
1429   1759   2089   2143   2473   2803   2857   3187   3517

(delta = 8)
  23    191    359   1283   1451   1619   2543   2711   2879
  31    199    367   1291   1459   1627   2551   2719   2887

 479   1229   1979   2789   3539   4289   5099   5849   6599
 487   1237   1987   2797   3547   4297   5107   5857   6607


---------------unusual patteern----------------------

                    G A H
                    F E D
                    B I C
(delta = 4)
  19   1279   2269   2539   3529   4519   4789   5779   7039
  23   1283   2273   2543   3533   4523   4793   5783   7043

(delta = 6)
```

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8 captures
18 Jul 2007 - 20 Jul 2016
JUN JUL JUL
18
2006 2007 2009
About this capture

```
2273   4751   6563   7229   9041 10853 11519 13331 15809
2281   4759   6571   7237   9049 10861 11527 13339 15817
```

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Mutsumi Suzuki
Magic Squares

Triplet prime squares with constant difference

```
(Maximum prime = 1999)
(difference = 6 is the minimum in the prime triplets found)
 151 1987 1361    157 1993 1367    163 1999 1373
1747 1481  271   1753 1487  277   1759 1493  283
1601   31 1867   1607   37 1873   1613   43 1879

The same primes yield another triplets;

(difference = 120)
  37 1759 1361    157 1879 1481    277 1999 1601
1747 1367   43   1867 1487  163   1987 1607  283
1373   31 1753   1493  151 1873   1613  271 1993

------------------------------------------------

(Maximium prime is 761)  (smallest squares)
(difference=42)
 89 677 359      131 719 441      173 761 443
557 419 149      599 461 191      641 503 233
479  29 617      521  71 659      563 113 701

The same primes yield another triplets;

(difference=60)
 71  641 359     131  701 419     191 761 479
557  441 113     617  461 173     677 521 233
443   29 599     503   89 659     563 149 719
```

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Mutsumi Suzuki
Magic Squares

A big family of 3x3 Magic square of prime numbers

It is not a simple twin nor trplet. A big family of prime squares with common central pivot number and with the same sums.

```
 179 1361  509
1013  683  353
 857    5 1187

 179 1277  593
1097  683  269
 773   89 1187

 173 1283  593
1103  683  263
 773   83 1193

 263 1229  557
 977  683  389
 809  137 1103

 263 1193  593
1013  683  353
 773  173 1103

 383 1109  557
 857  683  509
 809  257  983

 383 1019  647
 947  683  419
 719  347  983

 479  977  593
 797  683  569
 773  389  887

 353 1049  647
 977  683  389
 719  317 1013
-----------------
 353 1307  389
 719  683  647
 977   59 1013

 353 1217  479
 809  683  557
 887  149 1013

 347 1319  383
 719  683  647
 983   47 1019
```

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17 Jan 2007 - 20 Jul 2016
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17
2006 2007 2009
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Mutsumi Suzuki
Magic Squares

3x3 Magic Square of Prime numbers by Librandi

Mr. Vincenzo Librandi proposed a new method to consturuct magic squares by sequencial primes by using Librandi's triangle in 1999. His method was summarized in this page.

Recently (Nov. 2000) he applied his method to the 3x3 magic squares. The following is his mail.

```
Ciao, Mutsumi Suzuki
By the Librandi's triangle
3
6     11
9     16      23
12    21     30      39
15    26     37      48       59
18    31     44      57       70      83
= = = = = = = = = = = = = = = = =
defined from A[m,n]=2mn+m+n-1 (with m,n >=1)
A[m,n]=k; the integer set k is closely related to
the Librandi's triangle A(m,n) = 2 m n + m + n - 1
Prime number = 2k+3.
The set k={0,1,2,4,5,7,8,10,13,14,17,, };
Some more: k= 3h_1+1; (with h_1=0,1,2,3,4,,)
                k= 3h_2+2; (with h_2 =
0,1,2,4,5,,)

228 Magic Squares 3x3 are constructed by using
h_1< 5000; k<15000, and  Prime Numbers < 30000.

        h_1                 k=3h_1+1
p=2k+3

   1 1302  653       4 3907 1960      11 7817 3923
1304  652    0    3913 1957    1    7829 3917    5
 651    2 1303    1954    7 3910    3911   17 7823

    1  492 248       4 1477  745      11 2957 1493
  494  247   0    1483  742    1    2969 1487    5
  246    2 493     739    7 1480    1481   17 2963

   1 2702 1353       4 8107 4060      11 16217 8123
2704 1352    0    8113 4057    1   16229 8117     5
1351    2 2703    4054    7 8110    8111   17 16223

   1 2912 1458       4 8737 4375      11 17477  8753
2914 1457    0    8743 4372    1   17489  8747     5
1456    2 2913    4369    7 8740    8741    17 17483

   2 2911 1458       7 8734 4375      17 17471  8753
2913 1457    1    8740 4372    4   17483  8747    11
1456    3 2912    4369   10 8737    8741    23 17477

     3 182  94      10  547   283      23 1097   569
   184  93   2     553  280     7    1109  563    17
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.3x3.librandi.html Go DEC JAN JUL
9 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009 About this capture

```
  107    4  213     322   13   640     647   29  1283

    3  492  249      10 1477   748      23 2957  1499
  494  248    2    1483  745     7    2969 1493    17
  247    4  493     742   13  1480    1487   29  2963

    3 1302  654      10 3907  1963      23 7817  3929
 1304  653    2    3913 1960     7    7829 3923    17
  652    4 1303    1957   13  3910    3917   29  7823

    7 2316 1163      22 6949  3490      47 13901  6983
 2318 1162    6    6955 3487    19   13913  6977    41
 1161    8 2317    3484   25  6952    6971    53 13907

    7 2736 1373      22 8209  4120      47 16421  8243
 2738 1372    6    8215 4117    19   16433  8237    41
 1371    8 2737    4114   25  8212    8231    53 16427

    8  107   59      25  322   178      53  647   359
  109   58    7     328  175    22     659  353    47
   57    9  108     172   28   325     347   59   653

   17  196  108      52  589   325     107 1181   653
  198  107   16     595  322    49    1193  647   101
  106   18  197     319   55   592     641  113  1187

   17 2676 1348      52 8029  4045     107 16061  8093
 2678 1347   16    8035 4042    49   16073  8087   101
 1346   18 2677    4039   55  8032    8081   113 16067

   28   57   44      85  172   133     173  347   269
   59   43   27     178  130    82     359  263   167
   42   29   58     127   88   175     257  179   353

   28  447  239      85  1342  718     173 2687  1439
  449  238   27    1348  715    82    2699 1433   167
  237   29  448     712   88  1345    1427  179  2693

   28 4887 2459      85 14662  7378     173 29327 14759
 4889 2458   27   14668  7375    82   29339 14753   167
 2457   29 4888    7372    88 14665   14747   179 29333

   38 3887 1964     115 11662  5893     233 23327 11789
 3889 1963   37   11668  5890   112   23339 11783   227
 1962   39 3888    5887   118 11665   11777   239 23333

   38 4447 2244     115 13342  6733     233 26687 13469
 4449 2243   37   13348  6730   112   26699 13463   227
 2242   39 4448    6727   118 13345   13457   239 26693

   43  492  269     130  1477  808     263 2957  1619
  494  268   42    1483  805   127    2969 1613   257
  267   44  493     802  133  1480    1607  269  2963

   43 1262  654     130  3787 1963     263 7577  3929
 1264  653   42    3793 1960   127    7589 3923   257
  652   44 1263    1957  133  3790    3917  269  7583

   43 2242 1144     130  6727 3433     263 13457  6869
 2244 1143   42    6733 3430   127   13469  6863   257
 1142   44 2243    3427  133  6730    6857   269 13463
```

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9 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009
About this capture

```
   98  797  449     295  2392  1348      593  4787  2699
  799  448   97    2398  1345   292     4799  2693   587
  447   99  798    1342   298  2395     2687   599  4793

   98 1987 1044     295  5962  3133      593 11927  6269
 1989 1043   97    5968  3130   292    11939  6263   587
 1042   99 1988    3127   298  5965     6257   599 11933

  182 3261 1723     547  9784  5170     1097 19571 10343
 3263 1722  181    9790  5167   544    19583 10337  1091
 1721  183 3262    5164   550  9787    10331  1103 19577

  182 4451 2318     547 13354  6955     1097 26711 13913
 4453 2317  181   13360  6952   544    26723 13907  1091
 2316  183 4452    6949   550 13357    13901  1103 26717

  183 2422 1304     550  7267  3913     1103 14537  7829
 2424 1303  182    7273  3910   547    14549  7823  1097
 1302  184 2423    3907   553  7270     7817  1109 14543

  203 4712 2459     610 14137  7378     1223 28277 14759
 4714 2458  202   14143  7375   607    28289 14753  1217
 2457  204 4713    7372   613 14140    14747  1229 28283

  213  772  494     640  2317  1483     1283  4637  2969
  774  493  212    2323  1480   637     4649  2963  1277
  492  214  773    1477   643  2320     2957  1289  4643

  227  266  248     682   799   745     1367  1601  1493
  268  247  226     805   742   679     1613  1487  1361
  246  228  267     739   685   802     1481  1373  1607

  247 2456 1353     742  7369  4060     1487 14741  8123
 2458 1352  246    7375  4057   739    14753  8117  1481
 1351  248 2457    4054   745  7372     8111  1493 14747

  247 2666 1458     742  7999  4375     1487 16001  8753
 2668 1457  246    8005  4372   739    16013  8747  1481
 1456  248 2667    4369   745  8002     8741  1493 16007

  248 3677 1964     745 11032  5893     1493 22067 11789
 3679 1963  247   11038  5890   742    22079 11783  1487
 1962  249 3678    5887   748 11035    11777  1499 22073

  248 4627 2439     745 13882  7318     1493 27767 14639
 4629 2438  247   13888  7315   742    27779 14633  1487
 2437  249 4628    7312   748 13885    14627  1499 27773

  267 2436 1353     802  7309  4060     1607 14621  8123
 2438 1352  266    7315  4057   799    14633  8117  1601
 1351  268 2437    4054   805  7312     8111  1613 14627

  267 2886 1578     802  8659  4735     1607 17321  9473
 2888 1577  266    8665  4732   799    17333  9467  1601
 1576  268 2887    4729   805  8662     9461  1613 17327

  268 2017 1144     805  6052  3433     1613 12107  6869
 2019 1143  267    6058  3430   802    12119  6863  1607
 1142  269 2018    3427   808  6055     6857  1619 12113
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.3x3.librandi.html Go DEC JAN JUL
9 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009 About this capture

```
 317 2836 1578     952  8509 4735     1907 17021  9473
2838 1577  316    8515  4732  949    17033  9467  1901
1576  318 2837    4729   955 8512     9461  1913 17027

 448 4397 2424    1345 13192  7273    2693 26387 14549
4399 2423  447   13198  7270  1342   26399 14543  2687
2422  449 4398    7267  1348 13195   14537  2699 26393

 483 4362 2424    1450 13087  7273    2903 26177 14549
4364 2423  482   13093  7270  1447   26189 14543  2897
2422  484 4363    7267  1453 13090   14537  2909 26183

   493 882 689     1480  2647 2068     2963 5297 4139
   884 688 492     2653  2065 1477     5309 4133 2957
   687 494 883     2062  1483 2650     4127 2969 5303

 493 1052  774     1480  3157 2323     2963 6317 4649
1054  773  492     3163  2320 1477     6329 4643 2957
 772  494 1053     2317  1483 3160     4637 2969 6323

 493 1302  899     1480  3907 2698     2963 7817 5399
1304  898  492     3913  2695 1477     7829 5393 2957
 897  494 1303     2692  1483 3910     5387 2969 7823

 588 2017 1304     1765  6052 3913     3533 12107  7829
2019 1303  587     6058  3910 1762    12119  7823  3527
1302  589 2018     3907  1768 6055     7817  3539 12113

 653 1142  899     1960  3427 2698     3923 6857 5399
1144  898  652     3433  2695 1957     6869 5393 3917
 897  654 1143     2692  1963 3430     5387 3929 6863

 653 4262 2459    1960 12787  7378     3923 25577 14759
4264 2458  652   12793  7375  1957    25589 14753  3917
2457  654 4263    7372  1963 12790    14747  3929 25583

 742 1051  898     2227  3154 2695     4457 6311 5393
1053  897  741     3160  2692 2224     6323 5387 4451
 896  743 1052     2689  2230 3157     5381 4463 6317

 798 1807 1304     2395  5422 3913     4793 10847  7829
1809 1303  797     5428  3910 2392    10859  7823  4787
1302  799 1808     3907  2398 5425     7817  4799 10853

 668 3677 2174    2005 11032  6523     4013 22067 13049
3679 2173  667   11038  6520  2002    22079 13043  4007
2172  669 3678    6517  2008 11035    13037  4019 22073

1043 4362 2704    3130 13087  8113     6263 26177 16229
4364 2703 1042   13093  8110  3127    26189 16223  6257
2702 1044 4363    8107  3133 13090    16217  6269 26183

1053 2912 1984     3160  8737 5953     6323 17477 11909
2914 1983 1052     8743  5950 3157    17489 11903  6317
1982 1054 2913     5947  3163 8740    11897  6329 17483

1143 4262 2704    3430 12787  8113     6863 25577 16229
4264 2703 1142   12793  8110  3427    25589 16223  6857
2702 1144 4263    8107  3433 12790    16217  6869 25583

1162 3711 2438    3487 11134  7315     6977 22271 14633
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.3x3.librandi.html Go DEC JAN JUL
9 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009 About this capture

```
3594 2423 1252   10783  7270  3757   21569 14543  7517
2422 1254 3593    7267  3763 10780   14537  7529 21563

1263 2702 1984    3790  8107 5953     7583 16217 11909
2704 1983 1262    8113  5950 3787    16229 11903  7577
1982 1264 2703    5947  3793 8110    11897  7589 16223

1303 2912 2109    3910  8737 6328     7823 17477 12659
2914 2108 1302    8743  6325 3907    17489 12653  7817
2107 1304 2913    6322  3913 8740    12647  7829 17483

1352 2681 2018   4057  8044  6055     8117 16091 12113
2683 2017 1351   8050  6052  4054    16103 12107  8111
2016 1353 2682   6049  4060  8047    12101  8123 16097

1352 4011 2683   4057 12034  8050     8117 24071 16103
4013 2682 1351  12040  8047  4054    24083 16097  8111
2681 1353 4012   8044  4060 12037    16091  8123 24077

1372 3261 2318   4117  9784  6955     8237 19571 13913
3263 2317 1371   9790  6952  4114    19583 13907  8231
2316 1373 3262   6949  4120  9787    13901  8243 19577

1372 4451 2913   4117 13354  8740     8237 26711 17483
4453 2912 1371  13360  8737  4114    26723 17477  8231
2911 1373 4452   8734  4120 13357    17471  8243 26717

1577 2456 2018   4732  7369  6055     9467 14741 12113
2458 2017 1576   7375  6052  4729    14753 12107  9461
2016 1578 2457   6049  4735  7372    12101  9473 14747

1578 2457 2019   4735   372  6058     9473 14747 12119
2459 2018 1577   7378  6055  4732    14759 12113  9467
2017 1579 2458   6052  4738  7375    12107  9479 14753

1722 2911 2318   5167  8734  6955    10337 17471 13913
2913 2317 1721   8740  6952  5164    17483 13907 10331
2316 1723 2912   6949  5170  8737    13901 10343 17477

1808 3457 2634   5425 10372  7903    10853 20747 15809
3459 2633 1807  10378  7900  5422    20759 15803 10847
2632 1809 3458   7897  5428 10375    15797 10859 20753

1963 2912 2439   5890  8737  7318    11783 17477 14639
2914 2438 1962   8743  7315  5887    17489 14633 11777
2437 1964 2913   7312  5893  8740    14627 11789 17483

2173 2702 2439   6520  8107  7318    13043 16217 14639
2704 2438 2172   8113  7315  6517    16229 14633 13037
2437 2174 2703   7312  6523  8110    14627 13049 16223

2242 2631 2438   6727  7894  7315    13457 15791 14633
2633 2437 2241   7900  7312  6724    15803 14627 13451
2436 2243 2632   7309  6730  7897    14621 13463 15797

2243 2632 2439   6730  7897  7318    13463 15797 14639
2634 2438 2242   7903  7315  6727    15809 14633 13457
2437 2244 2633   7312  6733  7900    14627 13469 15803

2243 4242 3244   6730 12727  9733    13463 25457 19469
4244 3243 2242  12733  9730  6727    25469 19463 13457
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.3x3.librandi.html Go DEC JAN JUL
9 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009
About this capture

```
2681 2628 2737   8044  7885  8212   16091 15773 16427

3887 4836 4363  11662 14509 13090   23327 29021 26183
4838 4362 3886  14515 13087 11659   29033 26177 23321
4361 3888 4837  13084 11665 14512   26171 23333 29027

4278 4447 4364  12835 13342 13093   25673 26687 26189
4449 4363 4277  13348 13090 12832   26699 26183 25667
4362 4279 4448  13087 12838 13345   26177 25679 26693

4278 4627 4454  12835 13882 13363   25673 27767 26729
4629 4453 4277  13888 13360 12832   27779 26723 25667
4452 4279 4628  13357 12838 13885   26717 25679 27773

4278 4977 4629  12835 14932 13888   25673 29867 27779
4979 4628 4277  14938 13885 12832   29879 27773 25667
4627 4279 4978  13882 12838 14935   27767 25679 29873

4448 4977 4714  13345 14932 14143   26693 29867 28289
4979 4713 4447  14938 14140 13342   29879 28283 26687
4712 4449 4978  14137 13348 14935   28277 26699 29873
```

By Vincenzo Librandi
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Back to **Suzuki's Magic Squares**

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.librandi.html Go JUN JUL JUL
7 captures 18
18 Jul 2007 - 21 Jul 2016 2006 2007 2009
About this capture

Mutsumi Suzuki
[Magic Squares]

4x4 Magic Square of Prime numbers by Librandi

Mr. Vincenzo Librandi proposed a new method to consturuct 3x3 magic squares by sequencial primes by using Librandi's triangle in 1999. His method was summarized in this page.

He recently extended his method to 4x4 squares (Dec. 2000). The following is his mail in which the square of h_1 or h_2 are shown. The square of prime numbers can be created by converting the number h_1 to k= 3h+1 and then to the primes by p=2k+3. It can be written by a single equation;
prime number p = 2k+3 = 2(3 h_1 + 1) + 3 = 6h_1 + 5
or
prime number p = 2k+3 = 2(3 h_2 + 2) + 3 = 6h_2 + 7
------------His mail------------------------------------

```
Dear, Mutsumi Suzuki
By the Librandi's triangle  Prime number = 2k+3.
The set k={0,1,2,4,5,7,8,10,13,14,17,, };
Some more: k= 3h_1+1; (with h_1=0,1,2,3,4,,)
           k= 3h_2+2; (with h_2=0,1,2,4,5,,)

183 Magic Squares 4x4 are constructed by using
h_1< 20.000; k< 60.000, and Prime Numbers < 120.000.

249 Magic Squares 4x4 are constructed by using
h_2< 20.000; k< 60.000, and Prime Numbers < 120.000

(h_1 = => k=3h_1+1  = => p=2K+3)
(h_2 = => k=3h_2+2  = => p=2k+3)


h_1

   1 4453 4452    4       4 13360 13357    13      11 26723 26717    29
4449    7    8 4446   13348    22    25 13339   26699    47    53 26681
   9 4447 4448    6      28 13342 13345    19      59 26687 26693    41
4451    3    2 4454   13354    10     7 13363   26711    23    17 26729

   6 2633 2632    9      19  7900  7897    28      41 15803 15797    59
2459  182  183 2456    7378   547   550  7369   14759  1097  1103 14741
 184 2457 2458  181     553  7372  7375   544    1109 14747 14753  1091
2631    8    7 2634    7894    25    22  7903   15791    53    47 15809

   6 5343 5342    9      19 16030 16027    28      41 32063 32057    59
4454  897  898 4451   13363  2692  2695 13354   26729  5387  5393 26711
 899 4452 4453  896    2698 13357 13360  2689    5399 26717 26723  5381
5341    8    7 5344   16024    25    22 16033   32051    53    47 32069

   6 4448 4447    9      19 13345 13342    28      41 26693 26687    59
2439 2017 2018 2436    7318  6052  6055  7309   14639 12107 12113 14621
2019 2437 2438 2016    6058  7312  7315  6049   12119 14627 14633 12101
4446    8    7 4449   13339    25    22 13348   26681    53    47 26699

   6 5343 5342    9      19 16030 16027    28      41 32063 32057    59
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.librandi.html Go
JUN JUL JUL
18
2006 2007 2009
7 captures
18 Jul 2007 - 21 Jul 2016
About this capture

```
  41  248  247   44      124  745  742  133      251  1493  1487  269
 184  107  108  181      553  322  325  544     1109   647   653 1091
 109  182  183  106      328  547  550  319      659  1097  1103  641
 246   43   42  249      739  130  127  748     1481   263   257 1499

   41 15878 15877    44      124 47635 47632   133      251 95273 95267   269
15739   182   183 15736    47218   547   550 47209    94439  1097  1103 94421
  184 15737 15738   181      553 47212 47215   544     1109 94427 94433  1091
15876    43    42 15879    47629   130   127 47638    95261   263   257 95279

  41 2243 2242   44     124 6730 6727  133      251 13463 13457   269
2019  267  268 2016    6058  802  805 6049    12119  1607  1613 12101
 269 2017 2018  266     808 6052 6055  799     1619 12107 12113  1601
2241   43   42 2244    6724  130  127 6733    13451   263   257 13469

  41 4448 4447   44      124 13345 13342   133      251 26693 26687   269
2914 1577 1578 2911     8743  4732  4735  8734    17489  9467  9473 17471
1579 2912 2913 1576     4738  8737  8740  4729     9479 17477 17483  9461
4446   43   42 4449    13339   130   127 13348    26681   263   257 26699

   41 14073 14072    44      124 42220 42217   133      251 84443 84437   269
11484  2632  2633 11481    34453  7897  7900 34444    68909 15797 15803 68891
 2634 11482 11483  2631     7903 34447 34450  7894    15809 68897 68903 15791
14071    43    42 14074    42214   130   127 42223    84431   263   257 84449

   41 17453 17452    44      124 52360 52357   133      251 104723 104717    269
13134  4362  4363 13131    39403 13087 13090 39394    78809  26177  26183  78791
 4364 13132 13133  4361    13093 39397 39400 13084    26189  78797  78803  26171
17451    43    42 17454    52354   130   127 52363   104711    263    257 104729

  106 15878 15877   109      319 47635 47632   328      641 95273 95267   659
15739   247   248 15736    47218   742   745 47209    94439  1487  1493 94421
  249 15737 15738   246      748 47212 47215   739     1499 94427 94433  1481
15876   108   107 15879    47629   325   322 47638    95261   653   647 95279

  106 13133 13132   109      319 39400 39397   328      641 78803 78797   659
12589   652   653 12586    37768  1957  1960 37759    75539  3917  3923 75521
  654 12587 12588   651     1963 37762 37765  1954     3929 75527 75533  3911
13131   108   107 13134    39394   325   322 39403    78791   653   647 78809

 106 4448 4447  109      319 13345 13342   328      641 26693 26687   659
3889  667  668 3886    11668  2002  2005 11659    23339  4007  4013 23321
 669 3887 3888  666     2008 11662 11665  1999     4019 23327 23333  4001
4446  108  107 4449    13339   325   322 13348    26681   653   647 26699

  106 11483 11482   109      319 34450 34447   328      641 68903 68897   659
 9349  2242  2243  9346    28048  6727  6730 28039    56099 13457 13463 56081
 2244  9347  9348  2241     6733 28042 28045  6724    13469 56087 56093 13451
11481   108   107 11484    34444   325   322 34453    68891   653   647 68909

  106 15738 15737   109      319 47215 47212   328     641 94433 94427   659
11484  4362  4363 11481    34453 13087 13090 34444   68909 26177 26183 68891
 4364 11482 11483  4361    13093 34447 34450 13084   26189 68897 68903 26171
15736   108   107 15739    47209   325   322 47218   94421   653   647 94439

 181 4448 4447  184      544 13345 13342   553     1091 26693 26687  1109
4364  267  268 4361    13093   802   805 13084    26189  1607  1613 26171
 269 4362 4363  266      808 13087 13090   799     1619 26177 26183  1601
4446  183  182 4449    13339   550   547 13348    26681  1103  1097 26699

  181 13303 13302  184      544 39910 39907   553     1091 79823 79817  1109
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.librandi.html Go
JUN JUL JUL
18
2006 2007 2009
7 captures
18 Jul 2007 - 21 Jul 2016
About this capture

```
 181 4363 4362  184    544 13090 13087   553    1091 26183 26177  1109
2439 2107 2108 2436   7318  6322  6325  7309   14639 12647 12653 14621
2109 2437 2438 2106   6328  7312  7315  6319   12659 14627 14633 12641
4361  183  182 4364  13084   550   547 13093   26171  1103  1097 26189

 181 9348 9347  184    544 28045 28042   553    1091 56093 56087  1109
7424 2107 2108 7421  22273  6322  6325 22264   44549 12647 12653 44531
2109 7422 7423 2106   6328 22267 22270  6319   12659 44537 44543 12641
9346  183  182 9349  28039   550   547 28048   56081  1103  1097 56099

  181 14073 14072   184    544 42220 42217   553    1091 84443 84437  1109
10369  3887  3888 10366  31108 11662 11665 31099   62219 23327 23333 62201
 3889 10367 10368  3886  11668 31102 31105 11659   23339 62207 62213 23321
14071   183   182 14074  42214   550   547 42223   84431  1103  1097 84449

 246 2458 2457  249   739 7375 7372  748   1481 14753 14747  1499
2439  267  268 2436  7318  802  805 7309  14639  1607  1613 14621
 269 2437 2438  266   808 7312 7315  799   1619 14627 14633  1601
2456  248  247 2459  7369  745  742 7378  14741  1493  1487 14759

 246 2438 2437  249   739 7315 7312  748   1481 14633 14627  1499
2019  667  668 2016  6058 2002 2005 6049  12119  4007  4013 12101
 669 2017 2018  666  2008 6052 6055 1999   4019 12107 12113  4001
2436  248  247 2439  7309  745  742 7318  14621  1493  1487 14639

 246 2913 2912  249   739 8740 8737  748   1481 17483 17477  1499
2109 1052 1053 2106  6328 3157 3160 6319  12659  6317  6323 12641
1054 2107 2108 1051  3163 6322 6325 3154   6329 12647 12653  6311
2911  248  247 2914  8734  745  742 8743  17471  1493  1487 17489

  246 19293 19292   249    739 57880 57877   748    1481 115763 115757   1499
18489  1052  1053 18486  55468  3157  3160 55459 110939   6317   6323 110921
 1054 18487 18488  1051   3163 55462 55465  3154   6329 110927 110933   6311
19291   248   247 19294  57874   745   742 57883 115751   1493   1487 115769

 246 4453 4452  249    739 13360 13357   748    1481 26723 26717  1499
2459 2242 2243 2456   7378  6727  6730  7369   14759 13457 13463 14741
2244 2457 2458 2241   6733  7372  7375  6724   13469 14747 14753 13451
4451  248  247 4454  13354   745   742 13363   26711  1493  1487 26729

  246 17333 17332   249    739 52000 51997   748    1481 104003 103997   1499
13134  4447  4448 13131  39403 13342 13345 39394   78809  26687  26693  78791
 4449 13132 13133  4446  13348 39397 39400 13339   26699  78797  78803  26681
17331   248   247 17334  51994   745   742 52003  103991   1493   1487 104009

 266 1053 1052  269   799 3160 3157  808  1601 6323 6317 1619
 669  652  653  666  2008 1957 1960 1999  4019 3917 3923 4001
 654  667  668  651  1963 2002 2005 1954  3929 4007 4013 3911
1051  268  267 1054  3154  805  802 3163  6311 1613 1607 6329

  266 18763 18762   269    799 56290 56287   808    1601 112583 112577   1619
17454  1577  1578 17451  52363  4732  4735 52354  104729   9467   9473 104711
 1579 17452 17453  1576   4738 52357 52360  4729    9479 104717 104723   9461
18761   268   267 18764  56284   805   802 56293  112571   1613   1607 112589

  266 19293 19292   269    799 57880 57877   808    1601 115763 115757   1619
17454  2107  2108 17451  52363  6322  6325 52354  104729  12647  12653 104711
 2109 17452 17453  2106   6328 52357 52360  6319   12659 104717 104723  12641
19291   268   267 19294  57874   805   802 57883  115751   1613   1607 115769
```

.... and so on.

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.librandi.html Go
JUN JUL JUL
2006 18 2007 2009
7 captures
18 Jul 2007 - 21 Jul 2016
About this capture

```
  9 941 940  12     29 2825 2822   38     61 5653 5647   79
852 100 101 849   2558  302  305 2549   5119  607  613 5101
102 850 851  99    308 2552 2555  299    619 5107 5113  601
939  11  10 942   2819   35   32 2828   5641   73   67 5659

  9 851 850  12     29 2555 2552   38     61 5113 5107   79
552 310 311 549   1658  932  935 1649   3319 1867 1873 3301
312 550 551 309    938 1652 1655  929   1879 3307 3313 1861
849  11  10 852   2549   35   32 2558   5101   73   67 5119

   9 4016 4015   12      29 12050 12047    38     61 24103 24097    79
3582  445  446 3579   10748  1337  1340 10739   21499  2677  2683 21481
 447 3580 3581  444    1343 10742 10745  1334    2689 21487 21493  2671
4014   11   10 4017   12044    35    32 12053   24091    73    67 24109

   9 3036 3035   12     29 9110 9107   38     61 18223 18217    79
2652  395  396 2649   7958 1187 1190 7949   15919  2377  2383 15901
 397 2650 2651  394   1193 7952 7955 1184    2389 15907 15913  2371
3034   11   10 3037   9104   35   32 9113   18211    73    67 18229

    9 14781 14780    12      29 44345 44342    38     61 88693 88687    79
13907   905   906 13904   41723  2717  2720 41714   83449  5437  5443 83431
  907 13905 13906   904    2723 41717 41720  2714    5449 83437 83443  5431
14799    11    10 14782   44399    35    32 44348   88801    73    67 88699

   9 3581 3580   12      29 10745 10742    38     61 21493 21487    79
2652  940  941 2649    7958  2822  2825  7949   15919  5647  5653 15901
 942 2650 2651  939    2828  7952  7955  2819    5659 15907 15913  5641
3579   11   10 3582   10739    35    32 10748   21481    73    67 21499

    9 11666 11665    12      29 35000 34997    38     61 70003 69997    79
10617  1060  1061 10614   31853  3182  3185 31844 63709  6367  6373 63691
 1062 10615 10616  1059    3188 31847 31850  3179  6379 63697 63703  6361
11664    11    10 11667   34994    35    32 35003  69991    73    67 70009

    9 11666 11665    12      29 35000 34997    38     61 70003 69997    79
 8432  3245  3246  8429   25298   973 7 9740 25289   50599 19477 19483 50581
 3247  8430  8431  3244    9743 25292 25295  9734   19489 50587 50593 19471
11664    11    10 11667   34994    35    32 35003   69991    73    67 70009


.....   and so on
```

Back to [Suzuki's Magic Squares]

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.twinP.html Go JUN JUL MAY
6 captures 18
18 Jul 2007 - 20 Jul 2016 2006 2007 2011 About this capture

Mutsumi Suzuki
Magic Squares

Twin squares of 4x4 with twin primes

Twin primes are a pair of primes with differnce two. For examples, (3,5),(5,7),(11,13),(17,19),,, are such pairs.

If magic squares are constructed by the twin primes, the squares become twin squares in which each coressponding cells differs by two.

Twin squares of 4x4 can be constructed by the following twin primes;

```
41 71 179 197 227 641 827 1019 1289 1481 1667 2081 2111 2129 2237 2267
43 73 181 199 229 643 829 1021 1291 1483 1669 2083 2113 2131 2239 2269
```

Many squares can be constructed by these primes.
The following is the one of the examples.

```
2081 1019 1289  227     2 2 2 2     2083 1021 1291  229
  71  829 1481 2237  +  2 2 2 2  =    73  831 1483 2239
 197  641 1667 2111     2 2 2 2      199  643 1669 2113
2267 2129  179   41     2 2 2 2     2269 2131  181   43

----------------------------------

Another example of an arithmatic progression with constant
difference=180 is;

{59, 239, 419, 599}, {101, 281, 461, 641, 821},
{6947, 7127, 7307, 7487}, {10529, 10709, 10889, 11069},
{26699, 26879, 27059, 27239},

By these twin primes you can construct the following twin magic
squares;

  461  7487    59 10709          463  7489    61 10711
  239 10529   641  7307   and    241 10531   643  7309
11069   419  7127   101        11071   421  7129   103
 6947   281 10889   599         6949   283 10891   601
```

Back to **Suzuki's Magic Squares**

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.prime.html Go
AUG SEP NOV
26
2005 2006 2009
14 captures
26 Sep 2006 - 21 Jul 2016
About this capture

Mutsumi Suzuki
[Magic Squares]

4x4 Magic Square of Prime numbers

Three fundamental magic squares are constructed by sequential prime numbers. 200 prime numbers were checked in this calculation.

```
 set of the prime number is ...
  31,  37,  41,  43,  47,  53,  59,  61,
  67,  71,  73,  79,  83,  89,  97, 101        total is   4 * 258

101  47  31  79
 73  61  71  53
 43  67  59  89
 41  83  97  37
------------



 set of the prime number is ...
  37,  41,  43,  47,  53,  59,  61,  67,
  71,  73,  79,  83,  89,  97, 101, 103        total is   4 * 276

 41  37  97 101
103  83  47  43
 71  67  79  59
 61  89  53  73
------------

 53  37  89  97
 73 101  61  41
103  71  43  59
 47  67  83  79
------------
```

I was very surprised during the calculation,
to find that the sum of the following sequential 16 primes
was exactly 1600.

```
 set of the prime number is ...
 947, 953, 967, 971, 977, 983, 991, 997,
1009,1013,1019,1021,1031,1033,1039,1049        total is   4 *    4000
```

Back to **Suzuki's Magic Squares**

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2005 2006 2009
14 captures
26 Sep 2006 - 21 Jul 2016
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Mutsumi Suzuki
Magic Squares

Magic Square with Sequential Prime Numbers

The squares by sequential prime numbers in this page are from Abe's book "Study of Magic Squares."

They were created by G. Abe and A. Suzuki in 1957.

```
  17  79 101  43  73
  13 113  89  61  37
 109  19  41  47  97
 107  71  53  59  23
  67  31  29 103  83             13-113,  by Gakuho Abe
```

```
167  37 127  11 101  41
 47  71 157  97  83  29
  7  23  17 151 137 149
103 131  43  67  61  79
 53  59  31 139  89 113
107 163 109  19  13  73          7-167,  by Akio Suzuki
```

```
233  13  19 223  29 113 167
173  47 103 191  61  59 163
157 149  37  71 127  17 239
 83 181  79  41 131 193  89
  7 107 229 109 197 137  11
 43  73 151  23 199 211  97
101 227 179 139  53  67  31      7-239,  by Akio Suzuki
```

```
439  89  83  97 419 379 113 397
137 149 433 317 373 163 193 251
331 349 199 179 313 271 223 151
239 167 227 233 269 307 401 173
257 353 191 263 229 103 283 337
293 281 347 367 131 277 109 211
241 197 127 421 101 157 383 389
 79 431 409 139 181 359 311 107  79-439,   by Akio Suzuki
```

```
173  97 191 163 149 383 257 389 409
181 431 179 113 277 251 317 419  43
479 199 193 131 137 139 379 271 283
211  67 449 241 349 233 157  37 467
457 433  47 337 239  71  59 401 167
439 313 463 223 359 227  53  61  73
 83 461 127 263 151 331 311 443  41
109 103 293 373 197 229 397  89 421
```

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Mutsumi Suzuki
Magic Squares

7x7 Magic Square of Prime Numbers

1931	389	11369	1453	829	1307	3919
11159	2713	619	1097	3709	1721	179
409	887	3499	1511	1439	10949	2503
4759	1301	1229	10739	2293	199	677
1019	10529	2083	1459	467	4549	1091
1873	1249	257	4339	881	809	11789
47	4129	2141	599	11579	1663	1039

This panmagic square was constructed by Miller's method with meta-sequence of prime numbers.

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Mutsumi Suzuki
[Magic Squares]

Constellation Patterns in Panmagic Square

Constellation patterns of constant sums

Let us consider an example of a 5x5 panmagic square;

```
  1 22 18 14 10
 19 15  6  2 23
  7  3 24 20 11
 25 16 12  8  4
 13  9  5 21 17
```

Then, you can confirm that the sum of the following five numbers are the same 65.

```
  1  *  *  * 10    1  * 18  *  *    * 22  * 14  *    *  * 18  * 10
  *  *  *  *  *    * 15  *  *  *    *  *  6  *  *    *  *  *  2  *
  *  * 24  *  *    7  * 24  *  *    *  3  * 20  *    *  * 24  * 11
  *  *  *  *  *    *  *  *  *  *    *  *  *  *  *    *  *  *  *  *
 13  *  *  * 17    *  *  *  *  *    *  *  *  *  *    *  *  *  *  *

.....    and so on.
```

More complex patterns which yield constant sums are;

```
      *  *-18  *  *      *  *  *  *  *
      *  * -6  *  *      *  * -6  *  *
      *  *  *  *  *      *  *-24  *  *
      * 16  *  8  *      *  *  *  *  *
      *  *  *  *  *      *  9  * 21  *    ... sums are 0.


     -1  *  *  *  *      *  *  *  *  *
      * 15  6  2  *      *-15  *  *  *
      *  3 24  *  *      *  * 24 20 11
      * 16  *  *  *      *  * 12  8  *
      *  *  *  *  *      *  *  5  *  *    ... sums are 65

....
.....
```

Various such constellation patterns are known for the panmagic squares;

```
Patterns for 4x4 panmagic square;

small square ;  + +
                + +      = 34,

medium square;  +   +

                +   +    = 34,

large square;   +     +
```

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```
                    +    = 17,

airplane;       -
                 + +
                 +      = 17,

step or stack;  - -            - -
                   + +  =  +     +   =  0,


stack              -

                + + +   = 17,
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
Patterns for 5x5 panmagic square

small square(type 1);   +
                      + + +
                        +       = 65,


small square(type 2); +   +
                        +
                      +   +     = 65,

large square(type 1)     +

                     +   +   +

                         +      = 65,


large square(type 2) +       +

                         +

                     +       +  = 65,

(identical to;       + +
                     + +

                           +    = 65 ),

diagonal;            -
                         +
                       +
                           -    = 0,

stack(No. 1);          -
                       -

                     +   +      = 0,

stack(No. 2);          -

                     + + +
                     + + +      = 65,

airplane;            -
                       + + +
                       + +
```

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```
square;           +
                + + +
              + + w + +
                + + +
                  +       = 350 ( w  means double +  ),

squares;      +       +
                  -
                -   -
                  -
              +       +   = 0 ,

nested squares;
              + + + +
              + w w +
              + w w +
              + + + +

                        +   = 525,

stack;        -   -   -

                +   +
                + + +
                + + +
                +   +      = 175,

stack;            -

                +   +
              - + + + -
                +   +

                  -        = 175,


stack;            -

                + + +
              + w w w +
              + w w w +
                + + +      = 350,

diagonal;     -
                  + + +
                + + w +
                + w + +
                + + +
                        -   = 350,

airplane;  -
             + + + + +
             + + + +
             + + +
             + +
             +              = 350,
```

Please use the following examples for the numerical
confirmation;

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```
 8 11 14  1    25 16 12  8  4     3  6 42 25 48 36 15
               13  9  5 21 17    35 24 12  9 30 18 47
                                 27 44 23 17 11 14 39
                                  8 38 26 49 32 20  2
```

These patterns are easily derived from algebraic formula of magic squares. See more explanation here.

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Mutsumi Suzuki
Magic Squares

Total Number of Magic Squares

order N	Total number	(A) Panmagic Squres	(B) Selfcomplementary		(A) and (B)	Semi-magic squares	Composite magic squares
			axi-symmetrical	mirror image			
3	1	0	1	0	0	9(=1x6x6x2/8)	0
4	880	48(=3x16)	48(= A')	304	0	68688(=477x24x24x2/8)	48 (= A)
5	275305224	3600(=144x25)	48544	0	16	160 845 292 * 3600 (by Walter Trump)	0
6	?	0	0	51 016 459 * 24^4 (by Walter Trump)	0	?	0,(1476 semi-magic) by Mr.Setsuda
7	?	38102400(=777600x49)+?	?	0	?	?	0
8	?	?	?	?	?	?	360 (by Mr. Setsuda)

Panmagic square is a magic square in which the constant sum conditions are satisfied in all pan-diagonals.

When the same square (rotated or mirror image) can be generated by a complementary transformation in which the number "i" in the square are changed to the number "N*N+1-i", the square is self-complementary. Axi-symmetrical square can be transformed into a panmagic square by row- and column-exchanges, so the total number of these squares are same(prooved by Mr.Setsuda).

Semi-magic square is a magic square without the diagonal conditions.

Composite magic square is a square constructed by many small 2x2 sub-squares of the same sum. The following is an example of 8x8 composite square; sum of the all sub-square is 130.

```
 ------
| 1  58| 13  60  15  56   3  54
|      |
|47  24| 35  22  33  26  45  28
 ------
 49  10  61  12  63   8  51   6
             ------
 48  23  36 |21  34| 25  46  27
            |    --|---
 50   9  62 |11 |64|   7| 52   5
             ---+--    |
 32  39  20  37 |18  41| 30  43
                 ------
  2  57  14  59  16  55   4  53
```

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1 + 58 + 47 + 24 = 130;
... ...
21 + 34 + 11 + 64 = 130;
64 + 7 + 18 + 41 = 130;
It is known that there is no composit square of odd size nor half-even(6,10,14,,) size. 1476 composite(but semi-magic) squres of 6x6 are found by Mr. Setsuda.

Composite magic square is always pan-magic, but the pan-magic square is not always composite.

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2004 2007 2008
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The Magic Encyclopedia ™

Pan diagonal hypercubes of prime order

{note: investigative article}
(by Aale de Winkel)

(Acknowledgement: Closer analisis I realized that the method described below is a minor variation of <John R Hendricks>'s "digit equations". Analitic coordinates used in stead of regular)

Below a generalisation of the panmagic square investigation is presented, as novel theories (such as here presented) go, it is quite possible that some assumptions made are faulty. The reader is invited to study the below with carefull scruteny and show me the flaws (preferably with some counter example)

The main portion does not concider the magicness of the n-agonals and thus results in {diagonal monagonal} hypercubes, recently a somewhat difficult to formulate, but in practice rather simple condition on some digit changing permutations formulate the {diagonal magic} hypercube. The exact amount is curently not yet computed due to some illusive factors which are yet to be determined. For {perfect} hypercubes see the other article.

NOTE: though presentlyused for the {pandiagonal monagonal [!]} the {pandiagonal magic} and the {perfect} hypercubes of prime order, loosening or restricting conditions on parameters it is quite possible the construction method can be used to find other types of hypercubes. Also it is quite possible to apply different digit changing permutation along each 1-agonal direction, a possibility I'll investigate at some future date.

prime order pan diagonal hypercubes

basic ingredients of pandiagonal hypercubes

Latin hypercube generating formula $LH(a_j)$

factor:
$F = (^{(m-3)/2}{}_{n-1})$

Latin hypercubes obtained by formula

$LH(a_j)$: $LH[_ji] = (_{j=0}\sum^n a_j\ _ji)$ % m ; j ε [0,..,n-1]; i ε [0,..,m-1];
$a_j < a_{j+1}$; $a_0 = 1$; $a_j = 2$ .. (m - 1)/2

The latin hypercubes obtained by the above formula are in normalized position due to the condition $a_j < a_{j+1}$ (can't be equal because that spoils pandiagonality).
$a_0 = 1$ because because of digit changing, thus parameters define the LH's structure
the range of a_j avoids pan-flip variants introduces by parameter range (m+1)/2 .. m-1.

$(^{(m - 3)/2}{}_{n-1})$

m \ n	2	3	4	5	6	7
5	1	0	0	0	0	0
7	2	1	0	0	0	0
11	4	6	4	1	0	0
13	5	10	10	5	1	0
17	7	21	35	35	21	7
19	8	28	56	70	56	28

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basic
pandiagonal hypercubes

factor:
$G = F\ (^{F\ 2^{(n-1)}-1}{}_{n-1})\ (n-1)!$

the basic pandiagonal hypercubes

$H(a_{j,i}) = {}_{i=0}\sum^{n-1} m^{n-i-1}\ LH(a_{j,i})$

In order to retain the normalized position the highest component (denoted with i=0) need to remain in normalized position, the other component are added in posible panflip and transpositional variants, leaving the x-axis as is there are 2^{n-1} panflips, resulting in 2^{n-1} F posibilities of which 1 is already chosen, and n-1 LH's need be randomly selected, this explains the listed factor. The factor of (n-1)! is due to reordering of the lower components

$F\ (^{F\ 2^{(n-1)}-1}{}_{n-1})\ (n-1)!$
(note: values ?? too large for excell)

m \ n	2	3	4	5	6	7
5	1	0	0	0	0	0
7	6	6	0	0	0	0
11	28	3.036	107.880	32.760	0	0
13	45	14.820	4.744.740	180.300.120	20.389.320	0
17	91	142.926	??	??	??	??
19	120	341.880	??	??	??	??

pandiagonal hypercubes

factor:
$m!^n G/(2m)^n =$
$G((m-1)!/2)^n$

the pandiagonal hypercubes

{pandiagonal monagonal [!]}

$H(a_{j,i}) = {}_{i=0}\sum^{n-1} m^{n-i-1}\ LH(a_{j,i})_{=[perm(i)]}$

Applying independently digits changers to the various components generate all(?) possible pandiagonal hypercubes, which introduces a factor $(m!)^n$ (if not mistaken).
This however also introduces all panvariants which gives a deviding factor of $(2m)^n$ with:
2^n (reflection) ; m^n (panrelocation)

pandiagonal magic hypercubes

factors (see text):
$G_P m!$
$G_N (m-1)!$
$(G - G_P + G_N)*(?)$
The various qualities determine possible dividing factors

the pandiagonal magic hypercubes

{pandiagonal magic}

The hypercubes n-agonals are given by $[_0 0_{,k} 0_{,l} (m-1)]\ < _0 1_{,k} 1_{,l} - 1 >$
if the parameters (a_j) if thus that: $(a_{0\ 0}1 + \sum a_{k\ k}1 - \sum a_{l\ l}1)\ \%\ m = 0$
the digit $(\sum a_l\ (m-1))\ \%\ m$ needs to be changed to (m-1)/2 since
that digit is singular on the given n-agonal, the change to (m-1)/2 the n-agonal sums to the magic constant since the sum then also is m(m-1)/2

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28
2004 2007 2008
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gives an n-agonal with a single digit, changing that digit into (m-1)/2 the
latin hypercube n-agonal sums to m (m-1) / 2 and thus to its magic sum
this pathfinder corresponds with a corner $[c_i]$ c_1 = m-1 if Pf_i = -1; c_1 = 0 if Pf_i = 1

the digit to change to (m-1)/2 thus is $({}_{i=0}\sum^{n} a_i c_i)$ % m
the permutation =[(m-1)/2|d,p{{0..m-1}\(m-1)/2] changes the digit 'd' to (m-1)/2
while the remainder p[{0..m-1}\(m-1)/2] applies to all but the digit d of course

This only applies to parametervectors that combine multiple m with one of the n-agonal pathfinders the other parmetervectors no restrictions are neccessairy future analysis might reveal a factor which is sligthly less then the $(m!)^n$ above though the panrelocation factor can't be used,currenty I hold the figure therefore at
for order 7: $({}^{4 * 6!}{}_{3})$ = 3,977,165,760

Of the F latin hypercubes F_P have all n-agonals showing all digits
and the part F_N satisfy the 0%m affliction and have single digit n-agonals

which gives: $G_P = F_P({}^{F_P 2^{(n-1)} - 1}{}_{n-1})\ (n-1)!$ {pan n-agonal pan diagonal monagonal} hypercubes

while: $G_N = F_N({}^{F_N 2^{(n-1)} - 1}{}_{n-1})\ (n-1)!$ {n-agonal pan diagonal monagonal} hypercubes
when each component are associated with careful chosen digit changers
$G - G_P - G_N$ {n-agonal pan diagonal monagonal} hypercubes have
both types of components. (calculating the total of these is thus more difficult)
(F_P and F_N are yet to be determined)

F_P factors. Unknown counting argument (numbers manually obtained)

m \ n	2	3	4
5	1	0	0
7	2	0	0
11	4	3	0?
13	5	6	0?
17	7	15	2?
19	8	21	5?

Cube numbers where obtained in the {perfect} hypercube article. The tesseract numbers I'll have to correct for the non-pantriagonal tesseracts also in future upload the non-panquadragonal probably will get investigated

The studies above correspond with the prime order panmagic square investigation, since for squares pandiagonal and perfect are the same no further investigation is needed there. The perfect treshold of 2^n suggest none of the three order 7 cubes is perfect, a close look at the 1.518 order 11 cubes might reveal a dividing factor to derive the number of perfect cubes (supposing there is one)

SAMPLE: the 6 basic order 7 pandiagonal cubes

{pandiagonal monagonal}

The 4 possible LH's

LH(1,2,3)	LH(1,2,4)	LH(1,5,3)	LH(1,5,4)

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The upload onto the database of the above mentioned show clearly the correlations
LH(1,2,4) = LH(1,2,3)$^{\sim 2}$ LH(1,5,3) = LH(1,2,3)$^{\sim 4}$ and LH(1,5,4) = LH(1,2,3)$^{\sim 6}$
Thus showing that all order 7 cubes are based on the single latin cube LH(1,2,3)

{pandiagonal magic}

The 4 possible LH's (and digit chaging permutations)

LH(1,2,3)$_{=[3\|4,P[0,1,2,4,5,6]]}$	LH(1,2,4)$_{=[3\|0,P[0,1,2,4,5,6]]}$	LH(1,5,3)$_{=[3\|6,P[0,1,2,4,5,6]]}$	LH(1,5,4)$_{=[3\|2,P[0,1,2,4,5,6]]}$

LH(1,2,3) has single digit along the <1,1,-1> direction (1+2-3)%7 = 0, the corner position is [6,6,0] thus the digit to change to 3 is (1*6+2*6+3*0)%7 = 18%7 = 4
LH(1,2,4) has single digit along the <1,1,1> direction (1+2+3)%7 = 0, the corner position is [0,0,0] thus the digit to change to 3 is (1*0+2*0+4*0)%7 = 0
LH(1,5,3) has single digit along the <-1,1,1> direction (-1+5+3)%7 = 7%7 = 0, the corner position is [6,0,0] thus the digit to change to 3 is (1*6+5*0+3*0)%7 = 6
LH(1,5,4) has single digit along the <1,-1,1> direction (1-5+4)%7 = 0, the corner position is [0,6,0] thus the digit to change to 3 is (1*0+5*6+4*0)%7 = 30%7 = 2

Note: the counting arguments above did not taken into account that in case used parameters are lineair dependent in all the used latin hypercubes in a directional pair, doubly numbers appear. So the actual number are a bit lower then the Ca's result, by what factor I currrently don't know but will be investigated some future date.

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Mutsumi Suzuki
Magic Squares

Nonregular Panmagic Squares

Usual panmagic squares can be decomposed into two orothogonal Latin squares. For example, let us consider the following panmagic square;

```
15 16 22  3  9
 2  8 14 20 21
19 25  1  7 13     Matrix A
 6 12 18 24  5
23  4 10 11 17
```

in which each row, column, major- and pan-daigonal sums up to the same 65.
This matrix can be represented by the following arithmetic equation;

```
15 16 22  3  9     2  3  4  0  1       4  0  1  2  3   1  1  1  1  1
 2  8 14 20 21     0  1  2  3  4       1  2  3  4  0   1  1  1  1  1
19 25  1  7 13  =  3  4  0  1  2 x 5 + 3  4  0  1  2 + 1  1  1  1  1
 6 12 18 24  5     1  2  3  4  0       0  1  2  3  4   1  1  1  1  1
23  4 10 11 17     4  0  1  2  3       2  3  4  0  1   1  1  1  1  1

   Matrix A           Matrix B            Matrix C         Matrix I
```

The relation can be represented by:
A = B x 5 + C + I
in which the matrices B and C are 5-adic components of the original matrix A. In the matrices B and C, each number (0 through 4) appears excatry once in each row and column. Such a matrix is called Latin Square.

By overlapping the two Latin squares, you can obtain various combination of numbers at each point such as (0,0), (0,1), (0,2) ... (4,3) and (4,4).

If all the 25 sets appear once in the overlapped square, these two matrices are said to be orthogonal. Thus two orthogonal Latin squares yields a panmagic square. On the contrary, almost all the panmagic squares are decomposed into two orthogonal Latin squares. Such squares are called to be regular.

In 1940, A.L.Candy discoverd not regular panmagic squares. About the same period, Abe Gakuho discovered various nonrregular panmagic squares. According to his study, Candy's squares are called semi-irregular type (in which one of decomposed squares is Latin type).

Followings are the results of Abe's study, which can be seen in his book: "Researches In Magic Squares", by A. Hirayama and G. Abe, (1983)

--------- ----------- ---------

- A.L.Candy's semi-irregular panmagic squares and components;

```
 1  8 19 25 35 39 48   0  1  2  3  4  5  6     0  0  4  3  6  3  5
31 41 44  2 12 17 28   4  5  6  0  1  2  3     2  5  1  1  4  2  6
11 21 24 33 37 43  6   1  2  3  4  5  6  0     3  6  2  4  1  0  5
36 47  4 14 18 26 30   5  6  0  1  2  3  4     0  4  3  6  3  4  1
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.irregular.html Go DEC JAN JUL
9 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009 About this capture

```
 1  8 20 25 35 39 47   0  1  2  3  4  5  6     0  0  5  3  6  3  4
32 40 44  2 12 17 28   4  5  6  0  1  2  3     3  4  1  1  4  2  6
11 21 24 33 37 43  6   1  2  3  4  5  6  0     3  6  2  4  1  0  5
36 48  3 14 18 26 30   5  6  0  1  2  3  4     0  5  2  6  3  4  1
19 23 29 41 46  7 10   2  3  4  5  6  0  1     4  1  0  5  3  6  2
49  4 13 15 22 34 38   6  0  1  2  3  4  5     6  3  5  0  0  5  2
27 31 42 45  5  9 16   3  4  5  6  0  1  2     5  2  6  2  4  1  1
```

- Abe Gakuho's nonregular squares and components;

```
19  7  5 41 29 43 31   2  0  0  5  4  6  4     4  6  4  5  0  0  2
46 40 22  1  4 34 28   6  5  3  0  0  4  3     3  4  0  0  3  5  6
37 16 45 33 21 10 13   5  2  6  4  2  1  1     1  1  2  4  6  2  5
 3  6 42 25 48 36 15   0  0  5  3  6  5  2     2  5  6  3  5  0  0
35 24 12  9 30 18 47   4  3  1  1  4  2  6     6  2  4  1  1  3  4
27 44 23 17 11 14 39   3  6  3  2  1  1  5     5  1  1  2  3  6  3
 8 38 26 49 32 20  2   1  5  3  6  4  2  0     0  2  4  6  3  5  1
```

Matrices B and C are mirror image each other.

- Abe Gakuho's trnasformation;
  Regular sqaure A is transformed into nonregular B by pairwise exchange rule (octagonal exchange).

```
41 10  4 15 35 44 26     41  4 10 15 35 44 26
16 33 48 24 39  8  7     22 33 48 18 39  8  7
22 42  9  5 20 31 46     16 42  9 11 20 31 46
 3 18 29 49 23 40 13      3 24 23 49 29 34 13
47 27 38 11  1 21 30     47 27 38  5  1 21 36
14  2 19 34 45 25 36     14  2 19 40 45 25 30
32 43 28 37 12  6 17     32 43 28 37  6 12 17

   A  (Regular)              B (Nonregular)
```

- Nonregular sqaures constructed by Abe Gakuho's various exchange rules;

```
36 11 19 47 32 16 14     13 15 46  3 43 35 20
15 49 29 25  5 48  4     10 38 37 21 14 26 29
41 18  9 42  1 24 40     23  7 27 40  1 45 32
10 33 13 17 44 35 23     41 12 36 31 18  9 28
 7 22 45 34 27  3 37     22 25  4 30 42  5 47
46 30 21  8 38  6 26     17 44  6 48 33 16 11
20 12 39  2 28 43 31     49 34 19  2 24 39  8

  7-pairs exchanged       10-pairs exchanged


 3 30 28 18 36 11 49     13 21 47 15  3 40 36
17 34 10 44 14 33 23     33 29 10 26 43 27  7
47  9 40 21 16 29 13     24  4 37 41  6 19 44
24 19 32  8 46  7 39     23 48 20  5 38 30 11
 6 45  2 42 27 22 31     34 12 16 45 25  1 42
37 26 20 38  1 48  5      2 39 31  8 28 49 18
41 12 43  4 35 25 15     46 22 14 35 32  9 17

 12-pairs exchanged         9-pairs exchanged
```

- Symmetrical nonregular panmagic square

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.irregular.html Go DEC JAN JUL
9 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009
About this capture

```
35 32  8 41  5 43 11
19 44 12 49  2 22 27
 3 36 13 33 30 26 34
```

- Nonregular panmagic square of 9 order

```
41 30 52 61 31  1 21 81 51
11  9 24 77 66 44 16 67 55
71 40 29 47 63 14  5 20 80
59 10  8 25 76 65 39 18 69
75 54 42 33 46 62 34  4 19
70 58 28  3 27 78 50 38 17
23 74 53 43 13 64 57 36  6
12 72 60 32  2 26 79 49 37
 7 22 73 48 45 15 68 56 35
```

- Nonregular panmagic square of 11 order

```
111  26  29   9  19  82  65  77  91  61 101
 93  92  35 100 116  51  31   8  16  87  42
  5  21  88  58  70  90  34 105 117  53  30
106 119  52  27  10  22  80  59  68  89  39
 57  67  94  40 108 118  49  32  11  14  81
 33   3  15  79  56  72  71  66 107 115  54
 41 104 120  55  25  28  13  78  37  73  97
 83  62  75  96  38  85 121  47  50   2  12
 48  24   1  17  84  64  98  69  43 110 113
 74  44 102 114  46  23   6  18  86  63  95
 20 109  60  76  99  36 103 112  45   4   7
```

- Nonregular panmagic square of 13 order

```
 62  26  46  89 103   8 106  30 136  70 126 144 159
128  32 135  54 118 146 166  59  52  24  90  99   2
108 155 164  74  43  19  83 100   1 107  36 137  78
 14 101  81   7 117  37 142  73 119 147 162  57  48
 28 134  71 122 152 157  55  49  20  91 102  12 112
156 167  64  47  15  82  97   5 113  27 133  75 124
 96   9 105  29 140  72 130 154 168  60  41  17  84
 42  23  85 104  11 116  34 132  69 123 148 165  53
 77 125 145 160  58  44  22  79  94  10 111  39 141
  6 109  35 131  68 127 150 169  63  51  21  80  95
163  65  50  25  86  93   4 110  31 139  66 120 153
138  67 121 149 161  61  40  16  88  98  13 115  38
 87  92   3 114  33 143  76 129 151 158  56  45  18
```

This square is panmagic, but decomposed matrices are not only non-Latin but also non-magic. The sum of row and column are not constant!

- Examples of Abe's typical 8 classes of nonregular panmagic squares

```
 1 44  3 25 40 34 28
41 42 22  2 45  4 19
46  5 20 35 36 23 10
30 24 11 47 13 21 29
14 15 37 31 18 12 48
26  6 49  8 16 38 32
17 39 33 27  7 43  9      A.L.Candy (1940), Semi-nonregular
```

```
35  3 23 48 26  2 38
27 44 24  7 31 29 13
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.irregular.html Go DEC JAN JUL
9 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009
About this capture

```
 6 40 30 10 21 46 22      G. Abe (1981)

26 21 19 32 38  3 36
 6 45 22  9 14 33 46
28 37  4 48 34  8 16
13 18 30 42  2 39 31
44 25 10 20 29 40  7
43  5 49 23 11 17 27
15 24 41  1 47 35 12      W.H.Benson (1982)

22 30 17 11 40 20 35
13 21 29 23 31 25 33
32 26 41 14 36  2 24
37  3 46  5 27 42 15
49  8 16 45  4 47  6
12 48  7 43  9 38 18
10 39 19 34 28  1 44      G. Abe (1982)  Semi-nonregular

 9 19 45 26  4 24 48
27 38 20  8 47 29  6
33  1 25 41 18 21 36
17 49 30  7 22 39 11
44 13 10 43 35  2 28
 5 23 42 16 12 46 31
40 32  3 34 37 14 15

16 12 43  6 18 42 38
44  7 46 41 20 15  2
28  9 19 36  3 45 35
40 37  4 25 34 27  8
32 24 33 26 29 10 21
 1 47 13 11 49 31 23
14 39 17 30 22  5 48

32 28  5 41 45  2 22
37 33 24  3 26 14 38
27 11 44 36 35 21  1
 6 19 34 18  9 43 46
 8 39 17 12 20 31 48
25 29 47 42 10 15  7
40 16  4 23 30 49 13

37 34  4 40 17 27 16
11 26 25 41 36 30  6
45 13 29  2 21 18 47
 1  9 49 24 19 38 35
28 46 33 31  7  8 22
 5  3 20 23 43 42 39
48 44 15 14 32 12 10
```

Back to **Suzuki's Magic Squares**

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.irregular.html Go
9 captures
17 Jan 2007 - 21 Jul 2016
DEC JAN JUL
17
2006 2007 2009
About this capture

http://recordholders.org/en/records/magic.html Go
230 captures
16 Jan 2000 - 22 Oct 2018
APR JUN AUG
2005 14 2006 2007
About this capture

The Largest Magic Square

A **magic square** is a quadratic scheme of numbers which adds up vertically, horizontally and diagonally to the same sum.

Example: (sum is 15 for each row, column and diagonal)

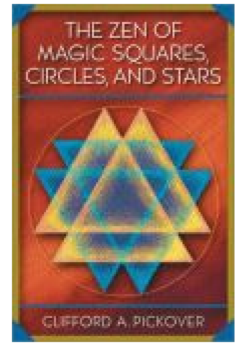
4	9	2
3	5	7
8	1	6

There is no such thing like a record for finding the world's largest magic square. There are well-known algorithms for constructing an arbitrarily large magic square. It is easy to *compute* very large magic squares. However, the records in this list are for *printing* or *writing* magic squares.

You can read more about magic squares at forum.swarthmore.edu/alejandre/magic.square.html.

Interesting records for multi-magic squares (not only the sum of the numbers but also the sum of their squares, cubes, etc. must be the same) can be found at www.multimagie.com.

BOOKS:



The Zen of Magic Squares, Circles and Stars

Solving Magic Squares

The Rules

- The magic square must be written/printed on paper. It is not sufficient just to calculate it by a computer.
- It is allowed to compose the magic square from many sheets of paper, but they MUST lay together to form one scheme of numbers. This scheme must be a square, not just any rectangle.
- To verify the sums in each row/column and diagonal a test run of the used computer program should be made under supervision of a computer/ mathematics specialist who can prove that the program is correct.

The World Recordss

```
 105 X  105 Richard Suntag (Pomona, USA)          1975
 501 X  501 Gerolf Lenz (Wuppertal, Germany)      1979
 897 X  897 Frank Tast + Uli Schmidt
            (Pforzheim, Germany)                  1987
1000 X 1000 Christian Schaller (Munich, Germany)  1988
2001 X 2001 Sven Paulus, Ralph Bülling, Jörg Sutter
            (Pforzheim, Germany)                  1989
2121 X 2121 Ralf Laue (Leipzig, Germany)          1991
3001 X 3001 Louis Caya (Sainte-Foy, Canada)       1994
```

Largest Magic Square Written by Hand

```
1111 X 1111 Norbert Behnke (Krefeld, Germany)     1990
```

http://recordholders.org/en/records/magic.html Go
APR JUN AUG
14
2005 2006 2007
230 captures
16 Jan 2000 - 22 Oct 2018
About this capture

http://mathforum.org/te/exchange/hosted/suzuki/Rand3x3.html Go DEC JAN JUL
10 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009 About this capture

Mutsumi Suzuki
Magic Squares

Randall's 3x3 semi-magic square of squares

Randall found out many 3x3 semi-magic squares of squares during his research on the magic square of squares.

```
common difference = 3,360           Semi-Magic Square
        2    58    82  gcd 2           2    94   113
       46    74    94  gcd 2         127    58    46    (1)
       97   113   127  gcd 1          74    97    82

   Magic Sum = 147^2  Odd diagonal sum = 10,092

common difference = 43,680          Semi-Magic Square
       62   218   302  gcd 2          62   313   394
      103   233   313  gcd 1         446   218   103    (2)
      334   394   446  gcd 2         233   334   302

   Magic Sum = 507^2  Odd diagonal sum = 142,572

common difference = 127,680         Semi-Magic Square
      146   386   526  gcd 2         146   713   802
      503   617   713  gcd 1         878   386   503    (3)
      718   802   878  gcd 2         617   718   526

   Magic Sum = 1083^2  Odd diagonal sum = 446,988

common difference = 665,280         Semi-Magic Square
      102   822  1158  gcd 6         102  1173  3026
      213   843  1173  gcd 3        3134   822   213    (4)
     2914  3026  3134  gcd 2         843  2914  1158

   Magic Sum = 3247^2  Odd diagonal sum = 2,027,052

common difference = 1,145,760       Semi-Magic Square
      158  1082  1522  gcd 2         158  1873  2186
     1103  1537  1873  gcd 1        2434  1082  1103    (5)
     1906  2186  2434  gcd 2        1537  1906  1522

   Magic Sum = 2883^2  Odd diagonal sum = 3,512,172

common difference = 1,367,520       Semi-Magic Square
      802  1418  1838  gcd 2         802  2722  2969
     2162  2458  2722  gcd 2        3191  1418  2162    (6)
     2729  2969  3191  gcd 1        2458  2729  1838

   Magic Sum = 4107^2  Odd diagonal sum = 6,032,172

common difference = 1,367,520       Semi-Magic Square
      802  1418  1838  gcd 2         802  2722  6161
     2162  2458  2722  gcd 2        6271  1418  2162    (7)
     6049  6161  6271  gcd 1        2458  6049  1838

   Magic Sum = 46,010,409  Odd diagonal sum = 6,032,172

common difference = 1,367,520       Semi-Magic Square
```

http://mathforum.org/te/exchange/hosted/suzuki/Rand3x3.html Go DEC JAN JUL
10 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009
About this capture

```
   Magic Sum = 48,783,606  Odd diagonal sum = 6,032,172

common difference = 1,367,520      Semi-Magic Square
     2162  2458  2722  gcd 2        2162  3191  6161
     2729  2969  3191  gcd 1        6271  2458  2729   (9)
     6049  6161  6271  gcd 1        2969  6049  2722

   Magic Sum = 52,814,646  Odd diagonal sum = 18,125,292

NOTE: There are 4 triads here, so quartets do exist!

common difference = 2,328,480      Semi-Magic Square
      147  1533  2163  gcd 21        147  2866  2562
     1886  2426  2866  gcd 2        2982  1533  1886   (10)
     2058  2562  2982  gcd 42       2426  2058  2163

   Magic Sum = 3847^2  Odd diagonal sum = 7,050,267

common difference = 3,756,480      Semi-Magic Square
      562  2018  2798  gcd 2         562  3634  4153
     2386  3074  3634  gcd 2        4583  2018  2386   (11)
     3673  4153  4583  gcd 1        3074  3673  2798

   Magic Sum = 5547^2  Odd diagonal sum = 12,216,972

common difference = 4,514,400      Semi-Magic Square
       35  2125  3005  gcd 5          35  3495  2958
     1785  2775  3495  gcd 15       3642  2125  1785   (12)
     2058  2958  3642  gcd 6        2775  2058  3005

   Magic Sum = 20,966,014  Odd diagonal sum = 13,546,875

common difference = 6,726,720      Semi-Magic Square
      577  2657  3713  gcd 1         577  4702  5426
     2942  3922  4702  gcd 2        6014  2657  2942   (13)
     4766  5426  6014  gcd 2        3922  4766  3713

   Magic Sum = 7203^2  Odd diagonal sum = 21,178,947

common difference = 7,862,400      Semi-Magic Square
     1581  3219  4269  gcd 3        1581  5820  7300
     4260  5100  5820  gcd 60       7820  3219  4260   (14)
     6740  7300  7820  gcd 20       5100  6740  4269

   Magic Sum = 9469^2  Odd diagonal sum = 31,085,883

common difference = 8,168,160      Semi-Magic Square
     1426  3194  4286  gcd 2        1426  5081  7753
     3079  4201  5081  gcd 1        8263  3194  3079   (15)
     7207  7753  8263  gcd 1        4201  7207  4286

   Magic Sum = 87,959,046  Odd diagonal sum = 30,604,908

common difference = 8,848,224      Semi-Magic Square
       49  2975  4207  gcd 7          49  4318  3885
      974  3130  4318  gcd 2        4893  2975   974   (16)
     2499  3885  4893  gcd 21       3130  2499  4207

   Magic Sum = 33,740,750  Odd diagonal sum = 26,551,875

In light of the 16 Semi-Magic squares found above, it becomes
```

http://mathforum.org/te/exchange/hosted/suzuki/Rand3x3.html Go DEC JAN JUL
10 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009 About this capture

```
Further computer searching for more semi-magic squares is in
progress.  Perhaps a parallel Web computer search might be
worthwhile?
```

Back to **Suzuki's Magic Squares**

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.semi.html Go JUN JUL MAY
6 captures 18 2006 2007 2011
18 Jul 2007 - 21 Jul 2016 About this capture

Mutsumi Suzuki
[Magic Squares]

Semi-magic Squares of 4 x 4

What is the semi-magic square ?

Magic square without diagonal conditions is called semi-magic square. The constant sum properties are satisfied only by the rows and columns.

If you exchange any two columns or any two rows, the results are also semi-magic squares. Thus, one semi-magic square yields many family squares by the row or column exchanges. The number of the family squares can be calculated by the permutation as 2*(4*3*2*1)^2. You can select a normalized square from the family as a representatives.

An example of the normalized square is;

```
       1 A B C
       D E F G
       H I J K
       L M N O

in which the follwoing coinditions are satisfied;

    1 < A < B < C

    1 < D < H < L

and

    A < D
```

The followings are the 477 such normalized squares.
Thus, there are 477*2*(4*3*2*1)^2 /8 = 68688 different semi-magic squares exist.

```
  1  2 15 16     1  2 15 16     1  2 15 16     1  2 15 16
  6 11  7 10     7  8  9 10     7  8  9 10     7  8  9 10
 13 12  4  5    12 11  6  5    12 13  4  5    12 13  6  3
 14  9  8  3    14 13  4  3    14 11  6  3    14 11  4  5
------------------------------------------------------------  4
  1  2 15 16     1  2 15 16     1  2 15 16     1  2 15 16
  7  8 10  9     7  8 10  9     7 10  6 11     7 10 11  6
 12 11  5  6    12 11  6  5    12 13  5  4    12  9  5  8
 14 13  4  3    14 13  3  4    14  9  8  3    14 13  3  4
------------------------------------------------------------  8
  1  2 15 16     1  2 15 16     1  2 15 16     1  2 15 16
  7 10 11  6     7 11  6 10     7 11  6 10     7 11 10  6
 12 13  5  4    12  8  9  5    12 13  4  5    12  8  5  9
 14  9  3  8    14 13  4  3    14  8  9  3    14 13  4  3
------------------------------------------------------------ 12
  1  2 15 16     1  2 15 16     1  2 15 16     1  2 15 16
  7 13  4 10     7 13  4 10     7 13  9  5     7 13 10  4
 12  8  9  5    12 11  6  5    12  8  4 10    12 11  6  5
 14 11  6  3    14  8  9  3    14 11  6  3    14  8  3  9
------------------------------------------------------------ 16
  1  2 15 16     1  2 15 16     1  2 15 16     1  2 15 16
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.semi.html Go JUN JUL MAY
6 captures 18
18 Jul 2007 - 21 Jul 2016 2006 2007 2011
About this capture

```
  1  2 15 16     1  2 15 16     1  2 15 16     1  2 15 16
  8  7 10  9     8  7 10  9     8  7 10  9     8  7 10  9
 11 13  4  6    11 13  6  4    12 11  5  6    12 11  6  5
 14 12  5  3    14 12  3  5    13 14  4  3    13 14  3  4
------------------------------------------------------------ 24
  1  2 15 16     1  2 15 16     1  2 15 16     1  2 15 16
  8  7 10  9     8  7 10  9     8  9 12  5     8  9 12  5
 12 14  3  5    12 14  5  3    11 13  3  7    11 13  4  6
 13 11  6  4    13 11  4  6    14 10  4  6    14 10  3  7
------------------------------------------------------------ 28
  1  2 15 16     1  2 15 16     1  2 15 16     1  2 15 16
  8 11  6  9     8 11  6  9     8 11 10  5     8 12  5  9
 12  7 10  5    12 14  3  5    12  7  6  9    11  7 10  6
 13 14  3  4    13  7 10  4    13 14  3  4    14 13  4  3
------------------------------------------------------------ 32
  1  2 15 16     1  2 15 16     1  2 15 16     1  2 15 16
  8 12  5  9     8 12  9  5     8 13  4  9     8 13  4  9
 11 13  4  6    11  7  6 10    11  7 10  6    11 12  5  6
 14  7 10  3    14 13  4  3    14 12  5  3    14  7 10  3
------------------------------------------------------------ 36
  1  2 15 16     1  2 15 16     1  2 15 16     1  2 15 16
  8 13 10  3     8 14  3  9     8 14  3  9     8 14  9  3
 11 12  5  6    12  7 10  5    12 11  6  5    12 11  6  5
 14  7  4  9    13 11  6  4    13  7 10  4    13  7  4 10
------------------------------------------------------------ 40
  1  2 15 16     1  2 15 16     1  2 15 16     1  2 15 16
  9  8 12  5     9  8 12  5     9 12  5  8     9 12  5  8
 10 13  4  7    11 14  3  6    10  7 11  6    11  6 10  7
 14 11  3  6    13 10  4  7    14 13  3  4    13 14  4  3
------------------------------------------------------------ 44
  1  2 15 16     1  2 15 16     1  2 15 16     1  2 15 16
  9 12  8  5     9 13  8  4     9 14  8  3    10 13  4  7
 11  6  7 10    10  7  6 11    11  6  7 10    11 14  6  3
 13 14  4  3    14 12  5  3    13 12  4  5    12  5  9  8
------------------------------------------------------------ 48
  1  2 15 16     1  2 15 16     1  2 15 16     1  3 14 16
 10 13  7  4    10 14  4  6    10 14  7  3     5 12  7 10
 11 14  3  6    11 13  7  3    11 13  4  6    13 11  4  6
 12  5  9  8    12  5  8  9    12  5  8  9    15  8  9  2
------------------------------------------------------------ 52
  1  3 14 16     1  3 14 16     1  3 14 16     1  3 14 16
  5 12 10  7     5 12 11  6     6  8  9 11     6  8  9 11
 13  8  4  9    13 10  7  4    12 10  7  5    12 13  4  5
 15 11  6  2    15  9  2  8    15 13  4  2    15 10  7  2
------------------------------------------------------------ 56
  1  3 14 16     1  3 14 16     1  3 14 16     1  3 14 16
  6  8  9 11     6  8 11  9     6  8 11  9     6 10  7 11
 12 13  7  2    12 10  5  7    12 10  7  5    12  8  9  5
 15 10  4  5    15 13  4  2    15 13  2  4    15 13  4  2
------------------------------------------------------------ 60
  1  3 14 16     1  3 14 16     1  3 14 16     1  3 14 16
  6 10  7 11     6 10 11  7     6 11  8  9     6 13  4 11
 12 13  4  5    12  8  5  9    12  7 10  5    12  8  9  5
 15  8  9  2    15 13  4  2    15 13  2  4    15 10  7  2
------------------------------------------------------------ 64
  1  3 14 16     1  3 14 16     1  3 14 16     1  3 14 16
  6 13  4 11     6 13 10  5     6 13 11  4     7 10  5 12
 12 10  7  5    12 11  2  9    12 10  7  5    11 13  6  4
 15  8  9  2    15  7  8  4    15  8  2  9    15  8  9  2
------------------------------------------------------------ 68
  1  3 14 16     1  3 14 16     1  3 14 16     1  3 14 16
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.semi.html Go JUN JUL MAY
6 captures 18
18 Jul 2007 - 21 Jul 2016 2006 2007 2011 About this capture

```
   1  3 14 16     1  3 14 16     1  3 14 16     1  3 14 16
   7 13 10  4     7 13 10  4     8  6  9 11     8  6  9 11
  11  6  8  9    11 12  2  9    10 12  7  5    12 10  7  5
  15 12  2  5    15  6  8  5    15 13  4  2    13 15  4  2
------------------------------------------------------------ 76
   1  3 14 16     1  3 14 16     1  3 14 16     1  3 14 16
   8  6 11  9     8  6 11  9     8  6 11  9     8  6 11  9
  10 12  5  7    10 12  7  5    10 13  4  7    10 13  7  4
  15 13  4  2    15 13  2  4    15 12  5  2    15 12  2  5
------------------------------------------------------------ 80
   1  3 14 16     1  3 14 16     1  3 14 16     1  3 14 16
   8  6 11  9     8  6 11  9     8  6 11  9     8  6 11  9
  12 10  5  7    12 10  7  5    12 15  2  5    12 15  5  2
  13 15  4  2    13 15  2  4    13 10  7  4    13 10  4  7
------------------------------------------------------------ 84
   1  3 14 16     1  3 14 16     1  3 14 16     1  3 14 16
   8  9  6 11     8  9 11  6     8  9 11  6     8 10  7  9
  12  7 10  5    12  7  5 10    12 15  5  2    12  6 11  5
  13 15  4  2    13 15  4  2    13  7  4 10    13 15  2  4
------------------------------------------------------------ 88
   1  3 14 16     1  3 14 16     1  3 14 16     1  3 14 16
   8 10  7  9     8 10 11  5     8 11  6  9     8 11  6  9
  12 15  2  5    12  6  7  9    10  7 12  5    12  5 10  7
  13  6 11  4    13 15  2  4    15 13  2  4    13 15  4  2
------------------------------------------------------------ 92
   1  3 14 16     1  3 14 16     1  3 14 16     1  3 14 16
   8 11  9  6     8 12  5  9     8 12  5  9     8 12  9  5
  12  5  7 10    10  6 11  7    10 13  4  7    10  6  7 11
  13 15  4  2    15 13  4  2    15  6 11  2    15 13  4  2
------------------------------------------------------------ 96
   1  3 14 16     1  3 14 16     1  3 14 16     1  3 14 16
   8 13  4  9     8 13  4  9     8 13  9  4     8 13 11  2
  10  6 11  7    10 12  5  7    10  7  5 12    10 12  5  7
  15 12  5  2    15  6 11  2    15 11  6  2    15  6  4  9
------------------------------------------------------------100
   1  3 14 16     1  3 14 16     1  3 14 16     1  3 14 16
   8 15  2  9     8 15  2  9     8 15  5  6     8 15  6  5
  12  6 11  5    12 10  7  5    12  9 11  2    12  7  4 11
  13 10  7  4    13  6 11  4    13  7  4 10    13  9 10  2
------------------------------------------------------------104
   1  3 14 16     1  3 14 16     1  3 14 16     1  3 14 16
   8 15  7  4     8 15  9  2     8 15  9  2     9 12  8  5
  12  6 11  5    12  5  7 10    12 10  7  5    11 15  2  6
  13 10  2  9    13 11  4  6    13  6  4 11    13  4 10  7
------------------------------------------------------------108
   1  3 14 16     1  3 14 16     1  3 14 16     1  4 13 16
   9 15  8  2     9 15  8  2    10  7 13  4     6  7 10 11
  11  6  5 12    11 12  5  6    11 15  2  6    12  9  8  5
  13 10  7  4    13  4  7 10    12  9  5  8    15 14  3  2
------------------------------------------------------------112
   1  4 13 16     1  4 13 16     1  4 13 16     1  4 13 16
   6  7 10 11     6  7 11 10     6  9  8 11     6  9  8 11
  12 14  3  5    12  9  8  5    12  7 10  5    12 14  3  5
  15  9  8  2    15 14  2  3    15 14  3  2    15  7 10  2
------------------------------------------------------------116
   1  4 13 16     1  4 13 16     1  4 13 16     1  4 13 16
   6 11  8  9     6 11  9  8     6 11 10  7     6 11 10  7
  12  5 10  7    12  5 10  7    12  5  8  9    12  5  9  8
  15 14  3  2    15 14  2  3    15 14  3  2    15 14  2  3
------------------------------------------------------------120
   1  4 13 16     1  4 13 16     1  4 13 16     1  4 13 16
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.semi.html Go JUN JUL MAY
6 captures 18
18 Jul 2007 - 21 Jul 2016 2006 2007 2011 About this capture

```
  1  4 13 16     1  4 13 16     1  4 13 16     1  4 13 16
  6 14 11  3     7  6 10 11     7  6 11 10     7  6 11 10
 12  9  8  5    12  9  8  5    12  9  8  5    12 15  2  5
 15  7  2 10    14 15  3  2    14 15  2  3    14  9  8  3
------------------------------------------------------------128
  1  4 13 16     1  4 13 16     1  4 13 16     1  4 13 16
  7  9  8 10     7  9  8 10     7 10  8  9     7 10 11  6
 12  6 11  5    12 15  2  5    12  5 11  6    12  5  8  9
 14 15  2  3    14  6 11  3    14 15  2  3    14 15  2  3
------------------------------------------------------------132
  1  4 13 16     1  4 13 16     1  4 13 16     1  4 13 16
  7 10 14  3     7 10 14  3     7 15  2 10     7 15  2 10
 11 12  2  9    11 12  5  6    12  6 11  5    12  9  8  5
 15  8  5  6    15  8  2  9    14  9  8  3    14  6 11  3
------------------------------------------------------------136
  1  4 13 16     1  4 13 16     1  4 13 16     1  4 13 16
  7 15 10  2     8  5 12  9     8  5 12  9     8  5 12  9
 12  9  8  5    10 11  6  7    10 11  7  6    10 14  3  7
 14  6  3 11    15 14  3  2    15 14  2  3    15 11  6  2
------------------------------------------------------------140
  1  4 13 16     1  4 13 16     1  4 13 16     1  4 13 16
  8  5 12  9     8  5 12  9     8  5 12  9     8  5 12  9
 10 14  7  3    11 10  6  7    11 10  7  6    11 15  2  6
 15 11  2  6    14 15  3  2    14 15  2  3    14 10  7  3
------------------------------------------------------------144
  1  4 13 16     1  4 13 16     1  4 13 16     1  4 13 16
  8  5 12  9     8  9  6 11     8  9  7 10     8  9 12  5
 11 15  6  2    10  7 12  5    11  6 12  5    10  7  6 11
 14 10  3  7    15 14  3  2    14 15  2  3    15 14  3  2
------------------------------------------------------------148
  1  4 13 16     1  4 13 16     1  4 13 16     1  4 13 16
  8  9 12  5     8 10  7  9     8 10  7  9     8 11  6  9
 11  6  7 10    11  5 12  6    11 15  2  6    10  5 12  7
 14 15  2  3    14 15  2  3    14  5 12  3    15 14  3  2
------------------------------------------------------------152
  1  4 13 16     1  4 13 16     1  4 13 16     1  4 13 16
  8 11  6  9     8 12  5  9     8 12  5  9     8 12  9  5
 10 14  3  7    10  7 14  3    11 15  6  2    11 15  2  6
 15  5 12  2    15 11  2  6    14  3 10  7    14  3 10  7
------------------------------------------------------------156
  1  4 13 16     1  4 13 16     1  4 13 16     1  4 13 16
  8 14  3  9     8 14  3  9     8 15  2  9     8 15  2  9
 10  5 12  7    10 11  6  7    11  5 12  6    11 10  7  6
 15 11  6  2    15  5 12  2    14 10  7  3    14  5 12  3
------------------------------------------------------------160
  1  4 13 16     1  4 13 16     1  4 13 16     1  4 13 16
  8 15  5  6     8 15  9  2     9  8  6 11     9  8 12  5
 11 12  9  2    11 12  5  6    10  7 12  5    10  7  6 11
 14  3  7 10    14  3  7 10    14 15  3  2    14 15  3  2
------------------------------------------------------------164
  1  4 13 16     1  4 13 16     1  4 13 16     1  4 13 16
  9 12  8  5     9 12  8  5     9 15  8  2    10  7 14  3
 10 15  2  7    10 15  7  2    10 12  7  5    11 15  2  6
 14  3 11  6    14  3  6 11    14  3  6 11    12  8  5  9
------------------------------------------------------------168
  1  4 13 16     1  4 14 15     1  4 14 15     1  4 14 15
 10 15  2  7     5  8 10 11     5  8 10 11     5  8 10 11
 11  6 14  3    12  9  7  6    12 13  3  6    12 13  7  2
 12  9  5  8    16 13  3  2    16  9  7  2    16  9  3  6
------------------------------------------------------------172
  1  4 14 15     1  4 14 15     1  4 14 15     1  4 14 15
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.semi.html Go JUN JUL MAY
6 captures 18
18 Jul 2007 - 21 Jul 2016 2006 2007 2011
About this capture

```
  1  4 14 15     1  4 14 15     1  4 14 15     1  4 14 15
  5 10 11  8     5 11  8 10     5 11 10  8     5 11 10  8
 12  7  6  9    12  6  9  7    12  6  7  9    12 13  7  2
 16 13  3  2    16 13  3  2    16 13  3  2    16  6  3  9
-------------------------------------------------------------180
  1  4 14 15     1  4 14 15     1  4 14 15     1  4 14 15
  5 13  6 10     5 13  7  9     5 13 10  6     6  7  9 12
 12  9 11  2    12 11  3  8    12  8  3 11    11 10  8  5
 16  8  3  7    16  6 10  2    16  9  7  2    16 13  3  2
-------------------------------------------------------------184
  1  4 14 15     1  4 14 15     1  4 14 15     1  4 14 15
  6  7  9 12     6  7 12  9     6  8 13  7     6  9  7 12
 11 13  8  2    11 10  5  8    11 12  2  9    11  8 10  5
 16 10  3  5    16 13  3  2    16 10  5  3    16 13  3  2
-------------------------------------------------------------188
  1  4 14 15     1  4 14 15     1  4 14 15     1  4 14 15
  6  9 12  7     6 12  7  9     6 12  9  7     6 12  9  7
 11  8  5 10    11  5 10  8    11  5  8 10    11 13  8  2
 16 13  3  2    16 13  3  2    16 13  3  2    16  5  3 10
-------------------------------------------------------------192
  1  4 14 15     1  4 14 15     1  4 14 15     1  4 14 15
  6 13  3 12     6 13  3 12     6 13  5 10     6 13  8  7
 11  8 10  5    11 10  8  5    11  9 12  2    11 12  2  9
 16  9  7  2    16  7  9  2    16  8  3  7    16  5 10  3
-------------------------------------------------------------196
  1  4 14 15     1  4 14 15     1  4 14 15     1  4 14 15
  6 13  8  7     6 13 10  5     7  6  9 12     7  6 12  9
 11 12  9  2    11  8  3 12    10 11  8  5    10 11  5  8
 16  5  3 10    16  9  7  2    16 13  3  2    16 13  3  2
-------------------------------------------------------------200
  1  4 14 15     1  4 14 15     1  4 14 15     1  4 14 15
  7  6 12  9     7  9  6 12     7  9 12  6     7 12  6  9
 10 13  3  8    10  8 11  5    10  8  5 11    10  5 11  8
 16 11  5  2    16 13  3  2    16 13  3  2    16 13  3  2
-------------------------------------------------------------204
  1  4 14 15     1  4 14 15     1  4 14 15     1  4 14 15
  7 12  6  9     7 12  9  6     7 13  6  8     7 13 12  2
 10 13  3  8    10  5  8 11    10 12  3  9    10  8  5 11
 16  5 11  2    16 13  3  2    16  5 11  2    16  9  3  6
-------------------------------------------------------------208
  1  4 14 15     1  4 14 15     1  4 14 15     1  4 14 15
  7 13 12  2     8  5 10 11     8  5 10 11     8  5 11 10
 10 11  5  8     9 12  7  6    12  9  7  6     9 12  6  7
 16  6  3  9    16 13  3  2    13 16  3  2    16 13  3  2
-------------------------------------------------------------212
  1  4 14 15     1  4 14 15     1  4 14 15     1  4 14 15
  8  5 11 10     8  5 11 10     8  5 11 10     8  9  7 10
  9 12  7  6    12  9  6  7    12  9  7  6    12  5 11  6
 16 13  2  3    13 16  3  2    13 16  2  3    13 16  2  3
-------------------------------------------------------------216
  1  4 14 15     1  4 14 15     1  4 14 15     1  4 14 15
  8  9 11  6     8 10  5 11     8 10 11  5     8 11  3 12
 12  5  7 10     9  7 12  6     9  7  6 12     9 13  7  5
 13 16  2  3    16 13  3  2    16 13  3  2    16  6 10  2
-------------------------------------------------------------220
  1  4 14 15     1  4 14 15     1  4 14 15     1  4 14 15
  8 11  3 12     8 11  5 10     8 11 10  5     8 12  3 11
  9 13 10  2     9  6 12  7     9  6  7 12     9 13 10  2
 16  6  7  5    16 13  3  2    16 13  3  2    16  5  7  6
-------------------------------------------------------------224
  1  4 14 15     1  4 14 15     1  4 14 15     1  4 14 15
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.semi.html Go
JUN JUL MAY
18
2006 2007 2011
6 captures
18 Jul 2007 - 21 Jul 2016
About this capture

```
  1  4 14 15     1  4 14 15     1  4 14 15     1  4 14 15
  8 13  3 10     8 13  3 10     8 13  6  7     8 13  6  7
  9 12  6  7     9 12 11  2     9 12  3 10     9 12 11  2
 16  5 11  2    16  5  6  7    16  5 11  2    16  5  3 10
------------------------------------------------------------232
  1  4 14 15     1  4 14 15     1  4 14 15     1  4 14 15
  8 13 11  2     8 13 11  2     8 13 11  2     8 13 11  2
  9  7  6 12     9 10  3 12     9 12  3 10     9 12  6  7
 16 10  3  5    16  7  6  5    16  5  6  7    16  5  3 10
------------------------------------------------------------236
  1  4 14 15     1  4 14 15     1  4 14 15     1  4 14 15
  8 16  3  7     8 16  7  3     9  6  7 12     9  6 12  7
 12  9 11  2    12  5 11  6    11  8 10  5    11  8  5 10
 13  5  6 10    13  9  2 10    13 16  3  2    13 16  3  2
------------------------------------------------------------240
  1  4 14 15     1  4 14 15     1  4 14 15     1  5 12 16
  9  6 12  7     9 16  7  2     9 16  7  2     6 10 11  7
 11 16  5  2    11  8  3 12    11  8 10  5    13  4  8  9
 13  8  3 10    13  6 10  5    13  6  3 12    14 15  3  2
------------------------------------------------------------244
  1  5 12 16     1  5 12 16     1  5 12 16     1  5 12 16
  6 10 11  7     6 11  8  9     6 11 10  7     6 11 15  2
 13  4  9  8    13 15  4  2    13 15  4  2    13  8  4  9
 14 15  2  3    14  3 10  7    14  3  8  9    14 10  3  7
------------------------------------------------------------248
  1  5 12 16     1  5 12 16     1  5 12 16     1  5 12 16
  6 11 15  2     6 15  4  9     6 15 11  2     7 13 10  4
 13 10  4  7    13 11  8  2    13  4  8  9    11 14  3  6
 14  8  3  9    14  3 10  7    14 10  3  7    15  2  9  8
------------------------------------------------------------252
  1  5 12 16     1  5 12 16     1  5 12 16     1  5 12 16
  7 14 10  3     7 14 10  3     8  4  9 13     8  4  9 13
 11  6  4 13    11 13  4  6    10 14  7  3    11 15  6  2
 15  9  8  2    15  2  8  9    15 11  6  2    14 10  7  3
------------------------------------------------------------256
  1  5 12 16     1  5 12 16     1  5 12 16     1  5 12 16
  8  4 13  9     8  4 13  9     8  4 13  9     8  4 13  9
 10 11  6  7    10 11  7  6    10 14  3  7    10 14  7  3
 15 14  3  2    15 14  2  3    15 11  6  2    15 11  2  6
------------------------------------------------------------260
  1  5 12 16     1  5 12 16     1  5 12 16     1  5 12 16
  8  4 13  9     8  4 13  9     8  4 13  9     8  4 13  9
 11 10  6  7    11 10  7  6    11 15  2  6    11 15  6  2
 14 15  3  2    14 15  2  3    14 10  7  3    14 10  3  7
------------------------------------------------------------264
  1  5 12 16     1  5 12 16     1  5 12 16     1  5 12 16
  8  9  4 13     8  9  6 11     8  9 13  4     8  9 13  4
 10 14  7  3    10  7 14  3    10  6  7 11    10 14  7  3
 15  6 11  2    15 13  2  4    15 14  2  3    15  6  2 11
------------------------------------------------------------268
  1  5 12 16     1  5 12 16     1  5 12 16     1  5 12 16
  8  9 14  3     8  9 15  2     8 10  7  9     8 10  7  9
 10  7  6 11    11 13  4  6    11  4 13  6    11 15  2  6
 15 13  2  4    14  7  3 10    14 15  2  3    14  4 13  3
------------------------------------------------------------272
  1  5 12 16     1  5 12 16     1  5 12 16     1  5 12 16
  8 10 13  3     8 11  6  9     8 11  6  9     8 11 13  2
 11 15  2  6    10  4 13  7    10 14  3  7    10 14  3  7
 14  4  7  9    15 14  3  2    15  4 13  2    15  4  6  9
------------------------------------------------------------276
  1  5 12 16     1  5 12 16     1  5 12 16     1  5 12 16
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.semi.html Go JUN JUL MAY
6 captures 18 2006 2007 2011
18 Jul 2007 - 21 Jul 2016 About this capture

```
  1  5 12 16     1  5 12 16     1  5 12 16     1  5 12 16
  8 14  3  9     8 14  3  9     8 14  9  3     8 14  9  3
 10  4 13  7    10 11  6  7    10  4  7 13    10 13  7  4
 15 11  6  2    15  4 13  2    15 11  6  2    15  2  6 11
------------------------------------------------------------284
  1  5 12 16     1  5 12 16     1  5 12 16     1  5 12 16
  8 15  2  9     8 15  2  9     8 15  9  2     9  8  4 13
 11  4 13  6    11 10  7  6    11  4  6 13    10 15  7  2
 14 10  7  3    14  4 13  3    14 10  7  3    14  6 11  3
------------------------------------------------------------288
  1  5 12 16     1  5 12 16     1  5 12 16     1  5 12 16
  9  8 13  4     9  8 15  2     9 15  2  8     9 15  2  8
 10  6  7 11    11 14  3  6    10 11  7  6    11 10  6  7
 14 15  2  3    13  7  4 10    14  3 13  4    13  4 14  3
------------------------------------------------------------292
  1  5 13 15     1  5 13 15     1  5 13 15     1  5 13 15
  6 10  4 14     6 10  4 14     6 12 14  2     6 12 14  2
 11 12  8  3    11 12  9  2    11  9  4 10    11 10  4  9
 16  7  9  2    16  7  8  3    16  8  3  7    16  7  3  8
------------------------------------------------------------296
  1  5 13 15     1  5 13 15     1  5 13 15     1  5 13 15
  6 14  4 10     7 10  8  9     7 10 11  6     7 11 14  2
 11 12  9  2    12 16  2  4    12 16  2  4    10 12  3  9
 16  3  8  7    14  3 11  6    14  3  8  9    16  6  4  8
------------------------------------------------------------300
  1  5 13 15     1  5 13 15     1  5 13 15     1  5 13 15
  7 11 14  2     7 12  4 11     7 12  4 11     7 12  9  6
 10 12  4  8    10  8 14  2    10 14  8  2    10 14  8  2
 16  6  3  9    16  9  3  6    16  3  9  6    16  3  4 11
------------------------------------------------------------304
  1  5 13 15     1  5 13 15     1  5 13 15     1  5 13 15
  7 14 11  2     7 16  2  9     7 16  9  2     8 12 11  3
 10 12  4  8    12 10  8  4    12  3  8 11     9  7  4 14
 16  3  6  9    14  3 11  6    14 10  4  6    16 10  6  2
------------------------------------------------------------308
  1  5 13 15     1  5 13 15     1  6 11 16     1  6 11 16
  8 14 10  2     8 16  3  7     7  4 10 13     7  4 13 10
  9 12  7  6    11  9 12  2    12 15  5  2    12  9  8  5
 16  3  4 11    14  4  6 10    14  9  8  3    14 15  2  3
------------------------------------------------------------312
  1  6 11 16     1  6 11 16     1  6 11 16     1  6 11 16
  7  4 13 10     7  5  9 13     7  9  8 10     7  9  8 10
 12 15  2  5    12 15  4  3    12  4 13  5    12 15  2  5
 14  9  8  3    14  8 10  2    14 15  2  3    14  4 13  3
------------------------------------------------------------316
  1  6 11 16     1  6 11 16     1  6 11 16     1  6 11 16
  7  9 13  5     7 10  8  9     7 10 13  4     7 15  2 10
 12  4  8 10    12 15  2  5    12 15  2  5    12  4 13  5
 14 15  2  3    14  3 13  4    14  3  8  9    14  9  8  3
------------------------------------------------------------320
  1  6 11 16     1  6 11 16     1  6 11 16     1  6 11 16
  7 15  2 10     7 15  9  3     7 15 10  2     7 15 10  2
 12  9  8  5    12  5  4 13    12  4  5 13    12  5  4 13
 14  4 13  3    14  8 10  2    14  9  8  3    14  8  9  3
------------------------------------------------------------324
  1  6 11 16     1  6 11 16     1  6 11 16     1  6 11 16
  8  3 14  9     8  3 14  9     8  3 14  9     8  3 14  9
 10 12  5  7    10 12  7  5    10 13  4  7    10 13  7  4
 15 13  4  2    15 13  2  4    15 12  5  2    15 12  2  5
------------------------------------------------------------328
  1  6 11 16     1  6 11 16     1  6 11 16     1  6 11 16
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.semi.html Go JUN JUL MAY
6 captures 18
18 Jul 2007 - 21 Jul 2016 2006 2007 2011 About this capture

```
  1  6 11 16      1  6 11 16      1  6 11 16      1  6 11 16
  8  4 15  7      8  9  4 13      8  9  4 13      8  9  7 10
 12 10  3  9     10  7 14  3     10 14  7  3     12 15  2  5
 13 14  5  2     15 12  5  2     15  5 12  2     13  4 14  3
-------------------------------------------------------------336
  1  6 11 16      1  6 11 16      1  6 11 16      1  6 11 16
  8  9 13  4      8  9 14  3      8  9 14  3      8 10  7  9
 10  5  7 12     10  7  4 13     12 15  2  5     12  3 14  5
 15 14  3  2     15 12  5  2     13  4  7 10     13 15  2  4
-------------------------------------------------------------340
  1  6 11 16      1  6 11 16      1  6 11 16      1  6 11 16
  8 10  7  9      8 12  5  9      8 12  5  9      8 13  4  9
 12 15  2  5     10  3 14  7     10 13  4  7     10  3 14  7
 13  3 14  4     15 13  4  2     15  3 14  2     15 12  5  2
-------------------------------------------------------------344
  1  6 11 16      1  6 11 16      1  6 11 16      1  6 11 16
  8 13  4  9      8 14  3  9      8 14  3  9      8 14  5  7
 10 12  5  7     10 12  7  5     12 10  5  7     12 10  3  9
 15  3 14  2     15  2 13  4     13  4 15  2     13  4 15  2
-------------------------------------------------------------348
  1  6 11 16      1  6 11 16      1  6 11 16      1  6 11 16
  8 14  7  5      8 14  7  5      8 15  2  9      8 15  2  9
 10  2 13  9     10 12  3  9     12  3 14  5     12 10  7  5
 15 12  3  4     15  2 13  4     13 10  7  4     13  3 14  4
-------------------------------------------------------------352
  1  6 11 16      1  6 11 16      1  6 11 16      1  6 11 16
  8 15  7  4      9  8  4 13      9  8  5 12      9  8 13  4
 12  3 14  5     10 15  7  2     10  7 15  2     10  5  7 12
 13 10  2  9     14  5 12  3     14 13  3  4     14 15  3  2
-------------------------------------------------------------356
  1  6 11 16      1  6 11 16      1  6 12 15      1  6 12 15
  9  8 13  4      9  8 15  2      7  4  9 14      7  4 14  9
 10 15  7  2     10  7  5 12     10 13  8  3     10 11  5  8
 14  5  3 12     14 13  3  4     16 11  5  2     16 13  3  2
-------------------------------------------------------------360
  1  6 12 15      1  6 12 15      1  6 12 15      1  6 12 15
  7  4 14  9      7  8  5 14      7  9  4 14      7  9  5 13
 10 13  3  8     10  9 13  2     10  8 13  3     10  8 14  2
 16 11  5  2     16 11  4  3     16 11  5  2     16 11  3  4
-------------------------------------------------------------364
  1  6 12 15      1  6 12 15      1  6 12 15      1  6 12 15
  7  9 14  4      7 11  3 13      7 11 14  2      7 11 14  2
 10  8  3 13     10  8 14  2     10  8  3 13     10 13  3  8
 16 11  5  2     16  9  5  4     16  9  5  4     16  4  5  9
-------------------------------------------------------------368
  1  6 12 15      1  6 12 15      1  6 12 15      1  6 12 15
  7 14  4  9      7 14  4  9      7 14  5  8      7 14  9  4
 10  3 13  8     10 11  5  8     10 11  4  9     10  3  8 13
 16 11  5  2     16  3 13  2     16  3 13  2     16 11  5  2
-------------------------------------------------------------372
  1  6 12 15      1  6 12 15      1  6 12 15      1  6 12 15
  8  3 10 13      8  3 10 13      8  3 13 10      8  3 13 10
  9 14  7  4     11 16  5  2      9 14  4  7      9 14  7  4
 16 11  5  2     14  9  7  4     16 11  5  2     16 11  2  5
-------------------------------------------------------------376
  1  6 12 15      1  6 12 15      1  6 12 15      1  6 12 15
  8  3 13 10      8  3 13 10      8  7  5 14      8  9  7 10
 11 16  2  5     11 16  5  2      9 10 13  2     11 16  2  5
 14  9  7  4     14  9  4  7     16 11  4  3     14  3 13  4
-------------------------------------------------------------380
  1  6 12 15      1  6 12 15      1  6 12 15      1  6 12 15
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.semi.html Go JUN JUL MAY
6 captures 18
18 Jul 2007 - 21 Jul 2016 2006 2007 2011 About this capture

```
  1  6 12 15     1  6 12 15     1  6 12 15     1  6 12 15
  8 11  5 10     8 11  5 10     8 11 13  2     8 11 13  2
  9  4 14  7     9 14  4  7     9  7  4 14     9 14  4  7
 16 13  3  2    16  3 13  2    16 10  5  3    16  3  5 10
-----------------------------------------------------------388
  1  6 12 15     1  6 12 15     1  6 12 15     1  6 12 15
  8 13  3 10     8 13 10  3     8 14  5  7     9  4  7 14
  9  4 14  7     9  4  7 14     9 11  4 10    11 16  5  2
 16 11  5  2    16 11  5  2    16  3 13  2    13  8 10  3
-----------------------------------------------------------392
  1  6 12 15     1  6 12 15     1  6 12 15     1  6 12 15
  9  4 14  7     9  4 14  7     9 16  5  4     9 16  7  2
 11  8  5 10    11 16  5  2    11  2 14  7    11  4  5 14
 13 16  3  2    13  8  3 10    13 10  3  8    13  8 10  3
-----------------------------------------------------------396
  1  6 13 14     1  6 13 14     1  6 13 14     1  6 13 14
  7  8  4 15     7  9 15  3     7 15  9  3     7 16  8  3
 10  9 12  3    10  8  4 12    10 11  8  5    11  2  9 12
 16 11  5  2    16 11  2  5    16  2  4 12    15 10  4  5
-----------------------------------------------------------400
  1  6 13 14     1  6 13 14     1  6 13 14     1  6 13 14
  8  7  4 15     8  7  4 15     8 10  4 12     8 11 10  5
  9 10 12  3     9 11 12  2     9  7 15  3     9 15  7  3
 16 11  5  2    16 10  5  3    16 11  2  5    16  2  4 12
-----------------------------------------------------------404
  1  7 10 16     1  7 10 16     1  7 10 16     1  7 10 16
  8  2 15  9     8  2 15  9     8  2 15  9     8  2 15  9
 11 12  5  6    11 12  6  5    11 13  4  6    11 13  6  4
 14 13  4  3    14 13  3  4    14 12  5  3    14 12  3  5
-----------------------------------------------------------408
  1  7 10 16     1  7 10 16     1  7 10 16     1  7 10 16
  8  2 15  9     8  2 15  9     8  2 15  9     8  2 15  9
 12 11  5  6    12 11  6  5    12 14  3  5    12 14  5  3
 13 14  4  3    13 14  3  4    13 11  6  4    13 11  4  6
-----------------------------------------------------------412
  1  7 10 16     1  7 10 16     1  7 10 16     1  7 10 16
  8  9  4 13     8  9  5 12     8  9  6 11     8  9  6 11
 11  6 15  2    11 15  6  2    12  3 14  5    12 14  3  5
 14 12  5  3    14  3 13  4    13 15  4  2    13  4 15  2
-----------------------------------------------------------416
  1  7 10 16     1  7 10 16     1  7 10 16     1  7 10 16
  8  9 13  4     8  9 15  2     8  9 15  2     8  9 15  2
 11 15  6  2    11  5  6 12    11  6  4 13    11 13  6  4
 14  3  5 12    14 13  3  4    14 12  5  3    14  5  3 12
-----------------------------------------------------------420
  1  7 10 16     1  7 10 16     1  7 10 16     1  7 10 16
  8  9 15  2     8 11  6  9     8 11  6  9     8 12  5  9
 12 14  3  5    12  2 15  5    12 14  3  5    11  2 15  6
 13  4  6 11    13 14  3  4    13  2 15  4    14 13  4  3
-----------------------------------------------------------424
  1  7 10 16     1  7 10 16     1  7 10 16     1  7 10 16
  8 12  5  9     8 13  4  9     8 13  4  9     8 14  3  9
 11 13  4  6    11  2 15  6    11 12  5  6    12  2 15  5
 14  2 15  3    14 12  5  3    14  2 15  3    13 11  6  4
-----------------------------------------------------------428
  1  7 10 16     1  7 10 16     1  7 11 15     1  7 11 15
  8 14  3  9     9  8 15  2     8  4 16  6     8 10  4 12
 12 11  6  5    11  5  6 12    12 14  5  3     9 14  6  5
 13  2 15  4    13 14  3  4    13  9  2 10    16  3 13  2
-----------------------------------------------------------432
  1  7 11 15     1  7 11 15     1  7 11 15     1  7 12 14
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.semi.html Go JUN JUL MAY
6 captures 18
18 Jul 2007 - 21 Jul 2016 2006 2007 2011 About this capture

```
  1  7 12 14     1  7 12 14     1  7 12 14     1  7 12 14
  8  2 11 13     8  2 13 11     8  2 13 11     8  2 13 11
 10 16  5  3     9 15  4  6     9 15  6  4    10 16  3  5
 15  9  6  4    16 10  5  3    16 10  3  5    15  9  6  4
------------------------------------------------------------440
  1  7 12 14     1  7 12 14     1  7 12 14     1  7 12 14
  8  2 13 11     8  6  5 15     8  9  6 11     8  9 13  4
 10 16  5  3     9 10 13  2    10 16  3  5    10 16  3  5
 15  9  4  6    16 11  4  3    15  2 13  4    15  2  6 11
------------------------------------------------------------444
  1  7 12 14     1  7 12 14     1  7 12 14     1  7 12 14
  8 10  5 11     8 10  5 11     8 10 13  3     8 10 13  3
  9  4 15  6     9 15  4  6     9  6  4 15     9 15  4  6
 16 13  2  3    16  2 13  3    16 11  5  2    16  2  5 11
------------------------------------------------------------448
  1  7 12 14     1  7 12 14     1  7 12 14     1  7 12 14
  8 11  2 13     8 11 13  2     8 13  2 11     8 13  2 11
  9  6 15  4     9  6  4 15     9  4 15  6    10  5 16  3
 16 10  5  3    16 10  5  3    16 10  5  3    15  9  4  6
------------------------------------------------------------452
  1  7 12 14     1  7 12 14     1  7 12 14     1  8  9 16
  8 13  4  9     8 13 11  2     8 15  5  6    10  7  4 13
 10  3 16  5     9  4  6 15     9 10  4 11    11  5 15  3
 15 11  2  6    16 10  5  3    16  2 13  3    12 14  6  2
------------------------------------------------------------456
  1  8  9 16     1  8  9 16     1  8  9 16     1  8  9 16
 10  7  4 13    10  7 14  3    10  7 14  3    10  7 15  2
 11 14  6  3    11  4  6 13    11 15  6  2    11 14  6  3
 12  5 15  2    12 15  5  2    12  4  5 13    12  5  4 13
------------------------------------------------------------460
  1  8  9 16     1  8  9 16     1  8  9 16     1  8 10 15
 10 15  6  3    10 15  7  2    10 15  7  2     9  4  7 14
 11  7 14  2    11  6  4 13    11  6 14  3    11 16  5  2
 12  4  5 13    12  5 14  3    12  5  4 13    13  6 12  3
------------------------------------------------------------464
  1  8 10 15     1  8 10 15     1  8 10 15     1  8 10 15
  9  5 16  4     9  6  7 12     9  6 14  5     9 16  4  5
 11 14  6  3    11  4 14  5    11  4  7 12    11  7 14  2
 13  7  2 12    13 16  3  2    13 16  3  2    13  3  6 12
------------------------------------------------------------468
  1  8 10 15     1  8 10 15     1  8 12 13     1  8 12 13
  9 16  7  2     9 16  7  2     9  4  5 16     9  5  4 16
 11  4  5 14    11  4 14  5    10 15  6  3    10 15  7  2
 13  6 12  3    13  6  3 12    14  7 11  2    14  6 11  3
------------------------------------------------------------472
  1  8 12 13     1  8 12 13     1  8 12 13     1  8 12 13
  9  6 16  3     9 16  2  7     9 16  5  4     9 16  5  4
 10 15  2  7    10  6 15  3    10  3  6 15    10  3 15  6
 14  5  4 11    14  4  5 11    14  7 11  2    14  7  2 11
------------------------------------------------------------476
  1  2 15 16
  6 11 10  7
 13  9  4  8
 14 12  5  3
------------------------------------------------------------477
```

Back to **Suzuki's Magic Squares**

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.semi.html Go JUN JUL MAY
6 captures 18
18 Jul 2007 - 21 Jul 2016 2006 2007 2011 About this capture

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.nested.html Go DEC JAN JUL
9 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009 About this capture

Mutsumi Suzuki
Magic Squares

Old Japanese Nested Magic Squares

The nested magic squares were studied completely by SEKI Takakazu(1642-1708), and TANAKA Yoshizane (1651-1719) the greatest mathematicians in the EDO erra in Japan. They called these sqaures as "parent and child squares", so we Japanese use the terminoology even now. SEKI wrote a book entitled "Methods of sqaures and circles" in 1683. The following nested squares are from his book.

Seki's 7x7 square;

12	11	10	45	46	49	2
47	20	19	35	37	14	3
44	34	24	29	22	16	6
7	17	23	25	27	33	43
8	18	28	21	26	32	42
9	36	31	15	13	30	41
48	39	40	5	4	1	38

Seki's 8x8 square;

59	5	4	62	63	1	8	58
9	18	17	49	50	42	19	56
55	20	28	33	29	40	45	10
54	44	38	31	35	26	21	11
12	43	39	30	34	27	22	53
13	24	25	36	32	37	41	52
51	46	48	16	15	23	47	14
7	60	61	3	2	64	57	6

According to ABE Gakuho's reserch, the same square was created by Antonie Arnolds (1612-?) and published in a book "Nouveaux Elements de geometrie" in 1690 by La Haye.

Seki's 9x9 square;

16	15	14	13	75	76	77	81	2
79	28	27	26	61	62	65	18	3
78	63	36	35	51	53	30	19	4
74	60	50	40	45	38	32	22	8
9	23	33	39	41	43	49	59	73
10	24	34	44	37	42	48	58	72
11	25	52	47	31	29	46	57	71
12	64	55	56	21	20	17	54	70
80	67	68	69	7	6	5	1	66

---

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.nested.html Go
9 captures
17 Jan 2007 - 21 Jul 2016
DEC JAN JUL
2006 17 2007 2009
About this capture

90	27	36	35	67	68	60	37	74	11
89	73	38	46	51	47	58	63	28	12
13	72	62	56	49	53	44	39	29	88
14	30	61	57	48	52	45	40	71	87
86	31	42	43	54	50	55	59	70	15
85	69	64	66	34	33	41	65	32	16
18	25	78	79	21	20	82	75	24	83
92	94	6	5	97	98	2	1	17	93

Tanaka's 11x11 square;
His squares are completely different from the Seki's squares.

119	108	8	104	4	102	106	2	6	111	1
10	99	86	88	26	90	24	22	93	21	112
13	28	83	76	74	40	38	79	37	94	109
117	30	42	71	66	69	50	49	80	92	5
15	97	44	52	58	65	60	70	78	25	107
19	95	81	55	63	61	59	67	41	27	103
113	31	47	54	62	57	64	68	75	91	9
115	33	45	73	56	53	72	51	77	89	7
12	35	85	46	48	82	84	43	39	87	110
17	101	36	34	96	32	98	100	29	23	105
121	14	114	18	118	20	16	120	116	11	3

Above data are from ABE's book.

About the same algorithm was implemeted in MATLAB by Srinath Avalchanule.

Back to **Suzuki's Magic Squares**

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.nested.html Go
9 captures
17 Jan 2007 - 21 Jul 2016
DEC JAN JUL
17
2006 2007 2009
About this capture

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.MURASHIN.html Go
DEC JAN MAY
17
2006 2007 2011
7 captures
17 Jan 2007 - 21 Jul 2016
About this capture

Mutsumi Suzuki
Magic Squares

Murashin's nested squares

A Japanese researcher Murashin created varioius nested squares.

The following is a small example of his multiple nested squares, in which you can find 3x3, 4x4, 5x5, 7x7, and 9x9 squares in a sigle matrix.

```
 --------------------------
|14 60 23 67|46 50 52 28 29|
|           |              |
|68 22 59 15|36 32 30 53 54|
|--------------------      |
| 9 73 71 11|40 58 25|31 51|
|           |        |     |
|69 13 35 47|26 41 56|44 38|
|           |        |     |
|45 37 17 65|57 24 42|49 33|
|--------------------------|
| 6 74  7 77|20 48 55|61 21|
|           |        |     |
| 3 81  2 78|62 34 27|66 16|
|           |        |     |
|75  5 76  8|10 70 43|19 63|
|           |        |     |
|80  4 79  1|72 12 39|18 64|
 ---------------------------
```

You can see another example of more complicated system.

It is very sad to say that all of his results are presented in Japanese,
but I think you can enjoy the great complicated systems of
magic squares in his page.

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http://robotics.eecs.berkeley.edu/~srinath/magic/ Go
MAY JUL SEP
14
2005 2006 2007
115 captures
25 Dec 2001 - 1 Feb 2017
About this capture

Nested Magic Squares

Algorithm by: Samavedula Sita Rama Sastry

Nested Magic Squares are magic squares with the special property that each sub-magic square within the original square is also magical, i.e the rows, columns, and diagonals add up to the same number (although to a number different than the original sum,... obviously)

For example, in the 8 x 8 magic square:

14	56	55	54	53	7	8	13
1	24	16	45	44	43	23	64
63	15	40	26	27	37	50	2
62	48	29	35	34	32	17	3
4	47	33	31	30	36	18	61
5	19	28	38	39	25	46	60
59	42	49	20	21	22	41	6
52	9	10	11	12	58	57	51

the inner 6 x 6 square

24	16	45	44	43	23
15	40	26	27	37	50
48	29	35	34	32	17
47	33	31	30	36	18
19	28	38	39	25	46
42	49	20	21	22	41

is also magical and the magic sum is 195. This nested nature persists all the way to the inner 4 x 4 square.

The page describes an algorithm to generate "nested magic squares" of even and odd sided dimensions. The algorithm was developed by Sri. S. S. R. Sastry. Although the algorithm for generating odd sided magic squares is much simpler, it was the algorithm for even sided magic squares which was developed first. For even sided magic squares, the methodology differs slightly for "double even sided magic squares" (i.e when dimension is divisible by 4) and "single even sided magic squares" (i.e when dimension is divisible by 2 but not by 4).

Tomas Ullrich jr. (tom_ullrich AT hotmail DOT com) has an excellent implementation of this algorithm on in Excel. Download the Excel file or the zipped version of the same.

Matlab files which implement the algorithm are also given.

- Algorithm for odd sided magic squares
- Algorithm for even sided magic squares

A few other Matlab files are provided here as general utilitles:

- ismagic.m: For checking whether a general n x n matrix is a simple magic square (nested-ness and other special properties are not checked). If its not a magic square, returns why not.

http://robotics.eecs.berkeley.edu/~srinath/magic/ Go MAY JUL SEP
115 captures 14
25 Dec 2001 - 1 Feb 2017 2005 2006 2007 About this capture

```
  ismag: 1 if magical, 0 if not
  whynot: if ismag == 0, then
    whynot returns the reason why ismagic fails
    whynot = 1 : not all elements from 1 to n^2 uniquely used.
           = 2 : not all rows and columns add up to the same number
```

- writemag.m For writing a general n x n matlab matrix as a ASCII file. Useful because the standard save function writes things as double precision digits instead of integers. I'm pretty sure I could have set some options, but small enough function...

```
» help writemag

    function writemag(magicsquare, fname)
```

- tablemag.m For generating html tables of magic squares. It also paints each nested square differently to illustrate the nested nature of the square. For example, a 7 x 7 square is rendered as:

10	48	46	45	6	8	12
1	18	36	35	16	20	49
3	13	28	21	26	37	47
43	33	23	25	27	17	7
41	31	24	29	22	19	9
39	30	14	15	34	32	11
38	2	4	5	44	42	40

Note however that the html code for the tables tends to be bloated. For example, the 7 x 7 square above takes 64 lines of html to render.

```
» help tablemag

   function tablemag(magicsquare, fname)
```

- colorstring.m This file is used by tablemag.m and should be placed in the same directory. This function takes a matlab colormap entry of the form [r g b] where `0 <= r,g,b <= 1` and returns a string which can be used as a colorname string for html documentation.

```
» help colorstring

   function colstr = colorstring(colarray)
   takes a matlab colormap entry of the form colarray = [r g b],
   where 0 <= r,g,b <= 1 and returns a string which can be used
   as a colorvalue attribute in html.
   For example,
       colorstring([0.2, 0.9, 0.6]) = '33e699'
```

Algorithm for even sided magic squares

Consider the construction of a magic square of dimension `n x n` where n is divisible by 2. We differentiate between 2 cases. When n is divisible by 4, i.e double even square and when n is not divisible by 4 i.e, single even square. The construction differs only slightly between these 2 cases. In both cases, the middle (n-2) x (n-2) square is filled with (n-2)^2 numbers from the middle of {1,...,n^2}. The periphery of the n x n square is filled with the first 2n-2 and last 2n-2 numbers from {1,...,n^2}. Here we describe how the first 2n-2 numbers i.e, from {1,..., 2n-2} are filled. The last 2n-2 numbers are filled opposing these so that the sum of opposing numbers is 1+n^2.

http://robotics.eecs.berkeley.edu/~srinath/magic/ Go
115 captures
25 Dec 2001 - 1 Feb 2017
MAY JUL SEP
14
2005 2006 2007
About this capture

2. In the following steps, we describe how to fill the numbers in `Sp` into the matrix. The numbers in `Lp` automatically follow in such a way that opposing numbers sum up to `n^2 + 1`.

3. Place 1 just below the top left corner

4. If n is a single even number i.e, not divisible by 4, then place 2 just to the right of the top left corner.

5. Fill in the next n-3 numbers in a sort of zig-zag pattern as shown in Figures 1 and 2.

0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0
0	0	0	0	0	0	0	2
0	0	0	0	0	0	0	3
4	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0
0	0	0	0	0	0	0	6
0	0	0	0	0	0	0	0

Fig. 1: Filling in numbers from 2 to n-2 when n is divisible by 2. (Here, n = 8)

0	2	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	3
0	0	0	0	0	0	0	0	0	4
5	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	7
0	0	0	0	0	0	0	0	0	8
9	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

Fig. 2: Filling in numbers from 3 to n-1 when n is not divisible by 4. (Here, n = 10)

6. Fill in the first and last cells of the first row with the last 2 numbers from `Sp`. At this stage, we will have:

13	0	0	0	0	0	0	14
1	0	0	0	0	0	0	0
0	0	0	0	0	0	0	2
0	0	0	0	0	0	0	3
4	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0
0	0	0	0	0	0	0	6
0	0	0	0	0	0	0	0

n = 8

17	2	0	0	0	0	0	0	0	18
1	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	3
0	0	0	0	0	0	0	0	0	4
5	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	7
0	0	0	0	0	0	0	0	0	8
9	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

n = 10

7. We are now left with some of the numbers from `Sp`. These have to be filled into the top and bottom rows of the square such that the following conditions are satisfied:
   - An equal number of elements of `Sp` appear in the top and bottom row. This includes the 2 numbers filled in the top row in the last step, and may also include 2 in the case when n is not divisible by 4.
   - The sum of the numbers in the top and bottom row are equal.

   This is accomplished using the matlab function distribute as follows:
   1. We first calculate how many numbers need to be filled in the bottom row. Call this `nlow`
   2. Calculate how many numbers are remaining from amongst `Sp`. Call these `remain`

http://robotics.eecs.berkeley.edu/~srinath/magic/ Go
115 captures
25 Dec 2001 - 1 Feb 2017
MAY JUL SEP
14
2005 2006 2007
About this capture

the numbers do add up to `reqdlowsum`.

6. If the sum cannot be attained by moving the smallest number amongst selected to the very left, move the next smallest number to the left and so on. Keep repeating till the sum is attained.

Once this distribution is done, we will have used up all the "smaller numbers". For the case, n = 8, we will get the following:

```
14  0   0   0   0   7   8  13
1   0   0   0   0   0   0   0
0   0   0   0   0   0   0   2
0   0   0   0   0   0   0   3
4   0   0   0   0   0   0   0
5   0   0   0   0   0   0   0
0   0   0   0   0   0   0   6
0   9  10  11  12   0   0   0
```

8. The numbers from `Lp` are then filled in so that the sum of "opposing" numbers is equal to 1 + n^2). This will give:

```
14  56  55  54  53   7   8  13
1    0   0   0   0   0   0  64
63   0   0   0   0   0   0   2
62   0   0   0   0   0   0   3
4    0   0   0   0   0   0  61
5    0   0   0   0   0   0  60
59   0   0   0   0   0   0   6
52   9  10  11  12  58  57  51
```

9. The algorithm then used recursively to fill in the n-2 x n-2 block of numbers in the middle. In Matlab speak:

```
>> lastsmall = 2*n-2;
>> magicsquare(2:n-1, 2:n-1) = evenmagic(n-2) + lastsmall;
```

Implementation

The following matlab functions implement the algorithm described above:

- evenmagic.m The main algorithm described above.
- distribute.m The algorithm mentioned at the end of step 4.

If you use the matlab files above, please retain the help comments acknowledging the source of the algorithm. I'd also greatly appreciate it if you dropped me a line at srinath_a@usa.net.

Results

The following text files contain some magic squares in plain ascii format. They were tested using the following matlab function ismagic.m

- mag30.txt a 30 x 30 magic square.
- mag40.txt a 40 x 40 magic square.
- mag80.txt a 80 x 80 magic square.

http://robotics.eecs.berkeley.edu/~srinath/magic/ Go MAY JUL SEP
115 captures 14
25 Dec 2001 - 1 Feb 2017 2005 2006 2007 About this capture

squares and will directly be explained using 2 examples without any equations. As with the even sided magic squares, because of the nested nature of the square, we only describe the method to fill the periphery. The inner square is filled with a recursize call to the same function. Consider filling a square of dimensions n x n (when n is not divisible by 2)

1. The periphery consists of the following numbers:
   - `Sp := {1, ..., 2 n - 2 }`
   - `Lp := {n^2 - 2 n + 3, ..., n^2}`
2. In the following steps, we describe how to fill the numbers in `Sp` into the matrix. The numbers in `Lp` automatically follow in such a way that opposing numbers sum up to `n^2 + 1`.
3. First we fill in all the odd numbers in `Sp` in the following manner:
   - For `n = 9`

```
0   0   0   0   0   0   0   0   0
1   0   0   0   0   0   0   0   0
3   0   0   0   0   0   0   0   0
5   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   9
0   0   0   0   0   0   0   0  11
0   0   0   0   0   0   0   0  13
0   0   0   0   0   0   0   0  15
0   0   0   0   7   0   0   0   0
```

   Here, the odd numbers in `Sp` are `{1,3,...,15}`. The middle odd number, 7, is placed at the center of the bottom row. The oddnumbers from `{1,...,5}` are placed in the first clumn starting from the 2nd row, while the odd numbers after the middle odd number, i.e from `{9,11,...,15}` are placed in the last column as shown.
   - For `n = 7`, we will have

```
0   0   0   0   0   0   0
1   0   0   0   0   0   0
3   0   0   0   0   0   0
0   0   0   0   0   0   7
0   0   0   0   0   0   9
0   0   0   0   0   0  11
0   0   0   5   0   0   0
```

   Notice that the manner of placing the odd numbers doesnt change from `n = 7` to `n = 9`.
4. The even numbers are then placed in the first and last row as follows:
   - The last 2 even numbers in `Sp` are placed in the first and last cells of the first row as shown (the numbers filled in this step are shown in red):

```
14   0   0   0   0   0   0   0  16        10   0   0   0   0   0  12
1    0   0   0   0   0   0   0   0        1    0   0   0   0   0   0
3    0   0   0   0   0   0   0   0        3    0   0   0   0   0   0
5    0   0   0   0   0   0   0   0        0    0   0   0   0   0   7
0    0   0   0   0   0   0   0   9        0    0   0   0   0   0   9
0    0   0   0   0   0   0   0  11        0    0   0   0   0   0  11
0    0   0   0   0   0   0   0  13        0    0   0   5   0   0   0
0    0   0   0   0   0   0   0  15                (n = 7)
0    0   0   0   7   0   0   0   0

                 (n = 9)
```

   - The remaining even numbers are filled in as shown: (for `n = 9`)

http://robotics.eecs.berkeley.edu/~srinath/magic/ Go
115 captures
25 Dec 2001 - 1 Feb 2017
MAY JUL SEP
14
2005 2006 2007
About this capture

```
0   0   0   0   0   0   0   0   9
0   0   0   0   0   0   0   0  11
0   0   0   0   0   0   0   0  13
0   0   0   0   0   0   0   0  15
0   2   4   6   7   0   0   0   0
```

i.e, the first half of the remaining even numbers go in the bottom row while the rest go in the top row as shown above. In exactly the same manner, the remaining even numbers for `n = 7`

```
10  0   0   0   6   8  12
1   0   0   0   0   0   0
3   0   0   0   0   0   0
0   0   0   0   0   0   7
0   0   0   0   0   0   9
0   0   0   0   0   0  11
0   2   4   5   0   0   0
```

5. At this stage, we have filled in all the numbers in `Sp`. The remaining peripheral numbers are filled in so that opposing numbers give a total of `1 + n^2`.
   For `n = 9`, we will have:

```
14  80  78  76  75   8  10  12  16
1    0   0   0   0   0   0   0  81
3    0   0   0   0   0   0   0  79
5    0   0   0   0   0   0   0  77
73   0   0   0   0   0   0   0   9
71   0   0   0   0   0   0   0  11
69   0   0   0   0   0   0   0  13
67   0   0   0   0   0   0   0  15
66   2   4   6   7  74  72  70  68
```

6. The inner square of dimension `n-2 x n-2` is filled in with a recursive call to the algorithm. In matlab speak,

```
>> lastsmall = 2*n - 2;
>> magicsquare(2:n-1, 2:n-1) = oddmagic(n-2) + lastsmall;
```

The following matlab function implements the algorithm described above:

- oddmagic.m The main algorithm described above.

If you use the matlab files above, please retain the help comments acknowledging the source of the algorithm. I'd also greatly appreciate it if you dropped me a line at srinath_a@usa.net.

Results

The following text files contain some magic squares in plain ascii format.

- mag51.txt a 51 x 51 magic square.
- mag75.txt a 75 x 75 magic square.
- mag99.txt a 99 x 99 magic square.

Last updated 05/16/2019 22:08:26

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.algebraform.html Go DEC JAN JUL
9 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009 About this capture

Mutsumi Suzuki
Magic Squares

Algebraic form of magic squares

- 3 x 3 square

```
a b c
d e f
g h i

Let h and i be the independent variables, then the
algebraic form of the magic square becomes;


      10-i     10-h    -5+h+i

    -10+h+2i    5     20-h-2i

      15-h-i    h        i
```

- Formula due to Edouard Lucas(from Lee Sallows' essay)

```
   c-b     c+a+b    c-a
  c-a+b      c     c+a-b
   c+a     c-a-b    c+b


           a is not equal to b
           a is not equal to 2b
           b is not equal to 2a
```

- 3 x 3 semi-magic square

```
Independent variables; e, f, h and i


        -15+e+f+h+i  15-e-h    15-f-i

          15-e-f       e         f

          15-h-i       h         i
```

- 4 x 4 square

```
Independent variables; h, j, k, L, n, o and p


   -34+h+L+n+o+p  -34+h-j+k+L+o+2p  68-h+j-k-L-n-2o-2p  34-h-L-p

      -h+j+k       68-h-k-L-n-o-2p   -34+h-j+L+n+o+2p      h
```

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9 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009 About this capture

- Bergholt's formula (from Lee Sallows' essay)

```
  A-a     C+a+c  B+b-c   D-b
 D+a-d     B      C     A-a+d
 C-b+d     A      D     B+b-d
  B+b     D-a-c  A-b+c   C+a
```

- Lee Sallows' generalized formula

```
   A      B+a    C+b    D+c
 C+c+x    D+b    A+a    B-x
 D+a-x     C     B+c   A+b+x
  B+b     A+c     D     C+a
```

- 4 x 4 panmagic square

```
Independent variables; L, n, o and p


          -17+L+o+p  17-L    17+L-n-o   17-L+n-p

             17-o    17-p   -17+n+o+p     17-n

            -L+n+o   L-n+p   34-L-o-p      L

           34-n-o-p    n         o         p
```

- 4 x 4 semi-magic square

```
Independent variables; f, g, h, j, k, L, n, o and p


         -68+f+g+h+j+k+L+n+o+p   34-f-j-n   34-g-k-o  34-h-L-p

                 34-f-g-h           f          g         h

                 34-j-k-L           j          k         L

                 34-n-o-p           n          o         p
```

- 5 x 5 square

```
    a b c d e
    f g h i j
    k L m n o
    p q r s t
    u v w x y

Independent variables;

     f, g, i, j, n, o, q, r, s, t, v, w, x and y.


Dependent variables are;
```

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9 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009
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```
d = 65-i-n-s-x,
e = 65-j-o-t-y,
h = 325-2g-2j-L-m-n-2o-r-2s-2t-2v-2w-2x-4y
k = -195-f+g-i+j+o+r+2s+2t+2v+2w+2x+4y,
L = 325+f-g+2i-2j-n-3o+q-r-2s-3t-3v-3w-3x-6y,
m = -65-i+j+o-q+t+v+w+x+2y,
p = 65-q-r-s-t,
u = 65-v-w-x-y
```

- Lee Sallows' generalized formula

A+a+x	B+b-z	C+c-v-x+z	D	E+d+v
C	D+d-x	E+a+v+x+y	A+b-v	B+c-y
E+b-u-x-y	A+c+u+x+z	B	C+d+v+w-z	D+a-v-w+y
B+d+y	C+a-u	D+b+u+w-y	E+c-w	A
D+c+u	E	A+d-u-w-z	B+a+z	C+b+w

- 5 x 5 panmagic square

Independent variables; q, r, s, t, v, w, x and y

-65+q+r+s+t+w+x	-q+x+y	65-r-v-w-x	65-s-w-x-y	-t+v+w
65-r-s-w-x	65-s-t-x-y	-65+q+r+s+v+w+x	-65+r+s+t+w+x+y	65-q-r-v-w
-65+r+s+v+w+x+y	s+t-v	65-q-r-s-w	65-r-s-t-x	q+r-y
65-q-r-s-t	q	r	s	t
65-v-w-x-y	v	w	x	y

Back to **Suzuki's Magic Squares**

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Please mail comments and suggestions to Suzanne Alejandre.

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.ambi3.html Go
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2006 2007 2011
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Mutsumi Suzuki
Magic Squares

AMBi Magic Square of order 3

Recently Lee Sallows create an AMBiMagic square. In the square, the orthogonals add to a constant sum, while the diagonals (including the broken diagonals) multiply to a constant product. Hence, he called "ambi": Additive-Multiplicative BImagic square.

Order 3 example using smallest integers:

```
 1  -3   2
-4  12  -8
 3  -9   6

  magic sum = 0, magic product = 72.
```

The general form for non-trivial ambimagics of order 3 is:

```
   a        -a-b       b
-a-ca   (c+1)(a+b)  -b-cb
  ca       -ca-cb     cb

which shows that the magic sum is always 0,
and the magic product is abc(a+b+ca+cb).
```

If you have any comments and/or suggestions, please send direct to him:

E-mail address: sallows@PSYCH.KUN.NL

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The Anti-Magic Square Project

This web site documents my 1999 summer research on a combinatorial design called the Anti-Magic square. Anti-Magic Squares are a variation on the heavily studied and well-understood magic square. In contrast, very little seems to be known about AMSs. These pages describe what was previously known about the structure and history of the AMS and also detail new discoverys regarding their enumeration and construction.

Thanks for your patience and understanding, as this page is still under construction!

								269
49	16	50	10	19	28	24	56	252
42	43	11	15	44	38	55	5	253
25	21	48	46	9	37	6	63	255
29	47	8	40	51	30	52	1	258
45	22	54	23	20	34	2	62	262
14	59	18	33	41	26	61	13	265
36	12	58	32	27	64	3	35	267
17	39	7	57	53	4	60	31	268
257	259	254	256	264	261	263	266	260

What is an Anti-Magic Square?

An *Anti-Magic Square* (AMS) is an arrangement of the numbers 1 to n^2 in a square matrix such that the row, column, and diagonal sums form a sequence of consecutive integers. [1]

The arrangement to the left is Anti-Magic because sorting the sums (numbers in black on the border) yields the sequence: 252, 253, 254, 255, 256, 257, 258, 259, 260, 261, 262, 263, 264, 265, 266, 267, 268, 269

This is an example of an AMS(8), or Anti-Magic Square of order 8, which comes from Madachy's *Mathematical Recreations*

Purpose

Given this definition, this research project aims to answer some of the following questions:

- What range of sums is it possible to have on the border?
- Is it always possible to construct such a design, or for certain n do they not exist?
- If they do exist for a particular order, how many of them are there?
- Are there any applications of this design to practical problems?

And of course, we aim to have fun doing it! After all this is classified as "Recreational Math!"

Table of Contents

- History of Magic and Anti-Magic Square research
- The structure of the Anti-Magic Square
- Enumeration Results
- Constructions for AMS(n)

http://io.uwinnipeg.ca/~vlinek/jcormie/ Go
294 captures
14 Aug 2003 - 23 Jul 2009
MAY JUL SEP
15
2005 2006 2007
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- C programs written for this project
- Math Research at The University of Winnipeg
- Magic Squares on the WWW
- [Coming Soon] Download the pre-print of "Investigating the Anti-Magic Square"

	14	59	60	28	32	61	55	72	22	98	501
487	12	42	38	65	63	26	54	23	80	84	
	88	46	64	25	57	68	47	69	18	7	489
496	85	62	39	71	40	37	51	17	79	15	
	8	31	76	35	50	58	43	78	30	91	500
492	87	53	29	75	49	44	81	20	52	2	
	6	34	56	24	74	70	21	77	48	92	502
490	89	82	83	96	19	99	13	5	1	3	
	491		488		504		505		493		

A present day Anti-Magic analogue to Durer's 1514 Magic Square

---

1. There has been some confusion about this definintion. Some people only require that the row, column and diagonal sums of a square be different to be called Anti-Magic. Such a design is actually called a *heterosquare*. A true AMS is a very special type of heterosquare.

Composed by *John Cormie* July 1999

Huge thanks go to my supervisor for the summer, Václav Linek

A research project funded by NSERC and The University of Winnipeg

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Recreational Mathematics > Magic Figures > Magic Squares

Multiplication Magic Square

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A square which is magic under multiplication instead of addition (the operation used to define a conventional magic square) is called a multiplication magic square. Unlike (normal) magic squares, the n^2 entries for an nth order multiplicative magic square are not required to be consecutive.

128	1	32
4	16	64
8	256	2

The above multiplication magic square has a multiplicative magic constant of 4096 and was found by Antoine Arnauld in *Nouveaux Eléments de Géométrie, Paris* in 1667 (Boyer).

18	1	12
4	6	9
3	36	2

1	15	24	14
12	28	3	5
21	6	10	4
20	2	7	18

The smallest possible magic constants for 3×3, 4×4, ... are 216, 5040, 302400, 25945920, ... (Sloane's A114060). The 3×3 solution (left) was found by Sayles in 1913 and also published by Dudeney (1917). Sayles also found the 4×4 solution (right), which was subsequently proved to be minimal by Borkovitz and Hwang (1983). The series of best known smallest largest element for an $n\times n$ multiplication magic square with $n=3$, 4, ... begins 36, 28, 45, 66, 91, 160, 225, ... (Boyer).

SEE ALSO: Addition-Multiplication Magic Square, Magic Square.
[Pages Linking Here]

REFERENCES:

Borkovitz, D. R. and Hwang, F. K. "Multiplicative Magic Squares." *Disc. Math.* **47**, 1-11, 1983.

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Sloane, N. J. A. Sequence A114060 in "The On-Line Encyclopedia of Integer Sequences."

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Mutsumi Suzuki
Magic Squares

Particular Magic Square of 4 x 4 (with only numbers 1 through 9)

I received a mail from Mr. Ron English on Sept. 19, 2000. He asked me that:

I am looking for some information on a square similar to a magic square. The square is a 4x4, but only the numbers from 1 to 9 are used. (numbers can repeat). I use the square to teach the analysis portion of programming.

Are you aware of any sites analysing the particular square?

The following is my answer.

```
--magic sum < 16-------Total number = 0-----------

--magic sum =16-------
2149 2149 2158 2167 2176 2185 2194 2239 2239 2248 2248 2284 2284 2293 2329
7621 8521 9421 9421 4921 4921 5821 4831 8431 3931 9331 3931 9331 4831 4741
3175 4363 3463 1375 3148 4327 3427 7144 5362 7135 4462 5317 2644 4417 8143
4831 2743 2734 4813 7531 6343 6334 3562 1744 4462 1735 6244 3517 6235 2563

2329 2347 2356 2365 2374 2374 2419 2428 2428 2437 2437 2446 2464 2473 2536
6523 7423 9223 2923 4723 9241 7351 3751 6424 2851 9151 9133 2824 1951 8134
4183 1195 1483 4147 1168 3643 6172 9133 3193 9124 4372 2482 3157 6118 2392
4741 6811 4714 8341 9511 2518 1834 2464 5731 3364 1816 3715 9331 7234 4714

2617 2635 2644 2644 2653 2716 2734 2734 2743 2743 2824 3139 3139 3139 3148
7153 4471 3571 5371 4471 4381 4336 6181 1681 3436 4246 4822 7531 8422 3922
4192 9322 9313 8422 8413 9142 2194 7342 9115 2185 3193 6244 4264 4462 6235
3814 1348 2248 1339 2239 1537 8512 1519 4237 9412 7513 3571 2842 1753 4471

3148 3148 3157 3157 3175 3175 3184 3184 3193 3229 3229 3247 3247 3256 3274
7531 9322 8431 9331 3931 4831 3922 9322 4822 6532 7441 7432 9241 9232 2941
2176 3562 1276 2464 4228 2149 4417 1744 3517 4174 5263 1186 3463 1474 5218
4921 1744 4912 2824 6442 7621 6253 3526 6244 3841 1843 5911 1825 3814 6343

3274 3292 3319 3346 3346 3364 3418 3418 3418 3427 3427 3463 3517 3517 3625
4732 4741 6424 9124 9142 9142 3652 6325 7261 6334 8161 2734 6244 7162 3481
1159 3418 4282 1582 2473 3742 9232 3292 5173 2194 4273 2158 3193 4183 9223
8611 6325 3751 3724 2815 1528 1474 4741 1924 5821 1915 9421 4822 2914 1447

3634 3634 3715 3724 4129 4147 4192 4219 4237 4246 4264 4417 4624 4624 4723
2581 3472 4291 5191 7432 9232 4732 6433 8251 9133 9133 6235 2482 3391 3247
9214 9412 8143 7243 4363 2563 2518 4273 3364 1573 2842 2293 9313 8224 1195
2347 1258 1627 1618 1852 1834 6334 2851 1924 2824 1537 4831 1357 1537 8611

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.with1-9.html Go DEC JAN MAY
8 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2011
About this capture

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.with1-9.html Go DEC JAN MAY
8 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2011
About this capture

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.with1-9.html Go DEC JAN MAY
8 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2011
About this capture

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.with1-9.html Go
DEC JAN MAY
17
2006 2007 2011
8 captures
17 Jan 2007 - 21 Jul 2016
About this capture

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.with1-9.html Go DEC JAN MAY
8 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2011
About this capture

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.with1-9.html Go DEC JAN MAY
8 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2011 About this capture

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.with1-9.html Go DEC JAN MAY
8 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2011 About this capture

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.with1-9.html Go DEC JAN MAY
8 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2011
About this capture

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.with1-9.html Go DEC JAN MAY
8 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2011
About this capture

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.with1-9.html Go DEC JAN MAY
8 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2011 About this capture

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.with1-9.html Go DEC JAN MAY 17 2006 2007 2011
8 captures
17 Jan 2007 - 21 Jul 2016
About this capture

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.with1-9.html Go DEC JAN MAY
8 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2011 About this capture

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.with1-9.html Go DEC JAN MAY
8 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2011
About this capture

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.with1-9.html Go DEC JAN MAY
8 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2011
About this capture

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.with1-9.html Go DEC JAN MAY
8 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2011
About this capture

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.with1-9.html Go DEC JAN MAY
8 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2011
About this capture

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.with1-9.html Go DEC JAN MAY
8 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2011 About this capture

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.with1-9.html Go DEC JAN MAY
8 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2011 About this capture

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.with1-9.html Go DEC JAN MAY 17 2006 2007 2011
8 captures
17 Jan 2007 - 21 Jul 2016
About this capture

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.with1-9.html Go DEC JAN MAY
8 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2011
About this capture

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.with1-9.html Go DEC JAN MAY
8 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2011
About this capture

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.with1-9.html Go DEC JAN MAY
8 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2011 About this capture

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.with1-9.html Go DEC JAN MAY
8 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2011
About this capture

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.with1-9.html Go DEC JAN MAY
8 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2011 About this capture

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.with1-9.html Go DEC JAN MAY
8 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2011 About this capture

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.with1-9.html Go DEC JAN MAY
8 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2011 About this capture

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1696 1786 1687 1885 1786 9166 8176 9562 8572 7177 9652 9553 8662 9148 5188
8725 9535 9625 8536 8626 4855 4945 1768 1858 5935 1669 1759 1759 6655 7924

4657 4666 4666 4666 4666 4666 4666 4666 4666 4675 4675 4675 4675 4675 4684
6691 3982 4882 4891 5773 5791 7573 7591 8482 4891 4891 6673 6691 9355 8428
8257 8149 7159 9238 5179 8248 4288 7357 5377 8239 9328 4279 7348 2596 1795
4837 7645 7735 5647 8824 5737 7915 4828 5917 6637 5548 8815 5728 7816 9535

4684 4684 4729 4729 4729 4738 4738 4738 4738 4747 4747 4756 4756 4756 4756
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1696 1795 7195 9175 8185 7186 9166 8176 9562 8167 6187 9148 9148 8158 5287
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4765 4765 4765 4765 4765 4828 4828 4837 4837 4846 4846 4846 4846 4855 4855
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4855 4855 4855 4927 4927 4927 4936 4936 4936 4945 4945 4945 4945 5179 5179
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6277 4792 4693 9175 7195 8185 9166 6196 7186 5296 6286 5395 6385 3478 7834
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5368 5368 5368 5368 5368 5368 5377 5377 5377 5377 5377 5377 5377 5377 5386
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5386 5395 5395 5395 5458 5458 5458 5458 5467 5467 5467 5467 5467 5467 5467
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5926 5287 5467 7645 8761 8941 1498 1678 5755 9661 9841 9841 1489 1489 1669

5476 5476 5539 5539 5539 5539 5539 5539 5539 5548 5548 5557 5557 5557 5557
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8 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2011
About this capture

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5656 5719 5728 5728 5737 5737 5737 5737 5746 5746 6178 6178 6259 6259 6259
4792 7384 7384 7393 7384 8284 8293 9184 2893 5593 7834 8743 5935 5944 6835
7159 9472 9562 9463 9652 8662 8563 7672 9148 6178 2479 7924 5467 5368 4477
6835 1867 1768 1858 1669 1759 1849 1849 6655 6925 7951 1597 6781 6871 6871

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8761 8851 8941 1498 1588 1678 6871 6691 6961 6781 1786 6871 1876 1966 7591

6358 6358 6358 6358 6358 6358 6358 6367 6367 6367 6367 6376 6376 6439 6439
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7861 7951 1597 7951 1597 1687 1957 8581 8941 1498 1858 9571 9751 6871 6691

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5755 6628 6682 7582 6628 6682 9355 5755 6637 6646 6664 6673 7555 9355 9382
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6961 6781 1876 1966 7771 1777 1777 8941 8851 8941 1498 1588 1498 1678 1948

6466 6466 6529 6529 6538 6538 6538 6538 6538 6538 6547 6547 6547 6547 6547
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9751 9841 6781 6871 7681 7951 1597 1867 1957 1957 1498 1768 1948 1858 1948

6628 6628 6628 6628 6637 6637 6718 6727 6727 6727 7267 7267 7267 7267 7357
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9553 9454 8464 7573 9742 7564 8473 9553 8563 7573 4558 3469 6934 5845 4666
1777 1867 1957 1957 1588 1948 1957 1768 1858 1948 7681 7861 1687 1867 7591

7357 8149 8374
6664 6772 4729
8824 7537 1768
1597 1984 9571
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--magic sum =23-------
2489 2489 2489 2498 2498 2498 2579 2579 2588 2588 2597 2597 2669 2669 2669
8951 8951 9851 8951 9851 9851 7952 8861 7961 9761 8861 9752 6953 7853 8771
6278 7367 6377 6368 5378 6467 6188 8366 8357 7466 7457 4388 7187 6197 9365
7835 6746 6836 7736 7826 6737 8834 5747 6647 5738 6638 8816 8744 8834 4748

2669 2678 2678 2678 2678 2687 2687 2687 2687 2696 2696 2696 2696 2759 2759
9671 6953 7853 7871 9671 6971 8753 8771 9653 6971 7871 8753 9653 6863 8681
8375 6188 5198 9356 8465 9347 4298 8456 4397 8348 8447 4388 4487 8186 9275
4838 9734 9824 5648 4739 6548 9815 5639 8816 7538 6539 9716 8717 7745 4838

2768 2768 2768 2768 2786 2786 2786 2786 2795 2795 2849 2849 2849 2858 2858
5963 6854 8681 9581 5981 6881 8654 9563 6881 8663 6773 7673 7682 5873 6764
8177 6197 9365 8375 9248 9347 4397 5486 8348 5477 9185 8195 9185 9176 7196
8645 9734 4739 4829 7538 6539 9716 7718 7529 8618 6746 6836 5837 7646 8735
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8 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2011 About this capture

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7583 5774 8483 4874 4883 8474 8483 4883 7574 5783 6674 6683 7961 8861 7961
8195 8186 7295 8177 9167 6395 7385 8168 6386 7268 6377 7367 7268 6278 6269
6827 8636 6818 9536 8537 7718 6719 9527 8618 9518 9518 8519 6845 6935 7835

3488 3488 3497 3497 3569 3569 3569 3578 3578 3578 3587 3587 3587 3596 3596
8861 9761 8861 9761 6962 7862 7871 6962 6971 7862 8762 9662 9671 8762 8771
5279 5378 5369 5468 7178 6188 8267 6179 8258 5189 4289 4388 6467 4379 6458
7925 6926 7826 6827 7844 7934 5846 8834 6746 8924 8915 7916 5828 8816 6728

3596 3659 3659 3659 3668 3668 3668 3668 3677 3677 3677 3677 3686 3686 3686
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5477 7349 7448 5468 9176 8186 9167 9266 8276 9158 5198 8366 6386 8159 9248
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3776 3776 3785 3785 3785 3794 3794 3848 3848 3848 3857 3857 3857 3866 3866
7664 9482 5891 6791 8582 6782 7682 6692 7583 7592 6674 8483 8492 4892 5774
4298 6476 8249 8348 6467 6359 6458 9176 7196 8186 6197 6296 7286 9158 6188
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3866 3866 3875 3875 3875 3884 3884 3884 3947 3947 3956 3956 3956 3965 3965
7574 8492 4883 4892 6674 5783 5792 6692 6584 6593 5684 7484 7493 4784 4793
5297 7376 7169 8159 5288 6269 7259 7358 7196 8186 7187 6296 7286 7178 8168
8816 5819 9626 8627 9716 9617 8618 7619 7826 6827 8726 7817 6818 9626 8627

3965 3974 3974 4298 4397 4478 4487 4568 4568 4577 4577 4586 4586 4658 4658
6584 5684 5693 8951 7961 7871 8771 6872 7781 6881 8681 7781 8672 6782 7691
6287 6278 7268 7637 8627 6269 5369 6179 7268 7259 6368 6359 4379 7178 8267
8717 9617 8618 4667 4568 6935 6926 7934 5936 6836 5927 6827 7916 6935 4937

4667 4667 4667 4667 4676 4676 4676 4676 4685 4685 4748 4757 4757 4766 4766
5882 6773 6791 8591 5891 7673 7691 8582 6791 7682 6692 5792 6683 4892 5783
7169 5189 8258 7367 8249 4289 7358 5378 7349 5369 8177 8168 6188 8159 6179
7835 8924 5837 4928 6737 8915 5828 6917 6728 7817 5936 6836 7925 7736 8825

4766 4766 4775 4775 4847 4856 4856 4865 4865 5279 5279 5369 5369 5369 5369
7583 8492 6683 7592 6593 5693 7493 4793 6593 7925 9752 6926 7826 8762 9662
5288 6377 5279 6368 7187 7178 6287 7169 6278 3488 8834 4487 3497 9734 8744
7916 5918 8816 6818 6926 7826 6917 8726 7817 8861 1688 8771 8861 1688 1778

5378 5378 5378 5378 5468 5468 5639 5639 5648 5729 5738 5738 6269 6269 6269
6926 7826 8762 9662 6827 8672 8474 9374 9374 8384 8384 9284 6935 7835 8753
3488 2498 9824 8834 3497 9734 9662 8672 8762 9572 9662 8672 4478 3488 8834
9761 9851 1589 1679 9761 1679 1778 1868 1769 1868 1769 1859 7871 7961 1697

6269 6278 6278 6278 6278 6359 6359 6368 6368 6368 6368 6377 6377 6458 6458
9653 6935 7835 8753 9653 6827 8672 5927 7736 7763 9572 6836 8663 6728 7682
7844 3479 2489 8924 7934 4586 8645 4577 2498 9824 7745 2489 8924 3596 9635
1787 8861 8951 1598 1688 7781 1877 8681 8951 1598 1868 9851 1589 8771 1778

6467 6467 6467 6467 6539 6548 6629 6629 6638 6638 6647 6647 6728 6728 6737
5828 6737 7673 8582 8465 9365 7484 8384 7475 9284 8375 9284 7394 8294 8294
3587 2498 9824 8735 8762 7862 9563 8573 9752 7673 8852 7763 9563 8573 8663
9671 9851 1589 1769 1787 1778 1877 1967 1688 1958 1679 1859 1868 1958 1859

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8 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2011
About this capture

```
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--magic sum =24-------
2499 2589 2598 2679 2679 2688 2688 2697 2697 2769 2769 2796 2796 2859 2868
9951 8961 9861 7953 8871 7971 9771 8871 9753 6963 9681 6981 9663 6873 5973
6378 8367 7467 6198 9366 9357 8466 8457 4398 8187 9375 9348 5487 9186 9177
7836 6747 6738 9834 5748 6648 5739 6639 9816 8745 4839 7539 8718 7746 8646

2868 2886 2886 2895 2949 2958 2967 2967 2976 2976 2985 2994 3489 3498 3579
6864 8664 9573 8673 7683 6774 5874 9483 4983 8574 7674 6783 8961 9861 7962
7197 5397 6486 6477 9195 8196 8187 7395 9168 6396 6387 7368 6279 5379 6189
9735 9717 7719 8619 6837 8736 9636 6819 9537 8718 9618 9519 7935 7926 8934

3579 3597 3597 3669 3669 3678 3678 3687 3687 3696 3696 3759 3759 3768 3768
7971 9762 9771 6972 7881 6981 7863 8763 9681 8781 9672 6882 8691 5982 9591
8268 4389 6468 8178 9267 9258 5199 4299 7467 7458 5478 9177 9276 9168 8376
6846 8916 6828 7845 5847 6747 9924 9915 5829 6729 7818 6846 4938 7746 4929

3786 3786 3795 3795 3849 3867 3867 3876 3876 3894 3948 3957 3957 3966 3966
5991 9582 6891 8682 7692 6774 9492 4992 7674 6792 7593 6684 8493 5784 7584
9249 6477 8349 6468 9186 6198 7386 9159 5298 7359 8196 7197 7296 7188 6297
7638 6819 7629 7719 5937 9825 5919 8637 9816 8619 6927 8826 6918 9726 8817

3975 3975 3984 4578 4587 4668 4668 4677 4677 4686 4686 4758 4767 4767 4776
4893 6684 5793 7881 8781 6882 7791 6891 8691 7791 8682 6792 5892 6783 7683
8169 6288 7269 7269 6369 7179 8268 8259 7368 7359 5379 8178 8169 6189 5289
9627 9717 9618 6936 6927 7935 5937 6837 5928 6828 7917 6936 7836 8925 8916

4776 4785 4857 4866 4866 4875 5379 5379 5739 6279 6279 6369 6369 6378 6378
8592 7692 6693 5793 7593 6693 7926 9762 9384 7935 9753 6927 9672 7836 8763
6378 6369 7188 7179 6288 6279 3498 9834 9672 3489 8934 4587 8745 2499 9924
6918 7818 7926 8826 7917 8817 9861 1689 1869 8961 1698 8781 1878 9951 1599

6468 6468 6639 6648 6729 6738 7269 7269 7359 7359 7368 7368 7458 7458 7467
6828 8682 8475 9375 8394 9294 6936 9663 6828 8682 5928 9582 6729 7692 5829
3597 9735 9762 8862 9573 8673 4578 7845 4686 8646 4677 7746 3696 9636 3687
9771 1779 1788 1779 1968 1959 7881 1887 7791 1977 8691 1968 8781 1878 9681

7467 7548 7638
6738 9366 7476
2598 7962 9852
9861 1788 1698
--magic sum =24-------Total number = 108-----------

--magic sum >24-------Total number = 0-----------
```

Back to **Suzuki's Magic Squares**

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21
2005 2006 2008
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Number Theory
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Addition-Multiplication Magic Square

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An addition-multiplication square is a square of integers that is simultaneously a magic square and multiplication magic square.

AdditionMultiplicationSquare8

In 1955, Horner found a square of order eight with addition magic constant 840 and multiplicative magic constant 2058068231856000, and largest number 243 (left figure; Horner 1955, Hunter and Madachy 1975). In 2005, Boyer found a smaller order-eight square above with addition constant 600, multiplicative constant 67463283888000, and largest number 225 (right figure). Boyer also found a square with smaller multiplicative constant 51407948592000, but larger addition constant (760) and largest number (333).

AdditionMultiplicationSquare9

The two addition-multiplication squares above have order nine with addition magic constants 848 and 1200 and multiplicative magic constants 5804807833440000 and 1619541385529760000, respectively (Hunter and Madachy 1975, Madachy 1979).

SallowsSquare

L. Sallows has constructed an interesting magic square in which the rows and columns have constant sum 0, while the toroidal diagonals have constant product 72.

SEE ALSO: Magic Square. [Pages Linking Here]

REFERENCES:

Horner, W. W. "Addition-Multiplication Magic Square of Order 8." *Scripta Math.* **21**, 23-27, 1955.

Hunter, J. A. H. and Madachy, J. S. "Mystic Arrays." Ch. 3 in *Mathematical Diversions.* New York: Dover, pp. 30-31, 1975.

Madachy, J. S. *Madachy's Mathematical Recreations.* New York: Dover, pp. 89-91, 1979.

LAST MODIFIED: November 28, 2005

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Mutsumi Suzuki
Magic Squares

Magic Stars of David (20 x 4 = 80)

David Star

```
            A

      B   C   D   E

        F       G              Condition of magic David star

      H   I   J   K            A+C+F+H = A+D+G+K = B+C+D+E =
                               B+F+I+L = H+I+J+K = E+G+J+L = 26
             L
```

If you get a magic David star, then you can create another three magic stars by the following exchange rules;

```
(Axis A-L);  B<--->I , C<--->H , D<--->K , E<--->J
(Axis B-K);  H<--->J , F<--->L , A<--->G , C<--->E
(Axis E-H);  A<--->F , B<--->D , K<--->I , G<--->L
```

Followings are 20 data of fundamental magic stars. Thus you can create 80 (20 x 4) stars from the data.

Data;

	A	B	C	D	E	F	G	H	I	J	K	L
1	1	8	2	9	7	11	10	12	3	5	6	4
2	1	7	2	9	8	12	10	11	4	5	6	3
3	1	5	2	10	9	11	8	12	4	3	7	6
4	1	5	2	10	9	12	7	11	3	4	8	6
5	1	8	3	9	6	12	11	10	4	7	5	2
6	1	8	3	11	4	10	9	12	2	7	5	6
7	1	5	3	11	7	10	6	12	2	4	8	9
8	1	3	4	8	11	12	7	9	5	2	10	6
9	1	7	4	12	3	11	8	10	2	9	5	6
10	1	2	4	12	8	10	6	11	5	3	7	9
11	1	4	5	6	11	12	10	8	7	2	9	3
12	1	10	5	7	4	11	12	9	3	8	6	2
13	1	4	5	7	10	11	6	9	3	2	12	8
14	1	4	5	10	7	8	6	12	3	2	9	11
15	1	3	5	11	7	12	4	8	2	6	10	9
16	1	2	6	10	8	12	4	7	3	5	11	9
17	1	3	6	12	5	11	4	8	2	7	9	10
18	1	4	7	9	6	8	5	10	2	3	11	12
19	1	2	7	11	6	8	5	10	4	3	9	12
20	1	2	7	12	5	10	4	8	3	6	9	11

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9 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009
About this capture

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21 captures
24 Mar 2004 - 25 Sep 2018
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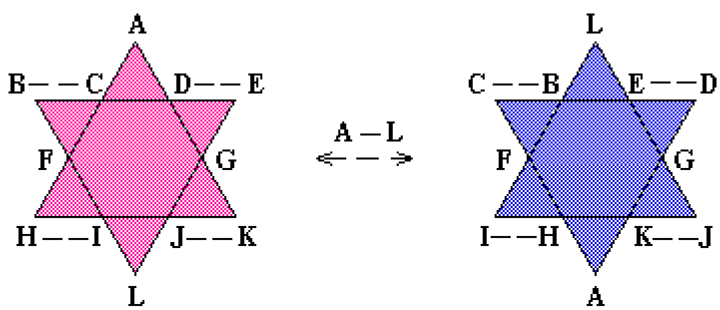
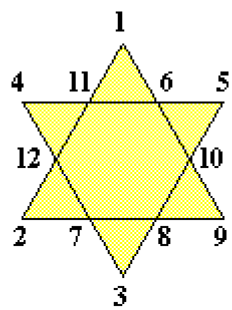
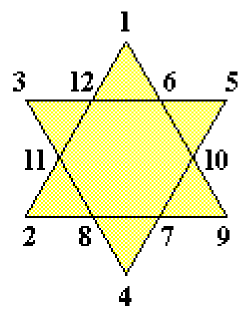
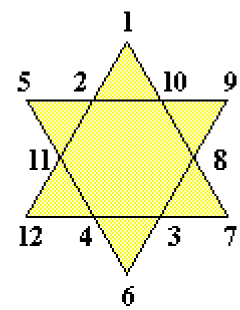
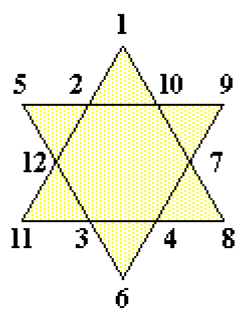
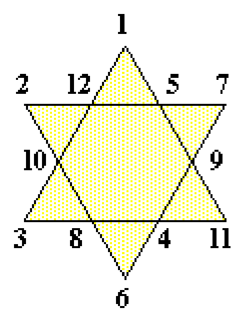


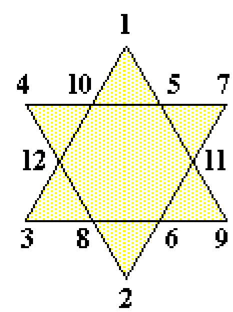


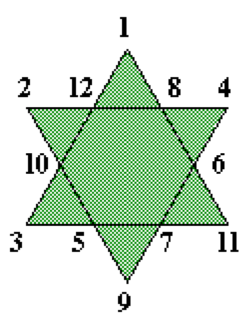


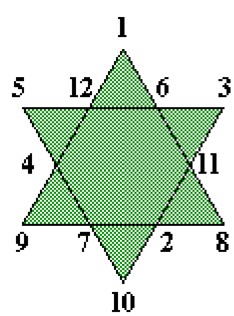


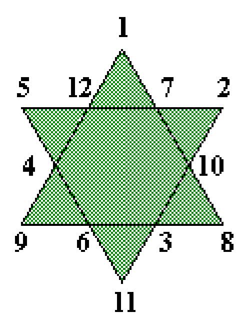




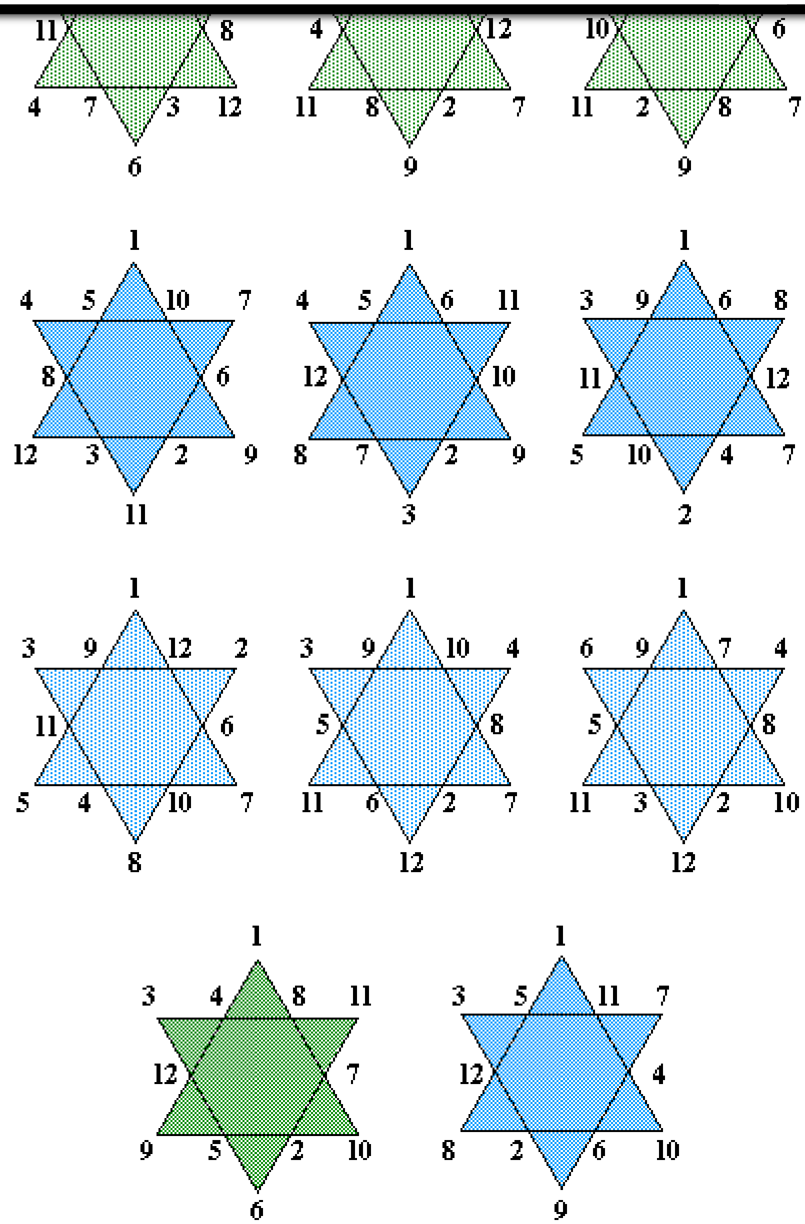








http://mathforum.org/alejandre/magic.star/magic.star.html Go
NOV JAN APR
17
2005 2007 2009
21 captures
24 Mar 2004 - 25 Sep 2018
About this capture



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Mutsumi Suzuki
21 August 1996

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http://mathforum.org/alejandre/magic.star/ Go FEB JUN DEC
172 captures 15
2 Feb 2002 - 28 Jun 2018 2005 2006 2007 About this capture

A Math Forum Web Unit
Suzanne Alejandre and Mutsumi Suzuki's

Magic Stars

Suzanne's Math Lessons || Magic Squares || Tessellation Tutorials

Contents

What is a magic star?

Magic star sets

Transforming magic stars

Combining exchange rules

Mutsumi Suzuki is Professor of Engineering in the Laboratory for Process Systems Engineering, Tohoku University, Sendai, Japan. His research interests include reduced gravity and chemical engineering, and process system engineering. Magic Squares are one of his hobbies, of which the magic stars outlined on these pages are an extension.

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9 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009
About this capture

Mutsumi Suzuki
Magic Squares

Special Magic Stars of David

David Star with circular sum conditions

```
                A

          B   C   D   E

            F       G            Condition of magic David star

          H   I   J   K          A+C+F+H = A+D+G+K = B+C+D+E =
                                 B+F+I+L = H+I+J+K = E+G+J+L = 26
                 L

Special Condition;

  A + B + H + L + K + E = 26

          or

  C + F + I + J + G + D = 26
```

Data;

A	B	C	D	E	F	G	H	I	J	K	L
1	4	12	7	3	11	8	2	5	9	10	6
1	3	11	8	4	12	7	2	5	9	10	6
1	4	10	5	7	12	11	3	8	6	9	2
1	5	9	10	2	12	7	4	3	11	8	6
1	3	9	6	8	11	12	5	10	4	7	2
1	3	9	12	2	11	6	5	4	10	7	8
12	10	6	1	9	5	2	3	4	8	11	7
11	7	8	1	10	4	2	3	6	5	12	9
10	11	5	1	9	7	3	4	2	8	12	6
9	7	10	1	8	2	4	5	6	3	12	11
11	6	7	1	12	3	4	5	9	2	10	8
5	12	7	1	6	4	9	10	2	3	11	8

Back to Suzuki's Magic Squares

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Home || The Math Library || Quick Reference || Search || Help

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http://mathforum.org/te/exchange/hosted/suzuki/MagicStar.David.Circle.html Go
9 captures
17 Jan 2007 - 21 Jul 2016
DEC JAN JUL
17
2006 2007 2009
About this capture

http://mathforum.org/te/exchange/hosted/suzuki/MagicStar.David.Prime.html Go DEC JAN JUL
9 captures 17
17 Jan 2007 - 12 Jun 2016 2006 2007 2009
About this capture

Mutsumi Suzuki
Magic Squares

Magic Stars of David (with Prime Numbers)

David Star of Prime Numbers

```
          A

    B   C   D   E

      F       G              Condition of magic David star

    H   I   J   K            A+C+F+H = A+D+G+K = B+C+D+E =
                             B+F+I+L = H+I+J+K = E+G+J+L = constant
          L
```

If you get a magic David star, then you can create another three magic stars by the following exchange rules;

```
(Axis A-L);  B<--->I , C<--->H , D<--->K , E<--->J
(Axis B-K);  H<--->J , F<--->L , A<--->G , C<--->E
(Axis E-H);  A<--->F , B<--->D , K<--->I , G<--->L
```

Data;

A	B	C	D	E	F	G	H	I	J	K	L
29	53	31	61	59	71	67	73	43	41	47	37
29	61	37	59	47	71	73	67	41	53	43	31
29	59	37	61	47	71	73	67	43	53	41	31
29	41	37	73	53	71	43	67	31	47	59	61
29	31	47	73	53	61	43	67	41	37	59	71
53	89	61	83	79	97	103	101	67	71	73	59
53	83	61	89	79	97	103	101	73	71	67	59
59	89	61	97	83	103	101	107	71	79	73	67
59	89	61	101	79	103	97	107	67	83	73	71
59	101	67	79	83	97	103	107	61	73	89	71
59	101	67	89	73	97	103	107	61	83	79	71
127	163	131	167	157	179	173	181	137	149	151	139
127	167	137	163	151	181	179	173	139	157	149	131
137	167	139	181	173	193	179	191	149	157	163	151
137	149	157	163	191	193	179	173	167	139	181	151
137	149	157	191	163	193	151	173	139	167	181	179
137	149	163	191	157	193	151	167	139	173	181	179
409	421	439	461	443	467	431	449	419	433	463	457
409	419	439	463	443	467	431	449	421	433	461	457
409	421	443	467	433	463	431	449	419	439	457	461
541	563	569	571	601	607	599	587	577	547	593	557
541	557	569	601	577	607	563	587	547	571	599	593
541	563	577	593	571	587	569	599	547	557	601	607
587	607	601	617	641	647	619	631	599	593	643	613
769	787	797	839	823	827	829	853	811	773	809	821

http://mathforum.org/te/exchange/hosted/suzuki/MagicStar.David.Prime.html Go
9 captures
17 Jan 2007 - 12 Jun 2016
DEC JAN JUL
17
2006 2007 2009
About this capture

```
1427 1453 1439 1447 1481 1483 1459 1471 1433 1429 1487 1451
1433 1481 1447 1483 1451 1489 1487 1493 1439 1471 1459 1453
1433 1439 1459 1493 1471 1489 1453 1481 1447 1451 1483 1487
2243 2273 2269 2287 2309 2333 2311 2293 2281 2267 2297 2251
2633 2647 2677 2699 2663 2689 2671 2687 2657 2659 2683 2693
```

Back to **Suzuki's Magic Squares**

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http://mathforum.org/te/exchange/hosted/suzuki/MagicStar.7.html Go
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9 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009
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Mutsumi Suzuki
[Magic Squares]

Magic Stars of Seven Points (38+34=72)

```
                 A

       B      C        D       E


         F                  G             Condition of magic David star

     H                           I

          J                K              A+C+F+H = H+J+L+N = N+K+G+E =

                  L                       E+D+C+B = B+F+J+M = M+L+K+I =

            M              N              I+G+D+A = 30
```

Data;

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	1	10	2	11	7	13	6	14	12	3	9	5	4	8
2	1	5	2	11	12	13	8	14	10	3	4	7	9	6
3	1	10	2	12	6	13	8	14	9	4	11	7	3	5
4	1	5	2	12	11	13	10	14	7	4	6	9	8	3
5	1	6	3	8	13	12	11	14	10	5	4	9	7	2
6	1	9	3	10	8	12	6	14	13	7	11	4	2	5
7	1	6	4	7	13	11	12	14	10	5	3	9	8	2
8	1	7	4	9	10	13	6	12	14	2	3	5	8	11
9	1	9	4	10	7	11	6	14	13	8	12	3	2	5
10	1	2	4	10	14	13	8	12	11	6	3	7	9	5
11	1	14	5	7	4	11	12	13	10	2	8	9	3	6
12	1	12	5	9	4	10	7	14	13	2	8	3	6	11
13	1	10	5	12	3	11	9	13	8	7	14	6	2	4
14	1	4	5	12	9	13	3	11	14	7	8	2	6	10
15	1	3	5	13	9	10	12	14	4	6	7	8	11	2
16	1	7	5	14	4	11	6	13	9	2	8	3	10	12
17	1	7	5	14	4	11	12	13	3	2	8	9	10	6
18	1	2	5	14	9	13	7	11	8	3	4	6	12	10
19	1	4	6	8	12	10	7	13	14	5	2	3	11	9
20	1	3	6	14	7	12	10	11	5	2	4	8	13	9
21	1	5	7	12	6	13	3	9	14	8	10	2	4	11
22	1	6	7	14	3	12	13	10	2	4	9	11	8	5
23	1	5	7	14	4	13	12	9	3	2	6	11	10	8
24	1	4	7	14	5	12	13	10	2	6	9	11	8	3
25	1	4	8	13	5	11	9	10	7	12	14	6	3	2
26	1	3	8	13	6	7	12	14	4	9	10	5	11	2
27	1	5	8	14	3	12	4	9	11	6	10	2	7	13
28	1	5	8	14	3	12	13	9	2	6	10	11	7	4
29	1	2	8	14	6	11	12	10	3	4	5	9	13	7
30	1	6	9	11	4	7	10	13	8	12	14	3	5	2
31	1	5	9	12	4	6	10	14	7	11	13	2	8	3
32	1	5	9	13	3	12	6	8	10	11	14	4	2	7
33	1	3	9	14	4	12	13	8	2	5	7	11	10	6

http://mathforum.org/te/exchange/hosted/suzuki/MagicStar.7.html Go DEC JAN JUL
9 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009
About this capture

38 1 3 11 14 2 13 9 5 6 10 12 8 4 7

and

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	2	6	1	11	12	14	9	13	8	3	5	10	7	4
2	2	9	1	12	8	14	5	13	11	4	10	6	3	7
3	4	6	1	10	13	14	9	11	7	2	3	12	8	5
4	4	9	1	13	7	14	3	11	10	5	12	6	2	8
5	4	7	1	14	8	12	2	13	10	5	11	3	6	9
6	4	7	1	14	8	12	9	13	3	5	11	10	6	2
7	5	8	1	9	12	11	2	13	14	4	6	3	7	10
8	5	8	1	9	12	14	3	10	13	2	4	7	6	11
9	5	7	1	13	9	14	8	10	4	6	11	12	3	2
10	5	8	1	14	7	13	9	11	2	3	10	12	6	4
11	5	7	1	14	8	13	9	11	2	4	10	12	6	3
12	6	14	1	8	7	10	11	13	5	2	9	12	4	3
13	7	13	1	5	11	12	4	10	14	3	6	8	2	9
14	7	11	1	6	12	9	3	13	14	8	10	4	2	5
15	7	11	1	6	12	14	4	8	13	3	5	10	2	9
16	7	10	1	6	13	14	5	8	12	2	3	11	4	9
17	7	11	1	13	5	14	4	8	6	3	12	10	2	9
18	8	14	1	5	10	9	11	12	6	3	7	13	4	2
19	8	13	1	6	10	9	2	12	14	3	7	4	5	11
20	8	10	1	6	13	12	2	9	14	3	4	7	5	11
21	8	10	1	6	13	14	5	7	11	2	3	12	4	9
22	9	14	1	3	12	7	10	13	8	4	6	11	5	2
23	10	14	1	2	13	8	6	11	12	3	4	9	5	7
24	11	14	1	2	13	6	8	12	9	3	4	10	7	5
25	11	14	1	3	12	5	6	13	10	2	4	7	9	8
26	11	14	1	3	12	8	9	10	7	2	4	13	6	5
27	11	14	1	3	12	10	7	8	9	4	6	13	2	5
28	11	14	1	9	6	5	2	13	8	4	12	3	7	10
29	11	14	1	9	6	10	7	8	3	4	12	13	2	5
30	12	14	1	2	13	7	5	10	11	3	4	9	6	8
31	12	14	1	2	13	8	6	9	10	3	4	11	5	7
32	12	14	1	11	4	7	5	10	2	3	13	9	6	8
33	13	14	1	6	9	4	3	12	8	2	7	5	10	11
34	13	14	1	8	7	4	3	12	6	2	9	5	10	11

Back to **Suzuki's Magic Squares**

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http://www.geocities.com/~harveyh/magicstar.htm Go
NOV OCT FEB
20
2005 2006 2007
54 captures
8 Oct 1999 - 24 Nov 2018
About this capture

Magic Stars

I hope you find find this page interesting and informative. I will be adding to it from my notes and future studies as time permits so please come back often.

So far, I have been concentrating mainly on finding the basic solutions for the different orders. There is much left to discover about the characteristics of the individual orders. Share with me the excitement of the search.

If you are also interested in Magic Stars, I would like to hear from you.

March 1, 2005 NEW 4 pages added. See bottom of contents!

Contents

Introduction	A basic **definition** of Magic Stars and the similarity to Magic Squares. Includes a diagram of the 3 Order-9 patterns and shows the order that numbers are assigned to the lines.
Basic and Equivalent Solutions	An explanation of which solutions are considered **basic** and which are **equivalent** solutions. The two requirements for a basic solution and converting an equivalent to a basic solution.
Complements and Index Numbers	Each solution has a **complement**. If the solution is basic the complement is an equivalent and must be normalized to arrive at it's basic solution. Includes a diagram of four Order-6 solutions to illustrate the above.
Examples of Magic Stars	Sixteen different diagrams from Order-5 to Order-11d Also shown is the solution number and the total number of solutions.
Examples of Magic Stars - 2	Sixteen different diagrams from Order-12a to Order-14e. Also shown is the solution number and the estimated total number of solutions.
Big Magic Stars	1 solution for pattern A of orders 15 to 20. Also blank graphs of the other patterns for each order.
A magic Star Definition.	What is a Magic Star? Here is a **formal definition** and an explanation of terms used in my discussion of magic stars. Included also are comparisons between the different orders.
Order-5 Magic Stars	Order-5 is not a pure magic star but there are 12 solutions using numbers 1 to 12 but omitting numbers 7 and 11. Another 12 solutions leave out the 2 and 6.
Order-6 Magic Stars	A list of the 80 basic solutions along with characteristics. 20 sets of 4. Super-magic stars. A tribute to H. E. Dudeney.
Order-7 Magic Stars	General characteristics. Lists of the 72 basic solutions for each of the 2 patterns.
	General characteristics. Lists of the 112 basic solutions for each of the 2 patterns.

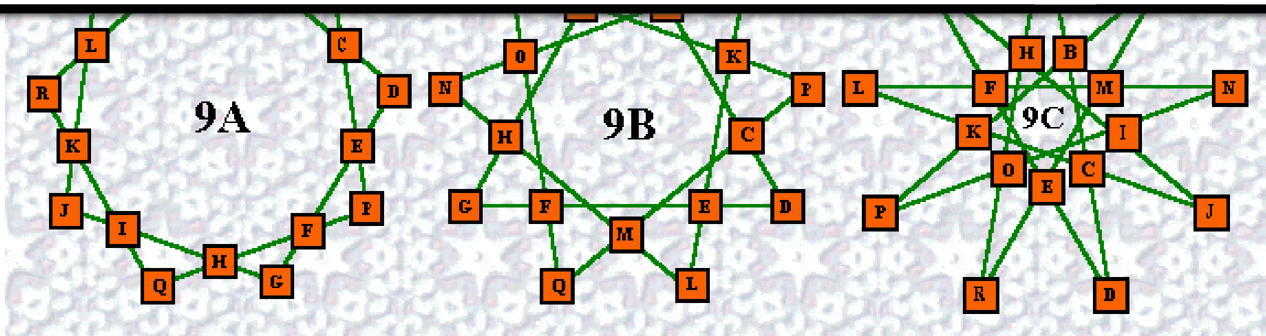
http://www.geocities.com/~harveyh/magicstar.htm Go NOV OCT FEB
54 captures 20
8 Oct 1999 - 24 Nov 2018 2005 2006 2007 About this capture

Order-10 Magic Stars	General characteristics. Condensed lists of basic solutions for each of the 3 patterns.
Order-11 Magic Stars	General characteristics. Condensed lists of basic solutions for each of the 4 patterns.
Prime Magic Stars	Magic Stars consisting of prime numbers. Lists of minimal solutions & consecutive primes solutions for orders 5 and 6.
Prime Magic Stars - 2	Diagrams and lists of minimal solutions & consecutive primes solutions for orders 7 A & B and 8 A & B.
Unusual magic stars	Patterns with combinations of stars or more then 4 numbers per line.
Iso-like magic stars	Stars that are transformations of magic squares. Also plusmagic and diammagic squares.
Trenkler Stars	Marian Trenkler defines stars as of 2 types. He also defines almost-magic & weakly-magic
3-D Magic Stars	This magic 8-point star contains 12 lines of 3 numbers, plus many other lines as a result of the missing numbers of the series forming a nucleus and two satellites.
Books dealing with Magic Stars	There are countless examples of individual magic stars scattered throughout the recreational mathematics literature, but I have only located two sources containing a serious discussion of this subject.
Magic Star Puzzles	Pictures showing star (and other magic object) puzzles. Some quite old. Also, some pencil-and-paper puzzles of magic objects.
Star Updates	This page, started in March, 2005, will contain material added to this site or links to sub-pages of such material.
Simon Whitechapel	Emails starting in 2001. Simon presents solutions for pattern A of magic stars from 15 to 100.
Jon Wharf	Emails starting in 2003. Jon confirms the total solution count for all orders and patterns from 6 to11, and provides the total solution count all order 12 patterns. He also supplies some solutions for all patterns of orders 13 and 14.
Andrew Howroyd	First contacted me in February, 2005. He also confirms all total solution counts and investigated permutations between patterns of orders 10 and 11.

Introduction

Magic stars are similar to Magic Squares in many ways. The order refers to the number of points in the pattern. A standard magic star always contains 4 numbers in each line and in a ***pure magic* star** they consist of the series from **1** to **2*n*** where ***n*** is the order of the star.

http://www.geocities.com/~harveyh/magicstar.htm Go
54 captures
8 Oct 1999 - 24 Nov 2018
NOV OCT FEB
20
2005 2006 2007
About this capture



The diagram above demonstrates also how the numbers are assigned to the cells one line at a time.
Note also, all orders greater then six consist of multiple patterns, each of which consist of a different list of basic solutions. I have found no reference in the literature to this fact

Of course, some star patterns have more then two line crossings (plus the two points) per line. See, for example, orders 9b and 9c above. In these cases, we could assign more then 4 numbers to a line in such a way that all lines sum the same. These too would be magic stars. However, to keep the variations to a manageable number, my studies have been limited to the cases where only the perimeter line junctions (i.e. the points and valleys) have numbers assigned to them.

Pattern naming convention. Originally I had rather arbitrarily assigned names a, b, c, etc to the various patterns of an order of magic star. In January, 2001, Aale de Winkel suggested a systematical way of applying these labels.
Imagine the points of a star diagram as being points on a circle. Then each point in turn is connected by a line to another point, by moving around the circle clockwise. If we step once and connect to the second point, the pattern is called 'A'. Stepping twice, and connecting to the third point, produces pattern 'B'. etc.
Another way to look at this subject:
'A' has 4 intersections per line, 'B' has 6, 'C' has 8, 'D' has 10, and 'E' (required for orders 13 and 14) has 12 intersections per line.

By Feb. 16, 2001, all relevant pages have been revised to show the new pattern names.

Basic & Equivalent Solutions

Each star has solutions that are apparently different but in fact are only rotations and/or reflections of the basic solution. The order-10 star with its 10 degrees of rotational symmetry, each of which may be reflected, has 20 apparently different solutions. Only one of these is considered the *basic solution.*

Two characteristics determine the ***Basic Solution***.

- The top point of the diagram has the lowest value of all the points.
- The valley to the right of the top point has a lower value then that of the valley to the left.

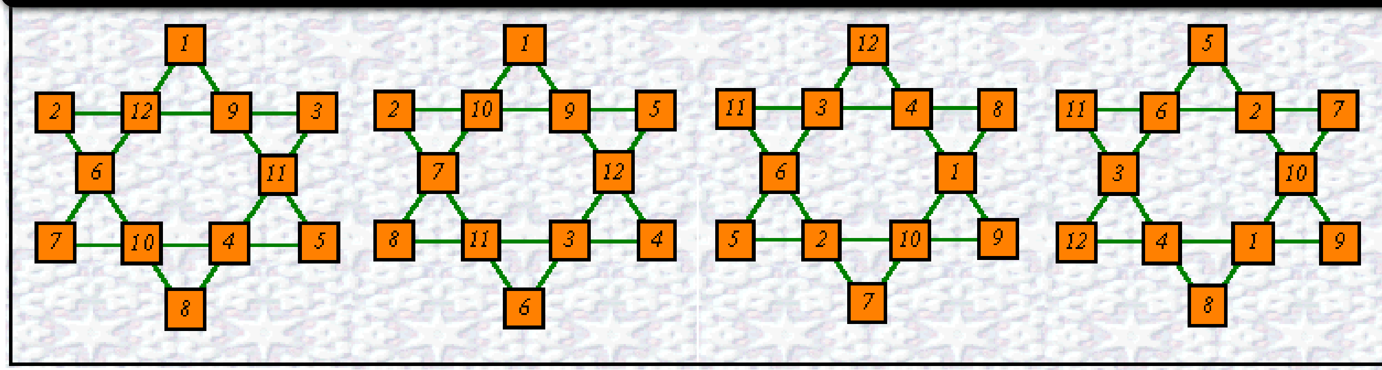
Any magic star solution may be converted to a basic solution by **normalizing** it, i.e. performing the necessary rotations and/or reflections so the solution confirms to the above criteria.

Any magic star can be converted to another magic star by adding or multiplying each number in the star by a constant. This feature also applies to magic squares.
Of course, the resulting star would not be *pure* (*normal*) because the number series would no longer be consecutive.

Top

Complements & Index Numbers

http://www.geocities.com/~harveyh/magicstar.htm Go NOV OCT FEB
54 captures 20
8 Oct 1999 - 24 Nov 2018 2005 2006 2007
About this capture



a. # 38 **b. # 39** **c. complement of # 39** **d. normalized c. = # 78**

Diag-ram	Solut-ion #	a	b	c	d	e	f	g	h	i	j	k	l	Compl. Sol. #	Compl. Pair #	description
a.	38	1	9	11	5	4	10	7	6	12	3	8	2	79	32	How solutions are written
b.	39	1	9	12	4	3	11	8	7	10	5	6	2	78	33	The next solution in index order
c.		12	4	1	9	10	2	5	6	3	8	7	11			Not a basic solution
d.	78	5	2	10	9	1	4	12	3	6	7	8	11	39	33	Diagram c. normalized by rotation 2 positions clockwise, then a horizontal reflection

If the original is a **basic solution**, the complement star will *not* be a basic solution. It is an equivalent, but after normalizing, it will be another basic solution. When enumerating solutions for magic squares, the complements are also counted as basic solutions. We will follow the same convention when counting and indexing the magic star solutions. This means that the number of solutions for each order of magic star must always be an even number and the number of complement pairs is exactly half the number of total solutions. To put it another way, all basic solutions come in pairs which are complements of each other.

The fact that all solutions have a pair partner determine some characteristics for a particular order. For example, if you find a solution with all odd numbers at the points, you can be confident another solution exists that has all even numbers at the points. Likewise, if a solution exists that has all the low numbers at the points, another one exists that has all the high numbers.

The complementing process works for *all* magic squares and *all* magic stars even if the numbers are not consecutive or do not start at 1. In such cases, the complementary number is obtained by subtracting from the sum of the first and last number in the series used. Even prime magic stars have a compliment, although because compliments of many of the prime numbers are not prime numbers, the resulting magic star will not be a prime magic star.

Order-5 magic stars come in pairs where the points of one member appear as the valleys of the other member. I call these pairs **Pcomp** because they are complements of each other, but not in the accepted sense.

Top

References for Magic Stars

Order-6 is the smallest *pure* magic star and the only one with only one star pattern (a fact not mentioned in the literature). In fact, in contrast to the voluminous literature for magic squares spanning 100's of years, there has been very little published on magic stars. The two main sources of information I have been able to locate are:

- H.E.Dudeney, *536 Puzzles & Curious Problems, Scribner's 1967.* Lots of info on order-6.

http://www.geocities.com/~harveyh/magicstar.htm Go NOV OCT FEB
54 captures
8 Oct 1999 - 24 Nov 2018
2005 20 2006 2007
About this capture

Mari�n Trenkler of Safarik University, Kosice, Slovakia published a paper on Magic Stars.
It is called "Magicke hviezdy" (Magic stars) and appeared in Obsory matematiky, fyziky a informatiky, 51(1998), pages 1-7. (Obsory = horizons (or line of sight) of mathematics, physics and informatics.

Magic squares, perhaps because they are quite ordered structures, have been studied for centuries. In contrast, magic stars have few similarities between orders, or for that matter even between patterns within an order. This makes it necessary to study each pattern individually

My studies (so far) include all basic solutions for orders 5 to 11 and most solutions for order-12, a total of 20 patterns. Also, many solutions for each of the 10 patterns of orders 13 and 14.

Here are 16 sample magic stars for all orders and patterns from five to eleven and here are the 14 patterns for orders twelve to fourteen. And here are 6 examples of pattern A stars of orders 15 to 20.
Also, be sure to check out Definitions and Details, and the Order-6 page. Over time, I intend to add more pages, covering details of the different orders, and including lists of solutions. So please check this site periodically.

Top **Please send me Feedback about my Web site!**

Harvey Heinz harveyheinz@shaw.ca
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http://mathforum.org/te/exchange/hosted/suzuki/Polygon.html Go DEC JAN JUN
10 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2008
About this capture

Mutsumi Suzuki
Magic Squares

Magic Polygon

```
Four Triangles;

      1
    5   6
  3   4   2      1 + 6 + 2 = 2 + 4 + 3 = 3 + 5 + 1 = 9


      1
    4   6
  5   2   3


      2
    3   5
  6   1   4


      4
    2   3
  6   1   5



Six Squares ;

  1  8  3
  5     7
  6  4  2


  1  7  5
  4     6
  8  3  2


  1  8  4
  7     3
  5  2  6


  1  6  7
  5     3
  8  2  4


  3  7  4
  6     2
  5  1  8


  3  5  7
  4     2
```

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10 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2008
About this capture

Six Pentagons

```
       1
    9     10
  4         3
   8       6
    2  7  5


       1
    5     8
 10         7
   2       6
    4  9  3


       1
    8     10
  7         5
   6       2
    3  4  9


       1
    6     9
 10         7
   3       2
    4  5  8


       2
    7     9
  8         6
   5       1
    4  3 10


       6
    4     5
  9         8
   3       1
    7  2 10
```

Twenty Hexagons;

```
      1
   7    11
 9         5
 6         8
 2         4
  12    10
      3


      1
   9    11
 7         5
```

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17 Jan 2007 - 21 Jul 2016 About this capture

```
      1
  10    11
 6         5
 4         9
 7         3
   8    12
      2


      1
   7     9
10         8
 3         6
 5         4
  11    12
      2


      1
   6    10
12         8
 2         4
 5         7
  11     9
      3


      1
  10    12
 8         6
 4         2
 7        11
   9     5
      3


      1
   7    10
11         8
 5         2
 3         9
  12     6
      4


      1
  10    11
 8         7
 6         9
 5         3
   2     4
     12


      2
   8    10
 9         7
 6         1
 4        11
```

http://mathforum.org/te/exchange/hosted/suzuki/Polygon.html Go DEC JAN JUN
10 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2008
About this capture

```
      3
   9    12
 7         4
 1        10
11         5
   2     8
      6


      1
   7    11
12         8
 3         2
 5        10
   9     4
      6


      1
   9    11
10         8
 4         7
 6         5
   2     3
     12


      2
   6     8
12        10
 3         1
 5         9
  11     7
      4


      2
  11    12
 7         6
 5         4
 8        10
   3     1
      9


      2
   8    12
10         6
 1         3
 9        11
   7     5
      4


      2
   8    11
10         7
 4         1
 6        12
   9     3
      5
```

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10 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2008
About this capture

```
12          8
 4          2
 5         11
   7      1
      9


      4
   6      7
12         11
 2          1
 8         10
   5      3
      9


      6
   4      9
12          7
 2          5
 8         10
   3      1
     11


      6
   5      9
11          7
 1          3
10         12
   4      2
      8
```

Heptagon   Total number = 118 ;

```
                A
            N       B
        M               C

      L                   D

    K                       E

      J                   F

         I      H      G
```

A	B	C	D	E	F	G	H	I	J	K	L	M	N	A
1	14	4	13	2	10	7	9	3	11	5	8	6	12	1
1	14	4	13	2	12	5	8	6	10	3	9	7	11	1
1	14	4	8	7	9	3	10	6	11	2	12	5	13	1
1	14	4	12	3	9	7	10	2	11	6	8	5	13	1
1	13	5	10	4	8	7	9	3	14	2	11	6	12	1
1	13	5	12	2	14	3	10	6	9	4	8	7	11	1
1	13	5	8	6	9	4	12	3	14	2	10	7	11	1
1	13	5	11	3	14	2	10	7	8	4	9	6	12	1
1	12	6	8	5	10	4	13	2	14	3	9	7	11	1

http://mathforum.org/te/exchange/hosted/suzuki/Polygon.html Go DEC JAN JUN
10 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2008
About this capture

1	14	5	13	2	12	6	4	10	7	3	9	8	11	1
1	13	6	9	5	11	4	14	2	8	10	3	7	12	1
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1	13	6	12	2	14	4	11	5	7	8	3	9	10	1
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2	11	8	10	3	14	4	12	5	9	7	1	13	6	2
2	13	6	12	3	14	4	10	7	5	9	1	11	8	2
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1	14	7	2	13	4	5	6	11	8	3	10	9	12	1
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1	14	7	12	3	10	9	2	11	6	5	4	13	8	1
1	14	7	3	12	6	4	13	5	8	9	2	11	10	1
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2	13	8	11	4	9	10	1	12	5	6	3	14	7	2

http://mathforum.org/te/exchange/hosted/suzuki/Polygon.html Go DEC JAN JUN 17 2006 2007 2008
10 captures
17 Jan 2007 - 21 Jul 2016
About this capture

2	13	8	1	14	3	6	5	12	7	4	9	10	11	2
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2	11	10	5	8	1	14	3	6	13	4	7	12	9	2
2	11	10	7	6	13	4	5	14	1	8	3	12	9	2
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3	11	9	2	12	1	10	8	5	14	4	6	13	7	3
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8	7	11	6	9	5	12	1	13	3	10	2	14	4	8
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8	7	11	1	14	2	10	3	13	4	9	5	12	6	8
8	7	11	5	10	2	14	3	9	4	13	1	12	6	8

total number = 118

Octagon ; Total number = 282 ;

```
                  A
              P       B
          O               C

        N                   D

      M                       E

        L                   F

          K               G
              J       H
                  I
```

http://mathforum.org/te/exchange/hosted/suzuki/Polygon.html Go DEC JAN JUN
10 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2008
About this capture

1	16	5	10	7	11	4	15	3	13	6	14	2	8	12	9	1
1	16	5	9	8	12	2	14	6	13	3	15	4	7	11	10	1
1	15	6	14	2	16	4	11	7	12	3	10	9	5	8	13	1
1	15	6	13	3	10	9	5	8	12	2	16	4	11	7	14	1
1	15	6	13	3	14	5	9	8	12	2	16	4	7	11	10	1
1	15	6	13	3	14	5	10	7	11	4	16	2	8	12	9	1
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http://mathforum.org/te/exchange/hosted/suzuki/Polygon.html Go DEC JAN JUN
10 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2008
About this capture

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http://mathforum.org/te/exchange/hosted/suzuki/Polygon.html Go DEC JAN JUN
10 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2008
About this capture

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http://mathforum.org/te/exchange/hosted/suzuki/Polygon.html Go DEC JAN JUN
10 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2008 About this capture

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http://mathforum.org/te/exchange/hosted/suzuki/Polygon.html Go DEC JAN JUN 17 2006 2007 2008
10 captures
17 Jan 2007 - 21 Jul 2016
About this capture

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 8 12  9  4 16  2 11  3 15  1 13  6 10  5 14  7  8
total number =         282
```

Back to **Suzuki's Magic Squares**

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Please mail comments and suggestions to Suzanne Alejandre.

http://mathforum.org/te/exchange/hosted/suzuki/MagicCube7.html Go DEC JAN JUL
7 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009 About this capture

Mutsumi Suzuki
Magic Squares

7 x 7 x 7 Magic Cube (by Norio Iriyama)

------------ Summary of mail from Norio Iriyama (Jan. 1997) ------------------

Å@ An algorithm of ÇVÇòÇVÇòÇV magic cube
(A method of three dimensional version of the Latin squares)

Features of the method;
(1) Every squares parallel to each surface of the cube is the complete magic squares
(2) Sum of the numbers in four diagonals of the cube are the same as the sum of the rows or columns of the squares.
(3) A fundamental sequence of numbers are repeatedly shifted of rotated in the algorithm.

(step-1) Make a Latin square for the first layer;

(step 1-1) Compose an arbitrary sequence of seven numbers;

```
4 5 6 0 1 2 3  ; The number "3 " must be located at the end position.
```

(step 1-2) Shift the sequence to the right or left by two or three steps.
Stuck the new sequence one by one to create a Latin square.
You can see the "knight-movement" in this Latin square.

```
4 5 6 0 1 2 3

      0 1 2 3 4 5 6

            3 4 5 6 0 1 2

                  6 0 1 2 3 4 5

                        2 3 4 5 6 0 1

                              5 6 0 1 2 3 4

                                    1 2 3 4 5 6 0

      |

      v

4 5 6 0 1 2 3

0 1 2 3 4 5 6

3 4 5 6 0 1 2
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicCube7.html Go DEC JAN JUL
7 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009 About this capture

```
        5 6 0 1 2 3 4

        1 2 3 4 5 6 0


        (Latin square)
```

(step-2) Latin square to a Latin cube;

The number "3" is located at the upper right corner of this Latin square, so, you must repeat two dimensional shift to the left-down (diagonal) direction to obtain six other layers of a cube;

```
   (layer 1)

  4 5 6 0 1 2 3

  0 1 2 3 4 5 6

  3 4 5 6 0 1 2

  6 0 1 2 3 4 5    (layer 2)

  2 3 4 5 6 0 1  ->2 3 4 5 6 0 1

  5 6 0 1 2 3 4    5 6 0 1 2 3 4

  1 2 3 4 5 6 0    1 2 3 4 5 6 0

                   4 5 6 0 1 2 3     (layer 3)

                   0 1 2 3 4 5 6 -> 0 1 2 3 4 5 6

                   3 4 5 6 0 1 2    3 4 5 6 0 1 2

                   6 0 1 2 3 4 5    6 0 1 2 3 4 5

                                    2 3 4 5 6 0 1     (layer 4)

                                    5 6 0 1 2 3 4 -> 5 6 0 1 2 3 4

                                    1 2 3 4 5 6 0    1 2 3 4 5 6 0

                                    4 5 6 0 1 2 3    4 5 6 0 1 2 3

   (layer 5)                                         0 1 2 3 4 5 6

 -> 3 4 5 6 0 1 2                                    3 4 5 6 0 1 2 ->

    6 0 1 2 3 4 5                                    6 0 1 2 3 4 5

    2 3 4 5 6 0 1                                    2 3 4 5 6 0 1
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicCube7.html Go DEC JAN JUL
7 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009
About this capture

```
        4 5 6 0 1 2 3    4 5 6 0 1 2 3

        0 1 2 3 4 5 6    0 1 2 3 4 5 6

                         3 4 5 6 0 1 2     (layer 7)

                         6 0 1 2 3 4 5 -> 6 0 1 2 3 4 5

                         2 3 4 5 6 0 1    2 3 4 5 6 0 1

                         5 6 0 1 2 3 4    5 6 0 1 2 3 4

                                          1 2 3 4 5 6 0

                                          4 5 6 0 1 2 3

                                          0 1 2 3 4 5 6

                                          3 4 5 6 0 1 2
```

The number "3" is located at the center of the cube (center of the fourth layer).
This is a Latin cube (natural extension of the Latin square to the three dimensional cube).

(step-3) Mirror images of the cube (or rotated cube);
If you start from a mirror image of the first layer, you can obtain a mirror image of the cube.

```
Examples of the mirror image of the first layer;


       first layer          mirror image-1      mirror image-2


      4 5 6 0 1 2 3         3 2 1 0 6 5 4       1 2 3 4 5 6 0

      0 1 2 3 4 5 6         6 5 4 3 2 1 0       5 6 0 1 2 3 4

      3 4 5 6 0 1 2         2 1 0 6 5 4 3       2 3 4 5 6 0 1

      6 0 1 2 3 4 5         5 4 3 2 1 0 6       6 0 1 2 3 4 5

      2 3 4 5 6 0 1         1 0 6 5 4 3 2       3 4 5 6 0 1 2

      5 6 0 1 2 3 4         4 3 2 1 0 6 5       0 1 2 3 4 5 6

      1 2 3 4 5 6 0         0 6 5 4 3 2 1       4 5 6 0 1 2 3
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicCube7.html Go DEC JAN JUL
7 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009 About this capture

If you overlap these three squares into one, then the resulted cube will be a natural extension of the Greaco-Latin square into the three dimensional cube, in which all 7x7x7 combination of digits (000-666) appears once in the cube.

```
10 '******************************************************

20 ' 7x7x7 MAGIC CUBE (Prime Order Cube) CONSTRACTION

30 '  (For other prime order cube, rewrite below line #80.)

40 '

50 '   By Norio Iriyama. 1997/1/15

60 '

70 '******************************************************

80 DEFINT A-Z:  N=7  'N=11 or 13 or 17,..Prime number > 6.

90 M=N-1:DIM X(M,M,M),CUBE(M,M,M) ' Array size = N^3

100 '=============== 1line = N numbers ====================

110 FOR I=0 TO M: X(I,0,0)=(I+M/2+1) MOD N: NEXT

120 ' Each number 0 to M must be in X(i,0,0) ;here i=0,..,M.

130 ' X(M,0,0) must be M/2;Others may be in arbitrary order.

140 '=============== 1square = N lines ====================

150 FOR J=1 TO M:FOR I=0 TO M

160   K=(3*J+I) MOD N : X(I,J,0)=X(K,0,0)

170 NEXT:NEXT

180 '=============== 1cube = N squares ====================

190 FOR K=1 TO M:FOR J=0 TO M:FOR I=0 TO M

200   X(I,J,K) = X( (I+1) MOD N, (J+M) MOD N, K-1)

210 NEXT:NEXT:NEXT

220 '============== 3 cube combination  => CUBE(i,j,k) ====

230 FOR K=0 TO M:FOR J=0 TO M:FOR I=0 TO M

240  U=X(I,J,K): V=X(J,I,K): W=X(J,K,I) 'Rotation the cube

250   'Other rotation may be used.

260   ' Ex.  u=x(i,j,k):v=x(m-j,m-i,k):w=x(m-j,m-k,m-i)

270  L=U*N*N+V*N+W+1: CUBE(I,J,K)=L: PRINT USING " ####";L;

280 NEXT:PRINT:NEXT:PRINT:NEXT
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicCube7.html Go DEC JAN JUL
7 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009 About this capture

229	248	316	48	67	135	161
41	60	128	154	222	290	309
196	215	283	302	34	53	121
295	27	95	114	189	208	276
107	182	201	269	337	20	88
262	330	13	81	100	175	243
74	142	168	236	255	323	6

113	188	207	275	301	26	94
268	343	19	87	106	181	200
80	99	174	242	261	336	12
235	254	329	5	73	141	167
47	66	134	160	228	247	322
153	221	289	315	40	59	127
308	33	52	120	195	214	282

4	72	147	166	234	253	328
159	227	246	321	46	65	140
314	39	58	133	152	220	288
126	194	213	281	307	32	51
274	300	25	93	119	187	206
86	112	180	199	267	342	18
241	260	335	11	79	105	173

287	306	31	50	125	193	212
92	118	186	205	280	299	24
198	273	341	17	85	111	179
10	78	104	172	240	266	334
165	233	259	327	3	71	146
320	45	64	139	158	226	252

http://mathforum.org/te/exchange/hosted/suzuki/MagicCube7.html Go DEC JAN JUL
7 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009 About this capture

171	239	265	333	9	84	103
326	2	77	145	164	232	258
138	157	225	251	319	44	70
293	312	37	63	131	150	218
56	124	192	211	286	305	30
204	279	298	23	98	117	185
16	91	110	178	197	272	340

62	130	149	224	292	311	36
217	285	304	29	55	123	191
22	97	116	184	210	278	297
177	203	271	339	15	90	109
332	8	83	102	170	245	264
144	163	238	257	325	1	76
250	318	43	69	137	156	231

338	21	89	108	176	202	270
101	169	244	263	331	14	82
256	324	7	75	143	162	237
68	136	155	230	249	317	49
223	291	310	42	61	129	148
35	54	122	190	216	284	303
183	209	277	296	28	96	115

Norio Iriyama: N.Iriyama@konica.co.jp

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http://mathforum.org/te/exchange/hosted/suzuki/MagicCube7.html Go
DEC JAN JUL
17
2006 2007 2009
7 captures
17 Jan 2007 - 21 Jul 2016
About this capture

http://mathforum.org/te/exchange/hosted/suzuki/MagicCube8.html Go JUN JUL JUN
4 captures 18
18 Jul 2007 - 21 Jul 2016 2006 2007 2013 About this capture

Mutsumi Suzuki
Magic Squares

8 x 8 x 8 Magic Cube (by Charles Hetherington)

```
--------------- Mail from Charles  Hetherington (Aug. 1997)------------------

             Construction of magic cube 8*8*8 using rotation

        ---------------------------------------------------------------------

(This cube will contain the numbers 0 to 511 as it is easier to create this way)


1. Form a square 8*8 as follows:-

        a)  insert digits 0 to 7 in top row (row 1) in any order.

        b)  First four digits are block A, remaining four are block B.

        c)  Form rows 3,5 and 7 as follows:-

                row 3 = block B, block A

                row 5 = block A reversed, block B reversed

                row 7 = block B reversed, block A reversed

        d)  row 2 is formed from row 1 as follows:

                 swap the first two pairs of digits

                 swap the last two pairs of digits

        e)  rows 4,6 and 8 are formed in the same way from rows 3,5 and 7.


Here is a specimen square:       0  6  7  1  5  3  2  4

                                 7  1  0  6  2  4  5  3

                                 5  3  2  4  0  6  7  1

                                 2  4  5  3  7  1  0  6

                                 1  7  6  0  4  2  3  5

                                 6  0  1  7  3  5  4  2

                                 4  2  3  5  1  7  6  0

                                 3  5  4  2  6  0  1  7


2. Form a cube based on your square as follows:-
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicCube8.html Go JUN JUL JUN
4 captures 18 2006 2007 2013
18 Jul 2007 - 21 Jul 2016 About this capture

square, and deriving the top row of each slice from the original square as follows:-

top row of slice 2 = row 3 of slice 1

top row of slice 3 = row 5 of slice 1

top row of slice 4 = row 7 of slice 1

top row of slice 5 = row 4 of slice 1

top row of slice 6 = row 2 of slice 1

top row of slice 7 = row 8 of slice 1

top row of slice 8 = row 6 of slice 1

You should find that you now have a cube in which all lines, diagonals and triagonals contain each of the digits 0 to 7.

3. First rotation:

Keeping slice 1 at the front of the cube rotate the whole cube 90 degrees anti-clockwise. The original cube we will call cube A , the rotated cube we will call cube B. Merge the two cubes to form cube AB, i.e each cell will now contain two numbers, the cube A number followed by the cube B number or vice versa (either way will lead to a successful, though different cube, bu, of course, use the same method throughout the cube!).

You should now find that every slice of your cube in all three dimensions contains all 64 possible combinations of two digits.

Putting cube B numbers before cube A numbers my specimen cube has slice 1 looking like this:

40	36	17	61	55	23	02	74
27	51	70	06	32	44	65	13
35	43	62	14	20	56	77	01
52	24	05	73	47	31	10	66
11	67	46	30	04	72	53	25
76	00	21	57	63	15	34	42
64	12	33	45	71	07	26	50

http://mathforum.org/te/exchange/hosted/suzuki/MagicCube8.html Go JUN JUL JUN
4 captures 18
18 Jul 2007 - 21 Jul 2016 2006 2007 2013 About this capture

4. Second rotation:

Take the original cube, cube A, and rotate it towards you in such a way that the top of the cube now faces you, and slice 1 now forms the base of the cube. We will call this cube in its new orientation cube C. Now merge cube C with cube AB to form the final cube which we will call cube ABC. (Again it does not matter in which position you insert the cube C numbers as long as you are consistent throughout the cube.) You should now find that cube ABC contains all the 512 combinations of three digits.

My specimen cube now has slice 1 looking like this (cube C numbers, then cube B numbers, then cube A numbers):

640	036	117	761	355	523	402	274
327	551	470	206	632	044	165	713
735	143	062	614	220	456	577	301
252	424	505	373	747	131	010	666
411	267	346	530	104	772	653	025
176	700	621	057	463	215	334	542
564	312	233	445	071	607	726	150
003	675	754	122	516	360	241	437

5. Treat the numbers in the cube as octal numbers and convert them into decimal numbers, giving you a magic cube containing the numbers 0 to 511. I find it more satisfying to leave it this way as the system might have some useful applications in computing, since the cube contains only nine-bit numbers, and has the property that in every possible line the first three bits, the middle three bits, and the last three bits are alway in unique combinations. Of course a conventional magic cube can be created by adding 1 to each number.

Postscript: I am not a mathematician by training, and had read no literature on magic squares or cubes before I stumbled on this method of

http://mathforum.org/te/exchange/hosted/suzuki/MagicCube8.html Go
JUN JUL JUN
18
2006 2007 2013
4 captures
18 Jul 2007 - 21 Jul 2016
About this capture

```
welcome comments and a more scientific analysis of the cube.

            Charles  Hetherington.


----------------------  End of Mail ----------------------------------
```

If any questions or comments, please contact direct to him: (E-mail address; HethChas@aol.com)

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5 captures 18 2006 2007 2009
18 Jul 2007 - 21 Jul 2016 About this capture

Mutsumi Suzuki
Magic Squares

Odd Squares by C-Language

I received a mail from "ahmed morsi" which states that:

```
=========== Mail starts ================================
Dear sir,

i just have purchaced a book to teach me the c language,
its an old book called "guide to c programming" by jack purdum,
i have wondered very much about a funtion in a progarm to calculate
the cells, in a matrix to solve an odd magic square,
i will be very thankfull for u if u could decipher the math behind
the magic,

this function calculates the values  to fill in the matrix

arguments list: int row  row to fill in
                int col  col to fill in
                int n    size of matrix
return value :  int      the magic number for this row and col
                         element of matrix
****************************
int term1,term2;
term1=col-row+(n-1)/2;
term2=col+col-row;
if (term1 >=n){
term1m -=n;
}
else {
if (term1 <0){
term1 +=n;
}
}
if (term2 >n){
term2 -=n;
}
else{
if (term2<=0){
term2 +=n;
}
}
return term1*n + term2;
}
i wish i can understand the math of this function ,its looks very elegant ,
so pls help me.
thanks alot.
bye.
==================Mail end==========================
```

It is really elegant!
It is a kind of transformation of coordinates;

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.OddbyC.html Go
JUN JUL JUL
18
2006 2007 2009
5 captures
18 Jul 2007 - 21 Jul 2016
About this capture

1) Prepare an ordinary simple lattice (I,J)

```
          -->J
       1 , 2 , 3
    I  4 , 5 , 6
       7 , 8 , 9
```

The number at the point (I,J) is (I-1)*3 + J
thus N(I,J) = (I-1)*3 + J
2) Rotete this lattice to the right by 45 degree;

```
           __1__
          |4 . 2|
         7|. 5 .|3
          |8_._6|
             9
```

3) Move the external numbers into the opposite space
and you get the magic square.

```
             j
           _____
          |4 9 2|
    i     |3 5 7|
          |8_1_6|
```

The number in a cell (i,j) was come from the original cell (I,J).
I think you can easily create functions I(i,j) and J(i,j) for
this transformation between ordinaly and magic squares.
Then the number of the magic sqaure is calculated by
N(i,j) = N(I(i,j), J(i,j))
In the language above, the following relations was used;
i --> row
j --> collumn
I-1 --> term1
J --> term2

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.byC.html Go JUN JUL JUL
5 captures 18 2006 2007 2009
18 Jul 2007 - 21 Jul 2016 About this capture

Mutsumi Suzuki
[Magic Squares]

C-Language program for 4x4 pan-magic squares

Andre Steenveld sent me a C-coded programm which creates all the 4x4 pan-magic squares.
His programm can be easily changed to any size of magic squares.
I was very impressed by his recursive and backtracking procedures.

You can see more detailed explanation of his recursion method. (.ps file written by himself)

```
<=== C code === cut here and save as victorian.c === C code ===>

/*

 *    sum-it.c   An engrossing Victorian game of patience and skill

 *

 *    by: Andre Steenveld. (a.steenveld@nedernet.nl), 1/1/2001

 *

 *    4th januari 2001.

 *    checking improved by Mutsumi Suzuki on mathematical matters,

 *

 *    It is simple to find all solutions of a 4x4 magic square using

 *    recursive backtracking. On my computer (300MHz pentium ][) it

 *    took about 2 minutes to find all 384 solutions.

 *    It is harder to find one by head!

 *

 *    (It is also easy to change this program for any nxn magic square

 *     or change the restrictions on the square.)

 */


#include < stdio.h >

#include < time.h >


#define bool   int

#define true   1

#define false  0
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.byC.html Go JUN JUL JUL
5 captures 18
18 Jul 2007 - 21 Jul 2016 2006 2007 2009 About this capture

```
bool check34(int a, int b, int c, int d);

bool validboard(void);

void initSumIt(void);

int  place(int s, int p);

void printboard(void);

void stone(int s);


int main(int argc, char** argv)

{

   time_t s, e;


   initSumIt();

   time(&s;);

   stone(16);

   time(&e;);

   printf("started at: %s\n", asctime(localtime(&s;)));

   printf("ended at:   %s\n", asctime(localtime(&e;)));

   printf("run for %.0f seconds.\n", difftime(e, s));

   exit(0);

}


bool check34(int a, int b, int c, int d)

{

   int s;


   s = board[a] + board[b] + board[c] + board[d];

   if ((board[a]==0) || (board[b]==0) || (board[c]==0) || (board[d]==0))

   {

      if (s<34)

      {

         s=34;
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.byC.html Go JUN JUL JUL
5 captures 18 2006 2007 2009
18 Jul 2007 - 21 Jul 2016 About this capture

```
        {
          s=0;
        }
     }
     return(s==34);
}

bool validboard(void)
{
   #define strict_checks          true
   #define exclude_mirrors        false
   #define include_extra_checks   false

   #define check(a,b,c,d) if (ok) ok=(check34(a-1,b-1,c-1,d-1))

   bool ok;

   ok = true;

#if strict_checks
   /* If you use more strict condition;                           */
   /* then you can obtain the most fundamental three squares.     */

   if ((board[0] > 0)&&(board[1] > 0)&&(board[3] > 0)&&(board[4] > 0)&&(board[12] > 0))
   {
      ok =(board[0]==1) &&
          (board[1] < board[3]) &&
          (board[4] < board[12]) &&
          (board[3] < board[12]);
   }
#endif /* strict_checks */

#if exclude_mirrors
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.byC.html Go JUN JUL JUL
5 captures 18
18 Jul 2007 - 21 Jul 2016 2006 2007 2009 About this capture

```
   /* If you use the condition the result may becom 48 (= 384/8). */

   if ((board[0] > 0)&&(board[3] > 0)&&(board[12] > 0)&&(board[15] > 0))
   {
     ok = (board[0] < board[3]) &&
          (board[0] < board[12]) &&
          (board[0] < board[15]) &&
          (board[3] < board[12]);
   }
#endif /* exclude_mirrors */

   /*  1   2   3   4 */
   /*                */
   /*  5   6   7   8 */
   /*                */
   /*  9  10  11  12 */
   /*                */
   /* 13  14  15  16 */

   /* It is OK to check only three of each group of four tests. */
   /* The total som is 4*34 so if three tests succeed the fourth will also! */

   check( 1,  2,  3,  4);
   check( 5,  6,  7,  8);
   check( 9, 10, 11, 12);
   /*check(13, 14, 15, 16);*/

   check( 1,  5,  9, 13);
   check( 2,  6, 10, 14);
   check( 3,  7, 11, 15);
   /*check( 4,  8, 12, 16);*/
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.byC.html Go JUN JUL JUL
5 captures 18 2006 2007 2009
18 Jul 2007 - 21 Jul 2016 About this capture

```
    check( 3,  8,  9, 14);
    /*check( 4,  5, 10, 15);*/

    check( 4,  7, 10, 13);
    check( 1,  8, 11, 14);
    check( 2,  5, 12, 15);
    /*check( 3,  6,  9, 16);*/

    //check( 1,  2,  5,  6);
    //check( 3,  4,  7,  8);
    //check( 9, 10, 13, 14);
    /*check(11, 12, 15, 16);*/

    //check( 6,  7, 10, 11);
    //check( 1,  4, 13, 16);
    //check( 2,  3, 14, 15);
    /*check( 5,  8,  9, 12);*/

    check( 5,  6,  9, 10);
    check( 7,  8, 11, 12);
    check( 1,  2, 13, 14);
    /*check( 3,  4, 15, 16);*/

    check( 2,  3,  6,  7);
    check(10, 11, 14, 15);
    check( 1,  4,  5,  8);
    /*check( 9, 12, 12, 16);*/

#if include_extra_checks
    /* The following checks are, strictly spoken, not needed */
    /* but they will speed up the process remarkably by forcing */
    /* to backtrack in an early stage */
    /* Try it by changing true to false and note the difference! */
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.byC.html Go JUN JUL JUL
5 captures 18 2006 2007 2009
18 Jul 2007 - 21 Jul 2016 About this capture

```
   check( 1,  2,  5,  6);

   check( 3,  4,  7,  8);

   check( 9, 10, 13, 14);

   /*check(11, 12, 15, 16);*/


   check( 6,  7, 10, 11);

   check( 1,  4, 13, 16);

   check( 2,  3, 14, 15);

   /*check( 5,  8,  9, 12);*/

#endif /* include_extra_checks */



   return(ok);

}


void stone(int s)

{

   int p;


   if (s>0)

   {

      for (p=place(s,0); p > 0; p=place(s,p))

      {

         if (validboard()) stone(s-1);

      }

   }

   else

   {

      printboard();

   }

   return;

}
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.byC.html Go
JUN JUL JUL
18
2006 2007 2009
5 captures
18 Jul 2007 - 21 Jul 2016
About this capture

```
{
   int i;

   if (p > 0) board[p-1]=0;
   i = p + 1;
   while ((board[i-1] > 0) && (i < 16)) i++;
   if ((board[i-1]==0) && (i <= 16))
   {
      board[i-1] = s;
   }
   else
   {
      i = 0;
   }
   return(i);
}

void printboard(void)
{
   #define println(r) printf("   %2d %2d %2d %2d\n", board[r*4], board[r*4+1], board[r*4+2], board[r*4+3])

   printf("Solution: %i\n", ++solution);
   println(0);
   println(1);
   println(2);
   println(3);
   printf("\n");
   return;
}

void initSumIt(void)
{
   int i;
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.byC.html Go JUN JUL JUL 18 2006 2007 2009
5 captures
18 Jul 2007 - 21 Jul 2016
About this capture

```
   return;

}


<=== cut and save as victorian.bas ===>


REM

REM   victorian.bas   -   victorian magic square.

REM

REM   by: Andre Steenveld. (a.steenveld@nedernet.nl), 1/1/2001

REM

REM   This code is also available in C.

REM   Mutsumi Suzuki has made remarks on improving the code

REM   His remarks are implemented in the C version only.

REM

REM   All variable names are in dutch ;-)



DEFINT A-Z

DECLARE FUNCTION max0% (s AS INTEGER, l AS INTEGER)

DECLARE FUNCTION check% (s AS INTEGER, l AS INTEGER)

DECLARE FUNCTION geldigbord% ()

DECLARE FUNCTION som% (a AS INTEGER, b AS INTEGER, c AS INTEGER, d AS INTEGER)

DECLARE SUB steen (s AS INTEGER)

DECLARE FUNCTION plaats (s AS INTEGER, p AS INTEGER)

DECLARE SUB init ()

DECLARE SUB printbord ()


   DIM SHARED bord(1 TO 16) AS INTEGER

   DIM SHARED oo AS INTEGER


   init

   steen (16)
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.byC.html Go JUN JUL JUL
5 captures 18
18 Jul 2007 - 21 Jul 2016 2006 2007 2009
About this capture

```
END

FUNCTION check (s AS INTEGER, l AS INTEGER)
   g = 1
   IF l > 0 AND s > 0 THEN
      IF l <> s THEN
         g = 0
      END IF
   END IF
   check = g
END FUNCTION

FUNCTION geldigbord
   g = som(1, 2, 5, 6)
   IF g = 0 THEN GOTO geldigbordexit

   g = som(3, 4, 7, 8)
   IF g = 0 THEN GOTO geldigbordexit

   g = som(9, 10, 13, 14)
   IF g = 0 THEN GOTO geldigbordexit

   g = som(11, 12, 15, 16)
   IF g = 0 THEN GOTO geldigbordexit

   g = som(1, 2, 3, 4)
   IF g = 0 THEN GOTO geldigbordexit

   g = som(5, 6, 7, 8)
   IF g = 0 THEN GOTO geldigbordexit

   g = som(9, 10, 11, 12)
   IF g = 0 THEN GOTO geldigbordexit
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.4x4.byC.html Go JUN JUL JUL 18 2006 2007 2009
5 captures
18 Jul 2007 - 21 Jul 2016
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```
   IF g = 0 THEN GOTO geldigbordexit

   g = som(1, 5, 9, 13)
   IF g = 0 THEN GOTO geldigbordexit

   g = som(2, 6, 10, 14)
   IF g = 0 THEN GOTO geldigbordexit

   g = som(3, 7, 11, 15)
   IF g = 0 THEN GOTO geldigbordexit

   g = som(4, 8, 12, 16)
   IF g = 0 THEN GOTO geldigbordexit

   g = som(1, 6, 11, 16)
   IF g = 0 THEN GOTO geldigbordexit

   g = som(4, 7, 10, 13)
   IF g = 0 THEN GOTO geldigbordexit

geldigbordexit:
   geldigbord = g
END FUNCTION

DEFSNG A-Z
SUB init
   FOR i = 1 TO 16
      bord(i) = 0
   NEXT i
   oplossing = 0
   oo = FREEFILE
   OPEN "sum-it.txt" FOR OUTPUT AS #oo
```

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5 captures 18
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```
DEFINT A-Z

FUNCTION plaats (s AS INTEGER, p AS INTEGER)

   IF p > 0 THEN bord(p) = 0

   IF p < 16 THEN

      i = p + 1

      DO WHILE bord(i) > 0 AND i < 16

         i = i + 1

      LOOP

      IF bord(i) > 0 THEN

         i = 0

      ELSE

         bord(i) = s

      END IF

   ELSE

      i = 0

   END IF

   plaats = i

END FUNCTION


DEFSNG A-Z

SUB printbord

   SHARED oplossing AS INTEGER

   oplossing = oplossing + 1

   PRINT "Oplossing:"; oplossing; TIME$

   PRINT #oo, "Oplossing:"; oplossing

   FOR i = 1 TO 16

      IF bord(i) < 10 THEN

         PRINT " ";

         PRINT #oo, " ";

      END IF

      PRINT bord(i);

      PRINT #oo, bord(i);

      IF i MOD 4 = 0 THEN
```

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5 captures 18
18 Jul 2007 - 21 Jul 2016 2006 2007 2009 About this capture

```
      END IF

   NEXT i

   PRINT

   PRINT #oo,

END SUB


DEFINT A-Z

FUNCTION som (a AS INTEGER, b AS INTEGER, c AS INTEGER, d AS INTEGER)

   s = bord(a) + bord(b) + bord(c) + bord(d)

   IF s < 34 AND (bord(a) = 0 OR bord(b) = 0 OR bord(c) = 0 OR bord(d) = 0) THEN

      s = 34

   END IF


   IF s = 34 THEN

      som = 1

   ELSE

      som = 0

   END IF

END FUNCTION


SUB steen (s AS INTEGER)

  IF s = 0 THEN

      printbord

   ELSE

      p = plaats(s, 0)

      DO WHILE p > 0

         IF geldigbord = 1 THEN steen (s - 1)

         p = plaats(s, p)

      LOOP

   END IF

END SUB
```

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Mutsumi Suzuki
Magic Squares

Algorithm of Even Order Magic Squares

Since 1990, we are enjoying chatters on a LAN of our University every day and night about various categories from Animation to Zionism. Magic Square was one of the pleasant problem in a mathematical category. The followings are some comments written on the category by Mr. Mitsuhiro Matsumoto who was an undergraduate student of Dept. Electric Engineering at that time (1990).

```
From: m.matsumoto@tainsbbms
Newsgroups: mathematics
```

1) First step; Let us consider an auxiliary matrix;

```
 4m order      4m+2 order

 1 2 3 4       1 2 3 4 5 6
 4 3 2 1       6 5 4 3 2 1
 4 3 2 1       1 2 3 4 5 6
 1 2 3 4       1 2 3 4 5 6
               6 5 4 3 2 1
               1 2 3 4 5 6
```

The sum of every row and column are the same for the 4m order matrix.
In the 4m+2 order matrix, however, sums are not the same. So, you modifies the matrix by exchanging some pair of numbers, such as 1-6 ,2-5 and 3-4.
If you exchange the numbers in the 6-th row, you get

```
    1 2 3 4 5 6
    6 5 4 3 2 1
    1 2 3 4 5 6
    1 2 3 4 5 6
    6 5 4 3 2 1
    6 5 4 3 2 1
```

2) Second step ; Modify diagonal numbers as;

```
 1 2 3 4 5 6        1 5 3 4 2 6
 6 5 4 3 2 1        6 5 4 3 2 1
 6 5 3 4 2 1   or   6 2 4 3 5 1
 1 2 3 4 5 6        1 2 4 3 5 6
 6 5 4 3 2 1        6 5 3 4 2 1
 1 2 4 3 5 6        1 2 3 4 5 6
```

3) Third step; Let denote this auxiliary matrix as A, then the magic square B of order N=4m or 4m+2 can be derived by

b_i,j = a_i,j + N (a_j,i - 1)

```
------------(end)-------------------------
```

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7 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009 About this capture

```
 1 2 3 4 5 6     1 5 3 4 2 6
 6 5 4 3 2 1     6 5 4 3 2 1
 6 5 3 4 2 1  or 6 2 4 3 5 1
 1 2 3 4 5 6     1 2 4 3 5 6
 6 5 4 3 2 1     6 5 3 4 2 1
 1 2 4 3 5 6     1 2 3 4 5 6
```

You can make the transpose A' by exchangeing the rows and columns as;
(a_ij ---> a_ji)

```
 1 6 6 1 6 1     1 6 6 1 6 1
 2 5 5 2 5 2     5 5 2 2 5 2
 3 4 3 3 4 4  or 3 4 4 4 3 3
 4 3 4 4 3 3     4 3 3 3 4 4
 5 2 2 5 2 5     2 2 5 5 2 5
 6 1 1 6 1 6     6 1 1 6 1 6
```

Then make (A'- 1) as;

```
 0 5 5 0 5 0     0 5 5 0 5 0
 1 4 4 1 4 1     4 4 1 1 4 1
 2 3 2 2 3 3  or 2 3 3 3 2 2
 3 2 3 3 2 2     3 2 2 2 3 3
 4 1 1 4 1 4     1 1 4 4 1 4
 5 0 0 5 0 5     5 0 0 5 0 5
```

Multiplying by 6, you get

```
 0 30 30  0 30  0     0 30 30  0 30  0
 6 24 24  6 24  6    24 24  6  6 24  6
12 18 12 12 18 18    12 18 18 18 12 12
18 12 18 18 12 12    18 12 12 12 18 18
24  6  6 24  6 24     6  6 24 24  6 24
30  0  0 30  0 30    30  0  0 30  0 30
```

You can get a magic square B by adding the matrix A on the above matrix.
I think you can undrstand that the above procedures can be written in the single formula as;

b_i,j = a_i,j + N (a_j,i - 1)

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6 Dec 1998 - 9 Mar 2008 2005 2007 2008
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Magic Squares and Cubes

In 1985, while between University and work, I was given "The Wonders of Magic Squares" by Jim Moran and published by Vintage Books which made a lot of the difficulty of making 6 by 6 magic squares.
I found quite a simple method of making even order magic squares and cubes, which I tried to send to the author via his publishers (it came back saying undeliverable) and to a couple of magazines who weren't interested.
I was reminded of it by a post to rec.puzzles and have put a description of it here .

My Self Referential Sentence

Someone brought "Metamagical Themas" by Douglas Hofstadter to work. It had examples of self referential sentences in it, and I decided to make my own.

This is a sentence which has been found by Adrian Smith using his personal computer, a bit of programming and exactly eleven a's, four b's, five c's, five d's, thirty eight e's, ten f's, six g's, thirteen h's, twenty six i's, six l's, five m's, twenty six n's, eleven o's, four p's, fourteen r's, thirty nine s's, twenty six t's, seven u's, nine v's, five w's, seven x's, eight y's and no other letters.

http://user.chollian.net/~brainstm/MagicSquare.htm Go
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15 Jan 2000 - 1 Oct 2015
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01
2000 2001 2002
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The Perfect Solution For the MAGIC - SQUARE

. ...KOREAN(ÇÑ±¹¾î·Î)... . Failed to open configuration file: "/usr2/ns-home/docs/wwwcount2.2/conf/ccc.conf"

Since July 1997

-- Yes, you can make all Magic Squares !! --

Stories

- **History of Magic Square**
  Suzanne Alejandre's Lo Shu Magic Square homepage shows a detail legend of Lo Shu in China. Magic squares have been around for over 3,000 years..

- **What's a Magic Square?**
  The following definition is a quote from Allan Adler's What is a Magic Square? homepage.

  A magic square is an arrangement of the numbers from **1** to **n^2** (n-squared) in an **n**x**n** matrix, with each number occurring exactly once, and such that the sum of the entries of any row, any column, or any main diagonal is the same. It is not hard to show that this sum must be **n(n^2+1)/2.**

- **What I'm saying is.. .**
  When I was young I saw a 3x3 magic square. It was just a kind of puzzle for me. As time passed, I saw the solution for magic squares of odd-series and some multiples of four, and I changed my mind. I started to find out the solution for all numbers. I tried to look for any books written on magic squares, but I could not find a regular solution for n=6,10,14,.. at anywhere. Even somebody said 'It's an unsolved mystery'. But, I found out the principle of constructing squares for other sizes and checked that sums are correct by using a computer. Perhaps a man I don't know has already solved this mystery. I hope that more information and news are exchanged at this site. Anyway, I am content to have solved it by myself. Now, the magic square is no more an unsolved mystery. What I'm saying here is "**It's Not Impossible!!**".

Solutions for the 3 types of Magic Square

If you remember solutions down here, You can construct any magic square(n>2).

- **The odd number series**(n=3,5,7,9,...)
  This solution that I'm going to demonstrate is just one of the common things that many people know.

- **A multiple of 4 series**(n=4,8,12,...)
  This solution is known, also. I have another method that is more simple and general, because this idea applies to the solution of the other sizes(n=6,10,...) more easily than other methods

http://user.chollian.net/~brainstm/MagicSquare.htm Go JUN DEC FEB
145 captures 01
15 Jan 2000 - 1 Oct 2015 2000 2001 2002 About this capture

- **One more solution of The other sizes series**
  Cheerio, GijsjebertiX introduces the solution.

Even though I don't explain the principle in detail, You can understand the idea well enough. If you have comments and suggestions, please mail to *Kwon Young Shin*.

Samples

- **The source program** in C-language
  This is a source program that I compiled and checked the Magic Squares using turbo-c 2.0 on PC. If you change some source code, You can create more magic squares even on other computers.

- **Magic Square samples**(n=11,12,14,16,18,22,26,30)

Other Magic Square links

- Mutsumi Suzuki's Magic Square Page

- Suzanne Alejandre's Magic Square Page

Back to Shin's homepage.

Thanks to Julianna Oh for helping me.

Shin, Kwon Young - brainstm@chollian.net
Last Update : 24 Jan 1998

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25 Jul 2003 - 2 May 2019
JUN DEC JAN
2007 08 2010
2008
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Grogono Magic Squares Home Page

Revision: Features in Recent Revisions

Same Author: Acid-Base Animated Knots Stereo Art

Home Page
Make Your Own
Choose by Size
How Many?
The Formula
Magic Carpets
Analysis
Magic Cubes
History
References
Contact
Downloads
Links
Glossary
Grogono Home

Introduction.

A Magic square is intriguing; its complexity challenges the mind. For order 4 and above the number of different magic squares is astonishing - and the number remains large even if we limit consideration to Pan-Magic squares. This website reflects my own fascination with these large numbers and presents techniques aimed at explaining and reducing the huge numbers by showing how this abundance can be reduced to a small number of underlying patterns or Magic Carpets.

Recent Addition

Do it yourself! Make your own magic square of any size up to 97x97.

Discoveries.

The development of this website was associated with several intriguing discoveries. Please look at the pages for the Order 4, Order 5, Order 6 magic squares.

Dedication.

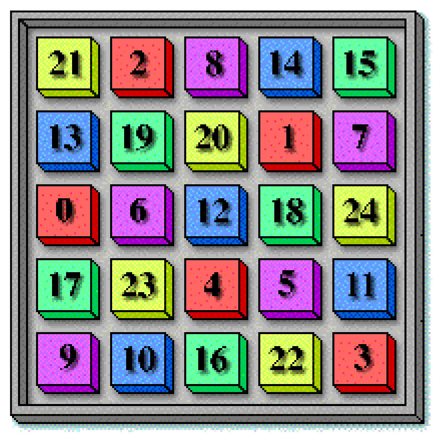
This Magic Square website is dedicated to my father E.B. Grogono (1909 - 1999) and was originally created at his bedside during his last illness. My fondest memories of him, from my earliest childhood to the final days of his life, center on his ability to transmit his love for, and fascination with, mathematics and science.

Revision

This revision uses up to date technology to make the website easier to manage and the material has been re-arranged to make it more accessible. A glossary has been added and the index system has been revised.

Now, Belatedly, Welcome!

Visit, play, learn about Magic Squares and Magic Carpets, make your Own Magic squares, and explore the techniques devised to understand pan-magic squares.



Glossary

If you want to check on the meaning of the terms used on this website, please review the Glossary

Pan-Magic Squares.

The Main focus of this website is Pan-Magic squares where even the broken diagonals add up to the Magic Sum, e.g., 60 in the square above (diagonal 13, 2, 16, 5, 24). Pan-magic squares have also been called Pan-Diagonal and Nasik.

Why start Magic Squares using zero?

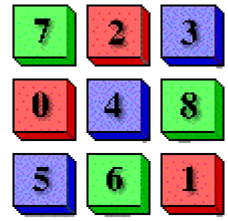
A glib answer might be because I like to and this is my site. A mathematical answer is that analysis (and construction) of magic squares is more logical, and the results easier to analyze, when the smallest number is 0. This is particularly true when the Magic Carpet approach is used to analyze or construct a magic square, e.g., to construct an order four magic square, four magic carpets would be required using: 8 & 0; 4 & 0; 2 & 0; and 1 & 0.

- **Traditional Magic Squares**, start at one, probably because magic squares were discovered first and analyzed later. Early counting systems didn't include either zero or negative numbers, so number one must have seemed a pretty good starting place.

http://www.grogono.com/magic/index.php Go JUN DEC JAN
171 captures 08
25 Jul 2003 - 2 May 2019 2007 2008 2010 About this capture

I am frequently asked to provide the Formula for Magic Squares. At the risk of spoiling some teacher's classwork assignments I have worked out a satisfactory answer and have devoted a page to this topic. (Thank you Danny Lawrence for making me do this and for sitting with me while I worked it out.) Two formulae are included, one for the prime-number orders, e.g., 5, 7, 11, 13, etc., and one for an order 4 square.

How Many Squares?



My fascination with magic squares grew from experimental attempts to count the total number of possible squares when squares which, apparently different, were really identical when appropriately reflected or rotated. A separate page lists the Number of Pan-Magic Squares for the Prime Number Order squares.

Unique Identifiers.

The process of counting and comparing regular panmagic squares generated a need to identify squares to facilitate ranking and comparison. Out of this grew a scoring system to uniquely identify any order 4 or order 5 pan-magic square.

The method I developed assigns a Unique Identifier to each square and is applicable to regular panmagic squares of orders 4 and 5. It depends on summing defined cells which have been multiplied by successively higher powers of the square's order. Although the technique could be extended to larger squares, the length of the expression, and the resulting magnitude of the numbers, makes it too unwieldy.

By the Same Author

If you have found this website useful, you are invited to visit one of my other teaching sites.

Two of these other sites are mounted on my main website but all three are treated as an independent website:

- **Acid-Base Tutorial**

  This website is aimed at physicians, physiologists, medical students, nurses, and other health care professionals. The Tutorial includes interactive diagrams and equations to make the material more interesting and more readily understood.

- **Animated Knots**

  This website is aimed at yachtsmen, scouts, climbers, fishermen and anyone else who needs to know how to tie Practical Safe Knots. Each animated knot "ties itself" automatically and can also be "tied" and "untied" slowly to reveal its structure.

- **Stereo Art**

  This website demonstrates how a vivid three-dimensional stereo image is created from a repeated stereo image pair. A collection of Stereo Art Images illustrates the technique.

Size: Index | 3x3 | 4x4 | 5x5 | 6x6 | 7x7 | 8x8 | 9x9 | 10x10 | 11x11 | 12x12 | 13x13

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.alg.pan.html Go DEC JAN JUL
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17 Jan 2007 - 20 Jul 2016 2006 2007 2009 About this capture

Mutsumi Suzuki
Magic Squares

Algorithm of Pan Magic Squares

The followings are notes on a LAN in Tohoku University written by Mr. Mitsuhiro Matsumoto who was an undergraduate student of Dept. Electric Engineering at that time (1990).

```
From: m.matsumoto@tainsbbms
Newsgroups: mathematics
Subject: Pan-Magic Square of odd order
```

Well... It is said that there are so called pan-magic squares. In the squares, the sum of the numbers are the same, not only in the majaor diagonals but also in any pan-diagonals. If you can not understand, perdon me and please see the followiong example.

```
  * . . . .      . * . . .      . . * . .
  . * . . .      . . * . .      . . . * .
  . . * . .      . . . * .      . . . . *
  . . . * .      . . . . *      * . . . .
  . . . . *      * . . . .      . * . . .

major diagonal        man-diagonals
```

We use two auxiliary matrices A and B.
Examples for 5 order are;

Matrix A;

```
  1  2  3  4  5
  4  5  1  2  3
  2  3  4  5  1
  5  1  2  3  4
  3  4  5  1  2
```

In which the number "1" moves like a Knight.

Matrix B;

```
  0 15  5 20 10
  5 20 10  0 15
 10  0 15  5 20
 15  5 20 10  0
 20 10  0 15  5
```

In which the number "0" moves as Knight.

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.alg.pan.html Go DEC JAN JUL
7 captures 17
17 Jan 2007 - 20 Jul 2016 2006 2007 2009
About this capture

```
 9 25 11  2 18
12  3 19 10 21
20  6 22 13  4
23 14  5 16  7
```

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Mutsumi Suzuki
Magic Squares

Algorithm for an 8 x 8 Magic Square

The following was a summary of broadecasted topic in a TV-News-Shaw ("News Station") entitled as "A mistery of the 100 Poem by 100 Poet" in 1994.

(How to make 8x8 magic square)
At first, arrange the sequential numbers 1, 2, 3, ... 62, 63, 64 in 8x8 square as ;

```
 1  2  3  4  5  6  7  8
 9 10 11 12 13 14 15 16
.....
.....
.....

57 58 59 60 61 62 63 64
```

Then, delete some numbers (four numbers from each row) from the matrix as shown as;

```
 1  *  *  4  5  *  *  8
 * 10 11  *  * 14 15  *
 * 18 19  *  * 22 23  *
25  *  * 28 29  *  * 32
33  *  * 36 37  *  * 40
 * 42 43  *  * 46 47  *
 * 50 51  *  * 54 55  *
57  *  * 60 61  *  * 64
```

Let us call this matrix as Rest-Matrix.
The matrix of the deleted numbers bcomes;

```
---------------------
    2  3        6  7
 9        12 13       16
17        20 21       24
...26 27  ...    ...
...
...
   58 59       62 63
----------------------
```

If you rotate this matrix 180 degree, then you get Rotated-Matrix as ;

```
----------------------
   63 62       59 58
....
....
24        21 20       17
16        13 12        9
    7  6        3  2
---------------------
```

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.8x8.html Go DEC JAN JUN
6 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2013
About this capture

mathematical reason afterwards.

Deleted numbers (2,3,6,7,,,62,63) can be rewritten in another form as; (65-63,65-62,65-59, ,,, 65-7,65-6,65-3,65-2).
Then the combined matirices bcomes as;

```
   1 ,  65-2 ,  65-3 ,     4 ,   5 ,  65-6 ,  65-7 , 8
65- 9,     10,     11, 65-12 , ...
65-17,     18,  ...
   25,  65-26,  ...
   ...    ...   ...
   ...                              65-62,  65-63 ,64
```

In this matrix, the sum of every quadruplet in row and column is always 130(=65+65).
For examples;

```
1 + (65-2) + (65-3) + 4 = 130
5 + (65-6) + (65-7) + 8 = 130
     ...
1 + (65-9) + (65-17)+25 = 130
     ...
```

In general, a series of number (i , j , k , L) satisfies the relation ;
(i + L) -(j + k) = 0
thus the sum of quadruple becoms;
i + (65-j) + (65-k) + L = 130
or
(65-i) + j + k + (65-L) = 130

---- ---- ---- ---- ---- ---- ---- ----
(How to make a 10x10 magic square)
If you use a series of number (19,20,21, ... , 80, 81, 82) instead of (1, 2, 3,... ,64), you can obtaine another magic square.
You can arrange the rest numbers (1, 2, ... 18, 83, 84, ... , 100) around the square (by trial and error method) and construct a 10x10 magic square.

---- ---- ---- ---- ---- ---- ---- ----
The TV News Shaw continued to discuss about the arrangement of the 100 poems in the same order as the magic square. However, I could not follow his story because I was strongly shocked by the method of creating magic squares and also because of my lack of a sense of poetry.

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17
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http://www.grogono.com/magic/index.php Go
171 captures
25 Jul 2003 - 2 May 2019
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Grogono Magic Squares Home Page

Revision: Features in Recent Revisions

Same Author: Acid-Base Animated Knots Stereo Art

Home Page
Make Your Own
Choose by Size
How Many?
The Formula
Magic Carpets
Analysis
Magic Cubes
History
References
Contact
Downloads
Links
Glossary
Grogono Home

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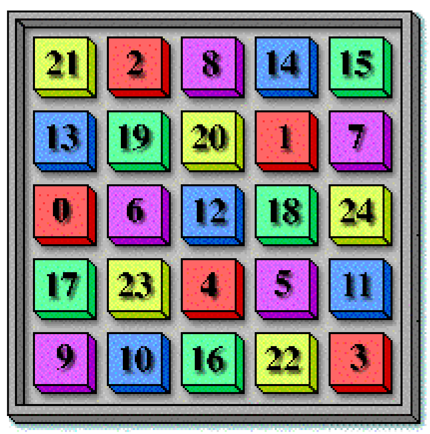

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Why start Magic Squares using zero?

A glib answer might be because I like to and this is my site. A mathematical answer is that analysis (and construction) of magic squares is more logical, and the results easier to analyze, when the smallest number is 0. This is particularly true when the Magic Carpet approach is used to analyze or construct a magic square, e.g., to construct an order four magic square, four magic carpets would be required using: 8 & 0; 4 & 0; 2 & 0; and 1 & 0.

- **Traditional Magic Squares**, start at one, probably because magic squares were discovered first and analyzed later. Early counting systems didn't include either zero or negative numbers, so number one must have seemed a pretty good starting place.

http://www.grogono.com/magic/index.php Go DEC JAN MAR
171 captures 17
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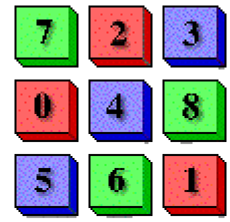
I am frequently asked to provide the Formula for Magic Squares. At the risk of spoiling some teacher's classwork assignments I have worked out a satisfactory answer and have devoted a page to this topic. (Thank you Danny Lawrence for making me do this and for sitting with me while I worked it out.) Two formulae are included, one for the prime-number orders, e.g., 5, 7, 11, 13, etc., and one for an order 4 square.



How Many Squares?

My fascination with magic squares grew from experimental attempts to count the total number of possible squares when squares which, apparently different, were really identical when appropriately reflected or rotated. A separate page lists the Number of Pan-Magic Squares for the Prime Number Order squares.

Unique Identifiers.

The process of counting and comparing regular panmagic squares generated a need to identify squares to facilitate ranking and comparison. Out of this grew a scoring system to uniquely identify any order 4 or order 5 pan-magic square.

The method I developed assigns a Unique Identifier to each square and is applicable to regular panmagic squares of orders 4 and 5. It depends on summing defined cells which have been multiplied by successively higher powers of the square's order. Although the technique could be extended to larger squares, the length of the expression, and the resulting magnitude of the numbers, makes it too unwieldy.

By the Same Author

If you have found this website useful, you are invited to visit my one of my other teaching sites.

Two of these other sites are mounted on my main website but all three are treated as an independent website:

- **Acid-Base Tutorial**

  This website is aimed at physicians, physiologists, medical students, nurses, and other health care professionals. The Tutorial includes interactive diagrams and equations to make the material more interesting and more readily understood.

- **Animated Knots**

  This website is aimed at yachtsmen, scouts, climbers, fishermen and anyone else who needs to know how to tie Practical Safe Knots. Each animated knot "ties itself" automatically and can also be "tied" and "untied" slowly to reveal its structure.

- **Stereo Art**

  This website demonstrates how a vivid three-dimensional stereo image is created from a repeated stereo image pair. A collection of Stereo Art Images illustrates the technique.

Size: Index | 3x3 | 4x4 | 5x5 | 6x6 | 7x7 | 8x8 | 9x9 | 10x10 | 11x11 | 12x12 | 13x13

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http://mathforum.org/te/exchange/hosted/suzuki/Vincent.html Go
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Mutsumi Suzuki
Magic Squares

Vincenzo Librandi's method for sequential primes<

Vincenzo Librandi wrote to me a new method of constructing magic squares by sequential primes.

He used a representaion of primes;

Prime number = A + 2 k

where A is odd number and k is integer. For example, A=3 and k={0,1,2,4,5,7,8,10,13,, } yield prime sequence {3,5,7,11,13,,17,19,23,,,}

He constructed a magic square by using the set k. He, then, transform the numbers in the the square to primes by the above equation. The result is a magic square of primes.

The integer set k is closely related to the Librandi's triangle A(m,n) = 2 m n + m + n - 1 which is a kind of Eratosthnes' sieve.

The following is his mail on Nov. 25, 1999.

```
Ciao, Mutsumi Suzuki

Data la matrice triangolare LIbrandi definita da
A(m,n)=2mn+m+n-1
3
6     11
9     16     23
12   21     30     39
15   26     37     48     59
= = = = = = = = = = = =  =
Detto k un elemento che non appartiene al
triangolo Librandi cosÏ ottenuto
si ha, per ogni k,  che 2k+3 = p (con p= primo)

Ho costruito, cosÏ i  Quadrati Magici che sono
stati
ottenuti proprio utilizzando i k che non
appartengono al TdL.
7   38  49   20   35
5   55  43   29   17
53   8  19   22   47
52  34  25   28   10
32  14  13   50   40

la cui somma delle righe, delle colonne e delle
diagonali Ë 149. I k utilizzati vanno da 5 a 53.
Rispetto al quadrato magico di Gakuho Abe

17   79 101  43  73
13  113  89  61  37
109  19  41  47  97
```

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6 captures
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19
2006 2007 2009
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possono utilizzare elementi pi facilmente
trattabili.

Seguendo la stessa via, il matematico Akio Suzuki ha composto, con i Numeri Primi, Quadrati magici 6*6 (utilizzando i k che non appartengono al TdL che vanno da 2 a 82); 7*7 (con i k che vanno da 2 a 118); 8*8 (con i k che vanno da 38 a 218); 9*9 (con i k che vanno da 17 a 238) e cosÏ via, che sfruttando
gli elementi K che non appartengono al TdL si ha:
Quadrato Magico 6*6

82	17	62	4	49	19
22	34	77	47	40	13
2	10	7	74	67	73
50	64	20	32	29	38
25	28	14	68	43	55
52	80	53	8	5	35

che Ë equivalente a quello di Akio Suzuki formato dai primi

167	37	127	11	101	41
47	71	157	97	83	29
7	23	17	151	137	149
103	131	43	67	61	79
53	59	31	139	89	113
107	163	109	19	13	73

e cosÏ per tutti gli altri Quadrati Magici.

Ciao Vincenzo Librandi

Back to **Suzuki's Magic Squares**

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Please mail comments and suggestions to Suzanne Alejandre.

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Mutsumi Suzuki
Magic Squares

Total Number of the 5x5 Magic Squares

There are too many magic squares of 5 order. So, let us examine one example.

```
  2 25 24  1 13
 11  9 10 18 17
 22 20 12  6  5
 16  8 15 19  7
 14  3  4 21 23
```

The first column is (2, 25, 24, 1, 13). It can be represented by a set of integer by negelecting the order of the number as;
R_1 = {1,2,13,24,25}.
Where, "R" means a row. In the same manner you can write as ;

R_2={9,10,11,17,18}
R_3={5,6,12,20,22}
R_4={7,8,15,16,19}
R_5={3,4,14,21,23}

Mathematical properties of these sets are;

(1) In each set, the number sums up to 65.
(2) The set does not overlap each other. Mathematically, you can write;
R_i AND R_j = { } (empty set) ,

You can write for the column in the same manner as;

C_1={2,11,14,16,22}
C_2={3,8,9,20,25}
C_3={4,10,12,1524}
C_4={1,6,18,19,21}
C_5={5,7,13,17,23}

The same properties as the row set are valid in the column set.
The third property between these sets is;

(3) Row and column sets overlaps by only one number. For exapmles;
R_1 AND C_1 = {11} .

You can get two diagonal sets;

D_1={2,9,12,19,23}
D_2={8,12,13,14,18}

In which the number sums up to 65 and

(4) Two diagonal sets overlap by one number (in this odd-order magic square). In this

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17 Jan 2007 - 21 Jul 2016 2006 2007 2013 About this capture

(3) The diagonal set overlaps by one numbere to the row or column set.

Thus, the problem of construction of magic square is translated to the searching problem of the sets each of which satisfies above conditions.

It yields the next problems. How do you select a set ? How many set are there ? How do you list them up? ...
You can easily list up the set by a systematic manner. The following list is in so-called a dictionary order.

{1,2,13,24,25}
{1,2,14,23,25}
{1,2,15,22,25}
{1,2,15,23,24}
...
...

{11,12,13,14,15}

Total number of the set is found to be 1394.

By the way,the magic square examined above is selected as an example for the first set. The next magic square corresponds to the last set (see the last column), and also to the first set (see the first row) simaltaneously;

```
  1  2 24 25 13
 23 21  3  4 14
 17  5 22  6 15
 16 18  9 10 12
  8 19  7 20 11
```

If you select twelve sets (5 row-, 5 column- and 2 diagonal-sets) which satisfy the above conditions, then you must check whether you can construct a magic square or not. Impossibility of the construction is often caused by the conditions for the diagonal set.

If you get a magic square by this method, then you can derive another square by row-column excahnge method.
If you exchange first row and fifth row, and then first column and fifth column, you can get another new magic square. Let us call the procedure by 1-5 exchange.
By the same manner, 1-2 and 4-5 exchange yields the other square. Let us call it 1-2-4-5 exchange. You can define the other exchange procedures, however it does not produce new squares. For example, 2-3 exchange is equivalent to the 1-5 exchange and 1-3-2-5 exchange is to 1-2-4-5.

Thus one combination of twelve set yields four magic squares.

There is another exchange method , complemental transform. If you exchage every number N in a magic square by 26-N (1 -> 25 , 2 -> 24 ,3->23 , ... , 25 -> 1), you get

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6 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2013 About this capture

This complemental transform is introduced in order to reduce the search area of the set.

It was found that the number of the self-complemental conbination set was 42817, and non-self-complemental was 18981219.
Thus the total number of the 5x5 magic square was found to be

18981219 x 8 + 42817 x 4 = 152021020

I have no self confidence to the result, because different number 275305224 was reported by Mr. M.Matsumoto. So, I would like to calculate again someday(but not immediately).

It took two months for me to calculate this number. Strictly speaking, it took 5 days machine-time to calculate the final program by the Pentium 100MHz computer. I really enjoyed programming, debugging and so on during these days.

Back to **Suzuki's Magic Squares**

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Please mail comments and suggestions to Suzanne Alejandre.

http://www.ff.iij4u.or.jp/~kanada/ccm/magic-square/index.html Go
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[Japanese version] [English version]
[Temporary Mirror Page (Fast!)] [Original Page (Newer?!)]

Magic Squares

Introduction

Magic squares of degree *N* is a collection of *N* by *N* columns, which contain integers from 1 to *N*. The sum of *N* integers of all the columns, all the rows, or a diagonal must be the same. A method of finding a magic square using CCM is explained here.

A method of finding a magic square using CCM

The applet below searches for a magic square. If you used this applet in its initial state, you can track the process by your eye in some extent. (If this applet is too large, you can use this small applet.) If you change the option value, which is ``medium speed (20 rps)'' in its initial state, to ``full speed,'' the computation will be done as quick as possible. (20 rps means that the rule is applied 20 times per second (rps = reductions per second). However, the real rps is less than 20.) You can start the computation again using the ``restart'' button. You probably find a different solution each time because random numbers are used, and the computation time is also different each time.

If you change the option, which is set to ``swapping rule'' initially, then you can change the production rule. The rules are explained in the computation method page, but they are briefly explained here. ``Swapping rule'' exchanges two integers in columns and ``rotation rule'' rotates three integers in three columns.

There are many ``local optima'' in the problem of finding a magic square. (That means this problem is not easy.) So, we have to use a method like simulated annealing (SA). A method called *the frustration accumulation method* (FAM), which is similar to SA but only uses local information (reference [1] or [2]) is used in the above applet. If you change the value of ``initial frustration'' or ``frustration factor,'' you can control the volume of frustration accumulation. If you set the value of ``initial frustration'' to 0, or if you set the value of ``frustration factor'' to 0, you can suppress the mechanism of frustration accumulation. Then, the probability of stopping the computation before finding a solution and the probability of non-terminating computing becomes higher. If you see a message, ``MOD = 0,'' the solution is found when the computation is terminated. However, if you see a lower value, the computation has been terminated without finding any solution.

Method of computation

If you are interested in the method of finding a magic square using CCM, see the computation method page. (Java applets are also used in the method page for explanation :-)) If you want to know more about the method, see reference [3]. (Unfortunately, there is no English paper on this subject.)

You can find conventional methods of finding magic squares through ``the Magic Square Page.'' However, I could not find an applet that finds a magic square using a conventional method (on August '96).

http://www.ff.iij4u.or.jp/~kanada/ccm/magic-square/index.html Go MAY JUL AUG
67 captures 10
2 Dec 1998 - 19 Jun 2016 2005 2006 2007 About this capture

- [1] Y. Kanada: Methods of Parallel Processing of Constraint Satisfaction Using CCM --- A Model for Emergent Computation, *SIG PPAI*, Japan Society for Artificial Intelligence, Feb, 1996.
- [2] IEICE SIG on Artificial Intelligence 95-AI95-16
- [3] IPSJ SIG on Symbol Processing 94-SYM-75-5

The source program of the above applet is here. However, this applet is the worst in the sense of object oriented programming for the sake of shortening its loading time. That means that everything is packed into one class.

[Return to Example home page]

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I appreciate if you send errata and comments to yasusi @ kanadas.com.
Created: 10/6/1996, Updated: 10/19/2003.

http://indra.com/~charliek/ Go
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Magic Squares and Hyper Cubes

Magic Squares and Hyp
Niwot
Benoit

Introduction

Magic squares are arrangements of numbers into squares, cubes, or hyper-cubes where the sum of each row and each column is identical. Additionally, the sum along the "principal diagonals" is also equal to the same number. The magic square below was known in antiquity in China, Greece, and Egypt.

2	9	4
7	5	3
6	1	8

It is interesting to note that subtracting a constant from each cell in a magic square or hyper-cube does not change its essential property: namely, that the sum of any row, column, or principal diagonal is identical. For example, the following magic square is obtained by subtracting 5 from each cell in the magic square above:

-3	4	-1
2	0	-2
1	-4	3

An interesting property about this square is that all rows, columns, and principal diagonals sum to 0. Also, it is easy to visually recognize symmetry in the square.

This web site contains:

- Examples
- Instructions
- Applications
- Theory
- Algorithm
- Symmetry - examples using "tuples"
- Generator - program for generating magic squares and Hyper Cubes
- Other Web Sites for Magic Squares and Cubes

Please see the Instructions Page before viewing the Magic Squares and Hyper Cubes Generator.

Site Map:

http://indra.com/~charliek/ Go FEB APR MAR
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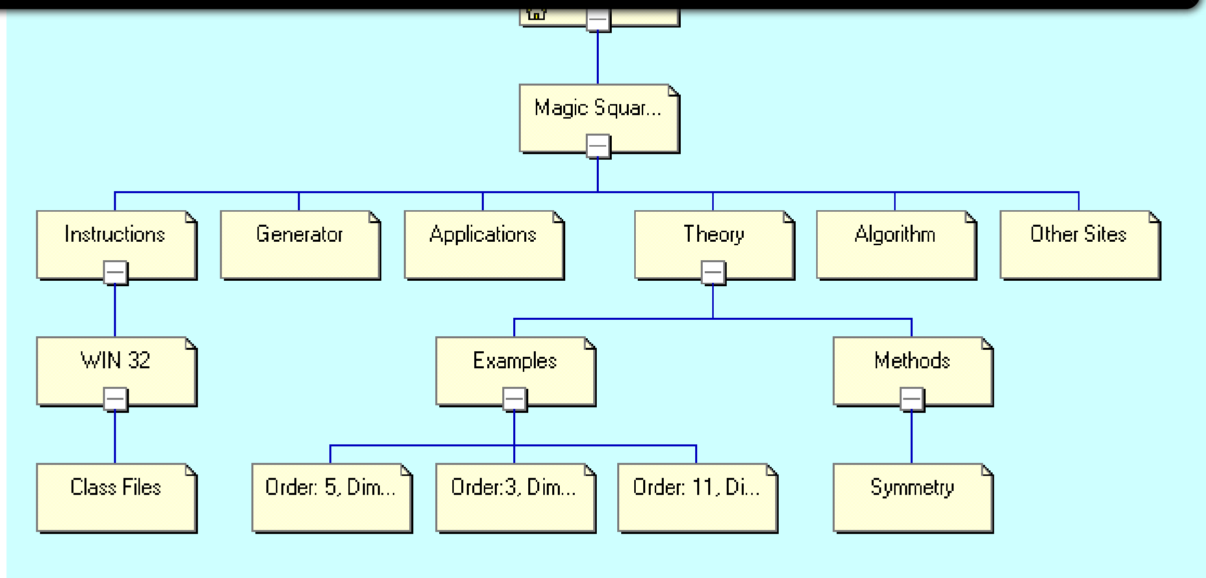

Postal address
P.O. Box 567; Niwot, CO 80544; USA
Electronic mail
General Information: Charlie.Kelly@broadband-inc.com

Software or web page matters:
Webmaster: webmaster@broadband-inc.com

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.algebra.html Go DEC JAN JUL
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Mutsumi Suzuki
Magic Squares

Algebraic approach to the magic square

Let us consider a matrix

```
A B C
D E F
G H I
```

and conditions for the magic square.

```
A + B + C = 15, therefore C = 15 - A - B    ...(1)
D + E + F = 15, therefore F = 15 - D - E    ...(2)
G + H + I = 15, therefore I = 15 - G - H    ...(3)

A + D + G = 15                              ...(4)
B + E + H = 15                              ...(5)
```

(1)+(2)+(3)+(4)+(5) yields C + F + I = 15.
Thus this condition is not independent.

The diagonal conditions are;

```
A + E + I = 15, therefore E = 15 - A - I     ...(6)
C + E + G = 15, therefore E = 15 - C - G     ...(7)
```

Substitute (3) into (6) and (1) into (7) you get;

```
E = -A + G + H
E = -G + A + B
```

Add each side then you get

```
2E = H + B                                     ...(8)
```

Substitution of Eq(8) into (5) yields;

```
3E = 15, and therefore E = 5.                  ...(9)
```

Substitute into (2),(6) and (8) yields

```
F = 10 - D                                     ...(10)
I = 10 - A                                     ...(11)
H = 10 - B                                     ...(12)
```

Eqs.(1),(7) and (9) yield

```
G = -5 + A + B                                 ...(13)
```

From Eqs(4) and (13) one get

```
D = 20 - 2A - B                                ...(14)
```

From (10) and (14) F = -10 + 2A + B ...(15) System of equations (1),(9),(11)-(15) are algebraic solutions in which seven variables E(constant),C,I,H,G,D and F can be calculated from two independent variables A and B.

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6 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009 About this capture

```
      20-2A-B   5   -10+2A+B

      -5+A+B   10-B  10-A
```

See more data by clicking here.

Thus, you can check the all possibility of magic square of 3x3 by the following procedure;

```
for A := 1 to 9 do begin
      for B := 1 to 9 do begin
                  E :=  5 ;
                  C := 15 - A - B ;
                  I := 10 - A ;
                  H := 10 - B ;
                  G := -5 + A + B ;
                  D := 20 - 2A - B ;
                  F :=-10 + 2A + B ;
                  {Check matrix routine}
       end;
end;
```

You can confirm that there is only one magic square of 3x3 by this method.

The number of independent variable "two" is calculated as;

```
 9(variables) - 7(conditions) = 2(independent variables)
```

Constellation Patterns which give a same sum

Two variables A and B are not specified number in the above calculatoins. Therefore the solutions means very common properties, which show us geometrical relationships.

For example, I = 10 - A or I + A = 10 means following pattern;

```
   A . .
   . . .
   . . I     I + A = 10
```

This relation is written symbolically by the following constellatoin patterns.

```
   + . .      . . +
   . . .      . . .
   . . +      + . .     Sum = 10
```

You can derive various patters by the same manner.

```
   . + .      . . .
   . . .      + . +
   . + .      . . .     Sum = 10
-------------------------------------------------------
   + + .      . + +     + . -     - . +
```

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6 captures
17 Jan 2007 - 21 Jul 2016
DEC JAN JUL
17
2006 2007 2009
About this capture

```
   . . .      . . .     + . .     . . +
   + + .      . + +     + . -     - . +       Sum = 5
-------------------------------------------------------
   W + .      . + W     . . .     . . .
   + . .      . . +     + . .     . . +
   . . .      . . .     W + .     . + W       Sum = 20
-------------------------------------------------------
   W + .      . + W     . . .     . . .
   . . -      - . .     . . -     - .
   . . .      . . .     W + .     . + W

   W . .      . . W     . - .     . - .
   + . .      . . +     + . .     . . +
   . - .      . - .     W . .     . . W       Sum = 10
-------------------------------------------------------
```

See more data by clicking here.

Calculation by the MATHEMATICA

You can obtain the same results by using the symbolic data processing language "MATHEMATICA".

For example, you can solve the simultaneous equations by the function "Solve" as;

```
In[1]:= Solve[{
       a + b + c  == 15,
       d + e + f  == 15,
       g + h + i  == 15,

       a + d + g  == 15,
       b + e + h  == 15,

       a + e + i == 15,
       c + e + g == 15 }]

Solve::svars: Warning: Equations may not give solutions for all "solve"
     variables.

Out[1]= {{f -> -5 + a + g, b -> 5 - a + g, c -> 10 - g, d -> 15 - a - g,

>     h -> 5 + a - g, i -> 10 - a, e -> 5}}
```

Back to **Suzuki's Magic Squares**

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Mutsumi Suzuki
Magic Squares

Randall's trial to find a 3x3 magic square of squares

Randall found out many 3x3 semi-magic squares of squares during his research on the magic square of squares.

The following is his mail on July 11, 1999.

```
Mutsumi:

I did a little research on my own, perhaps this might get others
interested?  Martin Gardner is offering
$100 reward, so I am trying (smile)  (use Courier text below, to see
proper formatting)
- Randall

Searching for a 3x3 magic square of squares -
Randall L. Rathbun June 11,1999


Introduction -

In Mathematical Recreations, Maurice Kraitchik listed the unique
3x3 magic square in a parametric solution form as

          m+x     m-(x+y)    m+y
(A)     m-(x-y)     m      m+(x-y)
          m-y     m+(x+y)    m-x

It can be quickly seen that the magic sum is 3m. If we let m=5
and x=1 and y=-3, we derive:

          6  7  2
(B)       1  5  9
          8  3  4

which is the familiar 3x3 magic square composed of integers 1..9.
As can be seen, there are eight conditions to be satisfied, for a
3x3 arrangement of numbers to make a magic square.  All the row
sums and columns sums have to be equal, and the two diagonal sums
also have to be the same as previous.


Analysis of relationships -

Suppose we make the following arrangement of algebraic variables:

      Magic List:
   1.  x          difference
   2.  x+a           a
   3.  x+2a          a
   4.  x+2a+b        b
   5.  x+3a+b        a
   6.  x+4a+b        a
   7.  x+4a+2b       b
```

http://mathforum.org/te/exchange/hosted/suzuki/Randall.html Go
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2006 2007 2009
6 captures
6 Jul 2007 - 21 Jul 2016
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squares of magic square (B) whose number matches the list number to obtain:

```
         x+4a+b    x+4a+2b   x+ a
(C)      x         x+3a+ b   x+6a+2b
         x+5a+2b   x+2a      x+2a+b
```

As can be quickly seen, the magic constant is 3x+9a+3b. Please note that x can be subtracted from each square, and still a magic square remains.

Looking for a square Magic square -

In trying to find a magic square composed of all squares, we note that our requirement says that x is square. If we break the list into 3 parts, we have:

```
(Da)     x^2         x^2+a       x^2+2a       are all squares
(Db)     x^2+2a+b    x^2+3a+b    x^2+4a+b     are all squares
(Dc)     x^2+4a+2b   x^2+5a+2b   x^2+6a+2b    are all squares
```

Rather than trying to find one square, say S^2, so that S^2+d and S^2+2d are squares, it is easier to select the middle square and find triads of squares an equal difference apart. This comes from rearranging x^2, x^2+a, and x^2+2a into x^2-a, x^2, x^2+a, since the desired property is kept.

I call the arrangement x^2-a, x^2, x^2+a a square triad, if all are squares. Do they exist? The answer is yes, and the smallest integer one is the familiar 1,25,49 or squares of 1,5,7 with difference 24. Can we find others? HINT: (The next difference is 96).

If we want to find a magic square of all squares, then by inspection of the magic list, we need to find three sets, corresponding to (Da), (Db) and (Dc), of triads of squares each with a common difference of a. Then we need two of the three sets of triads to be exactly b apart (from the highest member of one triad to the lowest member of another) assuming that we have arranged the three triads in correct order to start with.

Look again at the Magic List. The difference column tells us that we can start with x then the second is x+a, the third x+2a, however the fourth is now x+2a+b. The fifth and sixth differ by a, then the seventh makes a difference of b. The eighth and ninth then differ by a again. The difference rows tell us how to construct any magic square, with any a,b.

In short, we pick x a square, and find a,b such that they create squares. However it is easier finding or creating square triads.

Square triads with a common difference -

Do such triples of triads exist that share a common difference (which is a in the Magic List)?

The answer, surprisingly, is yes, and the smallest such set is (remembering to square the integers listed):

http://mathforum.org/te/exchange/hosted/suzuki/Randall.html Go JUN JUL JUL
6 captures 06
6 Jul 2007 - 21 Jul 2016 2006 2007 2009
About this capture

```
iii.          97  113  127
```

which comes from the fact that 1,29,41 and 23,37,47 is the first or smallest integer pair of square triads with common difference 840.

Once finding that these triads exist, then in order to see if a magic square of squares exist, we have to check the differences between the highest member of i., ii. or iii. and the lowest member of another set of i., ii., or iii.

In this example, we find that the difference between i. and ii. 46^2 - 82^2 does NOT equal the difference between ii. and iii. or 97^2 - 97^2, so this triple triad will not work to make a magic square of squares.

However surprising enough it does create a semi-magic square:

```
            2  94 113
(E)       127  58  46   Magic sum = 147^2
           74  97  82   except upper right to lower left
                        odd diagonal = 10,092
```

This square has seven of the eight conditions satisfied, in order to be a magic square!

An index square is used:

```
            1 6 8
(F)         9 2 4
            5 7 3
```

This is obtained by taking the indexed element in the i., ii. and iii. rows above and placing the appropriate one into the location specified by Index square (F). Using this index square, the elements of (i,ii,iii) created the semi-magic square (E).

In (E), all the columns and rows add up to 147^2, amazingly enough, and one diagonal 74,58,113 does. The other diagonal, 2,58,82 adds up to 3*58^2. So seven out of the eight conditions are satisfied.

Computer searching for more triads -

Ignoring non-primitive solutions, a computer search for triads yields the following 16 triples of triads and Semi-Magic squares: (one was actually a quartet, or 12 triads, 1 quartet)

```
common difference = 3,360          Semi-Magic Square
        2    58    82  gcd 2           2     94    113
       46    74    94  gcd 2         127     58     46    (1)
       97   113   127  gcd 1          74     97     82

   Magic Sum = 147^2  Odd diagonal sum = 10,092

common difference = 43,680         Semi-Magic Square
       62   218   302  gcd 2          62    313    394
      103   233   313  gcd 1         446    218    103    (2)
      334   394   446  gcd 2         233    334    302
```

http://mathforum.org/te/exchange/hosted/suzuki/Randall.html Go
6 captures
6 Jul 2007 - 21 Jul 2016
JUN JUL JUL
06
2006 2007 2009
About this capture

```
      503   617   713  gcd 1         878   386   503   (3)
      718   802   878  gcd 2         617   718   526

   Magic Sum = 1083^2  Odd diagonal sum = 446,988

common difference = 665,280        Semi-Magic Square
      102   822  1158  gcd 6         102  1173  3026
      213   843  1173  gcd 3        3134   822   213   (4)
     2914  3026  3134  gcd 2         843  2914  1158

   Magic Sum = 3247^2  Odd diagonal sum = 2,027,052

common difference = 1,145,760      Semi-Magic Square
      158  1082  1522  gcd 2         158  1873  2186
     1103  1537  1873  gcd 1        2434  1082  1103   (5)
     1906  2186  2434  gcd 2        1537  1906  1522

   Magic Sum = 2883^2  Odd diagonal sum = 3,512,172

common difference = 1,367,520      Semi-Magic Square
      802  1418  1838  gcd 2         802  2722  2969
     2162  2458  2722  gcd 2        3191  1418  2162   (6)
     2729  2969  3191  gcd 1        2458  2729  1838

   Magic Sum = 4107^2  Odd diagonal sum = 6,032,172

common difference = 1,367,520      Semi-Magic Square
      802  1418  1838  gcd 2         802  2722  6161
     2162  2458  2722  gcd 2        6271  1418  2162   (7)
     6049  6161  6271  gcd 1        2458  6049  1838

   Magic Sum = 46,010,409  Odd diagonal sum = 6,032,172

common difference = 1,367,520      Semi-Magic Square
      802  1418  1838  gcd 2         802  3191  6161
     2729  2969  3191  gcd 1        6271  1418  2729   (8)
     6049  6161  6271  gcd 1        2969  6049  1838

   Magic Sum = 48,783,606  Odd diagonal sum = 6,032,172

common difference = 1,367,520      Semi-Magic Square
     2162  2458  2722  gcd 2        2162  3191  6161
     2729  2969  3191  gcd 1        6271  2458  2729   (9)
     6049  6161  6271  gcd 1        2969  6049  2722

   Magic Sum = 52,814,646  Odd diagonal sum = 18,125,292

NOTE: There are 4 triads here, so quartets do exist!

common difference = 2,328,480      Semi-Magic Square
      147  1533  2163  gcd 21        147  2866  2562
     1886  2426  2866  gcd 2        2982  1533  1886  (10)
     2058  2562  2982  gcd 42       2426  2058  2163

   Magic Sum = 3847^2  Odd diagonal sum = 7,050,267

common difference = 3,756,480      Semi-Magic Square
      562  2018  2798  gcd 2         562  3634  4153
     2386  3074  3634  gcd 2        4583  2018  2386  (11)
     3673  4153  4583  gcd 1        3074  3673  2798
```

http://mathforum.org/te/exchange/hosted/suzuki/Randall.html Go JUN JUL JUL 06 2006 2007 2009
6 captures
6 Jul 2007 - 21 Jul 2016
About this capture

```
     1785  2775  3495  gcd 15        3642  2125  1785  (12)
     2058  2958  3642  gcd 6         2775  2058  3005

   Magic Sum = 20,966,014  Odd diagonal sum = 13,546,875

common difference = 6,726,720      Semi-Magic Square
      577  2657  3713  gcd 1          577  4702  5426
     2942  3922  4702  gcd 2         6014  2657  2942  (13)
     4766  5426  6014  gcd 2         3922  4766  3713

   Magic Sum = 7203^2  Odd diagonal sum = 21,178,947

common difference = 7,862,400      Semi-Magic Square
     1581  3219  4269  gcd 3         1581  5820  7300
     4260  5100  5820  gcd 60        7820  3219  4260  (14)
     6740  7300  7820  gcd 20        5100  6740  4269

   Magic Sum = 9469^2  Odd diagonal sum = 31,085,883

common difference = 8,168,160      Semi-Magic Square
     1426  3194  4286  gcd 2         1426  5081  7753
     3079  4201  5081  gcd 1         8263  3194  3079  (15)
     7207  7753  8263  gcd 1         4201  7207  4286

   Magic Sum = 87,959,046  Odd diagonal sum = 30,604,908

common difference = 8,848,224      Semi-Magic Square
       49  2975  4207  gcd 7           49  4318  3885
      974  3130  4318  gcd 2         4893  2975   974  (16)
     2499  3885  4893  gcd 21        3130  2499  4207

   Magic Sum = 33,740,750  Odd diagonal sum = 26,551,875
```

In light of the 16 Semi-Magic squares found above, it becomes interesting to conjecture that perhaps a Magic Square of all squares might exist. After all, there are an infinite number of Semi-Magic squares. Perhaps one of those is Magic!

Further computer searching for more semi-magic squares is in progress. Perhaps a parallel Web computer search might be worthwhile?

Back to **Suzuki's Magic Squares**

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http://www.innerx.net/personal/tsmith/FTsquare.html Go NOV DEC FEB
58 captures 04
8 Oct 1999 - 12 Apr 2019 2000 2001 2002
About this capture

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Freudenthal-Tits Magic Square:

Here are some approaches from other points of view:

- Geoffrey Dixon
- John Baez - Division Algebras
- C.H. Barton and A. Sudbery
- J. M. Landsberg - Algebraic Geometry

References

```
The E6-E7-E8 structures are based
on the Freudenthal-Tits Magic Square,
which shows relationships between
division algebras and matrix algebras.

In particular:

Division algebras define the rows of the Magic Square;

Jordan algebras define the columns of the Magic Square;
and
Lie algebras define the entries of the Magic Square.

The Jordan algebras are Hermitian matrices with
a symmetric product.
The Lie algebras are anti-Hermitian matrices with
an antisymmetric product.

The Magic Square includes ALL the exceptional Lie algebras,
but only some of the A, B, C, and D series Lie algebras.

There don't seem to be many references in standard textbooks.
I first read about it in
the article Jordan Algebras and their Applications,
by Kevin McCrimmon, Bull. AMS 84 (1978) 612-627, at pp. 620-621
and in
the unpublished 1976 Caltech notes of Pierre Ramond,
who I think learned about it from Feza Gursey at Yale.
Freudenthal wrote about it in Adv. Math. 1 (1964) 143, and
Tits in Indag. Math. 28 (1966) 223-237.

It is: (here I use Q for quaternion, and I follow McCrimmon
except that I correct a misprint of A6 that should (I think) be D6,
and I will also say that McCrimmon writes it as 4x5 instead of 4x4,
so that it is rectangle instead of square - other authors omit
the first column of McCrimmon's figure, and they get a 4x4 square,
but they don't have G2 as the derivation algebra of octonions O.)


        R       J3(R)       J3(C)       J3(Q)       J3(O)
```

http://www.innerx.net/personal/tsmith/FTsquare.html Go NOV DEC FEB 04 2000 2001 2002
58 captures
8 Oct 1999 - 12 Apr 2019
About this capture

Q	A1	C3	A5	D6	E7
O	G2	F4	E6	E7	E8

The columns are labelled
by Jordan algebras J = R, J3(R), J3(C), J3(Q), J3(O)
(where J3(K) is the algebra of 3x3 Hermitian matrices over K)

The rows are labelled
by composition algebras A = R, C, Q, O

It is a 4x5 rectangle, but the right 4 columns make a 4x4 square.

The 4x5 Magic Square entries are Lie algebras L formed
by the rule:

L = Der(A) + (A0xJ0) + Der(J)

where Der means derivation, + is direct sum, x is tensor product,
A0 are the pure imaginary elements of A, R0=S0, C0=S1, Q0=S3, O0=S7,
(here Sn means the algebra of tangent vectors to an n-dim sphere, and
S0,S1,S3 are Lie algebras and S7 is a Malcev algebra), and
J0 are the elements of trace zero of the Jordan algebra J.
(McCrimmon shows what the Lie products of such elements are,
on page 620 of his article in Bull. AMS).

Further, notice that
A1 is SU(2), A2 is SU(3), A5 is SU(6),
C3 is Sp(3) (denoted by some people Sp(6)),
D6 is SO(12) (same Lie algebra as Spin(12), and
G2, F4, E6, E7, and E8 are the exceptional Lie algebras.
The corresponding exceptional Lie groups are the subject
of the book Lectures on Exceptional Lie Groups by J. F. Adams,
published posthumously by Un. of Chicago Press in 1996,
edited by Zafer Mahmud and Mamoru Mimura.

To try to make the magic squares a little clearer,
here is the Magic Square with the dimensions
of the Lie algebras as entries:

	R	J3(R)	J3(C)	J3(Q)	J3(O)
R	0	3	8	21	52
C	0	8	16	35	78=52+1x26
Q	3	21	35	66	133=52+3x26+3
O	14	52	78	133	248=52+7x26+14

	R	J3(R)	J3(C)	J3(Q)

http://www.innerx.net/personal/tsmith/FTsquare.html Go NOV DEC FEB
58 captures 04
8 Oct 1999 - 12 Apr 2019 2000 2001 2002
About this capture

Q	3	21	35	66=21+3x14+3
O	14	52	78	133=21+7x14+14

	R	J3(R)	J3(C)
R	0	3	8
C	0	8	16=8+1x8
Q	3	21	35=8+3x8+3
O	14	52	78=8+7x8+14

	R	J3(R)
R	0	3
C	0	8=3+1x5
Q	3	21=3+3x5+3
O	14	52=3+7x5+14

To help a little more, consider the dimension of
3x3 matrices with entries Aij such that Aij = Aji*
(where * denotes conjugate)

If the entries of Aij are of dimension k
then the diagonal Aii are real, and
the matrix dimension is 3k + 3,
and if trace = sum of diagonals = 0, the dimension is 3k + 2.

Therefore:
for reals: 3x1 + 2 = 5;
for complex: 3x2 + 2 = 8;
for quaternion: 3x4 + 2 = 14;
for octonion: 3x8 + 2 = 26.

As for the first column,
which is rectangle part, not really part of the 4x4 square:

	R	
R	0	(no imaginary part)
C	0	(imaginary part dissipates)

http://www.innerx.net/personal/tsmith/FTsquare.html Go NOV DEC FEB
58 captures 04
8 Oct 1999 - 12 Apr 2019 2000 2001 2002
About this capture

Geoffrey Dixon shows how to construct F4, E6, E7, and E8 from a slightly different point of view:

- F4 = Spin(8) + SO(3) + 3x7 = 28 + 3 + 3x7 = 52
- E6 = Spin(8) + SU(3) + 6x7 = 28 + 8 + 6x7 = 78
- E7 = Spin(8) + Sp(3) + 12x7 = 28 + 21 + 12x7 = 133
- E8 = Spin(8) + F4 + 24x7 = 28 + 52 + 24x7 = 248

To get from Geoffrey Dixon's construction to my construction,

use the fibrations S7 = Spin(8) / Spin(7) and S7 = Spin(7) / G2

to break the 28 of Spin(8) into 14 + 7 + 7 of G2, S7, and S7,

and add the two 7's to his 3x7, 6x7, 12x7, and 24x7

to get my 5x7, 8x7, 14x7, and 26x7.

```
John Baez writes This Weeks Finds in Math Physics on the WWW.
His Week 64 describes E6;  his Week 90 describes E8;
and his Week 91 describes triality.

The Freudenthal-Tits Magic Square can be formulated
in the terms of his description of E8:

Start with D4 = Spin(8):

 28 =  28  +   0  +   0  +   0  +   0  +   0  +   0

Add spinors and vector to get F4:

 52 =  28  +   8  +   8  +   8  +   0  +   0  +   0

Now, "complexify" the 8+8+8 part of F4 to get E6:

 78 =  28  +  16  +  16  +  16  +   1  +   0  +   1

Then, "quaternionify" the 8+8+8 part of F4 to get E7:

133 =  28  +  32  +  32  +  32  +   3  +   3  +   3

Finally, "octonionify" the 8+8+8 part of F4 to get E8:

248 =  28  +  64  +  64  +  64  +   7  +  14  +   7


This way shows you that the "second" Spin(8) in E8
breaks down as  28 = 7 + 14 + 7
which is globally like two 7-spheres and a G2,
one S7 for left-action, one for right-action,
and a G2 automorphism group of octonions
that is needed to for "compatibility" of the two S7s.
```

http://www.innerx.net/personal/tsmith/FTsquare.html Go NOV DEC FEB
58 captures 04
8 Oct 1999 - 12 Apr 2019 2000 2001 2002
About this capture

In MAGIC SQUARES OF LIE ALGEBRAS, math.RA/0001083, C.H. Barton and A. Sudbery say: "... This paper is an investigation of the relation between Tit's magic square of Lie algebras and certain Lie algebras of 3 x 3 and 6 x 6 matrices with entries in alternative algebras. By reformulating Tit's definition in terms of trialities (a generalisation of derivations), we give a systematic explanation of the symmetry of the magic square. We show that when the columns of the magic square are labelled by the real division algebras and the rows by their split versions, then the rows can be interpreted as analogues of the matrix Lie algebras su(3), sl(3) and sp(6) defined for each division algebra. We also define another magic square based on 2 x 2 and 4 x 4 matrices and prove that it consists of various orthogonal or (in the split case) pseudo-orthogonal Lie algebras. ...

... Tits ... showed ... the so-called magic square of Lie algebras of 3 x 3 matrices whose complexifications are

```
    R   C     H   O
R   A1  A2    C3  F4
C   A2  A2xA2 A5  E6
H   C3  A5    B6  E7
O   F4  E6    E7  E8
```

The striking properties of this square are (a) its symmetry and (b) the fact that four of the five exceptional Lie algebras occur in its last row. ... The fifth exceptional Lie algebra, G2, can be included by adding a extra row corresponding to the Jordan algebra R . ...

... most exceptional Lie algebras are related to the exceptional Jordan algebra of 3 x 3 hermitian matrices with entries from the octonions, O. ... this relation yields descriptions of certain real forms of the complex Lie algebras

- F4 ... which can be interpreted as octonionic versions of ... the Lie algebra of antihermitian 3 x 3 matrices ...
- E6 ... which can be interpreted as octonionic versions of ... the Lie algebra of .... special linear 3 x 3 matrices and ...
- E7 which can be interpreted as octonionic versions of ... the Lie algebra of ... symplectic 6 x 6 matrices. ...".

Joseph M. Landsberg approaches the Freudenthal-Tits Magic Square from an Algebraic Geometry Point of View

In math.AG/9810140, J. M.Landsberg and Laurent Manivel say: "... This is the first paper in a series establishing new relations between the representation theory of complex simple Lie groups and the algebraic and differential geometry of their homogeneous varieties. In this paper we determine the varieties of linear spaces on rational homogeneous varieties, provide explicit geometric models for these spaces, and establish basic facts about the local differential geometry of rational homogeneous varieties. Let G be a complex simple Lie group, P a maximal parabolic subgroup. The space of lines on G / P in its minimal homogeneous embedding was determined ...[by Cohen and Cooperstein]... in terms of Lie incidence systems. There is a dichotomy between

http://www.innerx.net/personal/tsmith/FTsquare.html Go NOV DEC FEB
58 captures 04
8 Oct 1999 - 12 Apr 2019 2000 2001 2002
About this capture

higher dimensional linear spaces associated to non-short roots using Tits methods. For short roots, we provide explicit descriptions of the spaces we study, especially in the exceptional cases where we use Cayley's octonions. In all cases, each connected component of the variety of linear spaces on a G / P is quasi-homogeneous; more precisely, it is the union of a finite number of G-orbits. ...

... Here is a table of the G-minuscule varieties: there are four infinite series and two exceptional spaces.

... Here E and Q are the tautological and quotient vector bundles on the Grassmannian or their pullbacks to the varieties in question. S+ is the half spin representation of D5, and J3(O) is the space of 3 x 3 O-Hermitian matrices, the representation V_w1 for E6 ... G_w(O3,O6) may be interpreted as the space of O3 's in O6 that are null for an O-Hermitian symplectic form ...

... As an algebraic variety, G2 / P1 is a familiar space, G2 / P1 = Q5 in P6 . ... **G2** is not really an exceptional group, because it is defined by a generic form. ... The ... interpretation can be understood in terms of folding Dynkin diagrams:

This indicates that G2 / P1 should be be understandable in terms of D4 / P1 = Q6 , and in fact it is a generic hyperplane section. Im O in O should be thought of as the traceless elements, where the trace of an element is its "real" part and we call the hyperplane section { tr = 0 } . ...

... J3(O) ... a Jordan algebra ... There is a well-defined determinant on J3(O), which is defined by same expression as the classical determinant in terms of traces:

http://www.innerx.net/personal/tsmith/FTsquare.html Go NOV DEC FEB
58 captures 04
8 Oct 1999 - 12 Apr 2019 2000 2001 2002 About this capture

... F4 / P4 = OP2_0 . ... The description [of] ... **F4** in GL(J3(O)) ... [as F4 = { g in E6 | g+ = g- } ... is motivated by folding of Dynkin diagrams:

... Note that F4 is generated by SO3 and Spin8 ... This defines an automorphism of the Jordan algebra J3(O)_0 because of the triality principle. ...

... **E6** is the subgroup of GL(J 3(O)) = GL(27, C) preserving det. The notion of rank one matrices is also well defined and the Cayley plane, E6 / P1 = OP2 in P(J3(O)) is the projectivization of the rank one elements, with ideal the 2 x 2 minors ... Since alpha_1 is not short, all linear spaces on OP2 are described by Tits geometries. In particular, E6/ P3 is the space of lines on OP2 and E6 / P2 is the space of P5 's on OP2 ...

In math.AG/9902102, J. M.Landsberg and Laurent Manivel say: "... Complex simple Lie algebras were classified by Cartan and Killing 100 years ago. Their proof proceeds by reducing the question to a combinatorical problem: the classification of irreducible root systems, and then performing the classification. We present a new proof of the classification via the projective geometry of homogeneous varieties. Our proof is constructive: we build a homogeneous space X in PN from a smaller space Y in Pn via a rational map Pn -> PN defined using the ideals of the secant and tangential varieties of Y. Our proof has three steps.

- Among homogeneous varieties, there is a preferred class, the minuscule varieties ...
- We next construct all the fundamental adjoint varieties from certain minuscule varieties. ...
- Finally, we prove that these are all the adjoint varieties except for the two "exceptional" cases of Am and Cm. ...

... Our proof can be translated into a combinatorical argument: the construction consists of two sets of rules for adding new nodes to marked Dynkin diagrams. As a combinatorical algorithm, it is less efficient than the standard proof ...

... minuscule representations define algebraic structures that are cousins of Clifford algebras ... the raising and lowering action corresponds to Clifford multiplication. ...

In math.AG/9908039, J. M.Landsberg and L. Manivel say: "... We connect the algebraic geometry and representation theory associated to Freudenthal's magic square. We give unified geometric descriptions of several classes of orbit closures, describing their hyperplane sections and desingularizations, and interpreting them in terms of composition algebras. In particular, we show how a class of invariant quartic polynomials can be viewed as generalizations of the classical discriminant of a cubic polynomial. ...

... Freudenthal associates to each group in the square a set of preferred homogeneous varieties (k-spaces for each group in the k-th row). These spaces have the same incidence relations with the corresponding varieties for the groups in the same row. He calls the geometries associated to the groups of the rows respectively, 2-dimensional elliptic, 2-dimensional plane projective, 5-dimensional symplectic and metasymplectic. The distinguished spaces

http://www.innerx.net/personal/tsmith/FTsquare.html Go NOV DEC FEB
58 captures 04
8 Oct 1999 - 12 Apr 2019 2000 2001 2002
About this capture

The Severi varieties ... the projective planes over the composition algebras ... have the unusual property that a generic hyperplane section of a Severi variety is still homogeneous. Putting the resulting varieties into a chart we have:

... These varieties are homogeneous spaces of groups whose associated Lie algebras are:

This chart is called Freudenthal's magic square of semi-simple Lie algebras.

The magic square was constructed by Freudenthal and Tits as follows: Let A denote a complex composition algebra (i.e. the complexification of R , C , the quaternions H or the octonions O). For a pair (A ; B) of such composition algebras, the corresponding Lie algebra is

... To deduce the first line of the magic square from the second one we use the folding of a root system. ... Here is a chart summarizing the representations arising from folding:

... the notations are explained ...[in the paper]...".

In [math.AG/0107032](), J. M.Landsberg and L. Manivel say: "... we thought it might be interesting to parametrize the exceptional series by a = dim CA , where A is respectively the complexification of 0, R, C, H, O for the last five algebras in the exceptional series (so a = 0, 1, 2, 4, 8). ... The construction we use highlights the triality principle, since we put a natural Lie algebra structure on the direct sum

http://www.innerx.net/personal/tsmith/FTsquare.html Go
58 captures
8 Oct 1999 - 12 Apr 2019
NOV DEC FEB
04
2000 2001 2002
About this capture

where t(A) is a certain triality algebra associated to A . ... If A is a real Cayley algebra, it is a classical fact that T(A) is an algebraic group of type D4. ... we get the following types for the Lie algebra t(A) of T(A) ...

t(R)	t(C)	t(H)	t(O)
0	R2	so3 x so3 x so3	so8

... For B = O , our construction gives the last line of Freudenthal square. ... Consider the case of e8, i.e., A = O . ... Now we make a few observations on the weights of Ai. ... The weight structure is as follows:

...".

```
Here are some more references:

the book Nonassociative Algebras in Physics,
by the Estonians Jaak Lohmus, Eugene Paal, and Leo Sorgsepp,
Hadronic Press (1994) p. 58
and
the book Division Algebras by Geoffrey Dixon,
Kluwer (1994) chapter 8
and
the article Division Algebras ... by A. Sudbery
J. Phys. A:  Math. Gen. 17 (1984) 939-955
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http://mathforum.org/alejandre/magic.square/adler/ Go
166 captures
15 Oct 2002 - 18 Aug 2017
MAY JUN AUG
15
2005 2006 2007
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89 captures
2 Jun 2000 - 18 Feb 2019
MAR JUN SEP
16
2005 2006 2007
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Foundations of Mathematics
Geometry
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Latin Square

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An $n \times n$ Latin square is a Latin rectangle with $k = n$. Specifically, a Latin square consists of n sets of the numbers 1 to n arranged in such a way that no orthogonal (row or column) contains the same number twice. For example, the two Latin squares of order two are given by

$$\begin{bmatrix} 1 & 2 \\ 2 & 1 \end{bmatrix}, \begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix}, \quad (1)$$

the 12 Latin squares of order three are given by

$$\begin{bmatrix} 1 & 2 & 3 \\ 2 & 3 & 1 \\ 3 & 1 & 2 \end{bmatrix}, \begin{bmatrix} 1 & 2 & 3 \\ 3 & 1 & 2 \\ 2 & 3 & 1 \end{bmatrix}, \begin{bmatrix} 1 & 3 & 2 \\ 2 & 1 & 3 \\ 3 & 2 & 1 \end{bmatrix}, \begin{bmatrix} 1 & 3 & 2 \\ 3 & 2 & 1 \\ 2 & 1 & 3 \end{bmatrix}, \begin{bmatrix} 2 & 1 & 3 \\ 1 & 3 & 2 \\ 3 & 2 & 1 \end{bmatrix}, \begin{bmatrix} 2 & 1 & 3 \\ 3 & 2 & 1 \\ 1 & 3 & 2 \end{bmatrix}, \begin{bmatrix} 2 & 3 & 1 \\ 1 & 2 & 3 \\ 3 & 1 & 2 \end{bmatrix}, \begin{bmatrix} 2 & 3 & 1 \\ 3 & 1 & 2 \\ 1 & 2 & 3 \end{bmatrix}, \begin{bmatrix} 3 & 2 & 1 \\ 1 & 3 & 2 \\ 2 & 1 & 3 \end{bmatrix}, \begin{bmatrix} 3 & 2 & 1 \\ 2 & 1 & 3 \\ 1 & 3 & 2 \end{bmatrix}, \begin{bmatrix} 3 & 1 & 2 \\ 1 & 2 & 3 \\ 2 & 3 & 1 \end{bmatrix}, \begin{bmatrix} 3 & 1 & 2 \\ 2 & 3 & 1 \\ 1 & 2 & 3 \end{bmatrix}, \quad (2)$$

and two of the whopping 576 Latin squares of order 4 are given by

$$\begin{bmatrix} 1 & 2 & 3 & 4 \\ 2 & 1 & 4 & 3 \\ 3 & 4 & 1 & 2 \\ 4 & 3 & 2 & 1 \end{bmatrix} \text{ and } \begin{bmatrix} 1 & 2 & 3 & 4 \\ 3 & 4 & 1 & 2 \\ 4 & 3 & 2 & 1 \\ 2 & 1 & 4 & 3 \end{bmatrix}. \quad (3)$$

The numbers $N(n, n)$ of Latin squares of order $n = 1$, 2, ... are 1, 2, 12, 576, 161280, ... (Sloane's A002860). The number $N(n, n)$ of *isotopically distinct* Latin squares of order $n = 1$, 2, ... are 1, 1, 1, 2, 2, 22, 564, 1676267, ... (Sloane's A040082).

A pair of Latin squares is said to be orthogonal if the n^2 pairs formed by juxtaposing the two arrays are all distinct. For example, the two Latin squares

$$\begin{bmatrix} 3 & 2 & 1 \\ 2 & 1 & 3 \\ 1 & 3 & 2 \end{bmatrix} \quad \begin{bmatrix} 2 & 3 & 1 \\ 1 & 2 & 3 \\ 3 & 1 & 2 \end{bmatrix} \quad (4)$$

are orthogonal. The number of pairs of orthogonal Latin squares of order $n = 1$, 2, ... are 0, 0, 36, 3456, ... (Sloane's A072377).

The number of Latin squares of order n with first row given by $\{1, 2, \ldots, n\}$ is the same as the number of fixed diagonal Latin squares of order n (i.e., the number of Latin squares of order n having all 1s along their main diagonals). For $n = 1$, 2, ..., the numbers of such matrices are 1, 1, 2, 24, 1344, 1128960, ... (Sloane's A000479) and the total number of Latin squares of order n is equal to this number times $n!$.

A normalized, or reduced, Latin square is a Latin square with the first row and column given by $\{1, 2, \ldots, n\}$. General formulas for the number of *normalized* $n \times n$ Latin squares $L(n, n)$ are given by Nechvatal (1981), Gessel (1987), and Shao and Wei (1992), but the asymptotic value of $L(n, n)$ is not known (MacKay and Wanless 2005). The *total* number of Latin squares $N(n, n)$ of order n can then be computed from

$$N(n, n) = n!\,(n-1)!\,L(n, n). \quad (5)$$

The numbers of normalized Latin squares of order $n = 1$, 2, ..., are summarized in the following table (Sloane's A000315).

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3	1	
4	4	
5	56	Euler (1782), Cayley (1890), MacMahon (1915; incorrect value)
6	9408	Frolov (1890) and Tarry (1900)
7	16942080	Frolov (1890; incorrect), Norton (1939; incomplete), Sade (1948), Saxena (1951)
8	535281401856	Wells (1967)
9	377597570964258816	Bammel and Rothstein (1975)
10	7580721483160132811489280	McKay and Rogoyski (1995)
11	5363937773277371298119673540771840	McKay and Wanless (2005)
12	1.62×10^{44}	McKay and Rogoyski (1995)
13	2.51×10^{56}	McKay and Rogoyski (1995)
14	2.33×10^{70}	McKay and Rogoyski (1995)
15	1.5×10^{86}	McKay and Rogoyski (1995)

Sudoku is a special case of a Latin square.

SEE ALSO: 36 Officer Problem, Alon-Tarsi Conjecture, Euler Square, Kirkman Triple System, Lam's Problem, Partial Latin Square, Quasigroup, SOMA, Sudoku. [Pages Linking Here]

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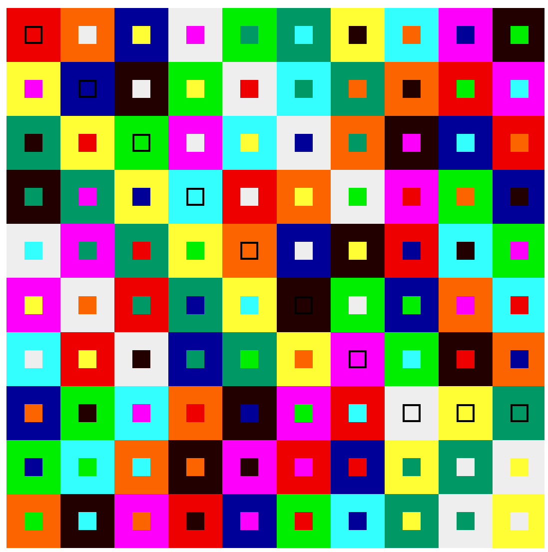
Graeco-Latin Squares

A Latin square of order n is a square array of size n that contains symbols from a set of size n. The symbols are arranged so that every row of the array has each symbol of the set occuring exactly once, and so that every column of the array has each symbol of the set also occuring exactly once.

Two Latin squares of order n are said to be orthogonal if one can be superimposed on the other, and each of the n^2 combinations of the symbols (taking the order of the superimposition into account) occurs exactly once in the n^2 cells of the array. Such pairs of orthogonal squares are often called Graeco-Latin squares since it is customary to use Latin letters for the symbols of one square and Greek letters for the symbols of the second square. In the example of a Graeco-Latin square of order 4 formed from playing cards, the two sets of symbols are the ranks (ace, king, queen and jack) and the suits (hearts, diamonds, clubs, spades). Here is an example of a Graeco-Latin square of order 10.



An Order 10 Graeco-Latin Square (10K)

The two sets of "symbols" are identical - they are the 10 colors: red, purple, dark blue, light blue, light green, dark green, yellow, gray, black and brownish-orange. The larger squares constitute the Latin Square, while the inner squares constitute the Greek square. Every one of the 100 combination of colors (taking into account the distinction between the inner and outer squares) occurs exactly once. Note that for some elemnts of the array (principally, but not exclusively, along the diagonal) the inner and outer squares have the same color, rendering the distinction between them invisible.

Euler knew (c. 1780) that there was not a Graeco-Latin square of order 2 and knew constructions when n is odd or divisible by 4. Based on much experimentation, he conjectured that Graeco-Latin squares did not exist for orders of the form 4k + 2, k = 0, 1, 2, ... In 1901, Gaston Tarry proved (by exhaustive enumeration of the possible cases) that there was no Graeco-Latin square of order 6 - adding evidence to Euler's conjecture. However, in 1959, Parker, Bose and Shrikhande were able to construct an order 10 Graeco-Latin square, and provided a construction for the remaining even values of n that are not divisible by 4 (of course, excepting n = 2 and n = 6).

It can be proved that the size of the set of mutually pairwise orthogonal Latin squares of order n cannot exceed n - 1. The search for a set of 9 mutually pairwise orthogonal Latin squares of order 10 is equivalent to the search

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conclusion that a set of 9 mutually orthogonal Latin squares of order 10 does not exist.

To read an entertaining and informative account of Graeco-Latin Squares, consult *"New Mathematical Diversions", by Martin Gardner, Simon & Schuster, 1966.*

Rob Beezer, beezer@ups.edu, Updated: Jan 9, 1995, Created: Nov 9, 1994

ANALYTICAL FORMULAE AND ALGORITHMS FOR CONSTRUCTING MAGIC SQUARES FROM AN ARBITRARY SET OF 16 NUMBERS [1)]

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In this paper we seek for an answer on Smarandache type question: may one create the theory of Magic squares 4×4 in size without using properties of some concrete numerical sequences? As a main result of this theoretical investigation we adduce the solution of the problem on decomposing the general algebraic formula of Magic squares 4×4 into two complete sets of structured and four-component analytical formulae.

1 Introduction

In the general case *Magic squares* represent by themselves numerical or analytical square tables, whose elements satisfy a set of definite basic and additional relations. The basic relations therewith assign some constant property for the elements located in the rows, columns and two main diagonals of a square table, and additional relations, assign additional characteristics for some other sets of its elements.

Judging by the given general definition of Magic squares, there is no difficulty in understanding that, in terms of mathematics, the problem on Magic squares consists of the three interrelated problems

a) elucidate the possibility of choosing such a set of elements which would satisfy both the basic and all the additional characteristics of the relations;

b) determine how many Magic squares can be constructed from the chosen set of elements;

c) elaborate the practical methods for constructing these Magic squares.

It is a traditional way to solve all mentioned problems with taking into account concrete properties of the numerical sequences from which the Magic square numbers are generated. For instance, by using this way problems was solved on constructing different Magic squares of natural numbers [1–5], prime numbers[6, 7], Smarandache numbers of the 1st kind[8] and so on. Smarandache type question[9] arises: whether a possibility exists to construct the theory of

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[1)] This paper has published in *Smarandache Notions J.* (1997) **8** (1-2-3)

Magic squares without using properties of concrete numerical sequences. The main goal of this paper is finding an answer on this question with respect to problems of constructing Magic squares 4×4 in size. In particular, in this investigation we

a) describe a simple way of obtaining a general algebraic formulae of Magic squares 4×4, required no use of algebraic methods, and explain why in the general case this formula does not simplify the solution of problems on constructing Magic square 4×4 (Sect. 2);

b) give a description of a set of invariant transformations of Magic squares 4×4 (Sect. 3);

c) adduce a general algorithm, suitable for constructing Magic squares from an arbitrarily given set of 16 numbers (Sect. 4);

d) discuss the problems of constructing Magic squares from the structured set of 16 elements (Sect. 5);

e) solve the problem of decomposing the general algebraic formula of Magic squares 4×4 into a complete set of the four-component formulae (Sect. 6).

2 Constructing the general algebraic formula of a Magic square 4×4

A table, presented in Fig. 1(2), consists of two orthogonal diagonal Latin squares, contained symbols A, B, C, D (L_1) and a, b, c, d (L_2). Remind[10, 11] that two Latin squares of order n are called

a) *orthogonal* if being superimposed these Latin squares form a table whose all n^2 elements are various;

b) *diagonal* if n different elements are located not only in its rows and columns, but also in its two main diagonals.

It is evident that the table 1(2) is transformed in the analytical formula of a Magic square 4×4 when its parameter $b = 0$. By using Fig. 1(2) we reveal the law governing the numbers of any Magic square 4×4 decomposed in two orthogonal diagonal Latin squares. For this aim we rearrange the sets of the symbols in the two-component algebraic formula 1(2) so as it is shown in Fig. 1(6). Further, a table 1(6) will be called *additional* one. Such name of the table is justified by the following:

a) the table 1(6), containing the same set of elements as the table 1(2), has more simple structure than the formula 1(2);

b) there exists a simple way of passing from this table to a Magic square 4×4: really, if one considers that Fig. 1(1) represents the enumeration of the cells in the table 1(6), then, for passing from this table to a Magic square it will be sufficient to arrange numbers in the new table 4×4 in the order corresponding to one in the *classical* square 1(5) {the Magic square of natural numbers from 1 to 16 }.

1	2	3	4
5	6	7	8
9	10	11	12
13	14	15	16

(1)

$A + c$	$B + b$	$C + d$	$D + a$
$D + d$	$C + a$	$B + c$	$A + b$
$B + a$	$A + d$	$D + b$	$C + c$
$C + b$	$D + c$	$A + a$	$B + d$

($2 – L_1 + L_2$)

-	-	-	-
$-w$	-	-	$+w$
$+w$	-	-	$-w$
-	-	-	-

($3 – W$)

$A + c$	B	$C + d$	$D + a$
$D + d - w$	$C + a$	$B + c$	$A + w$
$B + a + w$	$A + d$	D	$C + c - w$
C	$D + c$	$A + a$	$B + d$

($4 – L_1 + L_2 + W$)

3	5	12	14
16	10	7	1
6	4	13	11
9	15	2	8

(5)

A	$A + a$	$A + c$	$A + d$
B	$B + a$	$B + c$	$B + d$
C	$C + a$	$C + c$	$C + d$
D	$D + a$	$D + c$	$D + d$

(6)

$A + w$	$A + a$	$A + c$	$A + d$
B	$B+a+w$	$B + c$	$B + d$
C	$C + a$	$C+c-w$	$C + d$
D	$D + a$	$D + c$	$D+d-w$

(7)

Fig. 1. Constructing the general algebraic formula of a Magic square 4×4.

The more simple construction of the additional table in comparison with the formula 1(2) and the possibility of passing from the additional table to a Magic square suggest solving the analogous problems on constructing the corresponding additional tables instead of solving the problems on constructing Magic squares. Further we shall always perform this replacement of one problem by another.

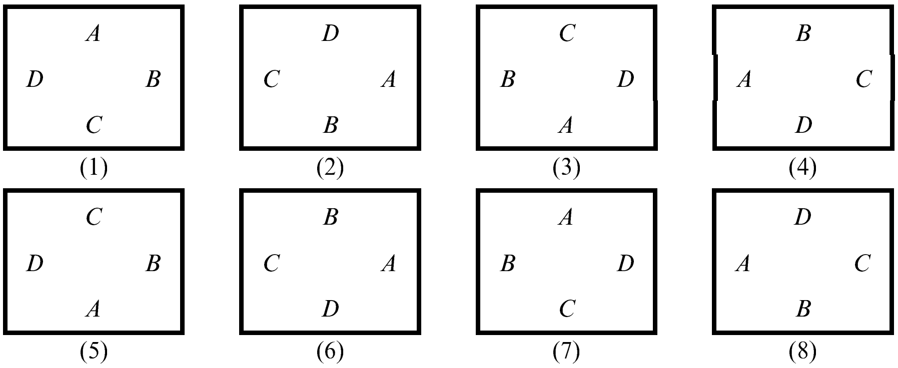
It is easy to establish by algebraic methods [12, 13] that the general algebraic formula of Magic square of order 4 contains 8 parameters. Thus it has one parameter less than the two-component algebraic formula, presented in Fig. 1(2) with $b = 0$. If one takes it into account, then there appears a natural possibility to seek a form for the general algebraic formula of a Magic square 4×4 basing, namely, on this two-component algebraic formula. It seems [7] that for introducing one more parameter in the algebraic formula 1(2) one may add cell-wise this formula to the Magic square, shown in Fig. 1(3) {it can be easily counted that the Magic constant of this square equals zero}. Thus, the general algebraic formula of a Magic square 4×4 {see Fig. 1(4)} is obtained as a result of the mentioned operation. Therefore it may be written in the simple analytical form

$$L_1 + L_2 + W. \qquad (1)$$

By analysing Fig. 1(7), in which the general formula of Magic square 4×4 is presented as the additional table, one may conclude, that the availability of eight but not of seven parameters results in a substantial violation of the simple regularity existing for the elements of the additional table 1(6) and by this reason, changing the problem on constructing a Magic square 4×4 by that on constructing the corresponding additional table, will not result in a facilitation of its solution in the general case {passing from the additional table 1(7) to the general algebraic formula of the Magic square 4×4 1(4) one may realise by means of the classical square 1(5) in the way mentioned above for the additional table 1(6)}.

3 A set of invariant transformations of a Magic square 4×4

By means of rotations by 90 degrees and mappings relative to the sides one can obtain from any Magic square 4×4 seven more new ones {see Fig. 2, from which one can judge on changes of a spatial orientation of a Magic square on the basis of the changes in arrangement of the symbols A, B, C and D}.



1	2	3	4
5	6	7	8
9	10	11	12
13	14	15	16

(9 – M_1)

1	3	2	4
9	11	10	12
5	7	6	8
13	15	14	16

(10 – M_2)

6	5	8	7
2	1	4	3
14	13	16	15
10	9	12	11

(11 – M_3)

6	8	5	7
14	16	13	15
2	4	1	3
10	12	9	11

(12 – M_4)

Fig. 2. A set of invariant transformations of a Magic square 4×4.

Besides for $n \geq 4$ there exist such internal transformations (*M-transformations*) of a Magic square $n \times n$ (permutations of its rows and columns) by which the assigned set of $[n/2]\{(2[n/2] - 2)!!\}$ Magic squares $n \times n$ can be obtained[7] from one square with regard for rotations and mappings, where the symbol

"a!!" means the product of all natural numbers which, firstly, are not exceeding a, and, secondly, coincide with it in an evenness; $[a]$ means the integer part of a. In particular, if the cells of any Magic square 4×4 are enumerated so, as it is shown in Fig. 2(9), and under M-transformations the specific permutations of the cells of the initial square are meant, then, in this case the all 4 possible M-transformations of a square 4×4 can be represented in the form of four tables, depicted in Fig. 2(9 - 12).

It is evident, that when studying Magic squares, constructed from the same set of elements, it is worthwhile, to consider the only squares which can not be obtained from each other by rotations, mappings and M-transformations. It is usually said about such a family of Magic squares, that it is assigned with regard for rotations, mappings and M-transformations.

4 The algorithm for constructing Magic squares from an arbitrary 16 numbers

A complete set of Magic squares 4×4 from an arbitrarily given set of 16 numbers with regard for rotations, mappings and M-transformations one may obtain by the following algorithm[7]:

1. Calculate the sum of all 16 numbers of the given set and, having divided it into 4, obtain the value of the Magic constant S of the future Magic square 4×4;

2. Find all possible presentations of the number S in four different terms each of them belonging to the given set of the numbers;

3. If the number of various partitionings is not smaller than 14, then, using the obtained list of partitionings, form all possible various sets of four Magic rows, containing jointly 16 numbers of the given set;

4. Among the sets of four rows, of the obtained list, find such pairs of the sets which satisfy the following condition: each row of the set has one number from various rows of the other set;

5. It is possible to construct Magic squares 4×4 from the above mentioned pairs, if among the earlier found Magic rows (partitionings of the number S) one succeeds in finding the two rows such that

– these rows do not contain identical numbers;

– each row contains one by one number from various rows both of the first and the second set of the pair.

When constructing Magic squares 4×4 from the obtained pairs of the sets consisting of four rows and the sets of the pairs of the rows corresponding to these pairs one should bear in mind that:

– a four-row pair of sets (see point 4) gives a set of Magic rows and columns for a Magic square 4×4;

– the found pairs of the rows (see point 5) are used for forming the Magic square diagonals;

– if it is necessary to seek for Magic squares with regard for rotations, mappings and M-transformations, then each differing pair of rows, found for the given pair of sets consisting of four rows, can be utilised for construction of only one Magic square 4×4;

– the algorithm can be easy realised as a computer program.

5 Constructing Magic squares from the structured set of 16 elements

We shall say that a Magic square of order 4 possesses *the structure* (contains a structured set of elements) if it is possible to construct from its elements the eight various pairs of elements with the sum equal to 1 /2 of the Magic square constant.

1	2	3	4
5	6	7	8
5	6	7	8
1	2	3	4

(1)

1	2	3	4
5	6	7	8
8	7	6	5
4	3	2	1

(2)

1	2	3	4
5	6	7	8
3	4	1	2
7	8	5	6

(3)

1	2	3	4
1	2	3	4
5	6	7	8
5	6	7	8

(4)

1	2	1	2
3	4	3	4
5	6	7	8
7	8	5	6

(5)

1	2	3	4
1	5	6	4
7	5	6	8
7	2	3	8

(6)

1	2	3	4
3	5	6	2
7	6	5	8
4	7	8	1

(7)

1	2	3	4
5	6	1	7
7	2	8	5
8	6	4	3

(8)

1	1	2	2
3	4	3	4
5	6	7	8
8	7	6	5

(9)

1	2	3	4
3	5	6	1
7	7	8	8
5	6	4	2

(10)

1	2	3	4
5	5	6	6
4	7	8	3
2	8	1	7

(11)

1	2	3	4
5	6	7	8
6	4	8	1
7	3	2	5

(12)

Fig. 3. A complete set of possible structural patterns in a Magic square 4×4, depicted in the implicit form.

For obtaining *the structural pattern* of a Magic square, it is sufficient to connect by lines each pair of the elements, forming this structure, directly in the Magic square. The other (*implicit*) way of representing the structural pattern of a Magic square 4×4 consists of the following: having chosen 8 various symbols we substitute each pair of numbers, forming the Magic square, by any symbol. As it has been proved by analytical methods[5], with account for rotations, reflections and M-transformations none Magic squares 4×4 exist, which contains in its cells 8 even and 8 odd numbers and has structure patterns another than ones shown in the implicit form in Fig. 3(1 – 6). In reality[7, 14] this statement is incorrect because for such Magic squares with respect of invariant transformations there exist 6 more new structure plots, depicted in Fig. 3(7 – 12). Basing on Fig. 3, for all structural patterns we shall construct a complete set of general structural analytical formulae. Thus, in this section we shall solve the problem *on decomposing* the general algebraic formula 1(4) in the structured ones.

I. Here we present a simple method suitable for constructing general algebraic formulae of Magic squares possessing the structural pattern 3(1 - 4). Besides, we point out some singularities of these four general structured analytical formulae.

As it has been established in Sect. 2 the general algebraic formula of a Magic square 4×4 may be represented, as the sum of the two diagonal Latin squares, formed by capital and small Latin letters {see Fig. 1(2)}, and the Magic square {Fig. 1(3)}, having a zero Magic constant. It turns out[7] that general structured algebraic formulae, having structural patterns 3(1 - 4), can be obtained if the required conditions of a structuredness at the fixed structural pattern are written out separately for each of the 3 tables, forming the general algebraic formula 1(4). In particular, diagonal Latin squares 1(2) and the Magic square 1(3) will have structural patterns 3(1 - 4) at the following correlations between their parameters {for convenience, the numbers of the written systems of equations are chosen so that they are identical with the numbers of structural patterns, shown in Fig. 3, by which these equations have been derived}:

$$\begin{array}{llll} 1.\ A+C=B+D, & 2.\ A+B=C+D, & 3.\ A+D=B+C, & 4.\ A+D=B+C, \\ \quad c=a+d. & \quad a=c+d, & \quad c=a+d, & \quad a=c+d, \\ & \quad e=0. & \quad e=0. & \quad e=0. \end{array} \tag{2}$$

Starting from the extracted system of equations (2) one can easily prove that:

1) The cells of an algebraic formula having the structural pattern 3(1) contain two sequences involving elements of the following form:

$$\begin{array}{ll} \text{a)} & a_1+e,\quad a_1+a,\quad a_1+a+d,\quad a_1+d,\quad a_1+b,\quad a_1+a+b+e, \\ & a_1+a+b+d,\quad a_1+b+d; \\ \text{b)} & a_2,\quad a_2+a,\quad a_2+a+d,\quad a_2+d-e,\quad a_2+b,\quad a_2+a+b, \\ & a_2+a+b+d-e,\quad a_2+b+d. \end{array} \tag{3}$$

One can see from a set of sequences (3) that the regularity existing between the symbols of an general algebraic formula, having structural pattern 3(1), is complicated due to the presence of the four elements containing the symbol e {as well as in the general algebraic formula of a Magic square 4×4 shown in Fig. 1(4)}. Consequently, the knowledge of the regularity existing between the elements of the general algebraic formula with structural pattern 3(1) can not be

$a_1 + b + 2c$	$a_1 + b$	$a_2 + c$	$a_2 + 2b + 3c$
$a_2 + b$	$a_2 + b + 2c$	$a_1 + c$	$a_1 + 2b + 3c$
$a_2 + b + 3c$	$a_2 + b + c$	$a_1 + 2b + 2c$	a_1
$a_1 + b + c$	$a_1 + b + 3c$	$a_2 + 2b + 2c$	a_2

(5)

a_2	$a_1 + 2b + c+ d$	$a_1 + c$	$a_2+ 2b + 2c+ d$
$a_2 + b$	$a_1 + b + 2c+ d$	$a_1 + b$	$a_2 + 2c + d$
$a_1+ 2b + 2c+ d$	$a_2 + b$	$a_2 + b + 2c+ d$	a_1
$a_1 + 2c + d$	$a_2 + c$	$a_2 + 2b + c+ d$	$a_1 + 2b$

(6)

$a_2 + b + 2c$	$a_1 + b$	a_2	$a_1 + 2c$
$a_1 + b + 2c$	$a_2 + c$	$a_1 - b + c$	$a_2 + 2b$
$a_1 - b$	$a_2 + 2b + c$	$a_1 + b + c$	$a_2 + 2c$
$a_2 + b$	$a_1 - b + 2c$	$a_2 + 2b + 2c$	a_1

(7)

a_1+2b	a_2+10b	a_1+4b	a_2+4b
$a_2 + b$	a_1+10b	a_2+8b	$a_1 + b$
a_2+9b	a_1	a_2+2b	a_1+9b
a_1+8b	a_2	a_1+6b	a_2+6b

(8)

$a_1 + 4b$	a_1+12b	a_1+10b	a_1+16b
a_1+11b	$a_1 + 8b$	$a_1 + 6b$	a_1+17b
a_1+14b	$a_1 + 7b$	a_1+21b	a_1
a_1+13b	a_1+15b	$a_1 + 5b$	$a_1 + 9b$

(10)

a_1	a_2+8b	a_2	a_1+8b
a_2+6b	a_1+6b	a_1+2b	a_2+2b
a_1+5b	$a_2 + b$	a_2+7b	a_1+3b
a_2+5b	$a_1+ b$	a_1+7b	a_2+3b

(9)

a_1+12b	a_1+16b	$a_1 + 4b$	a_1+10b
a_1+14b	$a_1 + 7b$	a_1+21b	a_1
a_1+11b	$a_1 + 6b$	$a_1 + 8b$	a_1+17b
$a_1 + 5b$	a_1+13b	$a_1 + 9b$	a_1+15b

(11)

$a_1 + 3b$	$(a_1 + a_2)/2 + 3b$	$(a_1 + a_2)/2 - b$	$a_2 + 5b$
$a_2 + 3b$	$a_2 + b$	$a_1 + 5b$	$a_1 + b$
$a_1 + 4b$	a_1	$a_2 + 4b$	$a_2 + 2b$
a_2	$(a_1 + a_2)/2 + 6b$	$(a_1 + a_2)/2 + 2b$	$a_1 + 2b$

(12)

Fig. 4. General algebraic formulae of a Magic square 4×4 with structural patterns 3(5 – 12).

problem on constructing such Magic squares 4×4 from a given structured set of 16 elements is easy to solve by means of these three formulae.

II. Taking into account that for structural patterns 3(1 - 4) there exists a simple method for constructing the general algebraic formulae (see point I) we present in Fig. 4 a set of 8 general algebraic formulae which possess only structural patterns of 3(5 - 12) {the form of representing these formulae is chosen so that it reveals the regularity existing between their elements}. Analysing the analytical formulae presented in Fig. 4 we may come to the following conclusions:

1) among the all above formulae, the formulae 10 and 11 have the most simple structure: the set, consisting of their 16 elements, is completely defined by the first element of the sequence a_1 and the value of the parameter b;

2) the sets of the symbols, contained in the formulae 5, 6, 7, 8 and 9, may be represented in the form of the two identically constructed sequences consisting of 8 elements {the reader can himself get assured that the same holds true also for general algebraic formulae possessing structural patterns 3(2 - 4)};

3) there are two arithmetical sequences, each containing 6 terms and having the same progression difference in the formula 12. Thus, the complication of the regularity, governing the symbols forming the algebraic formula 12, is caused only by four of its elements {compare with the above information concerning the general algebraic formula possessing structural pattern 3(1)}.

The main conclusion which may be drawn from the above written implies that for constructing Magic squares having the structural patterns 3(2 - 12) it is preferable to use the general algebraic formulae of Magic squares 4×4, corresponding to these structural patterns.

6 Four-component algebraic formulae of Magic squares 4×4

1. Four-component algebraic formulae of the classical Magic squares 4×4. Since a classical (Magic) square contains in its cells 16 different natural numbers N ($1 \leq N \leq 16$) then one may write[4, 12] the formula for decomposing the number N in 5 terms:

$$N = 8a + 4b + 2c + d + 1, \tag{4}$$

where the parameters a, b, c and d can assume only two values: either 0 or 1. By means of (4) any classical square 4×4 may be identically decomposed in 4 tables (a-, b-, c-, d-components) each of them containing 8 zeros and 8 units. From theoretical point of view[4] there exist the only three groups of classical squares 4×4:

1) *correct squares* — all the decomposition tables are by themselves Magic squares: they have in all the rows, columns and in the two main diagonals by 2 zeros and 2 units. Further such decomposition tables we shall denote as *A-form.*

2) *regular squares* — at least one of the decomposition tables differs from correct one by existing at least one of the components of the formula, which is necessarily a regular one: each of its rows and columns contains by two zeros and two units, but this condition being not preserved for the main diagonal.

Further such decomposition tables we shall denote as *B-form* if its both main diagonals contain 4 or 0 zeros (units) and *C-form* if its the main diagonals contain 1 or 3 zeros (units).

3) *irregular squares* — at least one of the decomposition tables differs from correct and regular one by existing at least one of the components of the formula has one row or one column where the number of the same symbols of one kind is distinct from two.

a_1	p_1	a_1	p_1
p_1	a_1	p_1	a_1
p_1	a_1	p_1	a_1
a_1	p_1	a_1	p_1

(1) – A_1

a_2	a_2	p_2	p_2
p_2	p_2	a_2	a_2
p_2	p_2	a_2	a_2
a_2	a_2	p_2	p_2

(2) – A_2

a_3	a_3	p_3	p_3
p_3	p_3	a_3	a_3
a_3	a_3	p_3	p_3
p_3	p_3	a_3	a_3

(3) – A_3

a_4	p_4	a_4	p_4
p_4	p_4	a_4	a_4
a_4	a_4	p_4	p_4
p_4	a_4	p_4	a_4

(4) – A_4

a_5	p_5	p_5	a_5
p_5	a_5	a_5	p_5
a_5	p_5	p_5	a_5
p_5	a_5	a_5	p_5

(5) – A_5

a_6	p_6	p_6	a_6
a_6	p_6	p_6	a_6
p_6	a_6	a_6	p_6
p_6	a_6	a_6	p_6

(6) – A_6

a_7	p_7	a_7	p_7
a_7	p_7	a_7	p_7
p_7	a_7	p_7	a_7
p_7	a_7	p_7	a_7

(7) – A_7

a_8	a_8	p_8	p_8
a_8	p_8	a_8	p_8
p_8	a_8	p_8	a_8
p_8	p_8	a_8	a_8

(8) – A_8

c_1	c_1	t_1	t_1
c_1	c_1	t_1	t_1
t_1	t_1	c_1	c_1
t_1	t_1	c_1	c_1

(9) – C_1

c_2	t_2	c_2	t_2
c_2	c_2	t_2	t_2
t_2	t_2	c_2	c_2
t_2	c_2	t_2	c_2

(10) – C_2

c_3	t_3	c_3	t_3
t_3	c_3	t_3	c_3
c_3	t_3	c_3	t_3
t_3	c_3	t_3	c_3

(11) – C_3

c_4	c_4	t_4	t_4
t_4	c_4	t_4	c_4
c_4	t_4	c_4	t_4
t_4	t_4	c_4	c_4

(12) – C_4

b_1	h_1	h_1	b_1
h_1	b_1	h_1	b_1
b_1	h_1	b_1	h_1
h_1	b_1	b_1	h_1

(13) – B_1

b_2	h_2	h_2	b_2
b_2	h_2	b_2	h_2
h_2	b_2	h_2	b_2
h_2	b_2	b_2	h_2

(14) – B_2

b_3	h_3	b_3	h_3
h_3	b_3	b_3	h_3
b_3	h_3	h_3	b_3
h_3	b_3	h_3	b_3

(15) – B_3

b_4	h_4	b_4	h_4
b_4	h_4	h_4	b_4
h_4	b_4	b_4	h_4
h_4	b_4	h_4	b_4

(16) – B_4

b_5	b_5	h_5	h_5
h_5	b_5	b_5	h_5
b_5	h_5	h_5	b_5
h_5	h_5	b_5	b_5

(17) – B_5

b_6	b_6	h_6	h_6
b_6	h_6	h_6	b_6
h_6	b_6	b_6	h_6
h_6	h_6	b_6	b_6

(18) – B_6

Fig. 5. A set of *A*-, *B*-, *C*-forms, suitable for constructing Magic squares 4×4.

As it can be proved by analytical methods

a) by using A-forms one may construct[4, 12] the only 11 different algebraic formulae of correct Magic squares and with account for rotations and reflections[7] the only 7 following

$$A_1 A_2 A_5 A_6,\quad A_1 A_2 A_3 A_5,\quad A_1 A_3 A_5 A_7,\quad A_1 A_2 A_6 A_7,$$
$$A_2 A_3 A_6 A_7,\quad A_3 A_5 A_6 A_7,\quad A_4 A_5 A_6 A_8, \tag{5}$$

will be different among them, where $A_1 - A_8$ forms are presented in Fig. 5(1 – 8);

b) by using B- and C-forms one may construct[4] with account for rotations, reflections and M-transformations the only 15 different algebraic formulae of regular Magic squares

$$\begin{aligned} &BCAA — && B_1C_1A_2A_3,\quad B_1C_2A_1A_4; \\ &BCBA — && B_1C_1B_2A_2,\quad B_1C_1B_3A_2,\quad B_1C_1B_3A_3,\quad B_1C_1B_4A_3, \\ & && B_1C_2B_2A_1,\quad B_1C_2B_5A_4,\quad B_1C_2B_6A_4; \\ &BCBB — && B_1C_1B_2B_3,\quad B_1C_1B_2B_4,\quad B_1C_1B_3B_4,\quad B_1C_2B_2B_5, \\ & && B_1C_2B_2B_6,\quad B_1C_2B_5B_6, \end{aligned} \tag{6}$$

where $C_1 - C_4$ and $B_1 - B_6$ forms are presented in Fig. 5(9 – 18).

c) for classical squares 4×4 the complete set of four-component algebraic formulae consists of algebraic formulae of the only correct and regular Magic squares[7] {see sets of formulae (5) and (6)}.

2. Four-component algebraic formulae of generalised Magic squares. Denote, first, A-components of a correct Magic square 4×4 by the symbols F_1, F_2, F_3 and F_4; second, the trivial Magic square, whose 16 cells are filled with units, by the symbol E. As it follows from point 1, any correct classical square 4×4 can be represented as the sum of 5 tables (the first 3 tables should be multiplied by 8, 4 and 2):

$$8F_1 + 4F_2 + 2F_3 + F_4 + E. \tag{7}$$

An algebraic generalisation of this notation is the expression

$$\alpha F_1 + \beta F_2 + \sigma F_3 + \delta F_4 + \varepsilon E, \tag{8}$$

which represents the general recording form of a Magic square 4×4 decomposable in the sum of the 4-th A-components. Since the numbers of a classical square 4×4 may be calculated from the formula (4), the formula (8) obviously permits to find the symbols contained in the cells of *the generalised correct* Magic square 4×4. In particular, there exist the following relations

1 — ε, 5 — ε +β, 9 — ε +α, 13 — ε +α +β, (9)
2 — ε +δ, 6 — ε +β +δ, 10 — ε +α +δ, 14 — ε +α +β +δ,
3 — ε +σ, 7 — ε +β +σ, 11 — ε +α +σ, 15 — ε +α +β +σ,
4 — ε+σ+δ, 8 —ε+β+σ+δ, 12 —ε+α+σ+δ, 16 —ε+α+β +σ+δ.

between natural numbers from 1 to 16 and the symbols of the generalised correct Magic square 4×4.

ε	ε + δ	ε + σ	ε + σ + δ
ε + β	ε + β + δ	ε + β + σ	ε + β + σ + δ
ε + α	ε + α + δ	ε + α + σ	ε + α + σ + δ
ε +α +β	ε +α + β +δ	ε +α +β +σ	ε +α +β +σ +δ

(1)

17	29	41	53
47	59	71	83
227	239	251	263
257	269	281	293

(2)

e	*e*+*d*	*e*+*c*	*e*+*c*+*d*
g	*g*+*d*	*g*+*c*	*g*+*c*+*d*
h	*h*+*d*	*h*+*c*	*h*+*c*+*d*
f	*f*+*d*	*f*+*c*	*f*+*c*+*d*

(3)

1	7	67	73
37	43	103	109
157	163	223	229
193	197	257	263

(4)

83	113	293	503
41	71	251	461
281	311	491	701
239	269	449	659

(5)

Components of formula				Correlations
a	*b*	*c*	*d*	between the parameters
A	*A*	*B*	*C*	$c = 2d$,
B	*C*	*A*	*A*	$a = 2b$,
A	*B*	*C*	*A*	$b = 2c$,
A	*B*	*B*	*C*	$b = c + 2d$,
B	*B*	*C*	*A*	$a = b + 2c$,
B	*B*	*B*	*C*	$a = c + b + 2d$.

(6)

Fig. 6. Examples of constructing additional tables for the generalised correct (1–5) and regular (2 – *AABC*, 4 – *ABBC*, 5 – *BBBC*) Magic squares 4×4.

Note that the cells of the table, shown in Fig. 6(1), contain a complete set of the symbols of the generalised correct Magic square 4×4. These symbols are arranged so that the first cell of the table contains the symbol ε, the second one contains the symbols ε + δ and so on. Thus, the mentioned table is *additional* by the definition and permits to construct various algebraic formulae of the generalised correct Magic squares of the fourth order for the assigned correct classical squares 4×4.

Change the form of recording the table 6(1) by introducing the new symbols g, h and f with the correlations $g = \varepsilon + \beta$, $h = \varepsilon + \alpha$, $f = \varepsilon + \alpha + \beta$. The new form of the table is shown in Fig. 6(3). The table 6(3) makes it clear that the rows of the initial additional table of the generalised correct Magic square 4×4 contain the sequences of four numbers formed by the same regularity. Let it be also noted, that the new table (as it may be easily verified) completely corresponds to the initial one only if between its parameters ε, g, h and f the correlation $\varepsilon + f = g + h$ is fulfilled. Thus, for constructing concrete examples of the generalised correct Magic squares, it is necessary to continue the search for the indicated sequences involving four numbers until one finds among their first terms the two pairs of numbers having the same sum.

For example, the generalised correct Magic square 4×4 may be formed from the following eight pairs of prime numbers "the twins": 29, 31; 59, 61; 71, 73; 101, 103; 197, 199; 227, 229; 239, 241; 269, 271.

One also may use the additional table, shown in Fig. 6(1), for constructing the algebraic formulae of *the generalised regular* Magic squares on the basis of the given classical squares 4×4. However, due to the fact that the condition of Magicity is not fulfilled on the diagonals of regular tables (see point 1) for obtaining algebraic formulae of Magic squares in this case one has to assign additional correlations between the parameters of the additional table. For the set (6) of regular formulae of the Magic square 4×4, these necessary correlations between the parameters of the additional table 6(1) have the form, depicted in Fig. 6(6).

It is noteworthy, that for the given type of a four-component regular formula the set of the symbols, positioned in the cells of additional tables of the generalised regular Magic squares 4×4, does not depend upon the form of additional correlations between the parameters of the additional table 6(1), in other words, it does not depend on the position of the *C*-form in the *a*-, *b*-, *c*-, *d*-decompositions of regular formulae. One can be immediately convinced in this by constructing on the basis of Fig. 6(1) all six additional tables for various algebraic formulae of the generalised regular Magic squares 4×4. Thus, if it is possible to construct one additional table for algebraic formulae of the type *AABC* or *ABBC* from the given set involving arbitrary 16 numbers, then it is also possible to construct the other additional tables of Magic squares of the given type, distinct from the above constructed one by the form of additional conditions for the parameters of the table 6(1). With regard for the above stated, only 3 additional tables, filled with prime numbers, for which the reader is referred to Fig. 6(2, 4, 5), suffice for constructing a complete family of different regular Magic squares 4×4.

1367	1468	2358	2457
1457	1458	2368	2367
1368	1467	2357	2458
1358	2467	1357	2468

(1)

2368	1467	2357	1458
2367	1457	1358	2468
2467	1357	1368	2458
1367	1468	2358	2457

(2)

1367	1458	2368	2457
1457	1468	2358	2367
1358	1467	2357	2468
1368	2467	1357	2458

(3)

1367	2368	1458	2457
2367	2358	1468	1457
2468	2357	1467	1358
1368	1357	2467	2458

(4)

1367	1468	2358	2457
1467	1458	2368	2357
1358	1457	2367	2468
1368	2467	1357	2458

(5)

1368	2367	2458	1457
1367	2358	2467	1458
2468	1358	1467	2357
2368	1357	1468	2457

(6)

Fig. 7. Examples of irregular four-component algebraic formulae of Magic squares 4×4.

In conclusion of this section we would like to draw attention that with regard for rotations, mappings and M-transformations there exist[7] 81 irregular four-component algebraic formulae of Magic squares 4×4. For instance, 6 formulae of such type are presented in Fig. 7 {for splitting the formulae, shown in Fig. 7, in four components, it suffices to retain in the formulae, at first, only the digits 1 and 2 (1st component), and then, only the digits 3 and 4 (2nd component), etc.}. Hence, the solution of the problem *on decomposing* the general algebraic formula 1(4) into a complete set of the four-component ones has following form: there are 7 formulae for correct Magic squares 4×4 {with account for rotations and reflections}, 15 and 81 formulae correspondingly for regular and irregular Magic squares 4×4 {with account for rotations, mappings and M-transformations}. Thus, it is *the main conclusion* of this section that the complete set of four-component analytical formulae of Magic squares 4×4 can not simplify the solution of the problem on constructing Magic squares 4×4 from an arbitrary given set of 16 numbers but it can make so for constructing the generalised correct and regular Magic squares 4×4.

7 Summary

As it have been demonstrated in this paper discussed Smarandache type question – whether a possibility exists to construct the theory of Magic squares without using properties of concrete numerical sequences – has the positive answer. However, to construct this theory for Magic squares 4×4 in size, the new type of mathematical problems was necessary to introduce. Indeed, in terms of algebra, any problems on constructing Magic squares without using properties of concrete numerical sequences may be formulated as ones on composing and solving the corresponding systems of algebraic equations. Thus, algebraic methods can be applied for

a) constructing the algebraic formulae of Magic squares;

b) finding the transformations translating an algebraic formula of a Magic square from one form into another one;

c) elucidating the general regularities existing between the elements of Magic squares;

d) finding for an algebraic formula of a Magic square, containing m freely chosen parameters, the equivalent set consisting of L algebraic formulae each containing the number of freely chosen parameters less than m.

The new for algebra the type of mathematical problems is presented in points (b) – (d). It is evident that without introducing these problems the algebraic methods are not effective themselves. For instance, in the common case (see Sect. 2) the general formula of Magic square 4×4 can not simplify the solution of problems on constructing Magic squares 4×4 from an arbitrary given set of 16 numbers. In particular, even when solution of discussed problems is sought by means of a computer, in calculating respect it is more preferable for obtaining the solution to use algorithm, described in Sect. 4, than one, elaborated on the base of the general formula of Magic square 4×4. But by means of decomposing the general algebraic formula of Magic squares 4×4 into complete sets of a defined type of analytical formulae one may decrease the common amount of freely chosen parameters in every such formula and, consequently, substantially simplify the regularity existing for the elements of every formula. In other words, for constructing Magic squares 4×4 from an arbitrary given set of 16 numbers there appears a peculiar possibility of using the set algebraic formulae with more simple structure instead of use one complex algebraic formula Magic square 4×4.

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Prime Magic Squares

ABSTRACT

A meta-sequence is defined to be a sequence consisting of k sub-sequences, with each sub-sequence containing k equally spaced elements. Two methods of generating prime magic squares, the Agrippe method and the knight's move method, are detailed and contrasted. The knight's move method is shown to be superior for certain cases, and is shown to be useful for generating magic squares from meta-sequences of numbers. It is conjectured that arbitrarily long meta-sequences of prime numbers exist, and may be used to generate prime magic squares. A 7×7 prime magic square is presented.

DEFINITION: *Arithmetic Sequence:* A sequence of natural numbers of the form $a + nd$, where a and d are fixed, and n is the cardinal position of the element in the sequence. For example, for the arithmetic sequence $S_i = \{s_0, s_1, s_2, s_3\} = \{3, 5, 7, 9\}$, we have $a = 3$, and $d = 2$. a is the *base* of the sequence, and d is the *distance* between elements of the sequence. The cardinality of a sequence may also be refered to as its *length.*

DEFINITION: *Meta-sequence:* A sequence composed of arithmetic sequences (called *sub-sequences*) of equal length and distance. The number of sub-sequences in a meta-sequence is equal to the number of elements in each sub-sequence. $M = \{S_0, S_1, ..., S_k\}$, where $S_i = \{s_i + 0d, s_i + 1d, ..., s_i + (k-1)d\}$. Notice that S_i is a sub-sequence, and s_i is an element of that sub-sequence. s_i is different for each element of the meta-sequence, but d is constant for all of them.

NOTE: A sequence with cardinality n^2 may be considered a meta-sequence with n elements.

DEFINITION: *Magic Square:* An $n \times n$ matrix which has the same sum (called the *magic sum*) for every row, column, and full diagonal.

DEFINITION: *Prime Magic Square:* A magic square comprised entirely of (unique) prime numbers.

Magic squares have been present in mathematics for thousands of years, and a treatment of their variations can be found in many recreational mathematics texts. This paper addresses the topic of $2n + 1$ by $2n + 1$ magic squares in general, and that of prime magic squares in particular.

As described in the definition, a magic square is comprised of a matrix which has a sequence of numbers, say from 1 to 9, placed within smaller square which subdivide it. Below is a typical magic square for the numbers 1 through 9.

4	9	2
3	5	7
8	1	6

The magic sum for this magic square is 15.

There are a plethora of different algorithms for generating magic squares. Two of the most common are the diagonal method described by Agrippe, and the knight's move method. The Agrippe diagonal method is used for making odd squares (squares with an odd side length) of any size from a single sequence. A basic outline of the Agrippe diagonal algorithm is as follows:

The Agrippe Diagonal Method

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1) Place the least element of the sequence in the square directly beneath the center sub-square.

2) Move diagonally downward to the right, (wrapping around where necessary), filling in the next box, if empty, with the next sequence element.

3) When a full box is encountered, move diagonally one box down and to the left from the full box, and proceed normally.

In this manner the entire square will be filled in, and the result will be a magic square.

Agrippe's diagonal method creates magic squares with several predictable properties. Obviously, the smallest element in the sequence will always be directly beneath the center of the square. Less obviously, the center square will contain the median of the sequence, and the square directly above the center will contain the greatest element of the sequence.

Agrippe's diagonal method suffices for creation of magic squares from a single sequence, and from the special case of a degenerate meta-sequence, that is, a meta-sequence which is also a sequence. However, in the case that a meta-sequence is not also a sequence, the algorithm described previously will fail. Thus, if we desire to create a magic square of prime numbers, we must find a sequence which is $3 \times 3 = 9$ long, or $5 \times 5 = 25$ long, and so forth. Since the longest arithmetic sequence of primes yet discovered is only 19 elements long, and begins in the billions, and since Agrippe's algorithm yields only a single magic square for a given sequence, the possibilities using known sequences are quite limited.

The knight's move algorithm, however, will generate a magic square from a meta-sequence. Thus, if we can find a meta-sequence with seven elements (see example in Appendix A), we have more options available to us. Here is the knight's move algorithm.

Knight's Move Algorithm

Given: for $\{n \geq 2, z = 2 \cdot n + 1, 3 \not| z\}$, A meta-sequence $M = \{S_0, S_1, .., S_z\}$.

1) Begin at any square, with $i = j = 0$.

2) Place $(S_i)_j$ in the current square.

3) Move two squares to the right, one square upwards

4) Increment j. If $j < z$, goto 2).

5) Move two squares downward, one square to the left.

6) Increment i. set $j = 0$. If $i < z$, goto 2).

One especially nice aspect of the knight's move algorithm is the ability to "begin" at any square of the matrix, and to use the sub-sequences of the meta-sequence in ANY order, so long as the order of the elements in the sub-sequence is preserved! Thus, for a meta-sequence of cardinality 5, since there are 5^2 possible starting positions, and $4 \cdot 3 \cdot 2 \cdot 1$ possible orderings of the 5 sub-sequences (don't forget the first is considered anchored since we are counting it as being able to start anywhere in the magic square), there are $5 \cdot 5 \cdot 4 \cdot 3 \cdot 2 \cdot 1 = 5 \cdot 5! = 600$ different magic squares! For a meta-sequence of cardinality 11, there would be $11 \cdot 11!$ different magic squares, or $439,084,800$ combinations. That's right, you can throw away the crossword puzzle book, there's a new calling in life!

A few practice runs with arbitrarily selected meta-sequences should be enough to convince you of the validity of the knight's move method. However, the *reason* it works is worth examining.

As mentioned earlier, a meta-sequence is comprised of z sub-sequences, with each sub-sequence containing z elements. When the knight's move algorithm is applied, this will generate a $z \times z$ magic square. Our magic sum – the sum of any row, column, or diagonal – is the mean of the entire meta-sequence.

Let us take the case of a meta-sequence of cardinality 5.

$$\begin{aligned} M = \{ \ & S_0 = \{a_0, a_1, a_2, a_3, a_4\}, \\ & S_1 = \{b_0, b_1, b_2, b_3, b_4\}, \\ & S_2 = \{c_0, c_1, c_2, c_3, c_4\}, \\ & S_3 = \{e_0, e_1, e_2, e_3, e_4\}, \\ & S_4 = \{f_0, f_1, f_2, f_3, f_4\} \\ & \} \end{aligned}$$

A magic square generated with the knight's move algorithm, starting in the upper left hand corner, would appear as pictured below. Note that this starting position, because of the nature of the meta-sequence, does not cause loss of generality with respect to starting position and sub-sequence order.

a_0	c_4	f_3	b_2	e_1
f_2	b_1	e_0	a_4	c_3
e_4	a_3	c_2	f_1	b_0
c_1	f_0	b_4	e_3	a_2
b_3	e_2	a_1	c_0	f_4

Examination of this square reveals that there is exactly one element from each sub-sequence in each row and column, and on each full diagonal. Furthermore, no two elements in a given row, column, or diagonal have the same position in their respective sub-sequences, as denoted by the subscript. Recall that since M is a meta-sequence, $S_0 = \{a + 0d, a + 1d, a + 2d, ...\}$ where d is a constant, the distance for ALL the sub-sequences. Since for $\{a_0 = a + nd, 0 \leq a < z\}$, a is present in all sums, we may remove a from the square without changing the difference between sums. This principal may be extended to all the elements in the magic square, leaving us with

$0d$	$4d$	$3d$	$2d$	$1d$
$2d$	$1d$	$0d$	$4d$	$3d$
$4d$	$3d$	$2d$	$1d$	$0d$
$1d$	$0d$	$4d$	$3d$	$2d$
$3d$	$2d$	$1d$	$0d$	$4d$

Again, since d is present in each box of the square, we may remove it to the outside of the magic square as a multiplier.

$d \times$

0	4	3	2	1
2	1	0	4	3
4	3	2	1	0
1	0	4	3	2
3	2	1	0	4

It is now obvious that the sum of each row, column, and main diagonal is identical, and so we have a genuine magic square! This principal applies to ALL odd magic squares generated by the knight's move algorithm, subject to the algorithm's constraints.

Why doesn't the knight's move algorithm work for side lengths divisible by three? An excellent question! In those cases, the row and column sums are all equal to the magic sum. However, when it comes time to add up the diagonals, the diagonal totals are different from the magic sum.

Let us take a closer look at how a sub-sequence gets distributed in the magic square by examining 7×7 and 9×9 examples with the first subsequence entered, starting from the bottom left corner.

				a_6		
		a_5				
a_4						
					a_3	
			a_2			
	a_1					
						a_0

						a_8		
				a_7				
		a_6						
a_5								
							a_4	
					a_3			
			a_2					
	a_1							
								a_0

Notice that in the 7×7 square only one element is on the diagonal, while in the 9×9 square, three elements are on the diagonal. The reason for this is difficult to find, but easy to see once it's revealed.

THEOREM: A magic square cannot be made using the knight's move algorithm for a meta-sequence if three divides the cardinality of the meta-sequence.

Proof: Think of a would-be magic square as a cartesian grid with the origin $(0, 0)$ contained in the lower left-hand box, and the square diagonally opposite it being $(z-1, z-1)$. One of the diagonals extends from $(0, z-1)$ to $(z-1, 0)$, and is composed of every point (s, t) where $s+t = z-1$. Suppose we're dealing with a grid where $z = 3n$, and a magic square exists for this grid. We know a single move will change our position (s, t) by $(+2, +1)$. We also know that we have a total of $(z-1)$ moves, not including returning to our starting position of $(z-1, 0)$. We are looking for all $i, 0 \leq i \leq (z-1)$, such that $((z-1)+2i)+(0+i) = z-1$. This simplifies as follows (remember, we're working in MOD z):

$$(z-1)+2i+0+i = z-1$$
$$3i = 0$$

Obviously, 0 is a solution. As well, if 3 divides z, there will be two other solutions, n and $2n$. Since we can have at most one element from a subsequence on a diagonal, we have a contradiction, QED.

Now that the basics of constructing magic squares from meta-sequences have been covered, we can move on to the method of generating meta-sequences of prime numbers.

Part 2: Arithmetic Sequences of Prime Numbers

Prime magic squares have been constructed, but the examples published before this paper have been quite small, 3×3 being the usual limit. Since the longest arithmetic sequence of primes yet discovered contains 19 elements, this would limit the size of the magic squares we could compose with the two methods discussed in this paper to 3×3. However, if we could find meta-sequences of primes, we could construct a larger square. This is not as impossible as it sounds: we have found meta-sequences of cardinality 7. Unfortunately, the time required to find a meta-sequence increases exponentially with respect to the cardinality of the meta-sequence. With a modicum of computer time (several thousand CPU hours on a relatively fast mini-computer), it should be possible to find prime meta-sequences of cardinality 11.

How do we know such meta-sequences exist?

CONJECTURE: There exist meta-sequences of cardinality k for finite k.

This conjecture is based upon the following theorem, and examples up to $k = 9$. Dirichlet $[1837]$ *If* $d \geq 2$ *and* $a \neq 0$ *are integers that are relatively prime, then the arithmetic progression*

$$a, a + d, a + 2d, \dots$$

contains infinitely many primes.

Clearly, if a is a prime number, we are guaranteed of generating a sequence containing an infinite number of primes for all values of d. We conjecture that it is not unreasonable to expect short sub-sequences within this infinite sequence to be composed of primes.

One difficulty with this conjecture is the size of the numbers involved in the meta-sequences. It was shown by Cantor that for an arithmetic sequence of n primes, the distance d must be divisible by the product of all primes less than or equal to d (unless the sequence begins with n in the event n is a prime number). In other words, a sequence of seven primes must have a distance $d = (2 \cdot 3 \cdot 5 \cdot 7) \cdot k$, except for the special case already noted. While this makes the search for large sequences easier in terms of primes which need to be checked, the direct implication is that the distance for larger sequences is ENORMOUS: for a sequence of 23 primes, excepting the case of a sequence beginning with 23, if it exists, you would have a minimum distance of $223{,}092{,}870$ between elements, for a minimum sequence span of just under five billion! Even on a supercomputer, the calculations required to find these sequences would be prohibitive.

Assuming this conjecture is correct, it is possible to make arbitrarily large prime magic squares, with the knight's move method enabling us to generate significantly larger squares per unit of computer time than Agrippe's method. An example of a 7×7 sequence prime magic square is given below. If you are interested in the source code used to verify the magic squares and to find the meta-sequences, do not hesitate to contact either of the authors.

For more information about all aspects of prime numbers *The Book of Prime Number*

Records by Paulo Ribenboim is an excellent source.

Keywords: Magic Squares; Numbers, prime; mathematics, recreational.

Production of arbitarily large prime magic squares

by

Miller, J., C. Price and J. Knox

DEFINITION: *PAP:* Acronym for *Prime Arithmetic Progression*, a set of primes $S = \{s_0, s_1, ..., s_n\}$, where $s_i = a + id$.

DEFINITION: *Triplet:* A PAP of cardinality 3. In this paper, a triplet is defined as $T = \{t_0, t_1, t_2\} = \{c - d, c, c + d\}$.

DEFINITION: *Magic Square:* A square matrix of numbers for which the sum of each row, column, and main diagonal is identical.

DEFINITION: *Prime Magic Square:* A Magic Square comprised of unique prime numbers.

The production of prime magic squares is typically a haphazard affair, fraught with guesswork and uncertainty. This paper presents an algorithm which should enable a sufficiently determined person to produce arbitrarily large odd prime magic squares. The approach we introduce is inspired by the 13×13 prime square created by an unknown prisoner and presented in

This square possesses many notable attributes:

1) *Pairwise symmetry.* Subject to certain constraints, each element of the square has a *partner* equidistant from the center, such that the average of the element and its partner is equal to the mean of the square.

2) *Position of the mean.* The mean of all elements in the square is the center element of the square.

3) *Construction by layers.* If the outside layer of the square is removed, the remaining square is still a magic square. In other words, this 13×13 square actually contains 5 smaller magic squares, one square each of $11 \times 11,\ 9 \times 9,\ 7 \times 7, 5 \times 5$ and 3×3, all nested about the same center element.

As a consequence of (1) and (2), we find that a given element, its partner, and the center (of a magic square of this form) comprise a triplet, $S_i = \{c - d_i, c, c + d_i\}$. Thus, for the case of the 13×13 prime magic square, we have $(13^2 - 1)/2 = 84$ triplets, each of which have the same c, namely the center element of the square.

Since traits (1),(2) and (3) are applicable to the construction of other prime magic squares, we shall employ arguments valid for all odd sized squares of size 3x3 or larger.

Divide a given square into four quadrants, with the two main diagonals comprising the borders of those quadrants. Note that the border elements are not considered members of any quadrant. We number the quadrants **I** through **IV**, proceeding counter-clockwise from the right quadrant.

The symmetry constraints are as follows:

(a) Elements on the borders are mirrored around the center of the square. For a given i for which S_i is comprised of border elements, the least and greatest elements of S_i are on the same diagonal, equidistant from the center of the square.

(b) The partner of a given element in **I** is located in **III**, in the same row, and the two are an equal number of columns from the center.

(c) The partner of a given element in **II** is located in **IV**, in the same column, and the two are an equal number of rows from the center.

Since c is present an element in every element of the square (via our definition of triplet), we may reduce each triplet to the form $S_i = c + \{-d_i, 0, d_i\}$ without affecting the inter-relationship of the sums of the square.

An example of each rule is given below:

					e		
		a					
		$-b$			$-d$	b	
$[c]+$				0			
			d				
						$-a$	
					$-e$		

This symmetry has special and quite desirable consequences. When the square is expressed in this form, the magic sum is zero. It is possible to achieve this sum by breaking the problem into smaller segments, but the discussion of this process is detailed, and so we shall limit our scrutiny to the sums of rows, and assume the properties described are applicable to the columns as well.

Let r_i denote an element of quadrant **I** or **III**, v_i an element of quadrant **II** or **IV**, and b_i an element of one of the two borders. The sign of a symbollic element (i.e. $-r_x$ does not imply that the element itself is not negative (ex: $-r_x = -(-7) = 7$).

A typical row appears as follows:

r_0	r_1	$\ldots$	r_i	b_0	v_0	v_1	$\ldots$	v_j	b_1	$-r_i$	$\ldots$	$-r_i$	$-r_0$

Because of the pairwise symmetry of **I** and **III**, the R_i triplets provide no net contribution to the row sum. Thus, we may restrict our efforts to solving the following equation:

$$\left(\sum_{k=0}^{j} v_k \right) + b_0 + b_1 = 0$$

Note that vertical symmetry guarantees simultaneous solution of the corresponding row on the other side of the center.

The solution for each row is not unique. From a given set of triplets we may derive many different magic squares. An obvious question to ask is whether we are assured of a magic square for a given set of triplets or not.

The answer is "no", but fair utilization of the triplets around a given prime may be expected. Results obtained so far range between 50% and 70% utilization: In other words, if we have 80 triplets, it is not unreasonable to expect to be successful generating a 9×9 prime magic square using 40 of those triplets.

An important question, then, is to determine where to start looking. We can make an estimate of the number of triplets centered about n. Let $N_2(n)$ be the number of pairs of primes $\{n_1, n_2\}$ such that $n_1 < n_2 \leq n$. From Grosswald [1982], we have the asymptotic form $N_2(n) \sim \frac{1}{2} n/\log^2 n$, the trivial extension of the asymptotic form for the number of primes less than n, $N_1(n) \sim n/\log n$. Now let n be the (common) second element for a set of triplets. The set of all pairs of primes less than or equal to n can be subdivided into: the set of all pairs of primes less than n; the lesser two elements of the members of the set of triplets; and other pairs of primes having upper element equal to n. So $N_2(n) - N_2(n-1)$ will be an estimate (strictly, it should be an upper bound, but see below) to the number of triplets centered about n. Let $f(x) = \frac{1}{2} x/\log^2 x$. The first derivative of $f(x)$ is $f'(x) = f(x) \cdot (\frac{2}{x}) \cdot (\frac{\log x - 1}{\log x}) \sim \frac{2}{x} f(x)$ and in general $f^{(m)}(x) \sim \frac{2m!}{x^m} f(x)$. Then for large x, $f(x) - f(x-1) = \sum_{m=1} (-)^{m-1} f^{(m)}(x) \sim x/\log^2 x$. So we estimate $N_t(n)$, the number of triplets centered on n, to be $N_t(n) \sim n/\log^2 n$. This estimate is borne out numerically, as shown by the following short table.

n	$N_t(n)$	$n/\log^2 n$
227	10	7.7
6491	100	84
166000	1250	1149

[Curiously, the number of *twin primes* (pairs of primes of the form $\{p-2, p\}$) less than n is given asymptotically by $1.5n/\log^2 n$.]

To generate a 33×33 magic square, $\frac{1}{2}(33^2 - 1) = 544$ triplets would be required. Doubling this (we assume that the algorithm is only 50% efficient in utilizing the available triplets), and inverting N_t, one needs to look for triplets centered about the next prime after $N_t^{-1}(1088) \approx 155000$, which is 155501, the 14314^{th} prime.

After we have this list, it should be possible to generate a 33×33 square, using the algorithm listed below. We assume the triplets are already generated, and that size desired has been determined.

Triplet's Algorithm

---

1) Set $worksize = SIZE$
2) Set $counter = worksize$
3) While ($counter\ mod\ 4 \neq 0$) and ($worksize > 5$)
   (a) Find triplets with differences a, b, d, s.t. $a + b = d$
   (b) If solved, place triplets on left and right sides of current work square.
   (c) If not solved, quit.
   (d) Decrement $counter$ by three.
4) While ($counter > 0$) and ($worksize > 5$)

   (a) Find triplets with differences a, b, e, f, s.t. $a + f = b + e$.

   (b) If solved, place triplets on left and right sides of current work square.

   (c) If not solved, quit.

   (d) decrement $counter$ by four.

5) If ($worksize \leq 5$), use special solves for square.

6) $counter = worksize$.

7) Loop through left side,trying all permutations of two elements (C_1, C_2) as possible corners.

   (a) $z = C_1 + C_2$. Find triplets a, b, e s.t. $a + z = b + e$

   (b) If solved, fix corners and place triplets. decrement counter by three.

   (c) If not solved, next permutation.

8) If not solved for corners, quit.

9) Repeat (3) and (4) above.

10) Decrement $worksize$ and go to (2).

The asthetics of this algorithm leave something to be desired, but it works, and works relatively quickly. We were able to generate a 41×41 prime magic square using less than two hours of CPU time on a VAX 8800. After completing the square, the only problem remaining was figuring out a presentable way to print it.

For anyone interested in using "spare" computer time to generate large prime squares, we offer our source code, which may either be acquired through the academic computer networks (internet and BITNET), or mailed on a 5.25" MS-DOS floppy, if you provide the floppy, a mailer, and postage. Electronic inquiries should be directed to *fuprime@acad3.fai.alaska.edu,* or *FUPRIME@ALASKA.BITNET.* Floppies, along with requests, should be sent to

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MAGIC CUBES

Marián TRENKLER

Since antiquity mathematicians (and not only them) have taken interest in constructing magic squares. Probably the first magic square ever created is the one shown in Fig.1. Its origin is shrouded in the mystical legends of ancient China. It became to be known as *Luo Shu (Luo river writing)*. There was no clear connection between this configuration and mathematical study until the time of *Yang Hui*, even though it was described in the sixth century. Another very famous magic square (Fig. 2) is in the paiting *Melancholy* ([3], p. 6) made by the famous renaissance artist *Albrecht Dürer* in 1514 (the year is formed in the middle of the lowest row).

4	9	2
3	5	7
8	1	6

Figure 1

16	3	2	13
5	10	11	8
9	6	7	12
4	15	14	1

Figure 2

A *magic square* of order n is a square matrix (square table) of order n containing natural numbers $1, 2, 3, \dots, n^2$ such that the sum of the numbers along any row, column, or main diagonal is a fixed constant. It is easy to see that this constant in a square of order n is $\frac{n(n^2+1)}{2}$.

In [3] and elsewhere we can find constructions of magic squares of order n for all natural numbers $n \neq 2$.

A generalization of magic squares are magic cubes. In Fig. 3 a magic cube of order 4 is depicted.

Definition. A *magic cube* of order n is a 3-dimensional matrix

$$\mathbf{Q}_n = [\mathbf{q}(i,j,k);\ 1 \le i,j,k \le n]$$

containing natural numbers $1, 2, 3, \dots, n^3$ such that

$$\sum_{x=1}^{n} \mathbf{q}(x,j,k) = \sum_{x=1}^{n} \mathbf{q}(i,x,k) = \sum_{x=1}^{n} \mathbf{q}(i,j,x) = \frac{n(n^3+1)}{2} \qquad \text{for all} \quad i,j,k = 1,\dots,n$$

Every element of a magic cube is uniquely determined by a triple of numbers (i,j,k) called coordinates of the element.

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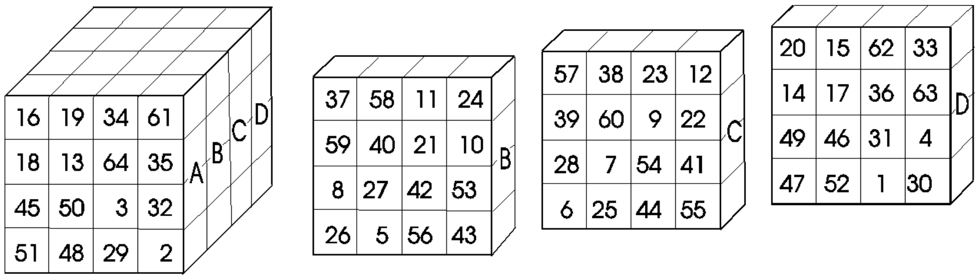

FIGURE 3

A magic square of order 1 is a magic cube of order 1. Because a magic square of order 2 does not exist a magic cube of order 2 does not exist either.

In this paper we prove the following theorem:

Theorem. *For every natural number $n \neq 2$ there exists a magic cube of order n.*

Before we prove this theorem we will consider Latin squares.

A *Latin square* $\mathbf{R}_n = [\mathbf{r}(i,j);\ 1 \leq i,j \leq n]$ of order n is a square matrix of order n such that every row and column is a permutation of the set of natural numbers $\{1,2,\dots,n\}$. Two Latin squares $\mathbf{R}_n = [\mathbf{r}(i,j)]$ a $\mathbf{S}_n = [\mathbf{s}(i,j)]$ of order n are called *orthogonal*, if an n^2 ordered pairs $[\mathbf{r}(i,j), \mathbf{s}(i,j)]$, where $i,j \in \{1,2,\dots,n\}$, are pairwise different.

Two orthogonal Latin squares of order 5 are depicted in Fig.4.

1	2	3	4	5
2	3	4	5	1
3	4	5	1	2
4	5	1	2	3
5	1	2	3	4

1	2	3	4	5
5	1	2	3	4
4	5	1	2	3
3	4	5	1	2
2	3	4	5	1

FIGURE 4

If you look carefully on this pair of orthogonal Latin squares you can easily find the rule for constructing any pair of orthogonal squares for every odd natural number n. This fact was already known to *L.Euler* at the beginning of 18th century. But it was not until 1960 when *R.C.Bose, S.S.Shrikhande a E.T.Parker* proved that two orthogonal Latin squares of order n exist if and only if $n \neq 2, 6$. We use this statement to prove our theorem.

Proof of the Theorem. Let $\mathbf{R}_n = [\mathbf{r}(i,j); 1 \leq i,j \leq n]$ and $\mathbf{S}_n = [\mathbf{s}(i,j); 1 \leq i,j \leq n]$ be two orthogonal Latin squares of order n and $\mathbf{M}_n = [\mathbf{m}(i,j); 1 \leq i,j \leq n]$ be a magic square of order n.

Let us define a magic cube $\mathbf{Q}_n = [\mathbf{q}(i,j,k); 1 \leq i,j,k \leq n]$ in the following way:

$$\mathbf{q}(i,j,k) = [\mathbf{s}(i,\mathbf{r}(j,k)) - 1]n^2 + \mathbf{m}(i,\mathbf{s}(j,k)) \qquad \text{for all } 1 \leq i,j,k \leq n$$

We will prove, in four steps, that $\mathbf{Q}_n$ is a magic cube.

1. All elements of squares $\mathbf{R}_n$ a $\mathbf{S}_n$ are from the set $\{1, 2, \ldots, n\}$ and all elements of $\mathbf{M}_n$ are from the set $\{1, \ldots, n^2\}$. It follows immediately that for all elements $\mathbf{Q}_n$ we have $1 \leq \mathbf{q}(i,j,k) \leq n^3$.

2. In this part we prove that no two elements of $\mathbf{Q}_n$ with different indices are identical. Let us suppose $\mathbf{q}(i,j,k) = \mathbf{q}(i',j',k')$. We show that this implies equalities

$$i = i', \quad j = j', \quad k = k'$$

From the definition of the $\mathbf{Q}_n$ it follows

$$[\mathbf{s}(i, \mathbf{r}(j,k)) - 1]n^2 + \mathbf{m}(i, \mathbf{s}(j,k)) = [\mathbf{s}(i', \mathbf{r}(j',k')) - 1]n^2 + \mathbf{m}(i', \mathbf{s}(j',k'))$$

By rearranging this equality we get

$$-[\mathbf{s}(i, \mathbf{r}(j,k)) - \mathbf{s}(i', \mathbf{r}(j',k'))]n^2 = \mathbf{m}(i, \mathbf{s}(j,k)) - \mathbf{m}(i', \mathbf{s}(j',k')) \tag{1}$$

Because all the elements of $\mathbf{M}_n$ are from the interval $< 1, n^2 >$, their difference is not a non-zero multiple of n^2. On the left is a whole multiple of n^2. Equality in (1) arises if $\mathbf{s}(i, \mathbf{r}(j,k)) - \mathbf{s}(i', \mathbf{r}(j',k')) = 0$. Hence

$$\mathbf{s}(i, \mathbf{r}(j,k)) = \mathbf{s}(i', \mathbf{r}(j',k')) \tag{2}$$

$$\mathbf{m}(i, \mathbf{s}(j,k)) = \mathbf{m}(i', \mathbf{s}(j',k')) \tag{3}$$

In a magic square no two elements are identical. If two elements of $\mathbf{M}_n$ are equal, then both their indices are the same, e.g. from (3) we have

$$i = i', \qquad \mathbf{s}(j,k) = \mathbf{s}(j',k')$$

By substitution $i' = i$ in (2) we get $\mathbf{s}(i, \mathbf{r}(j,k)) = \mathbf{s}(i, \mathbf{r}(j',k'))$. Because $\mathbf{S}_n$ is a Latin square, from the equality of the first indices the equality of the second indices follows, the following is true: $\mathbf{r}(j,k) = \mathbf{r}(j',k')$.

From the assumption that $\mathbf{S}_n, \mathbf{R}_n$ are orthogonal Latin squares and from the relation

$$[\mathbf{s}(j,k), \mathbf{r}(j,k)] = [\mathbf{s}(j',k'), \mathbf{r}(j',k')]$$

we get $j = j', \quad k = k'$.

3. Next we prove that the sum of numbers in every row is the same.

$$\sum_{x=1}^{n} \mathbf{q}(x,j,k) = \sum_{x=1}^{n} [\mathbf{s}(x, \mathbf{r}(j,k)) - 1]n^2 + \sum_{x=1}^{n} \mathbf{m}(x, \mathbf{s}(j,k)) =$$

$$= [\tfrac{n(n+1)}{2} - n]n^2 + n.\tfrac{n^2+1}{2} = n\tfrac{n^3+1}{2}$$

Similarly we get

$$\sum_{x=1}^{n} \mathbf{q}(i,x,k) = \sum_{x=1}^{n} \mathbf{q}(i,j,x) = n\frac{n^3+1}{2}$$

4. The above construction of magic squares is based on the use of two orthogonal Latin squares and therefore is not valid for $n = 6$. The magic cube $\mathbf{Q}_6$ can be found in [4].

Remark 1. If we found out how to construct a pair of orthogonal Latin squares for odd n, then, from the following, we can easily make a computer program which constructs magic cubes for every odd n. You can substitute a magic square $\mathbf{M}_n$ by the square $\mathbf{M}_n^* = [\mathbf{m}^*(i,j)]$, where $\mathbf{m}^*(i,j) = [\mathbf{r}(i,j) - 1]n^2 + \mathbf{s}(i,j)$ for all $1 \le i,j \le n$. In this square the sums on the diagonals need not be the same, therefore we do not use it.

Remark 2. The construction of the magic cube of order 4, shown in Fig.3, was based on the magic square shown in Fig.2 and from two orthogonal Latin squares shown in Fig.5.

1	2	3	4
2	1	4	3
3	4	1	2
4	3	2	1

1	2	3	4
3	4	1	2
4	3	2	1
2	1	4	3

Figure 5

Remark 3. By a generalization of the presented method magic hypercubes of order n ($n \ne 2, 6$) in the p-dimensional Euclidean space ($p \ge 4$) can be constructed. (See [5].)

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A CONSTRUCTION OF MAGIC CUBES

Marián TRENKLER

In this paper a *magic cube* of order n is a 3-dimensional matrix $\mathbf{Q}_n = \{\mathbf{q}_n(i,j,k);\ 1 \le i,j,k \le n\}$, containing natural numbers $1, 2, \dots, n^3$ such that the sums of the numbers along each row (n-tuple of elements having the same coordinates on two places) and also along each of its four great diagonals are the same. This contracts with a previous article [1] which considered magic cubes with no requirement for the diagonal sums.

In Figure 1 a magic cube $\mathbf{Q}_3$ is depicted. The sum of the three numbers in every row is 42. The sums of the numbers on the diagonals (the triplets $\{8,14,20\}$, $\{19,14,9\}$, $\{10,14,18\}$ and $\{6,14,22\}$) are 42 too.

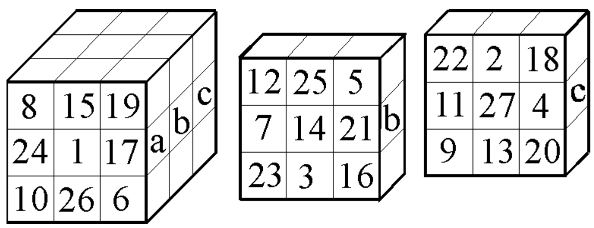

Figure 1 - Magic cube $\mathbf{Q}_3$

Using a pair of orthogonal Latin squares it was proved that such matrices of order n exist for each $n \ne 2$. Probably the first mention of a magic cube (of order 4) appead in a *P.Fermat*'s letter from April 1, 1640 (see [2, p. 365].) More information on magic squares and cubes can be found in books [2] and [3]. In this paper we describe, in three-step, a construction of a magic cube $\mathbf{Q}_n$ for every integer $n \ne 2$. (In a similar way we can construct a magic square $\mathbf{M}_n$ for every integer $n \ne 2$.)

1. If n is an odd integer, then a magic cube $\mathbf{Q}_n$ can be constructed using the following formula

$$\begin{aligned}\mathbf{q}_n(i,j,k) = {} & [(i-j+k-1) - n\lfloor\tfrac{i-j+k-1}{n}\rfloor]n^2 + [(i-j-k) - n\lfloor\tfrac{i-j-k}{n}\rfloor]n \\ & + [(i+j+k-2) - n\lfloor\tfrac{i+j+k-2}{n}\rfloor] + 1.\end{aligned}$$

The symbol $\lfloor x \rfloor$ denotes the integer part of x.

The Mathematical Gazette - March 2000 (súbor:mag_cube.tex)

The formula was derived using two mutually orthogonal Latin squares of odd order n $\mathbf{R}_n = \{\mathbf{r}(i,j) = (i+j+a - n\lfloor\frac{i+j+a}{n}\rfloor\}$ and $\mathbf{S}_n = \{\mathbf{s}(i,j) = (i-j+b) - n\lfloor\frac{i-j+b}{n}\rfloor\}$ where a and b are two constants and the formula is taken from [1, p. 57]. This formula can be rewritten as

$$\mathbf{q}_n^*(i,j,k) = \mathbf{s}(i,\mathbf{s}(j,k))n^2 + \mathbf{s}(i,\mathbf{r}(j,k))n + \mathbf{r}(i,\mathbf{r}(j,k)) + 1.$$

The constants a and b were chosen so that for $m = \frac{n+1}{2}$

$$\mathbf{s}(m,\mathbf{s}(m,m)) = \mathbf{s}(m,\mathbf{r}(m,m)) = \mathbf{r}(m,\mathbf{r}(m,m)) = \tfrac{n-1}{2}.$$

The proof of the correctness of our formula is similar to [1, p. 58]. The sum on every diagonal is the same because for each triple (i,j,k) from the definition of $\mathbf{Q}_n$ it follows ($\overline{x}$ denotes the number $n+1-x$)

$$\mathbf{q}_n(i,j,k) + \mathbf{q}_n(\overline{i},\overline{j},\overline{k}) = \sum_{k=0}^{2}(n-1)n^k + 2 = n^3 + 1$$

and

$$\mathbf{q}_n(\tfrac{n+1}{2}, \tfrac{n+1}{2}, \tfrac{n+1}{2}) = \tfrac{n^3+1}{2}.$$

The sum of numbers on each diagonal is $\frac{(n-1)}{2}(n^3+1) + \frac{(n^3+1)}{2} = \frac{n(n^3+1)}{2}$.

2. If $n = 4k$, $k = 1,2,3,\ldots$, then a magic cube $\mathbf{Q}_n$ can be constructed by the following formulas

$$\mathbf{q}_n(i,j,k) = (k-1)n^2 + (j-1)n + i \quad \text{if} \quad \mathcal{I}(i,j,k) \quad \text{is odd},$$
$$\mathbf{q}_n(i,j,k) = (n-k)n^2 + (n-j)n + (n-i) + 1 \quad \text{if} \quad \mathcal{I}(i,j,k) \quad \text{is even},$$

$$\text{where} \quad \mathcal{I}(i,j,k) = (i + \lfloor\tfrac{2(i-1)}{n}\rfloor + j + \lfloor\tfrac{2(j-1)}{n}\rfloor + k + \lfloor\tfrac{2(k-1)}{n}\rfloor).$$

In Figure 2 a magic cube $\mathbf{Q}_4$ is depicted. The sums of the four numbers in each row are 130. The sums of the numbers on the diagonals (the quadruples $\{1,43,22,64\}$, $\{4,42,23,61\}$, $\{13,39,26,52\}$ and $\{16,38,27,49\}$) are 130 too.

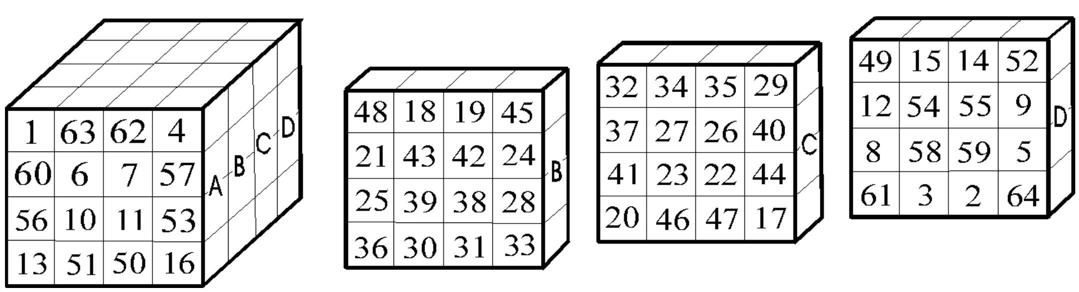

FIGURE 2 - MAGIC CUBE $\mathbf{Q}_4$

The proof of the correctness of our formulas follows from the following three facts

(i) No two elements with different coordinates are the same because $\mathcal{I}(\bar{i},\bar{j},\bar{k})$ is odd if and only if $\mathcal{I}(i,j,k)$ is odd.

(ii) The sums of numbers in the rows are the same because for every odd coordinate i (or j, or k) it holds

$$\begin{aligned} \mathbf{q}_n(i,j,k)+\mathbf{q}_n(i+1,j,k) &= n^3 && \text{or} \quad n^3+2,\\ \mathbf{q}_n(i,j,k)+\mathbf{q}_n(i,j+1,k) &= n^3-n+1 && \text{or} \quad n^3+n+1,\\ \mathbf{q}_n(i,j,k)+\mathbf{q}_n(i,j,k+1) &= n^3-n^2+1 && \text{or} \quad n^3+n^2+1. \end{aligned}$$

In every row there are $\frac{n}{4}$ pairs of elements whose sum is n^3 (or n^3-n+1 or n^3-n^2+1) and the same number of pairs whose sum is n^3+2 (or n^3-n+1 or n^3+n^2+1).

(iii) The sums on the diagonals are the same because for every triple (i,j,k) it is true

$$\mathbf{q}_n(i,j,k)+\mathbf{q}_n(\bar{i},\bar{j},\bar{k}) = n^3+1.$$

3. If $n=4k+2$, $k=1,2,3,\dots$, then a construction of a magic cube $\mathbf{Q}_n$ starts from a magic cube $\mathbf{Q}_{\frac{n}{2}}$ and an auxiliary cube $\mathbf{V}_n=\{\mathbf{v}_n(i,j,k)\}$ of order n. First we describe the construction of $\mathbf{V}_n$. In Figure 3 six layers of $\mathbf{V}_6$ are shown.

0	5	5	0	6	5
3	6	3	6	3	0
3	5	5	0	3	5
6	0	3	6	6	0
6	0	0	6	3	6
3	5	5	3	0	5

1*st* LAYER

7	2	2	7	1	2
4	1	4	1	4	7
4	2	2	7	4	2
1	7	4	1	1	7
1	7	7	1	4	1
4	2	2	4	7	2

2*nd* LAYER

0	5	5	6	0	5
3	6	0	3	3	6
6	0	3	6	6	0
3	5	5	0	3	5
6	0	3	6	6	0
3	5	5	0	3	5

3*th* LAYER

7	2	2	1	7	2
4	1	7	4	4	1
1	7	4	1	1	7
4	2	2	7	4	2
1	7	4	1	1	7
4	2	2	7	4	2

4*th* LAYER

5	0	5	0	6	3
3	6	3	6	3	0
0	3	3	6	3	6
5	6	5	0	0	5
5	0	5	3	3	5
3	6	0	6	6	0

5*th* LAYER

2	7	2	7	1	2
4	1	4	1	4	7
7	4	4	1	4	1
2	1	2	7	7	2
2	7	2	4	4	2
4	1	7	1	1	7

6*th* LAYER

FIGURE 3

This cube consists of 27 cubelets of order 2 each containing the numbers $0,1,\dots,7$ are contained. The arrangements of the numbers in cubelets is such that the sums of numbers in each row and each diagonal are the same, e.i. 21.

If $n = 6(2k+1)$ for $k = 1, 2, 3, \dots$, then $\mathbf{V}_n$ is obtained by the composition of $(2k+1)^3$ copies of $\mathbf{V}_6$ such that

$$\mathbf{v}_n(i,j,k) = \mathbf{v}_6(i - 6\lfloor \tfrac{i-1}{6} \rfloor, j - 6\lfloor \tfrac{j-1}{6} \rfloor, k - 6\lfloor \tfrac{k-1}{6} \rfloor) \quad \text{for all} \quad 1 \le i,j,k \le n.$$

If $n = 6(2k+1)+4$ for $k = 0, 1, 2, \dots$, then our construction starts from $\mathbf{V}_m$, where $m = n - 4$ and six matrices (in pairs of orders $m \times m \times m \times 2$ and $m \times 2 \times 2$ and $2 \times 2 \times 2$) called *blocks.* Blocks

$$\begin{aligned} \mathbf{A} = \{\mathbf{a}(i,j,k)\} \quad &\text{and} \quad \overline{\mathbf{A}} = \{\overline{\mathbf{a}}(i,j,k)\}, \quad 1 \le i,j \le m,\ 1 \le k \le 2, \\ \mathbf{B} = \{\mathbf{b}(i,j,k)\} \quad &\text{and} \quad \overline{\mathbf{B}} = \{\overline{\mathbf{b}}(i,j,k)\}, \quad 1 \le i \le m,\ 1 \le j,k \le 2, \\ \mathbf{C} = \{\mathbf{c}(i,j,k)\} \quad &\text{and} \quad \overline{\mathbf{C}} = \{\overline{\mathbf{c}}(i,j,k)\}, \quad 1 \le i,j,k \le 2 \end{aligned}$$

are defined by relations

$$\begin{aligned} \mathbf{a}(i,j,k) = \mathbf{b}(i,j,k) = \mathbf{c}(i,j,k) &= \mathbf{v}_m(i,j,k), \\ \overline{\mathbf{a}}(i,j,k) = \overline{\mathbf{b}}(i,j,k) = \overline{\mathbf{c}}(i,j,k) &= 7 - \mathbf{v}_m(i,j,k), \end{aligned}$$

for all define elements with coordinates (i,j,k).

The auxiliary cube $\mathbf{V}_n$ consists of a cube $\mathbf{V}_m$, three pairs of blocks $\mathbf{A}$ and $\overline{\mathbf{A}}$, six pairs of $\mathbf{B}$ and $\overline{\mathbf{B}}$ and four pairs of $\mathbf{C}$ and $\overline{\mathbf{C}}$. The blocks $\mathbf{C}$ and $\overline{\mathbf{C}}$ are situated by the vertices of $\mathbf{V}_n$, blocks $\mathbf{B}$ and $\overline{\mathbf{B}}$ are situated by the edges of $\mathbf{V}_n$ and blocks $\mathbf{A}$ and $\overline{\mathbf{A}}$ at the opposite faces of $\mathbf{V}_m$. In Figure 4a there are the first two layers of the auxiliary cube $\mathbf{V}_n$, in Figure 4b there are the x-th, for $x = 3, 4, 5, \dots, n-2$, layers and in Figure 4c there are the last two (the $(n-1)$-th and the n-th) layers.

Every diagonal of $\mathbf{V}_n$ is formed from diagonals of $\mathbf{C}$, $\mathbf{V}_m$ and $\overline{\mathbf{C}}$. It follows from this construction that the sum of numbers in every row and every diagonal of $\mathbf{V}_n$ is greater by 14 than the sum in any row of $\mathbf{V}_m$.

$\mathbf{c}(1,1,x)$	$\mathbf{c}(1,2,x)$	$\mathbf{b}(1,1,x)$	...	$\mathbf{b}(m,1,x)$	$\overline{\mathbf{c}}(1,1,x)$	$\overline{\mathbf{c}}(1,2,x)$
$\mathbf{c}(2,1,x)$	$\mathbf{c}(2,2,x)$	$\mathbf{b}(1,2,x)$	...	$\mathbf{b}(m,2,x)$	$\overline{\mathbf{c}}(2,1,x)$	$\overline{\mathbf{c}}(2,2,x)$
$\mathbf{b}(1,1,x)$	$\mathbf{b}(1,2,x)$	$\mathbf{a}(1,1,x)$	...	$\mathbf{a}(1,m,x)$	$\overline{\mathbf{b}}(1,1,x)$	$\overline{\mathbf{b}}(1,2,x)$
...	...	...	...	...	...	...
$\mathbf{b}(m,1,x)$	$\mathbf{b}(m,2,x)$	$\mathbf{a}(m,1,x)$	...	$\mathbf{a}(m,m,x)$	$\overline{\mathbf{b}}(m,1,x)$	$\overline{\mathbf{b}}(m,2,x)$
$\overline{\mathbf{c}}(1,1,x)$	$\overline{\mathbf{c}}(1,2,x)$	$\overline{\mathbf{b}}(1,1,x)$	...	$\overline{\mathbf{b}}(m,1,x)$	$\mathbf{c}(1,1,x)$	$\mathbf{c}(1,2,x)$
$\overline{\mathbf{c}}(2,1,x)$	$\overline{\mathbf{c}}(2,2,x)$	$\overline{\mathbf{b}}(1,2,x)$	...	$\overline{\mathbf{b}}(m,2,x)$	$\mathbf{c}(2,1,x)$	$\mathbf{c}(2,2,x)$

FIRST AND SECOND LAYER OF $\mathbf{V}_n$, $\quad x = 1, 2.$

$\mathbf{b}(x,1,1)$	$\mathbf{b}(x,1,2)$	$\mathbf{a}(x,1,1)$	$\dots$	$\mathbf{a}(x,m,1)$	$\overline{\mathbf{b}}(x,1,1)$	$\overline{\mathbf{b}}(x,1,2)$
$\mathbf{b}(x,2,1)$	$\mathbf{b}(x,2,2)$	$\mathbf{a}(x,1,2)$	$\dots$	$\mathbf{a}(x,m,2)$	$\overline{\mathbf{b}}(x,2,1)$	$\overline{\mathbf{b}}(x,2,2)$
$\mathbf{a}(x,1,1)$	$\mathbf{a}(x,1,2)$	$\mathbf{v}_m(1,1,x)$	$\dots$	$\mathbf{v}_m(1,m,x)$	$\overline{\mathbf{a}}(x,1,1)$	$\overline{\mathbf{a}}(x,1,2)$
$\dots$	$\dots$	$\dots$	$\dots$	$\dots$	$\dots$	$\dots$
$\mathbf{a}(x,m,1)$	$\mathbf{a}(x,m,2)$	$\mathbf{v}_m(m,1,x)$	$\dots$	$\mathbf{v}_m(m,m,x)$	$\overline{\mathbf{a}}(x,m,1)$	$\overline{\mathbf{a}}(x,m,2)$
$\overline{\mathbf{b}}(x,1,1)$	$\overline{\mathbf{b}}(x,1,2)$	$\overline{\mathbf{a}}(x,1,1)$	$\dots$	$\overline{\mathbf{a}}(x,m,1)$	$\mathbf{b}(x,1,1)$	$\mathbf{b}(x,1,2)$
$\overline{\mathbf{b}}(x,2,1)$	$\overline{\mathbf{b}}(x,2,2)$	$\overline{\mathbf{a}}(x,1,2)$	$\dots$	$\overline{\mathbf{a}}(x,m,2)$	$\mathbf{b}(x,2,1)$	$\mathbf{b}(x,2,2)$

$(x+2)$-*th* LAYER OF $\mathbf{V}_n$, $x = 1, 2, \dots, m$

$\overline{\mathbf{c}}(1,1,x)$	$\overline{\mathbf{c}}(1,2,x)$	$\overline{\mathbf{b}}(1,1,x)$	$\dots$	$\overline{\mathbf{b}}(m,1,x)$	$\mathbf{c}(1,1,x)$	$\mathbf{c}(1,2,x)$
$\overline{\mathbf{c}}(2,1,x)$	$\overline{\mathbf{c}}(2,2,x)$	$\overline{\mathbf{b}}(1,2,x)$	$\dots$	$\overline{\mathbf{b}}(m,2,x)$	$\mathbf{c}(2,1,x)$	$\mathbf{c}(2,2,x)$
$\overline{\mathbf{b}}(1,1,x)$	$\overline{\mathbf{b}}(1,2,x)$	$\overline{\mathbf{a}}(1,1,x)$	$\dots$	$\overline{\mathbf{a}}(1,m,x)$	$\mathbf{b}(1,1,x)$	$\mathbf{b}(1,2,x)$
$\dots$	$\dots$	$\dots$	$\dots$	$\dots$	$\dots$	$\dots$
$\overline{\mathbf{b}}(m,1,x)$	$\overline{\mathbf{b}}(m,2,x)$	$\overline{\mathbf{a}}(m,1,x)$	$\dots$	$\overline{\mathbf{a}}(m,m,x)$	$\mathbf{b}(m,1,x)$	$\mathbf{b}(m,2,x)$
$\mathbf{c}(1,1,x)$	$\mathbf{c}(1,2,x)$	$\mathbf{b}(1,1,x)$	$\dots$	$\mathbf{b}(m,1,x)$	$\overline{\mathbf{c}}(1,1,x)$	$\overline{\mathbf{c}}(1,2,x)$
$\mathbf{c}(2,1,x)$	$\mathbf{c}(2,2,x)$	$\mathbf{b}(1,2,x)$	$\dots$	$\mathbf{b}(m,2,x)$	$\overline{\mathbf{c}}(2,1,x)$	$\overline{\mathbf{c}}(2,2,x)$

$(n-2+x)$-*th* LAYER OF $\mathbf{V}_n$, $x = 1, 2$

FIGURE 4

If $n = 6(2k+1)+8$, than we repeat the previous construction.

We define a magic cube $\mathbf{Q}_n$ by the following relation

$$\mathbf{q}_n(i,j,k) = \mathbf{v}_n(i,j,k)\frac{n^3}{8} + \mathbf{q}_{\frac{n}{2}}(\lfloor \tfrac{i+1}{2} \rfloor, \lfloor \tfrac{j+1}{2} \rfloor, \lfloor \tfrac{k+1}{2} \rfloor).$$

A construction of magic squares

Similarly we can derive that a magic square $\mathbf{M}_n = \{\mathbf{m}_n(i,j);\ 1 \le i,j \le n\}$ of odd order n can be constructed using the following formula

$$\mathbf{m}_n(i,j) = [(i-j+\tfrac{n-1}{2}) - n\lfloor \tfrac{i-j+\frac{n-1}{2}}{n} \rfloor]n + [(i+j+\tfrac{n-3}{2}) - n\lfloor \tfrac{i+j+\frac{n-3}{2}}{n} \rfloor] + 1$$

and for $n = 4k$ by the formulas

$$\begin{aligned} \mathbf{m}_n(i,j) &= (i-1)n + j && \text{if} \quad \mathcal{I}(i,j) \quad \text{is odd,} \\ \mathbf{m}_n(i,j) &= (n-i)n + (n-j) + 1 && \text{if} \quad \mathcal{I}(i,j) \quad \text{is even,} \end{aligned}$$

$$\text{where} \quad \mathcal{I}(i,j) = (i + \lfloor \tfrac{2(i-1)}{n} \rfloor + j + \lfloor \tfrac{2(j-1)}{n} \rfloor).$$

Remark. Analogous formulas can be derived for magic d-dimensional hypercubes of order $n \neq 4k+2$, for every integer $k \geq 1$, and every $d \geq 4$. (See [1].) For example, if $d = 4$ and n is odd, then we start from the formula

$$\mathbf{q}_n^*(i,j,k,l) = \mathbf{s}(i,\mathbf{s}(j,\mathbf{s}(k,l)))n^3 + \mathbf{s}(i,\mathbf{s}(j,\mathbf{r}(k,l)))n^2 + \mathbf{s}(i,\mathbf{r}(j,\mathbf{r}(k,l)))n + \mathbf{r}(i,\mathbf{r}(j,\mathbf{r}(k,l))) + 1.$$

Let $n = 4k+2$ for $k = 1,2,3,\ldots$. Analogously to a magic cube $\mathbf{Q}_n$, we can construct a magic square $\mathbf{M}_n$ of order $n = 4k+2$. It was constructed using $\mathbf{M}_{\frac{n}{2}}$ and an auxiliary square $\mathbf{W}_n = \{\mathbf{w}_n(i,j)\}$. The construction of $\mathbf{W}_n$ starts from $\mathbf{W}_6$ (situated in the middle of Figure 5.) For example, in Figure 5 $\mathbf{W}_{10}$ is depicted which was obtain using $\mathbf{W}_6$. If $n = 6(2k+1)+4$ or $6(2k+1)+8$, then (for preserving the sum of numbers on its diagonals) the last two rows are changed. The elements of $\mathbf{M}_n$ are

$$\mathbf{m}_n(i,j) = \mathbf{w}_n(i,j)\frac{n^2}{4} + \mathbf{m}_{\frac{n}{2}}(\lfloor \tfrac{i+1}{2} \rfloor, \lfloor \tfrac{j+1}{2} \rfloor).$$

1	2	1	2	0	3	0	3	2	1
0	3	0	3	2	1	2	1	3	0
1	0	1	2	0	3	0	3	2	3
2	3	0	3	2	1	2	1	1	0
0	2	3	0	3	0	3	0	3	1
3	1	2	1	2	1	2	1	0	2
0	2	1	0	2	3	0	3	3	1
3	1	2	3	0	1	2	1	0	2
3	0	2	0	1	2	1	2	0	3
2	1	3	1	3	0	3	0	1	2

AUXILIARY SQUARE $\mathbf{V}_{10}$

FIGURE 5

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MAGIC RECTANGLES

Marián TRENKLER

On Figure 1 is depicted a spider web, which consists of three nine-gons and nine rays, which cross in 27 points. On those spots are drawn 27 circlets (dew-drops on a spider web).

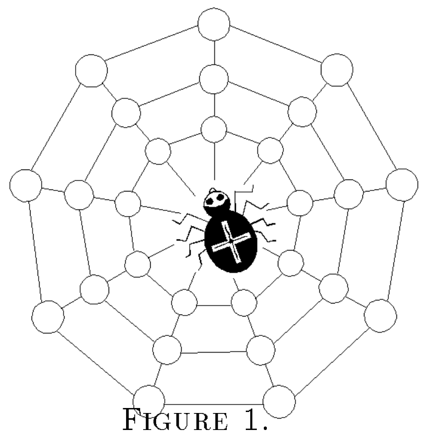

Figure 1.

Problem 1. Inscribe the numbers $1, 2, 3, \ldots, 27$ into the circlets, in such a way, that the sums of numbers on the perimeters of the 9-gons will be the same and also the sums on all the rays will be the same.

Such a problem (a mathematical brain-twister) is usually solved by trial and today we can also use computers. However it would be difficult if we had a web consisting of a hundred 200-gons.

Solution: In Figure 2 is a table consisting of three rows and nine columns. The sums of the numbers in each row and column are the same. If we inscribe the corresponding numbers into the circlets of the web we will get the solution of Problem 1. We explain how the table was made later.

4	18	20	13	27	2	22	9	11
21	5	16	3	14	25	12	23	7
17	19	6	26	1	15	8	10	24

Figure 2.

The Mathematical Gazette - March 1999

Problem 1 can be generalized. Let a spider's web consists of m circles and n rays. We will denote such a web $\mathcal{W}(m,n)$. $\mathcal{T}(m,n)$ will denote a rectangle which consists of $m.n$ squares arranged into m rows and n columns.

Problem 2. Inscribe all the numbers from the set $\{1,2,3,\ldots,mn\}$ into the circlets of the web $\mathcal{W}(m,n)$ so that the sums of numbers in the n-gons are the same and the sums on all the rays are the same.

A spider's web which can be evaluated in this way is called a *magic web* and such valuations are called *magic*. We will consider some pairs of parameters m and n for which the problem has or has not a solution in this paper.

A *magic square* $\mathbf{S}_n$ of order n is an $n \times n$ matrix (square table) containing the natural numbers $1, 2, \ldots, n^2$ in some order, and such that the sum of the number along any row, column, or main diagonal is a fixed constant. In [2] and elsewhere we can find constructions of magic squares of order n for all natural numbers $n \neq 2$. There is not a magic square of order 2, as the reader may easily verify. From the existence of $\mathbf{S}_n$ follows a magic valuation of a web $\mathcal{W}(n,n)$.

In what fallows we will not make use of the diagonal part of thedefenetion of the magic square.

Definition. *A magic rectangle* $\mathbf{M}_{m,n}$ of order m,n is a rectangle $\mathcal{T}(m,n)$ into the squares of which are inscribed all the natural numbers from the set $\{1,2,3,\ldots,mn\}$ when the sums in all the rows are the same and the sums in all the columns are the same.

We can suppose without loss of generality that $m \leq n$. It follows directly from the definition that $\mathbf{M}_{1,1}$ exists and $\mathbf{M}_{1,n}$ does not exist for $n \geq 2$.

A magic rectangle $\mathbf{M}_{m,n}$ is made up from mn squares which we denote as $\mathbf{m}(i,j)$ for $1 \leq i \leq m$, $1 \leq j \leq n$.

The sum of all numbers of a magic rectangle $\mathbf{M}_{m,n}$ is

$$\tau = \sum_{i=1}^{m} \sum_{j=1}^{n} \mathbf{m}(i,j) = \frac{1}{2} mn(mn+1).$$

The sum of all numbers in one row of $\mathbf{M}_{m,n}$ is $\rho = \frac{1}{2} n(mn+1)$ and in each column is $\sigma = \frac{1}{2} m(mn+1)$.

Theorem 1. *If one of the numbers m,n is even and the other is odd, then $\mathbf{M}_{m,n}$ does not exists.*

Proof. Without loss of generality we can suppose that m is even and n is odd. The product $n(mn+1)$ is an odd number and therefore σ is not an integer. This is not possible as σ is a sum of integers. $\square$

In individual proofs we describe constructions of corresponding magic rectangles while leaving the verification to the reader.

Theorem 2. *A magic rectangle* $\mathbf{M}_{2,2k}$ *exists for all* $k > 1$.

Proof. We inscribe numbers $1, 2, 3, \ldots, 2k$ into the first row of table $\mathcal{T}(m, n)$ and numbers $4k, (4k-1), (4k-2), \ldots, (2k+1)$ into the second one. The sums of numbers in all the columns (but not rows) will be the same. Differences of pairs of numbers in individual columns are

$$\{(4k-1), (4k-3), \ldots, 11, 9, 7, 5, 3, 1\}$$

and their sum is $4k^2$. If we exchange the pair of numbers in the j-th column the corresponding difference will change its sign and the sum will decrease. We have to show that we can assign the signs of the differences so that their sum becomes zero.

If k is even (so that the number of columns is a multiple of 4), interchange the pair of numbers in column j if and only if $j = 2(\mod 4)$ or $j = 3(\mod 4)$.

Ik k is odd (≥ 3) proceed as in the even case except that in the last six columns the switch is made in the first and third only. □

Theorem 3. *For all* $n > 2$ *a magic rectangle* $\mathbf{M}_{n,n^2}$ *exists.*

Proof. Generate an $n \times n^2$ array as a row, $\mathcal{T}_1, \mathcal{T}_2, \mathcal{T}_3, \ldots, \mathcal{T}_n$ of n $n \times n$ arrays constructed as follows: row $i+1$ of $\mathcal{T}_j$ is simply the first cyclic shift of row i, and for each $j > 0$, the first row of $\mathcal{T}_{i+1}$ is last row of $\mathcal{T}_j$. This inductive definition of the $n \times n^2$ array is completed by giving the first row of $\mathcal{T}_i$. This is $0, n^2, 2n^2, 3n^2, 4n^2, \ldots, (n-1)n^2$.

Now add (as matrices) a magic square $\mathbf{S}_n$ to each of the $\mathcal{T}_i$. The result is a magic rectangle $\mathbf{M}_{n,n^2}$. □

The construction of $\mathbf{M}_{3,9}$ (on Figure 2) is shown below.

4	9	2
3	5	7
8	1	6

0	9	18	9	18	0	18	0	9
18	0	9	0	9	18	9	18	0
9	18	0	18	0	9	0	9	18

THE CONSTRUCTION OF $\mathbf{M}_{3,9}$

Note. There is another magic rectangle $\mathbf{M}_{n,n^2}$ which we can obtain from a magic cube of order n (see [3]) by cutting it into n layers and inserting into an $n \times n^2$ array.

Corollary. *If* a, b *are natural numbers with* $a.b = n > 2$, *then there exists a magic rectangle* $\mathbf{M}_{an,bn}$.

Proof. The case $a = 1$ is just theorem 3.

For $a > 1$ use the same construction as in theorem 3, but arrange the $n \times n$ arrays in the pattern

$$\begin{array}{cccc} \mathcal{T}_1 & \mathcal{T}_2 & \ldots & \mathcal{T}_b \\ \mathcal{T}_{b+1} & \mathcal{T}_{b+2} & \ldots & \mathcal{T}_{2b} \\ & \ldots & \ldots & \\ \mathcal{T}_{(a-1)b+1} & \ldots & \ldots & \mathcal{T}_{ab} \end{array}$$

Theorem 4. *Given magic rectangles* $\mathbf{M}_{m,n}$ *and* $\mathbf{M}_{p,q}$*, a magic rectangle* $\mathbf{M}_{mp,nq}$ *is constructible.*

Proof. Construct the $np \times mq$ array $\mathcal{A}$, partitioned into p rows and q columns of $m \times n$ cells, each of which is $\mathbf{M}_{m,n}$.

Then construct the $mp \times nq$ array $\mathcal{B}$, also partitioned into cells of size $m \times n$. Each cell contains mn identical elements $mn \times [(i,j)$ entry of $\mathbf{M}_{p,q} - 1]$. Then $\mathcal{A} + \mathcal{B}$ is the required magic rectangle. □

It is shown below how a $\mathbf{M}_{6,12}$ is made using a pair of magic rectangles $\mathbf{M}_{2,4}$ and $\mathbf{M}_{3,3}$.

1	7	6	4
8	2	3	5

$\mathbf{M}_{2,4}$

8	1	6
3	5	7
4	9	2

$\mathbf{M}_{3,3}$

57	63	62	60	1	7	6	4	41	47	46	44
64	58	59	61	8	2	3	5	48	42	43	45
17	23	22	20	33	39	38	36	49	55	54	52
24	18	19	21	40	34	35	37	56	50	51	53
25	31	30	28	65	71	70	68	9	15	14	12
32	26	27	29	72	66	67	69	16	10	11	13

$\mathbf{M}_{6,12}$

From the given theorems follows the construction of $\mathbf{M}_{m,n}$ for many pairs of parameters m, n but still there are many pairs of m, n for which we cannot decide whether $\mathbf{M}_{m,n}$ exists. In the following pictures $\mathbf{M}_{3,5}$ and $\mathbf{M}_{3,7}$ are given. You have certainly noticed that the solution of problem 1 is $\mathbf{M}_{3,9}$.

1	10	14	9	6
15	2	7	11	5
8	12	3	4	13

$\mathbf{M}_{3,5}$

1	12	20	8	13	6	17
14	2	10	21	5	16	9
18	19	3	4	15	11	7

$\mathbf{M}_{3,7}$

We conclude with two problem which can be solved by using the previous results.

Problem 3. Prove that $\mathbf{M}_{n,2n}$ exists for all even $n \geq 4$.

Problem 4. Construct $\mathbf{M}_{3,n}$ for some other values of parameter $n \geq 11$.

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A CONSTRUCTION OF MAGIC HYPERCUBES

Marián TRENKLER

Since antiquity mathematicians (and not only them) have taken interest in constructing magic squares. Probably the first magic square ever created is the one shown in Fig.1. Its origin is shrouded in the mystical legends of ancient China. It became to be known as *"Luo Shu" (Luo river writing).* There was no clear connection between this configuration and mathematical study until the time of *Yang Hui*, even though it was described in the sixth century. Another very famous magic square (Fig. 2) is on the paiting *Melancholy* ([3], p. 6) made by the famous renaissance artist *Albrecht Dürer* in 1514 (the year is formed in the middle of the lowest row).

4	9	2
3	5	7
8	1	6

FIGURE 1

16	3	2	13
5	10	11	8
9	6	7	12
4	15	14	1

FIGURE 2

A *magic square of order* n is a square matrix (square table) of order n containing natural numbers $1, 2, 3, \dots, n^2$ such that the sum of the numbers along any row, column, or main diagonal is a fixed constant.

In [3] and elsewhere we can find constructions of magic squares of order n for all natural numbers $n \neq 2$.

A generalization of magic squares are magic hypercubes.

Definition. A *p-dimensional hypercube* $\mathbf{Q}_n^p$ *of order* n is a hypercube of the p-dimensional Euclidean space which consists of n^p elementary congruent (unital) hypercubes.

Every elementary hypercube of $\mathbf{Q}_n^p$ is uniquely determined by an n-tuplet of indices from the interval $< 1, n >$. By a *column* of $\mathbf{Q}_n^p$ we mean an n-tuple of elementary hypercubes whose have at (p-1) places the identical indices.

Definition. A magic square of order n is called a *magic 2-dimensional hypercube* $\mathbf{M}_n^2$ *of order* n. If $p \geq 3$, than a p-dimensional hypercube $\mathbf{Q}_n^p$, whose elementary hypercubes are coordinated by all natural numbers from the interval $< 1, n^p >$ such, that the sum of the numbers along any column is a fixed constant is called a *magic p-dimensional hypercube* $\mathbf{M}_n^p$.

Typeset by $\mathcal{A}\mathcal{M}\mathcal{S}$-TEX

An elementary hypercube with the associative number is called a *element* of a magic hypercube. Every element of $\mathbf{M}_n^p$ we denote by a symbol

$$\mathbf{m}(i_1, i_2, \dots, i_p) \qquad \text{for all} \quad 1 \le i_1, i_2, \dots, i_p \le n$$

The sum in every column of the magic hypercube $\mathbf{M}_n^p$ is $n\frac{n^p+1}{2}$

Before we formulate our result we consider Latin squares.

A *Latin square* $\mathbf{R}_n = [\mathbf{r}(i,j);\ 1 \le i,j \le n]$ *of order* n is a square matrix of order n such that every row and column is a permutation of the set of natural numbers $\{1, 2, \dots, n\}$. Two Latin squares $\mathbf{R}_n = [\mathbf{r}(i,j)]$ and $\mathbf{S}_n = [\mathbf{s}(i,j)]$ of order n are called *orthogonal*, if an n^2 orded pairs $[\mathbf{r}(i,j), \mathbf{s}(i,j)]$, where $i,j \in \{1, 2, \dots, n\}$, are pairwaise different.

Two orthogonal Latin squares of order 5 are depicted in Fig.3.

1	2	3	4	5
2	3	4	5	1
3	4	5	1	2
4	5	1	2	3
5	1	2	3	4

1	2	3	4	5
5	1	2	3	4
4	5	1	2	3
3	4	5	1	2
2	3	4	5	1

FIGURE 3

If you look carefully on this pair of orthogonal Latin squares you will easily find the rule for constructing any pair of orthogonal squares for every odd natural number n. This fact was already known to *L.Euler* at the beginning of 18th century. But it was not until 1960 when *R.C.Bose, S.S.Shrikhande a E.T.Parker* proved that two orthogonal Latin squares of order n exist if and only if $n \ne 2, 6$. We will use this statement to prove our theorem.

A generalization of Latin squares are Latin hypercubes.

Definition. A Latin square of order n is called a *2-dimensional Latin hypercube* $\mathbf{U}_n^2$. If $p \ge 3$, then there a hypercube $\mathbf{Q}_n^p$, whose elements are marked in such a way that in every column is a permutation of numbers from the set $\{1, 2, \dots, n\}$ is called a *Latin p-dimensional hypercube* $\mathbf{U}_n^p$ *of order* n.

In the paper [5] is proved that for all natural number $n \ne 2$ there it exists a magic cube $\mathbf{M}_n^3$. By a generation of the construction in [5] we prove the following theorem:

Theorem.

For all natural numbers $n \ne 2, 6$ *and* $p \ge 2$ *there exists a magic hypercube* $\mathbf{M}_n^p$.

Proof. A magic hypercube $\mathbf{M}_1^d$ of order 1 has only one element and therefore we suppose that $n \ge 2$

We prove the theorem by a construction of the magic hypercube $\mathbf{M}_n^p$, for all natural numbers $3 \le n \ne 6$ and $p \ge 3$. We use the mathematical induction with regard to a dimension of the space p.

Because a magic square of order 2 does not exist a magic hypercube $\mathbf{M}_2^p$ does not exist either. Let us suppose $2 < n \ne 6$.

If $p = 2$, then $\mathbf{U}_n^2$ is a Latin square of order n and $\mathbf{M}_n^2$ is a magic square of order n.

Let $p > 2$.

We suppose that a (p-1)-dimensional Latin hypercube $\mathbf{U}_n^{p-1} = [\mathbf{u}(i_1, i_2, \ldots, i_{p-1})]$ and a magic hypercube $\mathbf{M}_n^{p-1} = [\mathbf{m}(i_1, i_2, \ldots, i_{p-1})]$ are already constructed.

A p-dimensional Latin hypercube $\mathbf{U}_n^p = [\mathbf{u}(i_1, \ldots, i_p)]$ of order n and a p-dimensional magic hypercube $\mathbf{M}_n^p = [\mathbf{m}(i_1, \ldots, i_p)]$ of order n we define, for all $1 \le i_1, i_2, \ldots, i_p \le n$, by the following relations:

$$\mathbf{u}(i_1, i_2, \ldots, i_p) = \mathbf{u}(i_1, i_2, \ldots, i_{p-2}, \mathbf{r}(i_{p-1}, i_p))$$

$$\mathbf{m}(i_1, i_2, \ldots, i_n) = \{\mathbf{u}(i_1, i_2, \ldots, i_{p-2}, \mathbf{r}(i_{p-1}, i_p)) - 1\}n^{p-1} + \mathbf{m}(i_1, i_2, \ldots, i_{p-2}, \mathbf{s}(i_{p-1}, i_p))$$

We need to prove

(a) $\mathbf{U}_n^p$ is a Latin hypercube,
(b) elements of $\mathbf{M}_n^p$ are numbers from the interval $< 1, n^p >$,
(c) no two elements of $\mathbf{M}_n^p$ are equal,
(d) sums of elements in every column $\mathbf{M}_n^p$ are equal.

(a) Because $\mathbf{R}_n$ is a Latin square, both sets

$$\{\mathbf{r}(x, i_p, x) : x = 1, 2, \ldots, n\} \qquad \textit{and} \qquad \{\mathbf{r}(i_{p-1}, x) : x = 1, 2, \ldots, n\}$$

are permutations of all numbers from the interval $< 1, n >$ and therefore

$$\{\mathbf{u}(i_1, i_2, \ldots, i_{p-1}, \mathbf{r}(x, i_p) : x = 1, 2, \ldots, n\}$$

$$\{\mathbf{u}(i_1, i_2, \ldots, i_{p-1}, \mathbf{r}(i_{p-1}, x) : x = 1, 2, \ldots, n\}$$

are permutations on the interval $< 1, n >$. Because $\mathbf{U}_m^{p-1}$ is a Latin hypercube it follows that

$$\{\mathbf{u}(i_1, i_2, \ldots, i_{k-1}, x, i_{k+1}, \ldots, i_{p-2}, \mathbf{r}(i_{p-1}, i_p)) : x = 1, 2, \ldots, n\}$$

is a permutation of the set $\{1, 2, \ldots, n\}$ for all $x = i_1, i_2, \ldots, i_{p-2}$.

(b) All elements of the hypercube $\mathbf{U}_n^p$ are from the set $\{1, 2, \ldots, n\}$ and all elements of $\mathbf{M}_n$ are from the set $\{1, 2, \ldots, n^{p-1}\}$. It follows immediately that for all elements of $\mathbf{M}_n^p$ we have:

$$1 \le \mathbf{m}(i_1, i_2, \ldots, i_p) \le n^p \qquad \text{for all} \qquad 1 \le i_1, i_2, \ldots, i_p \le n$$

(c) Let us suppose that $\mathbf{m}(i_1, i_2, \ldots, i_p) = \mathbf{m}(i'_1, i'_2, \ldots, i'_p)$. We show that this implies $(i_1, i_2, \ldots, i_p) = (i'_1, i'_2, \ldots, i'_p)$.

From the definition of $\mathbf{M}_n^p$ it follows

$$\{\mathbf{u}(i_1, i_2, \ldots, i_{p-2}, \mathbf{r}(i_{p-1}, i_p)) - 1\}n^{p-1} + \mathbf{m}(i_1, i_2, \ldots, i_{p-2}, \mathbf{s}(i_{p-1}, i_p)) =$$

$$\{\mathbf{u}(i'_1, i'_2, \ldots, i'_{p-2}, \mathbf{r}(i'_{p-1}, i'_p)) - 1\}n^{p-1} + \mathbf{m}(i'_1, i'_2, \ldots, i'_{p-2}, \mathbf{s}(i'_{p-1}, i'_p))$$

By rearranging this equality we get

$$-\{\mathbf{u}(i_1, i_2, \ldots, i_{p-2}, \mathbf{r}(i_{p-1}, i_p)) - \mathbf{u}(i'_1, i'_2, \ldots, i'_{p-2}, \mathbf{r}(i'_{p-1}, i'_p))\}n^{p-1} =$$
$$\mathbf{m}(i_1, i_2, \ldots, i_{p-2}, \mathbf{s}(i_{p-1}, i_p)) - \mathbf{m}(i'_1, i'_2, \ldots, i'_{p-2}, \mathbf{s}(i'_{p-1}, i'_p)) \quad (1)$$

On the left (1) is a whole multiple of n^{p-1} and on the right is a difference of two elements of $\mathbf{M}_n^{p-1}$, which is not non-zero multiple of n^{p-1}. From (1) it follows two equalities

$$\mathbf{u}(i_1, i_2, \ldots, i_{p-2}, \mathbf{r}(i_{p-1}, i_p)) = \mathbf{u}(i'_1, i'_2, \ldots, i'_{p-2}, \mathbf{r}(i'_{p-1}, i'_p)) \quad (2)$$

$$\mathbf{m}(i_1, i_2, \ldots, i_{p-2}, \mathbf{s}(i_{p-1}, i_p)) = \mathbf{m}(i'_1, i'_2, \ldots, i'_{p-2}, \mathbf{s}(i'_{p-1}, i'_p)) \quad (3)$$

In $\mathbf{M}_n^{p-1}$ no two elements are identical and therefore from (3) it follows these $(p-1)$ equalities

$$i_1 = i'_1, \quad i_2 = i'_2, \ldots, \quad i_{p-2} = i'_{p-2}, \ \mathbf{s}(i_{p-1}, i_p) = \mathbf{s}(i'_{p-1}, i'_p)$$

By substitution of first $(p-2)$ equalities to (2) we get

$$\mathbf{u}(i_1, i_2, \ldots, i_{p-2}, \mathbf{r}(i_{p-1}, i_p)) = \mathbf{u}(i_1, i_2, \ldots, i_{p-2}, \mathbf{r}(i'_{p-1}, i'_p)) \quad (4)$$

Because $\mathbf{U}_n^{p-1}$ is a latin hypercube, from the equality of the first $(p-2)$ indices in (4) it follows

$$\mathbf{r}(i_{p-1}, i_p) = \mathbf{r}(i'_{p-1}, i'_p)$$

From the assumption that $\mathbf{R}_n$ a $\mathbf{S}_n$ are orthogonal Latin squares therefore from the relation

$$[\mathbf{r}(i_{p-1}, i_p), \mathbf{s}(i_{p-1}, i_p)] = [\mathbf{r}(i'_{p-1}, i'_p)\mathbf{s}(i'_{p-1}, i'_p)]$$

we get

$$i_{p-1} = i'_{p-1} \quad \text{and} \quad i_p = i'_p$$

(d) For all values $k = 1, 2, \ldots, p$ is true

$$\sum_{i_k=1}^{n} \mathbf{m}(i_1, i_2, \ldots, i_{p-2}, i_{p-1}, i_p) = \sum_{i_k=1}^{n} \{\mathbf{u}(i_1, i_2, \ldots, i_{p-2}, \mathbf{r}(i_{p-1}, i_p)) - 1\}n^{p-1} +$$

$$\sum_{i_k=1}^{n} \mathbf{m}(i_1, i_2, \ldots, i_{p-2}, \mathbf{s}(i_{p-1}, i_p)) = \{\tfrac{n(n+1)}{2} - n\}n^{p-1} + n.\tfrac{n^p+1}{2} = n\tfrac{n^p+1}{2}$$

This completed the proof.

Remark. The above construction of magic hypercubes is based on the use two orthogonal Latin squares and therefore is not valid for $n = 6$. The magic cube $\mathbf{M}_6^3$ can be found in [4].

Problem. In our hypercube we do not consider the sums on diagonals. If there exists a magic cube $\mathbf{M}_n^3$ (incidental a magic hypercube $\mathbf{M}_n^p$ for $p \geq 3$) such that the sum on diagonals is constant.

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MAGIC POWERS OF GRAPHS

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(Received October 30, 1995)

Summary: Necessary and sufficient conditions for a graph G that its power G^i, $i \geq 2$, is a magic graph and one consequence are given.

1. INTRODUCTION

In the paper only finite, undirected connected graphs are considered. By a *magic valuation* of a graph $\mathbf{G}$ we mean such an assignment of the edges of $\mathbf{G}$ by pairwise different positive numbers that the sum of assignments of edges meeting the same vertex is constant. A graph is called *magic* if it allows a magic valuation. This notion was introduced by J. Sedláček in [6]. Now, the *i-th power* $\mathbf{G}^i$, $i \geq 2$, of a graph $\mathbf{G}$ is the graph with the same vertex set as $\mathbf{G}$ and such that two vertices of $\mathbf{G}^i$ are adjacent if and only if the distance between these vertices in $\mathbf{G}$ is at most i.

Various properties of $\mathbf{G}^i$ have been studied, such as hamiltonicity, existence of some factors, etc. Some results can be found in [1] and [2] and [5].

Two different characterizations of magic graphs were published in [3] and [4]. Since, except of the complete graph $\mathbf{K}_2$ of order 2, no graph with less than 5 vertices is magic we confine ourselves to graphs of order $n \geq 5$.

By an *I-graph* we mean a graph $\mathbf{G}$ with a 1-factor $\mathbf{F}$ whose every edge is incident with an *end-vertex* (a vertex of degree 1) of $\mathbf{G}$. The symbol $\mathbf{P}_5$ denotes a path of length 5.

The aim of this paper is the following theorem.

Theorem. *Let a graph $\mathbf{G}$ have order $n \geq 5$. The graph $\mathbf{G}^2$ is magic if and only if $\mathbf{G}$ is not an I-graph and it is different from the path $\mathbf{P}_5$. The graph $\mathbf{G}^i$ is magic for all $i \geq 3$.*

2. PROOF OF THE THEOREM

First we shall formulate several necessary definitions. We say that a graph $\mathbf{G}$ is of *type* $\mathbb{A}$ if it has two edges e, f such that $\mathbf{G} - e - f$ is a balanced bipartite graph with the partition V_1, V_2, and the edge e joins two vertices of V_1 and f joins two vertices of V_2. A graph $\mathbf{G}$ is of *type* $\mathbb{B}$ if it has two edges e_1, e_2 such that $\mathbf{G} - e_1 - e_2$ is a graph with two

1991 *Mathematics Subject Classification.* 05C78.
Key words and phrases. magic graph, powers of graph, factor of graph.

components $\mathbf{G}_1$ and $\mathbf{G}_2$ such that $\mathbf{G}_1$ is a balanced bipartite graph with partition V_1, V_2 and $\mathbf{G}_2$ is a non-bipartite graph, and e_i joins a vertex of V_i with a vertex of $V(\mathbf{G}_2)$. As usual, $\Gamma(S)$ denotes the set of vertices adjacent to a vertex in the set S.

The proof of Theorem is an immediate consequence of the following five Lemmas and Theorem 1.

Theorem 1. *(Jeurissen [3].) A non-bipartite graph* $\mathbf{G}$ *is magic if and only if* $\mathbf{G}$ *is neither of type* $\mathbb{A}$ *nor of type* $\mathbb{B}$, *and* $|\Gamma(S)| > |S|$ *for every independent subset* $S \neq \emptyset$ *of* $V(\mathbf{G})$.

Lemma 1. *If* $\mathbf{G}$ *is an I-graph or it is a path* $\mathbf{P}_5$, *then* $\mathbf{G}^2$ *is not a magic graph.*

Proof. Every I-graph of order $2n$ has n end-vertices which form an independent subset S such that $|\Gamma(S)| = |S|$. Let $\mathbf{P}_5$ be a path $v_1v_2v_3v_4v_5v_6$. By omitting the edges v_2v_3 and v_4v_5 from $\mathbf{P}_5^2$ we obtain a bipartite graph which is a graph of type $\mathbb{A}$.

Lemma 2. *If* $\mathbf{G} + e$ *is a graph which arises by adding an arbitrary edge* e *to a non-bipartite magic graph* $\mathbf{G}$, *then* $\mathbf{G} + e$ *is a magic graph.*

The proof follows from Theorem 1 because by omitting an arbitrary edge of a graph of type $\mathbb{A}$ or $\mathbb{B}$ we do not obtain a magic graph.

Let $\mathbf{T}$ be a spanning tree of a graph $\mathbf{G}$. Lemma 2 implies that if the square of $\mathbf{T}$ is magic, then $\mathbf{G}^i$, for all $n \geq 2$, is magic. Therefore, in the next part we shall confine ourselves to graphs which are trees.

Lemma 3. *If* $\mathbf{T}$ *is a tree then* $|\Gamma(S)| \geq |S|$ *for every non-empty independent subset* S *of* $V(\mathbf{T}^2)$.

Proof. Let S be an independent subset of $V(\mathbf{T}^2)$. Then the distance $d(u,v) \geq 3$ in $\mathbf{T}$ for vertices $u, v \in S$, i.e. no vertex of the induced subgraph $\mathbf{H}$ on $V(\mathbf{T}) - S$ is joined with two vertices of S. We choose one internalvertex $w \in V(\mathbf{H})$ and define a mapping f from the set S into $\Gamma(S)$ in the following way: The image $f(v)$ of a vertex v is the vertex such that $d(v,w) - 1 = d(f(v), w)$. The proof follows from the fact that f is an injective mapping.

Lemma 4. *If* $V(\mathbf{T}^2)$ *contains an independent subset* S *such that* $|\Gamma(S)| = |S| = n > 0$, *then* $\mathbf{T}$ *is an I-graph of order 2n.*

Proof. If v is an internalvertex of $\mathbf{T}$ and $v \in S$ then there exists a vertex $z \in \Gamma(v)$ with $d(z,w) = d(v,w) + 1$ (the internalvertex w is chosen in the same way as in the proof of Lemma 3). The vertex z is not an image of any vertex $u \in S$ in the mapping f because in $\mathbf{T}^2$ the vertex v is joined by an edge with all vertices which in $\mathbf{T}$ have the distance 2. This fact together with the proof of Lemma 3 yield that then $|\Gamma(S)| > |S|$.

If an arbitrary end-vertex $t \notin S$, then t is not the image of any vertex of S and so $|\Gamma(S)| > |S|$.

Every vertex of S is joined to at least two vertices of $\mathbf{T} - S$ and so it follows from the assumption $|\Gamma(S)| = |S|$ that every internal vertex is uniquely assigned to a vertex of S.

Lemma 5. *No graph* $\mathbf{T}^2$*, different from* $\mathbf{P}_5^2$*, is a graph of type* $\mathbb{A}$ *or* $\mathbb{B}$.

Proof. First we show that $\mathbf{T}^2$ different from $\mathbf{P}_5^2$ cannot be a graph of type $\mathbb{A}$. We suppose that the order of $\mathbf{T}$ is at least 6, because any graph of type $\mathbb{A}$ has an even order. If $\mathbf{T}$ has a vertex of degree at least 4, then $\mathbf{T}^2$ has, as a subgraph, the complete graph $\mathbf{K}_5$. By omitting an arbitrary pair of edges from $\mathbf{K}_5$ we obtain a graph with chromatic number 3, i.e. a non-bipartite graph. If $\mathbf{T}$ has a vertex of degree 3, then $\mathbf{T}$ contains a subgraph isomorphic to one of the graphs which are depicted in Fig.1. In both cases, by omitting two edges we obtain a subgraph with at least one triangle. If $\mathbf{T}$ is a path $\mathbf{P}_n$, $n \geq 6$, then $\mathbf{T}^2$ has at least 3 edge-disjoint triangles.

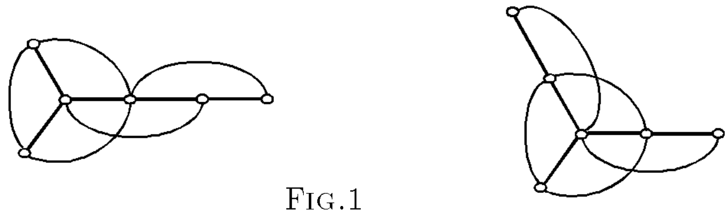

FIG.1

Every graph of type $\mathbb{B}$ is 2-edge-connected. From $\mathbf{T}^2$ we obtain a disconnected graph only if we omit a pair of edges incident with an end-vertex of $\mathbf{T}$ and so the non-bipartite part consists of one vertex while the other part is not a bipartite graph.

3. A CONSEQUENCE OF THE THEOREM

A spanning subgraph $\mathbf{F}$ of the graph $\mathbf{G}$ is called a (1-2)-*factor* of $\mathbf{G}$ if each of its components is an isolated edge or a circuit. We say that a (1-2)-factor *separates edges* e and f, if at least one of them belongs to $\mathbf{F}$ and neither the edge part nor the circuit part contains both of them. In [4] the following theorem is proved.

Theorem 2. *(Jezný, Trenkler) A graph* $\mathbf{G}$ *is magic if and only if every edge belongs to a (1-2)-factor, and every pair of edges* e, f *is separated by a (1-2)-factor.*

From Lemma 3 and Theorem 2 we get the following

Corollary. *Let* $\mathbf{G}$ *be a graph of order* ≥ 5 *and* e *its arbitrary edge. The graph* $\mathbf{G}^i$, $i \geq 2$, *has a (1-2)-factor which contains the edge* e *if and only if* e *is not an internaledge of an* I*-graph and* $i = 2$.

Proof. No pair of end-vertices of an I-graph $\mathbf{G}$ is joined by an edge in $\mathbf{G}^2$ because every (1-2)-factor of $\mathbf{G}^2$ is a 1-factor. The internaledge of an I-graph does not belong to the same (1-2)-factor. Evidently, every edge of $\mathbf{P}_5^2$ belongs to a 2-factor. The sufficient condition follows from Theorem 2.

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CHARACTERIZATION OF MAGIC GRAPHS

Samuel Jezný and Marián TRENKLER

I. Introduction

We shall consider a non-orientable finite graphs $\mathbf{G} = [V(\mathbf{G}), E(\mathbf{G})]$ without loops, multiple edges or isolated vertices. If there exists a mapping f from the set of edges $E(\mathbf{G})$ into positive real numbers such that

(i) $f(e_i) \neq f(e_j)$ for all $e_i \neq e_j;\ e_i, e_j \in E(\mathbf{G})$,

(ii) $\sum_{e\in E(G)} \eta(v,e)f(e) = r$ for all $v \in V(\mathbf{G})$,

$$\text{where } \eta(v,e) = \begin{cases} 1 & \text{when vertex } v \text{ and the edge } e \text{ are incident and} \\ 0 & \text{in the opposite case,} \end{cases}$$

then the graph $\mathbf{G}$ is called *magic.* The mapping f is called a *labelling* of $\mathbf{G}$ and the value r is the index of the label f. We say that a graph $\mathbf{G}$ is *semimagic* if there exists a mapping f into positive real number which satisfies only the condition (ii). If a semimagic graph $\mathbf{G}$ has a label with index r we shall say that $\mathbf{G}$ has index r.

To study magic graphs was suggested by J.Sedláček [3]. Some sufficient conditions for the existence of magic graphs are established in [2], [4] and [5]. A characterization of regular magic graphs in terms of cycles is given by M.Doob [1]. J.Mülbacher [2] used matrix theory to prove two neccesary conditions for existence of magic graphs. These condition are weaker than of theorem 2 of this paper.

First we shall formulate several neccesary definitions.

A subgraph $\mathbf{F} = [V(\mathbf{F}), E(\mathbf{F})]$ is called a *factor* of $\mathbf{G}$ if the sets $V(\mathbf{G})$ and $V(\mathbf{F})]$ are the same. A factor $\mathbf{F}$ is a (1-2)-*factor* if each of its components is a regular graph of degree one or two. By symbol $\mathbf{F}^1$, resp. $\mathbf{F}^2$ we denote the subgraph of $\mathbf{F}$ which consists of all isolated edges, or of all cycles of $\mathbf{F}$ and the neccesary vertices, respectively. We say that a (1-2)-*factor separates* the edges e_1 ans e_2, if at least one of them belongs to $\mathbf{F}$ and neither $\mathbf{F}^1$ nor $\mathbf{F}^2$ contains both of them.

The aim of this paper is to characterize all magic graph using the notion of separating edges by (1-2)-factor.

II. Semimagic graphs

In this part we state some results about semimagic graphs which we shall use to prove the main result.

Czechoslovak Mathematical Journal 33(108), 1982, pages 435-438 (Math.Rewiews #85e:05 031)

Lema 1. *If* **G** *is a semimagic graph with the index r, then*

a) *each isolated edge of* **G** *has the label r,*
b) *a connected part of* **G** *having more that one edge contains no vertex of degree one.*

The proofs of these statements follow from the definition of a semimagic graph.

Lema 2. *Let a semimagic graph* **G** *contain an even cycle* **C***, then there exists a semimagic factor* **H** *of* **G** *which does not contain all edges of* **C**.

Proof. Let f be a semimagic labelling of **G** and let $m = min\{f(e) : e \in E(\mathbf{G})\}$. We denote the edges of **C** by $e_1, e_2, \dots, e_{2n}$ and suppose that $f(e_1) = m$.
We define a new labelling h of **G**:

$$\begin{aligned} h(e_{2i-1}) &= f(e_{2i-1}) - m, \\ h(e_{2i}) &= f(e_{2i}) + m \qquad \text{for} \quad i = 1, 2, \dots, n, \\ h(e_j) &= f(e_j) \qquad \text{for all} \quad e_j \notin E(\mathbf{C}). \end{aligned}$$

Obvioustly $h(e_1) = 0$. By omitting all edges with $h(e) = 0$ from **G** we obtain a factor which does not contain all edges of **C** and has the same index as the graph **G**.

A graph **D** is called a *dumbbell* if it consists of two odd cycles $\mathbf{C}_1$ and $\mathbf{C}_2$ without common vertices joined by a path **P** or if it consists only of two cycles $\mathbf{C}_1$ and $\mathbf{C}_2$ with only one common vertex.

Lema 3. *Let a semimagic graph* **G** *contain as a subgraph a dumbbell* **D***, then there exists a semimagic factor* **H** *of* **G** *which does not contain all edges of* **D**.

Proof. Let f be a semimagic labelling of **G** with a dumbbell **D** which consists of two cycles $\mathbf{C}_1$, $\mathbf{C}_2$ and a path **P** or only of two cycles $\mathbf{C}_1$, $\mathbf{C}_2$. We denote $m = min\{m_1, m_2\}$ where $m_1 = min\{f(e) : e \in E(\mathbf{C}_1) \cup E(\mathbf{C}_2)\}$ and $m_2 = \frac{1}{2} min\{f(e) : e \in E(\mathbf{P})\}$. Let e' be an edge of **D** such that $f(e) = m$. We define an axiliary labelling p. The edges of $\mathbf{C}_i$ have alternating values 1 and -1 and the edges of **P** the values 2 and -2 such that the sum at each vertex is zero, and the value of e' is negative. All other edges of **G** have value 0. We consider a new labelling

$$h(e) = f(e) + m.p(e) \quad \textit{for all} \quad e \in E(\mathbf{G}).$$

All edges having $h(e) > 0$ form a semimagic factor **H** of **G** which has the same index as **G**.

From the lemas 2 and 3 it follows:

Lema 4. *If* **G** *is a semimagic graph, then there exists a semimagic (1-2)-factor* **F** *of* **G** *with the same index.*

Lema 5. *If* **G** *is a semimagic graph, then every edge e' of* **G** *is contained in a (1-2)-factor.*

Proof. Let e' be an arbitrary edge of **G** and **F** some (1-2)-factor of **G**. There are two possible cases: either $e' \in E(\mathbf{F})$ or $e' \notin E(\mathbf{F})$. We must consider only the second.
Let q be an auxiliary labeling such that

$q(e) = 2$ for all $e \in E(\mathbf{F}^1)$,
$q(e) = 1$ for all $e \in E(\mathbf{F}^2)$,
$q(e) = 0$ for all $e \notin E(\mathbf{F})$.

Let $m = min\{\frac{f(e)}{q(e)} : e \in E(\mathbf{G})\}$. We consider a new labelling

$$h(e) = f(e) - m.q(e) \qquad \text{for all} \quad e \in E(\mathbf{G}) \qquad .$$

Omitting from the graph $\mathbf{G}$ all edges for which $h(e) = 0$ we obtain a semimagic factor $\mathbf{H}$ which contains the edge e'. Let $\mathbf{F}'$ be an (1-2)-factor of $\mathbf{H}$. (Note that $\mathbf{F}'$ is also a (1-2)-factor of $\mathbf{G}$.) If $e' \notin E(\mathbf{F}')$ we repeat the construction described after. By a finite number of repetitions we obtain a (1-2)-factor of $\mathbf{G}$ which contains the edge e'.

Lema 6. *If every edge of* $\mathbf{G}$ *belongs to a (1-2)-factor, then* $\mathbf{G}$ *is a semimagic.*

Proof. A semimagic labelling of $\mathbf{G}$ is obtained by a finite number of repetitions of the following construction.

Let f be a labelling with non-negative numbers such that the sum of the labels of edges incident with each vertex is the same. (Note that every graph has such a labelling.) Let e be an edge with $f(e) = 0$ and $\mathbf{F}$ one (1-2)-factor such that $e \in E(\mathbf{F})$. We define a new labelling

$h(e) = f(e) + 2m$ for all $e \in E(\mathbf{F}^1)$,
$h(e) = f(e) + \ m$ for all $e \in E(\mathbf{F}^2)$,
$h(e) = f(e)$ for all $e \notin E(\mathbf{F})$,

where $m = max\{f(e) : e \in E(\mathbf{G})\} + 1$.

Theorem 1. *The graph* $\mathbf{G}$ *is semimagic if and only if every edge is contained in a (1-2)-factor.*

From the previous lemas it follows:

III. Characterization of magic graphs

Lema 7. *If every couple of edges* e_1, e_2 *of a semimagic graph* $\mathbf{G}$ *is separated by a (1-2)-factor, then* $\mathbf{G}$ *is magic.*

Proof. Let f be a semimagic labelling of $\mathbf{G}$. If $f(e_1) \neq f(e_2)$ for all couple of edges e_1, e_2 then $\mathbf{G}$ is magic. In the opposite case we choose a (1-2)-factor $\mathbf{F}$ which separates e_1 and e_2 and define a new labelling h as in the proof of lema 6. After a finite number of repetitions of the previous step we obtain a magic graph.

The previous lemas yield the proof of our main result.

Theorem 2. *A graph* $\mathbf{G}$ *is magic if and only if*

(i) *every edge of* $\mathbf{G}$ *belongs to a (1-2)-factor,*
(ii) *every couple of edges* e_1, e_2 *is separated by a (1-2)-factor.*

Consequence. *If* $\mathbf{G}$ *is a magic graph then there exists a labellins with positive integers.*

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ACTA ARITHMETICA
XCII.2 (2000)

Magic p-dimensional cubes of order $n \not\equiv 2 \pmod 4$

by

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A *magic p-dimensional cube* of order n is a p-dimensional matrix

$$\mathbf{M}_n^p = |\mathbf{m}(i_1, \dots, i_p) : 1 \le i_1, \dots, i_p \le n|,$$

containing natural numbers $1, \dots, n^p$ such that the sum of the numbers along every row and every diagonal is the same, i.e. $n(n^p + 1)/2$. (*Note.* A magic 1-dimensional cube $\mathbf{M}_n^1$ of order n is given by an arbitrary permutation of the natural numbers $1, \dots, n$.)

By a *row* of $\mathbf{M}_n^p$ we mean an n-tuple of elements $\mathbf{m}(i_1, \dots, i_p)$ which have identical coordinates at $p-1$ places. A magic p-dimensional cube $\mathbf{M}_n^p$ contains pn^{p-1} rows. A *diagonal* of $\mathbf{M}_n^p$ is an n-tuple $\{\mathbf{m}(x, i_2, \dots, i_p) : x = 1, \dots, n,\ i_j = x \text{ or } i_j = \overline{x} \text{ for all } 2 \le j \le p\}$. The symbol $\overline{x}$ denotes the number $n+1-x$, and $\lfloor x \rfloor$ denotes the integer part of x. Every p-dimensional cube has exactly 2^{p-1} great diagonals.

Figure 1 depicts a magic cube $\mathbf{M}_3^3$.

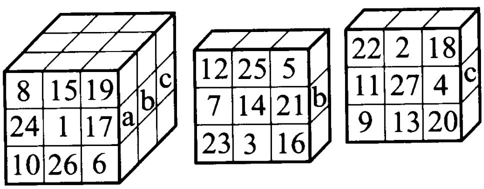

Fig. 1. Magic cube $\mathbf{M}_3^3$

A special case, for $p = 2$, of a magic p-dimensional cube $\mathbf{M}_n^p$ is a magic square. The first references to magic squares can be found in ancient Chinese and Indian literature. They have been the object of study of many mathematicians (e.g. Pierre de Fermat, Leonard Euler), but not only of them (also e.g. Arabian astrologers, Benjamin Franklin). A very famous magic square is in the painting *Melancholy* ([2, p. 147]) made by Albrecht Dürer in

2000 *Mathematics Subject Classification*: 11A99, 15A99.

1514. The construction of a magic square of order 3 appears in the tragedy *Faust* by J. W. Göthe. Probably, the first magic cube appeared in a letter of P. Fermat from 1640.

There is a lot of information and results about magic squares and cubes in the 1917 book by W. S. Andrews. A revised and enlarged edition [2] was published in 1960. More up-to-date information and references can be found in a paper by Allan Adler [1]. Knowledge of magic p-dimensional cubes can find its use not only in recreational mathematics, but also in many fields of mathematics and physics (see [1]). Although many papers have been published concerning magic squares and cubes, relatively little is known about magic p-dimensional cubes for $p \geq 4$. A universal algorithm for their construction has probably not been published yet. The construction of an $\mathbf{M}_n^3$ for every $n \neq 2$ is in [4]. In [3] there is a construction of "magic p-dimensional cubes" without the constant sum on diagonals.

46	8	69	17	78	28	60	37	26
62	42	19	51	1	71	10	80	33
15	73	35	55	44	24	53	6	64
59	39	25	48	7	68	16	77	30
12	79	32	61	41	21	50	3	70
52	5	66	14	75	34	57	43	23
18	76	29	58	38	27	47	9	67
49	2	72	11	81	31	63	40	20
56	45	22	54	4	65	13	74	36

Fig. 2. Magic cube $\mathbf{M}_3^4$

Figure 2 shows the nine layers of an $\mathbf{M}_3^4$. The element $\mathbf{m}(1,1,1,1) = 46$ is in four rows containing the triplets $\{46, 8, 69\}$, $\{46, 62, 15\}$, $\{46, 17, 60\}$ and $\{46, 59, 18\}$. On the eight diagonals there are the triplets

$$\begin{aligned} &\{\mathbf{m}(1,1,1,1) = 46, 41, 36\}, && \{\mathbf{m}(1,1,1,3) = 69, 41, 13\}, \\ &\{\mathbf{m}(1,1,3,1) = 15, 41, 67\}, && \{\mathbf{m}(1,1,3,3) = 35, 41, 47\}, \\ &\{\mathbf{m}(1,3,1,1) = 60, 41, 22\}, && \{\mathbf{m}(1,3,1,3) = 26, 41, 56\}, \\ &\{\mathbf{m}(1,3,3,1) = 53, 41, 29\}, && \{\mathbf{m}(1,3,3,3) = 64, 41, 18\}. \end{aligned}$$

(*Note.* This picture is a magic square of order 9 with some special proprieties.) This magic 4-dimensional cube was constructed using the following formula (from Theorem 1):

$$\begin{aligned} \mathbf{m}(i_1, i_2, i_3, i_4) = & \left[\left(i_1 - i_2 + i_3 - i_4 + \frac{n+1}{2} - 1\right) \pmod n\right] n^3 \\ & + \left[\left(i_1 - i_2 + i_3 + i_4 - \frac{n+1}{2} - 1\right) \pmod n\right] n^2 \end{aligned}$$

$$+\left[\left(i_1 - i_2 - i_3 - i_4 + 3\frac{n+1}{2} - 1\right) \pmod n\right] n$$
$$+\left[\left(i_1 + i_2 + i_3 + i_4 - 3\frac{n+1}{2} - 1\right) \pmod n\right] + 1.$$

This paper is concerned with the construction of a magic p-dimensional cube of order n for every $n \not\equiv 2 \pmod 4$ and $p \geq 1$.

THEOREM 1. *A magic p-dimensional cube* $\mathbf{M}_n^p$ *of order n exists for every odd natural number n and every natural number p.*

Proof. We define a magic p-dimensional cube $\mathbf{M}_n^p = |\mathbf{m}(i_1, \ldots, i_p)|$ of odd order n by

$$\mathbf{m}(i_1, \ldots, i_p) = \sum_{k=0}^{p-1} m_k(i_1, \ldots, i_p) n^k + 1,$$

where

$$m_k(i_1, \ldots, i_p) = \left[\sum_{x=1}^{k} (-1)^{x-1} i_x + (-1)^k \sum_{x=k+1}^{p} i_x + C_k\right] \pmod n$$

(note $\sum_{x=1}^{0}(-1)^{x-1} = 0$) and

$$C_k = (-1)^{k+1}[p - k - (k+1) \pmod 2]\frac{n+1}{2} - 1.$$

The constant C_k is chosen so that

$$m_k\left(\frac{n+1}{2}, \frac{n+1}{2}, \ldots, \frac{n+1}{2}\right) = \frac{n-1}{2} \qquad \text{for all } 0 \leq k \leq p-1.$$

The proof consists of four steps. First, we prove that each element of $\mathbf{M}_n^p$ is in $\{1, \ldots, n^p\}$; second, no two elements of $\mathbf{M}_n^p$ with different coordinates are equal; third, the sums of elements in all rows are the same; fourth, the sums of elements on the diagonals are also the same.

1. Because $0 \leq m_k(i_1, \ldots, i_p) \leq n-1$ for all $0 \leq k \leq p-1$ we get $1 \leq \mathbf{m}(i_1, \ldots, i_n) \leq n^p$ for every element of $\mathbf{M}_n^p$.

2. Suppose that $\mathbf{m}(i'_1, \ldots, i'_p) = \mathbf{m}(i_1, \ldots, i_p)$. The definition of $\mathbf{M}_n^p$ gives

$$\sum_{k=0}^{p-1} m_k(i'_1, \ldots, i'_p) n^k + 1 = \sum_{k=0}^{p-1} m_k(i_1, \ldots, i_p) n^k + 1.$$

Hence

$$\sum_{k=0}^{p-1} [m_k(i'_1, \ldots, i'_p) - m_k(i_1, \ldots, i_p)] n^k = 0.$$

Because the differences in brackets are less than n we get p equations

$$m_k(i'_1,\dots,i'_p) = m_k(i_1,\dots,i_p) \quad \text{for all } 0 \le k \le p-1.$$

By rearranging them according to the definition of $\mathbf{M}_n^p$ we get

$$(\mathrm{E}_0) \qquad (i'_1 + i'_2 + i'_3 + \dots + i'_p + C_0) \pmod n = (i_1 + i_2 + i_3 + \dots + i_p + C_0) \pmod n,$$

$$(\mathrm{E}_1) \qquad (i'_1 - i'_2 - i'_3 - \dots - i'_p + C_1) \pmod n = (i_1 - i_2 - i_3 - \dots - i_p + C_1) \pmod n,$$

$$(\mathrm{E}_2) \qquad (i'_1 - i'_2 + i'_3 - \dots + i'_p + C_2) \pmod n = (i_1 - i_2 + i_3 - \dots + i_p + C_2) \pmod n,$$

$$(\mathrm{E}_3) \qquad (i'_1 - i'_2 + i'_3 - \dots - i'_p + C_3) \pmod n = (i_1 - i_2 + i_3 - \dots - i_p + C_3) \pmod n,$$

$$\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots$$

$$(\mathrm{E}_{p-1}) \qquad (i'_1 - i'_2 + \dots + (-1)^{p-1} i'_p + C_{p-1}) \pmod n = (i_1 - i_2 + \dots + (-1)^{p-1} i_p + C_{p-1}) \pmod n.$$

By adding (E_0) and (E_1) we get either $2i'_1 = 2i_1$ or $2i'_1 = 2i_1 + n$ or $2i'_1 = 2i_1 - n$. Because $i'_1 \le n$ and n is odd we get $i'_1 = i_1$. Replace i'_1 by i_1 in (E_1), (E_2), $\dots$, (E_{p-1}). From the relations rearranged in this way, by adding (E_1) and (E_2) we get $i'_2 = i_2$. Continuing in this manner, we get $i'_3 = i_3$, $i'_4 = i_4, \dots, i'_p = i_p$.

3. For every $k = 0, 1, \dots, p-1$ the set $\{m_k(i_1,\dots,i_{j-1},i_j,i_{j+1},\dots,i_p) : i_j = 1,\dots,n\}$ is equal to $\{0, 1, \dots, n-1\}$ and therefore

$$\sum_{i_j=1}^{n} m_k(i_1,\dots,i_p) = \frac{n(n-1)}{2} \quad \text{for all } 1 \le j \le p.$$

This implies that every row sum is

$$\sum_{i_j=1}^{n} \mathbf{m}(i_1,\dots,i_p) = \sum_{i_j=1}^{n} \sum_{k=0}^{p-1} [m_k(i_1,\dots,i_p) n^k + 1]$$

$$= \sum_{k=0}^{p-1} \frac{n(n-1)}{2} n^k + n = \frac{n^{p+1} - n}{2} + n = \frac{n(n^p + 1)}{2}.$$

4. From the definition of $\mathbf{M}_n^p$ it follows that for every p-tuple $(i_1,\dots,i_p)$,

$$m_k(i_1,\dots,i_p) + m_k(\bar{i}_1,\dots,\bar{i}_p) = n - 1;$$

hence

$$\mathbf{m}(i_1, \ldots, i_p) + \mathbf{m}(\bar{i}_1, \ldots, \bar{i}_p) = \sum_{k=0}^{p-1}(n-1)n^k + 2 = n^p + 1.$$

There are $(n-1)/2$ pairs of elements on each diagonal whose sum is $n^p + 1$, and in the center of $\mathbf{M}_n^p$ there is the element

$$\mathbf{m}\left(\frac{n+1}{2}, \frac{n+1}{2}, \ldots, \frac{n+1}{2}\right) = \frac{n^p+1}{2}.$$

Each diagonal sum is

$$\frac{n-1}{2}(n^p+1) + \frac{n^p+1}{2} = \frac{n(n^p+1)}{2}.$$

This completes the proof. ∎

THEOREM 2. *A magic p-dimensional cube $\mathbf{M}_n^p$ of order n exists for every natural number $n \equiv 0 \pmod 4$ and for every natural number p.*

We define a magic p-dimensional cube $\mathbf{M}_n^p = |\mathbf{m}(i_1, \ldots, i_p)|$ of order $n \equiv 0 \pmod 4$ by

$$\mathbf{m}(i_1, \ldots, i_p) = \begin{cases} \displaystyle\sum_{k=1}^{p}(i_k - 1)n^{k-1} + 1 & \text{if } \displaystyle\sum_{j=1}^{n}\left(i_j + \left\lfloor \frac{2(i_j-1)}{n} \right\rfloor\right) \text{ is odd,} \\ \displaystyle\sum_{k=1}^{p}(\bar{i}_k - 1)n^{k-1} + 1 & \text{in the opposite case.} \end{cases}$$

The assertion of Theorem 2 follows from the following three facts:

1. No two elements with different coordinates are equal because $\sum_{j=1}^{n}(i_j + \lfloor 2(i_j-1)/n \rfloor)$ is odd if and only if $\sum_{j=1}^{n}(\bar{i}_j + \lfloor 2(\bar{i}_j - 1)/n \rfloor)$ is odd.

2. The row sums are equal because for every odd coordinate i_j,

$$\mathbf{m}(i_1, \ldots, i_{j-1}, i_j, i_{j+1}, \ldots, i_p) + \mathbf{m}(i_1, \ldots, i_{j-1}, i_j + 1, i_{j+1}, \ldots, i_p) = n^p - n^{j-1} + 1 \quad \text{or} \quad n^p + n^{j-1} + 1.$$

In every row there are $n/4$ pairs of elements with sum $n^p - n^{j-1} + 1$ and the same number of pairs with sum $n^p + n^{j-1} + 1$.

3. The diagonal sums are the same because for every p-tuple $(i_1, \ldots, i_p)$,

$$\mathbf{m}(i_1, \ldots, i_p) + \mathbf{m}(\bar{i}_1, \ldots, \bar{i}_p) = n^p + 1.$$

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Received on 19.4.1999
and in revised form on 16.7.1999 (3587)

ACTA ARITHMETICA
XCVI.4 (2001)

Magic p-dimensional cubes

by

MARIÁN TRENKLER (Košice)

A *magic p-dimensional cube* of order n is a p-dimensional matrix

$$\mathbf{M}_n^p = |\mathbf{m}(i_1, \ldots, i_p) : 1 \le i_1, \ldots, i_p \le n|,$$

containing natural numbers $1, \ldots, n^p$ such that the sum of the numbers along every row and every diagonal is the same.

By a *row* of $\mathbf{M}_n^p$ we mean an n-tuple of elements $\mathbf{m}(i_1, \ldots, i_p)$ which have identical coordinates at $p-1$ places. A *diagonal* of $\mathbf{M}_n^p$ is an n-tuple $\{\mathbf{m}(x, i_2, \ldots, i_p) : x = 1, \ldots, n,\ i_j = x \text{ or } i_j = 2^p + 1 - x \text{ for all } 2 \le j \le p\}$. A magic p-dimensional cube $\mathbf{M}_n^p$ has pn^{p-1} rows and 2^{p-1} diagonals. The symbol $\lfloor x \rfloor$ denotes the integer part of x. A magic 1-dimensional cube $\mathbf{M}_n^1$ of order n is given by an arbitrary permutation of integers $1, \ldots, n$. Evidently, a magic p-dimensional cube of order 2 for $p \ge 2$ does not exist.

In [5] there is a construction of $\mathbf{M}_n^3$ for every $n \ne 2$ and in [6] it is proved that a magic p-dimensional cube $\mathbf{M}_n^p$ of order n exists for every integer p and $n \not\equiv 2 \pmod 4$. (The reader can find more information in [2, 3, 5, 6].) These results are improved in

THEOREM. *A magic p-dimensional cube $\mathbf{M}_n^p$ of order n exists if and only if $p \ge 2$ and $n \ne 2$ or $p = 1$.*

Before we begin the proof, we demonstrate a construction of a magic square $\mathbf{M}_6^2$. The construction starts from four copies of a Latin square $\mathbf{U} = |\mathbf{u}(i_1, i_2) : 1 \le i_1, i_2 \le 3|$ of order 3 defined by the relation $\mathbf{u}(i_1, i_2) \equiv (i_1 - i_2) \pmod 3$. We insert these squares into a 6×6 table, so that Latin squares are symmetric about the lines going through the centres of two opposite sides. All elements of Latin squares are replaced by $0, 1, 2, 3$ as shown in Figure A. On the left hand side in every cell there is an element of the Latin square, and its substitution on the right hand side.

2000 *Mathematics Subject Classification*: 11A99, 15A99, 05B15.

$0\to 3$	$2\to 0$	$1\to 1$	$1\to 3$	$2\to 1$	$0\to 1$
$1\to 1$	$0\to 3$	$2\to 0$	$2\to 1$	$0\to 1$	$1\to 3$
$2\to 0$	$1\to 1$	$0\to 3$	$0\to 1$	$1\to 3$	$2\to 1$
$2\to 3$	$1\to 0$	$0\to 2$	$0\to 0$	$1\to 2$	$2\to 2$
$1\to 0$	$0\to 2$	$2\to 3$	$2\to 2$	$0\to 0$	$1\to 2$
$0\to 2$	$2\to 3$	$1\to 0$	$1\to 2$	$2\to 2$	$0\to 0$

Fig. A

$27+6$	7	$9+2$	$27+2$	$9+7$	$9+6$
$9+1$	$27+5$	9	$9+9$	$9+5$	$27+1$
8	$9+3$	$27+4$	$9+4$	$27+3$	$9+8$
$27+8$	3	$18+4$	4	$18+3$	$18+8$
1	$18+5$	$27+9$	$18+9$	5	$18+1$
$18+6$	$27+7$	2	$18+2$	$18+7$	6

Fig. B

By multiplying all elements by 9 and adding elements of four copies of a magic square $\mathbf{M}_3^2$ we obtain the magic square $\mathbf{M}_6^2$ of order 6 which is shown in Figure B.

Proof of the Theorem. For $n \not\equiv 2 \pmod 4$ the proof is in [6]. That paper gives the construction of $\mathbf{M}_n^p$ for $n \equiv 1 \pmod 2$ or $n \equiv 0 \pmod 4$ and $p \geq 2$.

Let $n \equiv 2 \pmod 4$, $n \neq 2$ and $p \geq 2$ be two fixed natural numbers and let $m = n/2$. The construction of $\mathbf{M}_n^p$ is described in 6 steps.

1. Let $\mathbf{D} = |\mathbf{d}(j,x) : 1 \leq j \leq m, 1 \leq x \leq 2^p|$ be a matrix defined by the following relations:

$$\mathbf{d}(1,x) = 2^{p-1} \cdot 2^{x \,(\mathrm{mod}\, 2)} - \left\lfloor \frac{x+1}{2} \right\rfloor,$$

$$\mathbf{d}(2,x) = 2^{p-1} \cdot 2^{(x+1)\,\mathrm{mod}\, 2)} - \left\lfloor \frac{x+1}{2} \right\rfloor,$$

$$\mathbf{d}(3,x) = x + (-1)^x \left\lfloor \frac{x-1}{2^{p-1}} \right\rfloor [(p+1) \pmod 2],$$

$$\mathbf{d}(j,x) = \begin{cases} x-1, & j = 4,6,8,\dots,m-1, \\ 2^p - x, & j = 5,7,9,\dots,m. \end{cases}$$

This definition yields the following facts which are crucial in our construction:

(a) for every $1 \leq x \leq 2^p$,

$$\sum_{j=1}^{m} \mathbf{d}(j,x) = \frac{n}{4}(2^p - 1) - \frac{1}{2} + \left[x + \left\lfloor \frac{x-1}{2^{p-1}} \right\rfloor (p+1)\right] \pmod 2,$$

(b) $\{\mathbf{d}(j,1),\dots,\mathbf{d}(j,2^p)\} = \{1,\dots,2^p\}$ for all $1 \leq j \leq m$,

(c) $\mathbf{d}(1,x) + \mathbf{d}(1,2^p - x + 1) = 2^p - 1$ for all $1 \leq x \leq 2^{p-1}$ (this is important only for $p \equiv 0 \pmod 2$).

2. Let σ be a permutation of the set $\{1,\dots,2^p\}$ which satisfies:

(i) if the number of ones in the binary representation of the number $k-1$ is even (odd) then $\sigma(k)$ is an even (odd) number for every $k = 1,\dots,2^{p-1}$,

(ii) if $k \leq 2^{p-1}$ then $\sigma(k) \leq 2^{p-1}$,

(iii) if $2^{p-1} < k \leq 2^p$ then $\sigma(k) = 2^p - \sigma(2^p - k + 1)$.

3. Let $\mathbf{U} = |\mathbf{u}(i_1, \ldots, i_p) : 1 \le i_1, \ldots, i_p \le m|$ be a p-dimensional matrix defined by

$$\mathbf{u}(i_1, \ldots, i_p) = \Big(\sum_{x=1}^{p} (-1)^{x+1} i_x \Big) \pmod m.$$

Every row of $\mathbf{U}$ is the set $\{0, 1, \ldots, m-1\}$. If $p \equiv 1 \pmod 2$ then the diagonal $\{\mathbf{u}(i, \ldots, i) : i = 1, \ldots, m\}$ of $\mathbf{U}$ is the set $\{0, 1, \ldots, m-1\}$. If $p \equiv 0 \pmod 2$ then it is $\{0, 0, \ldots, 0\}$.

4. Let $\mathbf{V}_{(k)} = |\mathbf{v}_{(k)}(i_1, \ldots, i_p) : 1 \le i_1, \ldots, i_p \le m|$, $1 \le k \le 2^p$, be p-dimensional matrices defined by

$$\text{if} \quad \mathbf{u}(i_1, \ldots, i_p) = q \quad \text{then} \quad \mathbf{v}_{(k)}(i_1, \ldots, i_p) = \mathbf{d}(q, \sigma(k)).$$

5. Let $\mathbf{M}_{(k)} = |\mathbf{m}_{(k)}(i_1, \ldots, i_p) : 1 \le i_1, \ldots, i_p \le m|$, $1 \le k \le 2^p$, be p-dimensional matrices defined by

$$\mathbf{m}_{(k)}(i_1, \ldots, i_p) = \mathbf{v}_{(k)}(i_1, \ldots, i_p) m^p + \mathbf{m}(i_1, \ldots, i_p),$$

where $\mathbf{m}(i_1, \ldots, i_p)$ is the element of $\mathbf{M}_m^p$ which is constructed in [6].

Because $\mathbf{v}_{(j)}(i_1, \ldots, i_p) \ne \mathbf{v}_{(k)}(i_1, \ldots, i_p)$ for all $j \ne k$ and from the previous relation it follows that:

(a) no two elements $\mathbf{m}_{(k)}(i_1, \ldots, i_p)$ with different coordinates or indices are equal,

(b) the row sum of $\mathbf{M}_{(k)}$ for fixed k is the same, i.e.

$$\left[\frac{m}{2}(2^p - 1) + \frac{(-1)^\omega}{2} \right] m^p + \frac{m(m^p + 1)}{2}, \qquad \text{where } \omega = 1 \text{ or } 2,$$

(c) if $p \equiv 1 \pmod 2$ then $\sum_{i=1}^{m} \mathbf{m}_{(k)}(i, \ldots, i)$ is equal to the row sum of $\mathbf{M}_{(k)}$, if $p \equiv 0 \pmod 2$ then

$$\sum_{i=1}^{m} \mathbf{m}_{(k)}(i, \ldots, i) = \mathbf{d}(1, \sigma(k)) m^{p+1} + m(m^p + 1)/2.$$

6. We define a magic p-dimensional cube $\mathbf{M}_n^p = |\mathbf{m}(i_1, \ldots, i_p) : 1 \le i_1, \ldots, i_p \le n|$ of order $n \equiv 2 \pmod 4$ by

$$\mathbf{m}(i_1, \ldots, i_p) = \mathbf{m}_{(k)}(i_1^*, \ldots, i_p^*),$$

where $i_j^* = \min\{i_j, n + 1 - i_j\}$ and $k = \sum_{x=1}^{p} \lfloor \frac{i_x - 1}{m} \rfloor 2^{x-1} + 1$.

From the definition of $\mathbf{M}_n^p$ we get:

(a) every row of $\mathbf{M}_n^p$ consists of one row of $\mathbf{M}_{(j)}$ and one row of $\mathbf{M}_{(k)}$ which have different row sums,

(b) every diagonal of $\mathbf{M}_n^p$ consists of $\mathbf{m}_{(k)}(i, \ldots, i)$, $\mathbf{m}_{(2^p+1-k)}(i, \ldots, i)$, $i = 1, \ldots, m$. If $p \equiv 1 \pmod 2$ then $\mathbf{M}_{(k)}$ and $\mathbf{M}_{(2^p-k+1)}$ have different row sums. If $p \equiv 0 \pmod 2$ then the row sums of $\mathbf{M}_{(k)}$ and $\mathbf{M}_{(2^p-k+1)}$ are the same.

It is easy to see that $\mathbf{M}_n^p$, which is a union of 2^p matrices $\mathbf{M}_{(k)}$, satisfies the conditions for a magic p-dimensional cube.

REMARK 1. Magic squares have fascinated people for centuries. Mathematicians have studied many properties of magic squares and formulated problems which have not been solved. (See [1].) We can formulate similar problems for magic cubes, too.

REMARK 2. Another "magic" p-dimensional cube was studied by J. Ivančo. In [4] it is proved that if $4 \le p \equiv 0 \pmod 2$ then the edges of a p-dimensional cube can be labelled by integers $1, 2, \ldots, 2^{p-1}p$ in such a way that the sum of the labels of edges incident to each vertex is the same.

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Received on 16.12.1999
and in revised form 26.4.2000 (3729)

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57 captures 08
13 Dec 2000 - 5 Mar 2018 2000 2002 2003
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Mark Swaney on the History of Magic Squares

4 9 2
3 5 7
8 1 6

This is a magic square of order 3 (three numbers to the side of the square). If you add up any row, column, or diagonal, it sums to the same number, 15. There are magic squares of order 4, 5, 6, etc.

See this link for a listing of magic squares of order 3 through 11:

http://www.pse.che.tohoku.ac.jp/~msuzuki/MagicSquare.byMATLAB.html

My friend Mark Swaney has been working on the history of Magic Squares and has said yes to my passing on some of his preliminary results with the following warning:

You gotta tell them that it's just ripped hot off the neurons, and may have a detail or two out of place. I'm reading all this stuff and then roaring off an epistle. Later, I always think I should have done it differently, but what the hell? Also, I find that I like to write a lot of text when I'm feeling radioactive.

After Mark's review of the history of Magic Squares, I have listed some further information and references on the squares.

Mark:

I am still getting references and picking up information, so the following is subject to revision and expansion.

The history of magic squares is murky, mysterious, and has not been well researched by academics. Consequently the claims are contradictory, and in some cases exaggerated. Very little is known about the origin of magic squares. Next to nothing is known about the movement of the idea of a magic square before about 1300 AD. Three cultures are known to have created magic squares, the Chinese, the Indian, and the Arabic. In each culture they were viewed as having supernatural properties.

http://www.netmastersinc.com/secrets/magic_squares.htm Go JUL FEB APR
57 captures 08
13 Dec 2000 - 5 Mar 2018 2000 2002 2003
About this capture

The first magic square in history was created in China by an unknown mathematician, probably sometime before the first century AD. Called the Lo Shu square, it is a magic square of 3 that was said to have appeared on the back of a turtle that came up out of the river. Lo Shu supposedly means "river map" and the story of the appearance of the turtle had to do with a sacrifice to the river god. Right from the beginning we are seeing an essentially mathematical construction combined with the supernatural. I have not found an analysis of the story of the turtle and the Lo Shu square from the point of view of folklore or mythology that would shed more light on the story. The Lo Shu square is later associated with the floor plan of a mythical palace, that of Ming'tang. Again, this is fragmentary, I have seen a diagram that shows the floor plan, but no explanation as to what the thinking about the square was, why it was used as a floor plan for a palace, or other information to flesh out the picture. The Lo Shu square is also connected to the I-Ching, though there is no explicit plan of correspondence that I know of. The oldest documents that refer to the Lo Shu square are ambiguous, but one reference lists a Shu Ching in 650 BCE who makes a reference to the "river map" which may be the magic square of 3. In 500 BCE, and 300 BCE, the river map is mentioned, but no explicit magic square is given. In 80 AD Ta Tai Li Chi gives the first clear reference to a magic square. In 570 AD Shuzun gives an actual description of a magic square of 3. Not until 1275 do we hear of the Chinese making squares of order larger than 3. Norman Biggs says that this is because the Chinese regarded the Lo Shu square as an object of the supernatural, rather than as an object of human curiosity, and it was therefore not a subject for study.

India

We find the first magic square of 4 in the first century in India by a mathematician named Nagarajuna. This is all that I know at the moment about the early development of the magic square in India. However, India is the birthplace of much superior mathematics, and was advanced in other areas of combinatorics at an early date. I would be surprised if it did not eventually turn out that India has an older tradition involving magic squares. Still, this approximate date is interesting for other types of analysis. The next known date in the Indian development is an 11th or 12th century Jaina inscription that includes a magic square of 4. This particular magic square of 4 has unusual properties not found in other magic squares before that time, and the whole class of squares having these properties is called "Jaina squares", including squares of order larger than 4. I have no information on the document, why it includes the magic square, or what

http://www.netmastersinc.com/secrets/magic_squares.htm Go JUL FEB APR
57 captures 08
13 Dec 2000 - 5 Mar 2018 2000 2002 2003
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Islam

The first magic squares of 5 and 6 appear in an encyclopedia in Baghdad about 983 AD by Ikhw'n al-Saf' Ras'il, though several earlier Arab mathematicians also wrote about magic squares. How it came to pass that the Arabs acquired knowledge of magic squares is unknown. It is not known if they invented them separately or if they were introduced to them by another culture. Biggs assumes that the Arabs got the idea from the Chinese, though he doesn't know how the connection was made. I think it far more likely that the Arabs got magic squares from the same source that they got decimal arithmetic, namely India. The Arab Jihad of the 7th century succeeded in conquering portions of India, and the Arabs absorbed a great deal of Indian mathematics and astronomy. It is known that many other aspects of combinatorial mathematics passed from India to the Arabs in this way. Al-Buni was an Arab mathematician that worked on magic squares and also believed in the mystical properties of magic squares, though no details on this number mysticism are available. Al-Buni did his work on the squares about 1200 AD. Sources have also referred to the Arabs using magic squares in making astrological calculations and predictions, again no details are given. The association of the squares with astrology and the heavens appears to be original with the Arabs, but again, much is unknown concerning the Indian tradition.

Europe

It is from the Arabs that the West finally receives the idea of magic squares. In 1300 Manual Moschopoulos, a Greek Byzantine scholar, writes a mathematical treatise on the subject of the magic squares. Moschopoulos' book builds on the work of Al-Buni who preceded him. Western authors are quick to point out that Moschopoulos treats the squares in a purely mathematical way in contrast to the mystical ideas of the Arabs. Moschopoulos is generally considered to be the first westerner to know of the squares. A mistaken attribution of knowledge to Theon of Smryna in about 130 AD has continued to be cited, but the "square" in question is definitely not a magic square, being just a natural square.

After Moschopoulos, in the 1450's Luca Pacioli of Italy worked on magic squares and owned a large collection of examples of magic squares. With Pacioli we come to the doorstep of the known Western mystical tradition concerning magic squares. What Pacioli himself believed about the squares I don't know, but in the 1480's Italy was to see the birth of the Renaissance which revolutionized European

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57 captures
13 Dec 2000 - 5 Mar 2018
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Pico Della Mirandola wrote the "Nine Hundred Theses" - much of it based on the translations of older Jewish Kabbalistic texts. Artists like Albrecht Durer eagerly absorbed the new perspective painting based on the mathematical developments of Della Franscisca, who was popularized by the later books of Pacioli.

In about 1510 Cornielius Agrippa, that problematical character, wrote "De Occulta Philosophia" in which he expounds on the powers of the magic squares, and supplies examples of them in the orders 3- 9. This book became famous throughout Europe and was very influential until the counter-reformation and the witch-hunts that followed. Most what is commonly thought of about Agrippa is the result of the witch-hunts and propaganda, i.e. he was a sorcerer, he was in league with the devil, etc. The truth about Agrippa and his book is much more complex than that, and in the explanation of Agrippa's book we get the first inkling of a detailed worked out system of mysticism concerning magic squares. However, though we find out some details about the squares in their role as supernatural devices, we are still left with conflicts and unanswered questions.

In 1514 Albrecht Durer made his famous woodcut "Melancholia I," which features a magic square of 4 on the wall behind the "brooding genius" that became the archetype of all the "thinker" type sculptures in later years. The reason for the magic square of 4 being included in the woodcut has been analyzed by the authors of "Saturn and Melancholy". Briefly, the square of 4 is the square of Jupiter. The planet jupiter was considered beneficial and was associated with the "sanguine" humor. Even today we speak of someone's being "jovial" at a party. Durer's brooding genius suffers from melancholia, which we call depression, and the square of Jupiter was thought to bring down the influence of the planet Jupiter, thereby helping to cure the depression.

The Squares and the Planets

This is an example of the theory of magic propounded by Marsilio Ficino. Ficino's magic is a kind of sympathetic magic where objects, colors, sounds, etc. are all categorized as to what "influences" they excite. Ficino's influences come primarily from the planets, the Sun, Moon, Mercury, Venus, Mars, Jupiter, and Saturn. The magic is aimed at "drawing down" the influence or power of specific planets in order to accomplish some end, such as protection from disease or a psychological cure. In this magic we see the role of the squares as being the mathematical archetypes of the planets themselves. As each square has a set of characteristic numbers, these numbers then also carry the influences of the various planets. In this way certain numbers can be said to be

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57 captures 08
13 Dec 2000 - 5 Mar 2018 2000 2002 2003 About this capture
how the particular planets come to be associated with particular squares. More than one source has it that the correspondences between the squares and the planets were the invention of Agrippa himself. The description of Agrippa and his book by Francis Yates makes it appear that Agrippa made no original contributions to magical theory in his book, but merely collected the thought of others. Other sources simply say that the Arabs assigned the squares to the planets. David Fidler in his book "Jesus Christ, Sun of God" says that the arrangements came from the Babylonians. The ancient system of cosmology had 7 planets, each in a concentric shell that rotated around the earth. The Babylonians believed that the closest planet was the moon, followed by Mercury, Venus, the Sun, Mars, Jupiter, and Saturn. They placed the order of the squares such that the smallest squares were associated with the farthest planets, thus Saturn is 3, Jupiter is 4, etc. This relationship is important for several reasons, but the one reason that is most striking is the fact that the system assigns the square of 6 to the sun. By making this assignment, the system is made to resonate with one of the most ancient of numerological systems, namely that of the Sumerians. It was the Sumerians with their Solar worship and their sexigesimal counting system that firmly fixed the hours of the day at 24, sun nominally rising at 6:00AM and setting at 6:00PM, and who gave us the still used 360 degree circle. The association of the number 6 with the sun is a very ancient western tradition. Pythagoras on account of numerical theory called 6 the first "perfect" number. In view of these facts, the magic square of 6 with a sum total of 666 must have made quite an impression even in the 14th century, the earliest date that modern conventional scholarship will allow a western knowledge of magic squares.

Other points may be considered from the assignment of squares to planets. First, consider that the ordering of the planets does not follow the simple digits. That is, there is no planet associated with the number 1 or the number 2. Does this mean that the correspondences were made based on the squares (there is no magic square of 2) and not simply on the single digit numbers 1-7? If this is the case then we might infer that the ancient Babylonians had knowledge of magic squares. The whole issue of the use by the author of the book of Revelations of the number 666 to represent the Anti-Christ, in a passage that also includes the only unmistakable reference in the Bible to the practice of gematria has been but barely dealt with. Does this passage have to do with magic square numerology? Can other names and phrases in the New Testament have had their values constructed in such a way as to yield gematria values that have numerological

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57 captures 08
13 Dec 2000 - 5 Mar 2018 2000 2002 2003
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tantalizing possibilities, as yet not definitively answered by scholarship.

Mark Swaney, January, 2000

Dan W. writes:

Below are the magic square numbers and their attributions to the planets. If you recognize any of these numbers from astrology, astronomy, ancient texts, musical tuning theory, the proportions of buildings, sacred geometry, mathematics, physics, architecture, art history or anywhere at all, please let me know.

Planet
side of square
boxes in square
sum of any symmetrical group of four boxes
sum of any line - horizontal, vertical, diagonal
sum of perimeter values of the square
sum of the entire square

saturn 3 - 9 - xx - 15 - 40 - 45

jupiter 4 - 16 - 34 - 34 - 102 - 136

mars 5 - 25 - 52 - 65 - 208 - 325

sun 6 - 36 - 74 - 111 - 370 - 666

venus 7 - 49 - 100 - 175 - 600 - 1225

mercury 8 - 64 - 130 - 260 - 910 - 2080

moon 9 - 81 - 164 - 369 - 1312 - 3321

Mark Swaney writes:

The squares of 5 and 8 have a direct to relationship to the numerical cosmology/religion of the Mayans. Read any text on their culture to find their sacred numbers which are 4, 13, 20, 52, & 260. If Dan had listed the numbers for the additional squares of 10,11,12,&13, you could see the natural mathematical affinity that exists between 4 and 13. As it is, check

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57 captures
13 Dec 2000 - 5 Mar 2018
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16 + 1 = 17. This number for the square of 13 is 169 + 1 = 170.

Catherine Yronwode writes:

This point has long puzzled me -- who assigned each of these magic number squares to a planet -- and by what logical reasoning? Has ANY logical reason EVER been given for the assignments? If so, did it make sense.?

Mark Swaney replies:

I am continuing to research the squares, and one of the many questions that I want to answer is just the one you have asked. Several sources credit Agrippa with the assignment of the squares to the planets, but that is certainly not true, as Agrippa did not originate any of the Magic he lists in his Occult Philosophy. At this time, I don't have any definitive answer, and I don't believe that the question has been tackled by acedemics. Fidler says that the Babylonians originated the system, that is the ORDER of planets, Saturn, Jupiter, Mars, Sun, Venus, Mercury, Moon. This specific order (one of 7! = 5040 possibilities) was known long before Agrippa's time, because it is given in the Sepher Yetzirah, circa 300AD. The question is though, when and who and why did the magic squares get assigned to the planets? An interesting point is that there is no planet with the number 1 or 2, (there is no magic square of two.) The best speculation is that the assignments were made by the Arabs, because it is known that the Arabs incorporated Magic Squares with their Astrological calculations. It is the classical position (such as has been researched - meaning NOT MUCH) that Magic Square esotericism passed to the West from the Arabs in about the 13th century.

Now there are a couple of points to make about the assignment of the squares to the planets. First off, who ever came up with the arrangement contrived it so that the Sun was assigned to the number 6. In doing so, the Sumerian numerical/religious structure was preserved, because it was the Sumerians who originally established the association of 6 with the Sun. They were Solar worshipers, and they also possessed a base 60 numbering system. They gave us 360 degree circles, and a time system that has the Sun rising (nominally) at 6 and setting at 6. So the famous or infamous Square of the Sun is esoterically consistent with the oldest Western culture.

For those who like to find a pattern common to modern knowledge of the Solar system, consider that the Sun and the Moon are "special cases". Their

http://www.netmastersinc.com/secrets/magic_squares.htm Go
57 captures
13 Dec 2000 - 5 Mar 2018
JUL FEB APR
08
2000 2002 2003
About this capture
is (from top down), Mercury, Venus, Mars, Jupiter, Saturn. In just the proper order that we know them to be. Five objects ordered properly is a random chance of 1 in 5! = 120. I consider it possible that the assignment of the squares to the planets was made as the result of a serious (and not too far wrong) attempt to order the planets according to their actual arrangement in the sky. Such an effort would be doomed to inaccuracy by the fact that the planets actually move around the Sun and not the Earth as was believed.

Notice also that in the Tree of Life (a fairly modern geometry - probably from about the 17th century) the planets are shown almost in an orbital system about the SUN. Exceptions being Saturn and Mercury. However, also note that with the Earth as the 10th square/planet, the Sun, Moon, and Earth are shown in the position of a solar eclipse.

Dan W writes:

Here is a quote from page 377 of William Eisen's The Cabalah of Astrology (1986)

"Eventually Ptolemy�s Tetrabiblos was translated into Arabic in the 8th century by the Jewish astrologer Al Batrig Mashallah of Baghdad, and for the next 500 years, up until the middle of the 13th century, [Ralph William] Holden [in his book The Elements of House Division, 1977,] traces the passing of the astrological torch into the hands of the great Muslim astrologers. A renowned school of astronomy and astrology was established in Baghdad and flourished for many years. Among the most important literary works to be produced during this period was the Elements of Astrology, written by Al Biruni in the 11th century. This book carried the Equal House system of Ptolemy even further. These men thoroughly understood the value of the Solar Houses (where the Sun is placed at the ascendant, or at the East point in the chart), and they established a system of Arabian Points, or Parts. The position of the Moon then became the �Point of Fortune,� Mercury the �Point of Commerce,� Venus the �Point of Love,� etc. The houses in which these sensitive points appeared, when compared with the actual houses of the birth chart, thus enhanced the over-all interpretation of the horoscope to a remarkable degree."

Dan W comments:

The translation of the Tetrabiblos was done by a **Jewish** astrologer and we know that later the rabbi of Damascus was deep into magic square Kabbalah mysticism around 1500. Further the magic square references in Aggrippa's The Occult Philosophy show associations with Hebrew, indicating a Jewish source. We

http://www.netmastersinc.com/secrets/magic_squares.htm Go JUL FEB APR
57 captures 08
13 Dec 2000 - 5 Mar 2018 2000 2002 2003
About this capture

The place of this syncretism was probably in Baghdad. Now Baghdad is in Mesopotamia, the site of the ancient civilizations of Sumeria and Babylonia where the order of the planets used in assigning the magic squares was first worked out.

Mark Swaney writes:

The Brethern of Purity: I'm still working on the main leads, but the background information is very interesting in itself. The BP were a group of Ismaili scholars. The Ismaili are a sub-sect of the Shia brand of Islam, and are and were, considered heretics by the other Moslems. The history on this sect is obscure and I am working on finding out some more about the Ismaili, but the main points I know are these. The Ismailis have/had their own Imam, like a Pope I think, except the position is hereditary, Ismaili Imams are not the same as those of the other Shias. They were oppressed vigorously, and many Ismailis were killed in wars of suppression waged by the orthodox Sunni who were in power in Egypt, the Fatimids. At the time of the production of the Rasail of Ikhwan as-Safa, or the Encyclopedia of the Brethren of Purity, the Ismailis were an underground organization in the neighborhood of Baghdad, which was under the rule of the Fatimids in Egypt.

The BP were said to have been organized a century or so before the time of the Rasail, but no one is exactly sure when they started. Anyway, it seems that the Imam in about 989 AD decided to have the BP produce an encyclopedia. This was because the BP represented the intelligentsia of the Ismailis at the time, and because they were already an organized group. Under the direct supervision of the Imam, the scholars of the BP met secretly in a cave and began work on the Rasail. After the completion of the Rasail, copies were made and one was placed in every Mosque in the area in and around Baghdad.

The purpose of the Rasail was to reconcile Greek philosophy with the precepts of the Ismaili sect, to show that the beliefs of the Ismailis were in accord with the scientific knowledge of the day! Now keep in mind that this book, the Rasail, contains the FIRST recorded example of a magic square of 6. All the numbers in the New Testament that relate to the multiples of 37 are said by Fidler and Michell to be based on the square of the sun. However, the straight academic world says "whoa!" the first magic square of 6 was invented by the ARABS 1000 years AFTER the NT was written. The Greeks are NOT supposed to have any knowledge of magic squares at all. But, when we look further, it turns

http://www.netmastersinc.com/secrets/magic_squares.htm Go JUL FEB APR
57 captures 08
13 Dec 2000 - 5 Mar 2018 2000 2002 2003 About this capture
knowledge that was accepted and common to the Greeks in the 10th century, otherwise how could the Rasail have performed as it was intended?

So we have a new lease on the idea that MAYBE there was a knowledge of magic squares in Greece in antiquity. Or still possible, and just as intriguing, the Babylonians. We are talking about Baghdad where this heretical Islamic sect creates the Rasail, the sum of all knowledge that contains magic squares and proclaims that the Ismailis are scientifically correct in their beliefs.

There is more. Ever hear of Hassan a-Sabah? Well, if not, look him up. He is considered the inventor of the modern 20th century intelligence service, 1000 years ahead of his time. The words Assassin and Hashish? They derive from the name of the warrior/terrorists organized by Hassan a-Sabah, the Hashishim. Who were they? You guessed it, the Ismailis. I am now looking into the links between a-Sabah and the BP. It gets very interesting, doesn't it?

Mark Swaney writes further:

I have found that the BP and the Ismailis were
specifically influenced by Neo-Platonism in the 8th century. I have located a reference that should be of some help in understanding the role of the magic squares in the Ismaili beliefs.

Neoplatonists: An Introduction Into the Thought of the Brethern of Purity, Allen&Unwin, London 1982.

another reference is;

Early Philosophical Shiism by P.E. Walker, Cambridge, 1993.

I am also finding information on the theory of the concentric spheres mentioned by Fidler, as well as information on Al-Biruni.

Ancient Cosmologies
Allen & Unwin London 1975.

Dan W writes:

The relation between the Assassins and the BP is weird in the extreme. See if you can find out anything about the

http://www.netmastersinc.com/secrets/magic_squares.htm Go JUL FEB APR 08 2000 2002 2003
57 captures
13 Dec 2000 - 5 Mar 2018
About this capture

Mark Swaney writes:

More on the BP, Sabah, etc. The BP are thought to have been formed about the same time as the formation of the Ismaili sect, about three hundred years before the publication of the Rasail in the 10th century. The sects of Islam seem to all be named after the person whom that sect originally believes to be the Imam. I have read so many names of Imams that I am a little confused as to who is who, but the Imam that preceded the split that created the Ismailis was a very educated man, and very interested in philosophy. It is he who is credited with infusing the Ismailis with a philosophically based belief system. I have read a critique of the story of Adam and Eve by an medevial Ismaili writer that is in my mind remarkable for it's very modern analysis of the story. The Ismaili brand of Islam (which still has millions of followers) is described by modern scholars of religion as "gnostic" and "neoplatonic". The Ismaili cosmology is certainly concerned with the hierarchy of the universe. Their belief in the succession of the Imams as the living representatives of God on Earth was fused with the Platonic/Kabbalistic Theory of Emanation at a very early period. I am fascinated by the thought of these medieval Islamic Mystics, they certainly deserve attention and consideration for their contributions to the thread of thoughts that we pursue.

Sabah is another mystery and a famous character from the late 11th century in Iran. Hassan a-Sabah was also known by the moniker "The Old Man of the Mountain". Almost everything that we know about Sabah has been written by his enemies. So we should give the guy a break and try to look at him objectively. Actually, what is known about Sabah for sure is that he must be considered a genius. He founded an intelligence service that was unrivaled in the world until the 20th century. He invented what his enemies call terrorism, his modern friends would call it "guerilla warfare". He was a military genius and after occupying the "Eagle's Nest", his famous fortress in northern Iran, he never lost it, and he conquered several other forts in the surrounding area. His battles with the Seljuck Turks made history. Sabah converted to the Ismaili faith as a young man, and he is still considered by the modern Ismailis to be a Hero of the Faith. True, he was supposed to have been cruel and bloodthirsty. Yeah, and your mother wears army boots.

The really interesting thing about Sabah for our studies is that in addition to being a military genius, he was also known to be a scholar. The organization he created, the Hashishim, or Assassins, was a "Masonic" military organization. By the way, the words Assassin and Hashishim and Hashish are all thought to be corruptions of Sabah's first name, Hassan. The Assassins were in essence

http://www.netmastersinc.com/secrets/magic_squares.htm Go JUL FEB APR
57 captures 08
13 Dec 2000 - 5 Mar 2018 2000 2002 2003 About this capture

But the organization was not solely based on military/political adventures. That's the mystery. Sabah was known to have amassed a large library in his fortress. He was known to have had an interest in mathematics, and to have encouraged the study of mathematics and philosophy by his followers. The Assassins practiced initiation rites, and had strict grades of hierarchy, so that modern historians have described them as "Masonic" in nature. Sabah and the Assassins also had intriguing contacts with the Crusaders that I am now trying to find out more about. All this is hugely interesting for all the obvious reasons.

The initiation rites are the probable source of the story about Sabah's use of drugs to fool initiates into thinking they had gone to heaven when in reality they were only in Sabah's garden. This story was written by Marco Polo who passed through the area of the Eagle's Nest 150 years after Sabah and the Assassins. There is no other documentation to back it up, and so it must be taken with a grain of salt. Personally, I think that no matter how much hash someone ate, it is very unlikely that they would wake up after falling asleep and think themselves to be in heaven. But the available evidence does indicate that the Assassins practiced some form of discipline that may have bordered on modern theories of mind control. Another example of Sabah's prescient inventions.

After the Mongols conquered the Eagle's Nest in the late 13th century, the Assassins and the Ismailis in general declined from any power in the political sense. The Mongols burned the library at the Eagle's Nest, so no books by Sabah or the Assassins survive today. The whole essence of the organization built by Sabah rested on obedience, faith, and above all else, secrecy. We should not be surprised that a great deal of the knowledge of the Assassins was lost. We should also keep in mind that secrecy was one of the hallmarks of the gnostics and other early mystery cults.

Dan Washburn writes:

Hmmm. Since we know so little about them its hard to tell what kind of disciplines the Assassins practiced. As you say, the rumor is drugs. However, now that I think about it, if they were supposed to visit paradise, maybe they were practicing some form of Ascension similar to Jewish merkabah mysticism, which involves trance visits to the heaven world. Also if the Assassins were truly gnostic, then ascension is an even more likely methodology, since the gnostics and hermetics were practitioners of ascending through the seven spheres of the planets. Ah ha - another connection to the seven planets which are connected to the squares. You might take a look at Dan Merkur's book ***Gnosis*** to get more of an idea on all this.

http://www.netmastersinc.com/secrets/magic_squares.htm Go JUL FEB APR
57 captures 08
13 Dec 2000 - 5 Mar 2018 2000 2002 2003 About this capture
of Purity's book the Rasail may have assigned the magic squares to the planets, but I will have to wait until I can get my hands on some source material that finally gets down to the dirty details of just WHAT the BP saw in the squares, and why. The background data certainly suggests to me that the BP associated the squares with the planets in accordance with the medieval cosmology.

That puts us at about 990 AD for the publication of the Rasail that contains the first recorded example of a magic square of 6. The interesting thing about this fact is the inherent nature of the number 6. Here is where the mathematics provides some clues. Has you ever tried to create a magic square? If you study the squares mathematically you will see that different orders have different properties and some are easy and some are difficult. In brief, there are even numbers and there are odd numbers. Further, the even numbers come in two varieties, those that are evenly divisible by 4 and those that are not. Each magic square has a particular pattern that is made by connecting the numbers in order as they appear in the square. Odd order magic squares have patterns that are symmetrical about a principal diagonal. Even squares that are divisible by 4 have patterns that either have symmetry about 1 or 2 axis that are either horizontal or vertical or they may have no symmetry at all. But squares of 6, 10, 14, 18 etc. are strange. The patterns of the un-evenly even squares have no symmetry. There are other aspects of the UE squares that make them unusual.

Magic squares are related mathematically to another kind of square number arrangement called a Latin square (also called Greco-Latin squares). Methods of constructing magic squares by using Latin squares were published by a later mathematician named De LaHire. Latin squares have been (and are) studied by number theorists and also have found applications in modern technology. The idea of a Latin square is to arrange items with attributes in rows and columns so that each row and column has 1 and only 1 of each kind of attribute. For example, make a Latin square of 4 by using 16 cards, 4 from each suit in the order Ace, King, Queen, Jack. Now arrange the cards in a square so that each row and each column has 1 each of the suits and 1 each of the ranks. When you have done it, you have a Latin square. Now in later history the most famous of the mathematicians took up the problem of magic squares, among them being Euler, the greatest mathematician of all time. Euler studied magic squares and Latin squares. One of his famous unsolved problems was the Euler Conjecture - a statement to the effect that UE Latin Squares are impossible. Actually, if I remember it right, the EC had been disproved by 1960, in as much as larger UE Latin squares (such as a LS of 10) can be constructed, however they proved Euler right in the case of a Latin Square of 6. It's impossible.

The paper I received from the University of New South Wales on the Magic Squares of Manuel Moschopoulos, written in 1306 AD, is the first above-ground western writing that tells how to construct a magic square. But it is deficient in that it only gives methods for constructing odd and evenly-even squares. It says nothing about how to make

http://www.netmastersinc.com/secrets/magic_squares.htm Go JUL FEB APR 08 2000 2002 2003
57 captures
13 Dec 2000 - 5 Mar 2018
About this capture
any of the real combinatorial principals that magic squares are ultimately based on. Except that you can't make a magic square of 6 by resorting to such simplistic methods. That one you have to do the hard way.

From the mathematical point of view of the construction of a square of 6 is a more difficult task, and the appearance of the first magic square of 6 is far more significant mathematically than the first appearance of a square of 7 or 8 or 9. Did the medieval mystic/mathematicians understand these points? They must have. And yet we do not see any publication of their methods. Al-Buni the Arab mathematician who wrote about magic squares around 1200 AD may have known how to construct a square of 6, but the references I have so far indicate that he only gave the methods later published by Moschopoulos. The Rasail Ikhwan as-Safa is therefore crucial to our quest because it back dates knowledge of the square of 6 to sometime before 990AD in the west.

Dan Washburn Writes (04/02/00)

Nigel Pennick's ***Magical Alphabets*** has a section on magic squares in the chapter on the hebrew alphabet and also a chapter titled 'magic squares, literary labyrinths, and modern uses.'

Here is a quote from the hebrew alphabet chapter, p34:

"In Hebrew magic each planet can be seen as a symbol of one of the Sephirah on the tree of life. Saturn signifies Binah, the third Sephirah, whilst Jupiter, corresponds with the fourth Sephirah. Chesed. Mars parallels the fifth Sephirah, Geburah, whilst Mercury is the eighth Sephirah, Hod. This planetary scheme was the basis of Assyrian and Babylonian ziggurats, of which the ill-fated Tower of Babel was an example. In their purest cosmologically defined form, each of the ziggurats� seven stages or platforms represented one of the seven planets. The magic squares are arranged in a sequence that starts with the smallest grid at the outermost. For structural reasons, the outermost square on a ziggurat was the largest. However, it was ruled by the corresponding magic square, and painted in the corresponding colour. The engraving of the Khorsabad ziggurat, reproduced in Fig. 10, gives a good idea of the principle.

Summary of ziggurat drawing:
level 7 - moon - white
level 6 - mercury - blue
level 5 - venus - green
level 4 - sun - yellow
level 3 - mars - red
level 2 - jupiter - orange
base level - saturn - black

http://www.netmastersinc.com/secrets/magic_squares.htm Go JUL FEB APR
57 captures 08
13 Dec 2000 - 5 Mar 2018 2000 2002 2003 About this capture
numbers added together is 45. This is the square most commonly used by European magicians. Its traditionally associated colour is black, signifying the outermost planet and the bottom tier of the ziggurat."

Anyone know anything about ziggurats? Does this color scheme actually go back to Sumerian/Babylonian sources or is it a later occultist's dream? When did the magic squares become color coordinated? This is the first I've heard of it. Did Aggrippa mention this in his 'Occult Philosophy' (I saw a translation of the book at Borders the other day but haven't had time to look at it)? Or is this an invention of S. L. MacGregor Mathers or one of the other Golden Dawn boys?

I've known that the tiers of the ziggurat represented the planets but always assumed that it was an allegorical ascension thru the heavenly spheres to the realm of the fixed stars in an order of the planets that started with the nearest to the earth and progressed outward. The order outlined here seems to be a mirror image of the heavens. With saturn at the base the ascension of the pyramid is a descent thru the planets.

This may offer an explanation for something that has troubled scholars of Merkabah mysticism, the form mysticism took in Judaism for the thousand years before the rise of the Kabbalah around 1200 AD. In a trance the mystic ascends through seven visionary palaces to the throne chariot of God, the Merkabah. The movement is upward but the existent texts refer to it as the Decent to the Merkabah. If the seven palaces are based on the seven planets, then the visionary may indeed be descending through the heavenly spheres.

Mark Swaney Writes (04/17/00)

Have received a fairly exhaustive list of references and information on magic squares and their history from David Singmaster, the English mathematician and Rubick's Cube expert. Dr. Singmaster has sent to me a pile of references about a quarter inch thick. This material is exclusively REFERENCE material, so that the complete works cited would fill a truck, I'm sure. It's taken the weekend just to read through and assimilate the material, and there is much in it that is new to me, and bears directly on problems we are interested in.

The first news is that we have new information on the question of the assignment of the squares to the planets. The following is a list I made up last night from the Singmaster chronology and reference.

http://www.netmastersinc.com/secrets/magic_squares.htm Go JUL FEB APR 08 2000 2002 2003
57 captures
13 Dec 2000 - 5 Mar 2018
About this capture
Nadruni. I don't know anything more about this document except that Nadruni gives the same associations of the squares with the planets as that later given by Agrippa, 3 - Saturn, 4 - Jupiter, 5 - Mars, 6 - Sun, 7 - Venus, 8 - Mercury, 9 - Moon.

Another Arab manuscript, untitled, author unknown, circa 1466, gives a reverse mapping of squares to planets, i.e. 3 - Moon, 4 - Mercury, etc.

The first known European set of Magic Squares associated with the planets is in a 15 century Latin manuscript in Cracow, described as Jagiellonian MS #753. The reference does not say what the explicit ordering is, or who wrote it, or exactly when, or for what purpose.

In 1498 Pacioli wrote DeViribus, which gives squares and planets in the same relationship as Nadruni and later Agrippa. This is important as a possible source for Albrecht Durer's square shown in Melancholia I.

In 1531 Agrippa publishes De Occulta Philosophia, the second book of which gives magic squares associated with the planets in the well-known order 3 - Saturn, 4 - Jupiter, etc.

In 1539 Cardan writes Practica Arithmetica and gives the squares and planets in the reverse as that published by Nadruni, Pacioli and Agrippa.

Several interesting points to made about this information even in advance of receiving the works cited are;

1. The association of planets to squares is first PUBLISHED in the Arab world in sometime in the mid 14th century.

2. The mapping of planets to squares is given in two orders, each the reverse of the other, and each mapping is used in both the European and Arabic publications. Attention DAN WASBURN - you asked about the order of planets vs. squares in your post on magic squares and Ziggurats, indicating a possible confusion about the Merkabah mystics as to whether they are asending or descending. It appears that there were TWO "traditional" orders of planets.

3. Each of the orders results in the square of 6 being assigned to the Sun. This is due to the position of the Sun in the "center" of the list of planets, an at least allegorically helio-centric system. As I have said, this has implications for us in our interest in the numerology of the square of 6.

Another interesting assertion in the Singmaster material is a reference to

http://www.netmastersinc.com/secrets/magic_squares.htm Go JUL FEB APR
57 captures 08
13 Dec 2000 - 5 Mar 2018 2000 2002 2003 About this capture
we will be sure to investigate for obvious reasons. If supportable, this would put a new light on the order of planets given in the Sepher Yitzarah, written in about the 3rd century in Palestine, and push back knowledge of the squares in the West 11 centuries.

As a "bonus" for me especially, Singmaster has references to many mathematicians and puzzle-authors who have contributed to magic square literature over the years. Quite unexpectedly, I discover that Dr. Singmaster has excerpts from the notebooks of CHARLES BABBAGE, the famous English mathematician inventor and "grandfather of the computer". It seems that Babbage was interested in Latin Squares, Magic Squares, and Magic Cubes.

Along this line, (though not concerned with my main interest in the squares as magical devices) we can add some famous names to the list of people who squandered their time wrestling with these devices. Among them are;

Leonard Euler - often considered the world's greatest mathematician - studied Latin Squares and Magic Squares, author of the famous "Euler Conjecture".

Pierre Fermat - super-famous author of the finally-proved "Fermat's Last Theorm" - Fermat conceived and produced the world's first Magic Cube, also discussed magic triangles with Frenicle.

M. Mersenne - friend of Fermat's and fellow number theorist.

Bernard Frenicle - friend and correspondent of Fermat and Mersenne - first to list and produce all the 880 possible magic squares of 4.

Benjamin Franklin - worked with large magic squares and magic circles.

Charles Babbage - the 19th century genius who first described the concept of the modern computer and who attempted to build one - called a "difference engine"

Additional news to pass along - the Singmaster material provides the starting point for a LARGE research project, including as it does virtually all the previous research along the lines we wish to continue. What is clear from a review of everything I have collected is that while some information is known, a lifetime could be devoted to working on the history of magic squares and the associated religious/magical ideas. The contributions of the Indians in particular has not been very well understood, and the authors disagree among themselves as to the sources of the Arab magic squares, Indian or Chinese.

http://www.netmastersinc.com/secrets/magic_squares.htm Go JUL FEB APR
57 captures 08
13 Dec 2000 - 5 Mar 2018 2000 2002 2003 About this capture

information on sources) treat the larger subject of the relationship between mathematics and mystical experiences and philosophy. I think the territory is just waiting for someone to make a PhD dissertation on the subject. Any takers?

Finally, I have run out of time to write today, but there is more, such as the several sources that recommend that the magic square of 3 be used as a remedy for a hard labor during childbirth, such as the 5 15th century cast iron plates found in central China in 1958 with the magic square of 6 inscribed on them, such as a reference to the Chinese god of the POLE STAR (attention Barry!) and a description of the path of this god through the "houses" of the Lo Shu square. Information on Chinese beliefs about the Ming-Tang Palace and the Emperor.

In short, enough meat to chew on for quite a while. Anybody wanna dive in and help find and analyze this stuff?

Mark Swaney

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More information and links

China

Because there are 64 slots in the 8x8 matrix of the Magic Square of Mercury and because magic squares were important in China, I wondered if there was any connection with the 64 hexagrams of the I Ching.

I discovered an essay by Tayagi Nagasiva on Magic Squares and the I Ching at

http://www.hollyfeld.org/heaven/Avidyana/Dozen/cl.mgksqrs.fn

Quote from John Opsopaus (site http://www.cs.utk.edu/~mclennan/BA/PT/M19.html)

4 9 2
3 5 7
8 1 6

http://www.netmastersinc.com/secrets/magic_squares.htm Go JUL FEB APR
57 captures 08
13 Dec 2000 - 5 Mar 2018 2000 2002 2003 About this capture
much greater antiquity for this form of temple is indicated, firstly, by a temple of this plan being essential for Imperial worship, and, secondly, that in the 7th century B.C., during the time of the warring Lords, it was believed to have been used by Wu, the alleged founder of the Chou dynasty in 1025 B.C., when sacrificing to his ancestors. Moreover, if this tradition be correct, the Magic Square form of temple may ultimately be of Scythian origin, introduced at this time from Bactria, or ancient Iran, with the foreign mercenaries from the West, to whose help Wu owed his success in establishing a new dynasty." (From Bactria it may be traceable back to Mesopotamia.)

The Ming-T'ang had twelve stations for the monthly "Proclamation of Space and Time." There is one station for each line segment on the perimeter of the square, that is, two for each corner (even) square, one for each side (odd) square. The eight squares on the perimeter represent the eightfold year (3 = vernal equinox, 9 = summer solstice, 7 = autumnal equinox, 1 = winter solstice). The central square corresponds to the additional days of the year beyond the twelve lunar months represented by the twelve line segments of the outer squares. Thus the Son of Heaven visited the central room of the temple (numerically 5, the Emblem of the Center) at "the end of summer - a critical period when the transition was made from the yang seasons to the yin seasons" (Granet, Rel. Ch. 67). Alternately, the twelve line segments of the perimeter can represent the solar year and the zodiac. Thus the representation of Time; the temple also represented Space by assigning 8+3 = east, 4+9 = south, 2+7 = west, 6+1 = north (the same four numbers as the elements, though not the same pairs of squares); opposing directions balance to 20, as do opposing elements. (Granet, Rel. Ch. 66-8; Stapleton, "Antiq. Alch.")

Blofeld (I Ching, 218) says that mankind once understood how the Lo-Shu Square is connected with the (apparently illogical) Later Heaven Sequence of the I Ching, but that it has been forgotten and now only the gods know it. I certainly have not been able to find it. (The connection established by Hacker (41) seems to me to be contrived, although it is remarkable enough that any connection can be established at all.)

Christianity

To get a look at some work by Dan Gleason relating the 888 of Jesus to the 666 of the magic square of the Sun click on the link below:

http://www.jesus8880.com/gematria/666.htm

Islam

Kieth Critchlow has a chapter on Magic Squares in Islam in his book ***Islamic Patterns***.

http://www.netmastersinc.com/secrets/magic_squares.htm Go JUL FEB APR
57 captures 08
13 Dec 2000 - 5 Mar 2018 2000 2002 2003
About this capture

http://www.vh.org/welcome/UIHC/MedMuseum/ArtThatHeals/10Knowledge.html

21. Diagrams from the Book of Buni, the Geez translation of a version of the "Sun of Knowledge" (Shams al-Marif), a book attributed to Al-Buni, an Egyptian author of the thirteenth century. Each diagram containing figures or letters is accompanied by its method of use. Book of Buni, eighteenth century to nineteenth century, parchment, 27.5 x 24 cm. Private collection. Photo courtesy of Guy Vivien

A quotation from John Opsopaus:

Magic Square of 3

4 9 2
3 5 7
8 1 6

According to the Theory of Balance attributed to 8th century Muslim alchemist Jabir ibn Hayyan (based on 3rd century works by Zosimos and others), the Cosmos and everything in it is made from the numbers 1, 3, 5, 8, 17 and 28; they are the foundation of all matter, of every science, and even of any possible language. The first four numbers were assigned by the Jabirian alchemists to the elements, 1=fire, 3=earth, 5=water, 8=air. The sum of these is 17, which is the fifth number. The Gnomon, which gives the larger square, sums to 4+9+2+7+6 = 28, the sixth number, the second Perfect Number.

Quoted from the following site:

http://www.cs.utk.edu/~mclennan/BA/PT/M19.html

Judaism

I've been reading Aryeh Kaplan's ***Meditation and the Kabbalah***, He has a chapter on the Kabbalistic writings of Rabbi Joseph Tzayach (1505-1573) the Rabbi of Damascus.

Kaplan says that magic squares were well known in ancient India and China and that they were introduced into the west in the 1400s by Moschopulus of Constatinople. Kaplan believes

http://www.netmastersinc.com/secrets/magic_squares.htm Go JUL FEB APR
57 captures 08
13 Dec 2000 - 5 Mar 2018 2000 2002 2003 About this capture

His system attributes the traditional magic squares to the seven planets but goes on to attribute higher order magic squares to the Sephira on the Tree of Life, a Jewish mystical diagram: The square of ten to Kether, of 11 to Chokmah, etc. skipping the square of 15, so that Malkuth is the 20x20 matrix.

Tzayach apparently had a system that involved meditating on the color, number, and letter forms in one room after another in a square. Each row was called a house and each box a room.

What we might be seeing here is a form of Merkabah Ascension. Up through the spheres of the 7 planets and then through 10 (usually 7 in other literature) palaces of the King to the throne of God. The position of meditation described is that of Elijah on Mt. Carmel, sitting cross legged with head between the knees, a position associated with Merkabah Ascension.

Magic square lore may have passed back and forth between Jewish and Muslim mystics.

General

David Singmaster gives a number of dates relating to the history of Magic Squares in his "Chronology of Recreational Mathematics."

http://www.geocities.com/SiliconValley/9174/recchron.html

Here are some book references (I have not looked at) from the bilbiography at

http://www.pse.che.tohoku.ac.jp/~msuzuki/refference.html

Edward Falkener, "Games ancient and oriental and how to play them : being the games of the ancient Egyptians, the hiera gramme of the Greeks, the ludus latrunculorum of the Romans and the oriental games of chess, draughts, backgammon and magic squares" :New Dover ed:New York : Dover Publications , (1961)

Soror A.L. ,Compton, Madonna, "Western mandalas of transformation : magical squares, tattwas, qabalistic talismans", St. Paul, MN, U.S.A. : Llewellyn Publications , (1995)

Richard Webster, "Talisman magic : yantra squares for tantric divination", St. Paul, Minn., U.S.A. : Llewellyn Publications , (1995)

http://www.netmastersinc.com/secrets/magic_squares.htm Go
JUL FEB APR
57 captures 08
13 Dec 2000 - 5 Mar 2018
2000 2002 2003
About this capture

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291 captures 14
11 Jun 2002 - 20 Jan 2019 2005 2006 2007 About this capture

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Magic Squares

Suzanne's Math Lessons || Suzanne's Tessellation Lessons

Magic squares received their name because there are so many relationships between the sums of the numbers filling the squares.

Students often believe that "mathematics" was "written" by one person. In these pages you will find that the magic square **mathematical game** has existed throughout history and in many different parts of the world. Math is all around us and your mind will *see* it when you're ready!

What is a Magic Square?

Allan Adler defines and discusses some special properties of magic squares.

Magic Squares - History, Mathematics, Geography

Lo Shu Magic Square

The Back of the Divine Tortoise
Classroom Activity
China - the country of Lo Shu

Albrecht Dürer's Magic Square

Albrecht Dürer - Engraving of Melancholia
Al brecht Dürer - engraver
More about Albrecht Dürer
Classroom Activity
Germany - the country of Albrecht Dürer
GEOM ART RY - Ralph Martel

Benjamin Franklin's 8x8 Magic Square

The World of Benjamin Franklin - the Franklin Institute
Classroom Activity
Pennsylvania, U.S.A. - Benjamin Franklin's State

http://mathforum.org/alejandre/magic.square.html Go JUN JUL OCT
291 captures 14
11 Jun 2002 - 20 Jan 2019 2005 2006 2007 About this capture

- **Where's the Math? - with Allan Adler**
  - **Classroom activities: multiplying magic squares**

    Constructing magic squares
    Defining the magic square; special properties
    Exploring the math
    Review: Squaring a magic square

- **Mike Morton's Magic Square Java Applet**

- **Updated Magic Square Java Applet by Pavel Safronov and Michael McKelvey**

- **Dubi Kaufmann's Magic Square Puzzle**

- **H. B. Meyer's 5 x 5 Magic Square Generator**

- **Special magic square unit by Neil Abrahams**
  - **The Franklin Square**

    Background and Lesson Information
    Construction Algorithm
    Observations and Proofs: Rows
    Columns and General Observations
    Columns and General Observations, cont.
    Questions, Suggestions & References

- **Other Magic Square Links**
  - **Mutsumi Suzuki's Magic Square Page**
  - Magic Squares, Magic Stars & Other Patterns by Harvey D. Heinz
  - Fabrizio Pivari's Simple Magic Square png maker
  - Grog's Magic Squares
  - Interactive Magic Square by Lee-Anne Grunwald
  - MathWorld: Magic Squares by Eric W. Weisstein
  - Multimagic Squares by Christian Boyer
  - Solving Magic Squares by Kevin Brown

- **Mutsumi Suzuki's Magic Stars**
  - What is a Magic Star?
  - Magic Star Sets
  - Transforming Magic Stars
  - Combining Exchange Rules

http://mathforum.org/alejandre/magic.square.html Go JUN JUL OCT
291 captures 14
11 Jun 2002 - 20 Jan 2019 2005 2006 2007
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This site is listed in the BBC Education Web Guide.

http://philip-hefti.ch/eng/comp/satorcycle.htm Go
MAR MAY JUL
08
2002 2005 2009
5 captures
18 Jun 2002 - 23 Jul 2009
About this capture

Home
Biography
Compositions
Press Reviews
Photos
Recordings
Mailinglist
Contact
Links

[Deutsch]

Philip Hefti (*1975)

SATOR Cycle (from 2002)

Description:

The following five compositions are united in the SATOR Cycle

1. SATOR Concerto for Clarinet and Orchestra (2002)
2. AREPO Concerto for Violin and Orchestra (2004)
3. TENET 4 Songs for Soprano and Ensemble (2003)
4. OPERA
5. ROTAS Concerto for Piano and Orchestra (2004/05)

additive component: 'Mosaic' Cycle

The S A T O R - Square

S A T O R
A R E P O
T E N E T
O P E R A
R O T A S

This letter square consists of 5 words, which can be read forward and backwards and result in this special case in a different meaning (palindromes). This composition of words written in the Latin language is more than 1.500 years old and can be translated as follows:

Arepo (name) the sow man (sator) holds (tenet) the cart (rotas, the wheels) with effort.

As this translation hardly results in a satisfying sense, scholars speculated many centuries and still have not found an accurate interpretation. Only a free translation could make more sense.

The Creator (sator) hiddenly (arepo, repere = creep; a-repo: from the "crept-away") steers (tenet) the wheels (rotas) of the world (opera = his work).

More freely: **Out of the hidden, the Creator keeps the world going.**

This square is already very old and existed for centuries in German, Latin, Greek and Coptic spellings. It appeared first in the 4. and 5. century in Asia Minor on charms of bronze. Since the 8. century it is found in Latin manuscripts of German monasteries, later it was also cut in stone or carved in wood at church and secular buildings. In the late Middle Ages, the square, which had been spread throughout whole Europe so far, moved ahead to America.

For many centuries it had been considered to be a charming symbol against plague, hunger, fire and demons. It could be found on notes and tools, carved in doors and portals, written in books, cut in bread. Still in the 18. century so-called satorplates (plates, which carry the symbol) had been used as fire extinguishers in Saxony. By throwing them into the fire, it would be able to avoid the danger - so people hoped.

http://philip-hefti.ch/eng/comp/satorcycle.htm Go MAR MAY JUL
5 captures 08
18 Jun 2002 - 23 Jul 2009 2002 2005 2009
About this capture

```
          P
          A
   A      T      O
          E
          R
P A T E R N O S T E R
          O
          S
   O      T      A
          E
          R
```

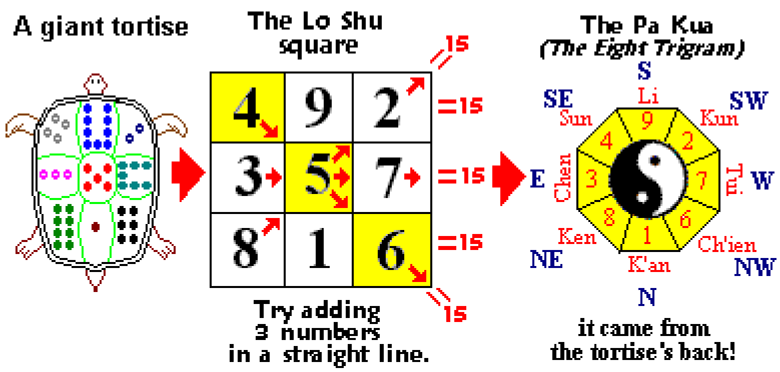
In 1926, Felix Grosser published an interpretation, which applies as the most probable solution of the problem until today. Grosser connected the letters in a certain symmetrical way and could read the following sequence of words: PATER NOSTER A O, PATER NOSTER A O. (A and O stand thereby for alpha and omega, for the beginning and the end of the Greek alphabet or for "from the beginnig to the end of time").

Therefore the Sator-square would have to be considered an early Christian cryptic sign, which the Christians of the archaic church used as a secret symbol for identification purposes. Who could read it, was regarded as consecrated and trustworthy.

http://sunflower.singnet.com.sg/~cecil/tortise.htm Go
26 captures
30 Aug 1999 - 27 Jan 2007
SEP JAN FEB
16
2005 2007 2008
About this capture

[Time Dimension] - [Contents | Previous | Home]

The Lo Shu Square : The Legend of the Giant Tortise



According to ancient Chinese legends, a giant tortoise surfaced from the River Lo in central China around 4,000 years ago. The ancients found a pattern on a tortise shell *(see extreme right picture)*. There were circular dots of numbers that were arranged in a three by three nine grid pattern on it's shell.

The pattern of numbers in any given direction - horizontal, vertical or diagonal add up to a total of 15 *(see middle picture above)*. This is equal to the 15 days in each of the 24 cycles of the Chinese solar year.

The significance of the arrangements of the numbers on the giant tortise feature prominently in the following:

1. The Chinese system of time dimension also takes into account number 9. Time is divided into 9 ages, each lasting 20 years. Three 20 year ages make up one period. A full cycle takes 180 years. Each period is assigned a number, from one to nine.

2. The origins of The Eight Types of Houses Theory makes use of the Pa Kua or *The Eight Trigram* of the *I Ching (Book of Changes)* to look diagnose a home.

3. The Lo Shu square became the basic theory of The Flying Star School of Feng Shui.

CONTENTS PREV HOME

http://www-groups.dcs.st-and.ac.uk/~history/Mathematicians/Durer.html Go
MAY JUL JAN
155 captures 02
19 Apr 1998 - 24 Jul 2018 2005 2006 2007
About this capture

Albrecht Dürer

1471 - 1528

Click the picture above
to see seven larger pictures

Dürer was a German artist who is known for his work as an engraver. The foundations of descriptive geometry are laid in Dürer's treatise on human proportions published in Nuremberg after his death in 1528.

Full MacTutor biography [Version for printing]

List of References (23 books/articles)

Some Quotations (3)

A Poster of Albrecht Dürer

Mathematicians born in the same country

Show birthplace location

Honours awarded to Albrecht Dürer
(Click below for those honoured in this way)

Planetary features	**Crater Dürer** on Mercury

Other Web sites

1. The Galileo Project
2. The Catholic Encyclopedia
3. Mark Harden's Artchive (More self portraits and other works)
4. George W Hart (Dürer's polyhedra)

Previous (Chronologically) Next Main Index
Previous (Alphabetically) Next Biographies index

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http://www-history.mcs.st-andrews.ac.uk/Mathematicians/Durer.html

http://mathforum.org/te/exchange/hosted/suzuki/chani.welch.html Go DEC JAN JUN
6 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2013
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Mutsumi Suzuki
Magic Squares

Magic Squares - Chani Welch

Chani Welch
ma163sbj
Presented 5/17/95

DEFINITION/CONSTRUCTION:

A magic square consists of an NxN (N = 3,4,5...) matrix of numbers.

These numbers are usually consecutive integers (not a requirement). There are two types of magic squares - odd and even. Both odd and even magic squares have the following property:

(1) The sum of all rows and all columns should equal the same amount.

Odd magic squares have these additional properties:

(1) The sum of each main diagonal should equal the same amount as the sum of each row and column.
(2) The sum of any two numbers geometrically equidistant from the center should be two times the amount of the center number.

Even magic squares have this additional property:

(1) The sum of any two numbers geometrically equidistant from the center should equal the sum of the first and last numbers in the series of numbers you are working with.

Here is an example of an odd and an even magic square:

7x7 (odd):

30	39	48	1	10	19	28
38	47	7	9	18	27	29
46	6	8	17	26	35	37
5	14	16	25	34	36	45
13	15	24	33	42	44	4
21	23	32	41	43	3	12
22	31	40	49	2	11	20

Odd: The sum of each row, column, and diagonal equals 175. The sum of any two numbers equidistant from the center equals 50.

8x8 (even):

1	63	62	4	5	59	58	8
56	10	11	53	52	14	15	49
48	18	19	45	44	22	23	41
25	39	38	28	29	35	34	32
33	31	30	36	37	27	26	40
24	42	43	21	20	46	47	17
16	50	51	13	12	54	55	9
57	7	6	60	61	3	2	64

Even: The sum of each row and column equals 260. The sum of any two numbers equidistant from the center equals 65.

Note that in the odd 7x7 magic square, the center number is 1/2 the sum of the first and last numbers in the consecutive series 1-49. This holds true for any odd magic square in which the numbers are consecutive integers.

Formula for finding the total of each column (and row):

http://mathforum.org/te/exchange/hosted/suzuki/chani.welch.html Go DEC JAN JUN
6 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2013 About this capture

2. Let N equal the number of columns squared, then use this formula: N(N+1)/2 to find the total sum of the series.
   For example, in a 7x7 magic square, 7 squared equals 49, so the total sum of the series 1-49 equals: 49(49+1)/2 = 1225.
3. Since 7X = the total sum of the series, 1225/7 = 175 = the sum of each column (and row).

Once you know what the sum of each row and column should be, it will be easier to check your magic sqaure for correctness.

There are many ways to construct magic squares, once you have the basic rules down. I have found that the easiest way to construct odd and even magic squares is to use a more geometric approach, vs. an arithmetic approach. It is difficult to explain the geometric approach here, so a detailed description will be given in class. I would not suggest using an arithmetic approach on larger magic squares because it is quite time consuming (not to mention a big fat headache!). If you happen to miss clas the day I show you my oh-so-wonderful technique for solving these guys, check out "Magic Squares and Cubes", by W.S. Andrews (In the Science and Engineering library), or simply come up to me and ask me to show you!

For reference purposes, however, I will now try to give a description for the simplest methods of solving magic squares:

My favorite method for solving odd magic squares is Loubere's method, which he derived from methods used in India. Odd Squares: Think of the NxN magic square grid as a cylinder (i.e. fold the ends backward until they meet, forming a cylinder). We'll use a 7x7 magic square as an example. First, place the number 1 in the center of the top row. Next, put 2 on the bottom row and the column to the right of the center column. 3 will be placed 1 row up and 1 column over from 2, 4 will be placed 1 row up and 1 column over from 3. 5 will wrap around to the other side of the cylinder, 6 will be placed 1 row up, 1 col over from 5, 7 will be 1 row up, 1 column over from 6. This should look like a diagonal line running up the "cylinder":

```
* * * 1 * * *
* * 7 * * * *
* 6 * * * * *
5 * * * * * *
* * * * * * 4
* * * * * 3 *
* * * * 2 * *
```

Since 7 is now blocked, place 8 one row beneath 7, and repeat the same process. When you place a number on the top row, place the next number on the bottom row in an adjacent column to start a new spiral. If the number is on the right edge, the next number should "wrap around" to the other side of the cylinder, continuing its upward spiral (with the exception of the upper right hand corner). For example:

```
30 *  *  1  10 19 28
*  *  7  9  18 27 29
*  6  8  17 26 *  *
5  14 16 25 *  *  *
13 15 24 *  *  *  4
21 23 *  *  *  3  12
22 *  *  *  2  11 20
```

Now go back and look at the complete 7x7 square to examine the complete pattern.

Even Squares: Even sqares are a lot more fun to solve, and there are many ways to solve them. My favorite solution, developed by Agrippa (1510 A.D.), is as follows:

http://mathforum.org/te/exchange/hosted/suzuki/chani.welch.html Go DEC JAN JUN 17 2006 2007 2013
6 captures
17 Jan 2007 - 21 Jul 2016
About this capture

```
                 19 20 21 22 23 24
                 25 26 27 28 29 30
                 31 32 33 34 35 36
```

Now consider the reverse of that order:

```
                 36 35 34 33 32 31       "ro" will denote reverse
                 30 29 28 27 26 25        ordinary.
                 24 23 22 21 20 19
                 18 17 16 15 14 13
                 12 11 10 9  8  7
                 6  5  4  3  2  1
```

Now, fill in a 8x8 grid using an ordinary order on both main diagonals and on a diamond pattern around the sqaure, and use reverse ordinary order on the remaining cells.

For example:

```
      O  ro ro O  O  ro ro O          1        4  5        8
      ro O  O  ro ro O  O  ro            10 11       14 15
      ro O  O  ro ro O  O  ro            18 19       22 23
      O  ro ro O  O  ro ro O          25       28 29       32
      O  ro ro O  O  ro ro O          33       36 37       40
      ro O  O  ro ro O  O  ro            42 43       46 47
      ro O  O  ro ro O  O  ro            50 51       54 55
      O  ro ro O  O  ro ro O          57       60 61       64
```

GENERAL HISTORY:

Chinese Method:

The Chinese constructed even squares much the same way as the method described above, except their "ordinary" order was from top to bottom, beginning in the upper left hand corner. This was because of the use of bamboo strips as writing material. The first Chinese magic square is seen in the scroll of the river Loh - the Loh-Shu, a scroll believed to have been created by Fuh-Hi, the mythical founder of Chinese civilization, who lived from 2858 to 2738 B.C.

The scroll is a 3x3 magic square, where odd numbers are expressed as white dots, or yang symbols, and even numbers are expressed as black dots, or yin symbols. The odd numbers are supposed to be symbols of heaven, while even numbers are symbols of the earth. The first appearance of the Loh-Shu in the form of a magic square was in writings from the time period between the latter part of the Chou dynasty (951-1126 A.D.) and the beginning of the Southern Sung dynasty (1127-1133 A.D.). A later example of what is believed to be a similar Chinese magic square is the map of Ho. Looking at the construction of the map of Ho, however, it is not readily apparent that it is a magic square, since the numbers are from one to ten, and the construction does not resemble any patterns of magic squares we've seen so far.

Confucius (551-479 B.C.) wrote appendices to the Yih King, and this passage, written around 500 B.C., describes his philosophy on numbers:

> "...The numbers belonging to heaven are five, and those belonging to earth are five. The numbers of these two series correspond to each other, and each one has another that may be considered its mate. The heavenly numbers amount to 25, and the earthly to 30. The numbers of heaven and earth together amount to 55. It is by these that the changes and transformations are effected and the spiritlike agencies kept in movement."

Looking at the Chinese philosophy on numbers and the differences in their "magic squares", it is evident that the arrangement of odd

http://mathforum.org/te/exchange/hosted/suzuki/chani.welch.html Go DEC JAN JUN
6 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2013 About this capture

Egypt:

In Egypt, magic squares were used to represent the difference between order and chaos. Squares made up of two or four cells were said to represent chaos because they were incapable of forming magic squares. Magic squares 3x3 or larger were dedicated to the sun, moon, and planets in the form of talismans. The talismans were made by taking a magic square and placing it in a polygon with the number of sides of the polygon equal to the root of the square (i.e. a 3x3 magic square was placed in a triangle, a 5x5 was placed in a pentagon, etc..) These polygons were then placed in a circle, and in between the sides of the polygon and the circle were inscribed signs of the zodiac. Then, the "good" or "evil" name of the corresponding planet was written on the talisman. It is rumored that Pythagoreas, who traveled through Egypt at that time (500 B.C.), was greatly influenced by the Egyptian philosophy on magic squares and numbers.

India:

Not much can be said for certain of magic squares in India, since many of the people who have developed upon Indian methods are from the 17th to 19th century. Many sources I have looked at, however, have suggested that magic sqares have Indian roots, since the natives wear them as talismans, and certain architectural works contain them.

Benjamin Franklin:

Franklin is worth mentioning here for the unusual "properties" of his 8x8 and 16x16 magic squares. Not only did all the columns and rows of his magic squares equal the same amount, but other patterns existed, such as his "bent" diagonals and squares within the square, that totaled up to the same amount as the rows and columns. I have provided diagrams of these patterns in the handout I gave out in class.

Magic Squares in Europe:

Magic squares were introduced into Europe in the 15th century. The most notable names in devloping methods for solving magic squares are Agrippa (De Occulta Philosophia (II, 42) - 1510), Bachet (Problems plaisans et delectables - 1624), De La Loubere (Relation du Royaume de Siam - 1693), Ozonam (Recreations Mathematiques - 1697), Poignard, and De La Hire.

The methods used by Agrippa and Bachet for solving both odd and even magic squares are given in the handout. Loubere's method (the "cylinder" method) is given in the handout as well.

Ozonam uses ideas similar to Agrippa and Bachet, but his method is a bit more complicated, so I will not go through the trouble of describing his earlier magic squares. In Ozonam's later work, Recreations Mathematiques et Physiques (1750), he uses the concept of the "knight's move" to construct magic squares. Anyone who has ever played chess will be familiar with the movement of a knight on a chessboard. For those of you who don't play chess, however, a knight moves in a "L" shaped pattern - two squares up and one square over, or one square up and two squares over, are both acceptable movements for a knight. Using this concept, Ozonam was able to construct a magic square by taking a grid and moving in "L" shaped patterns around the grid, landing on each cell in the grid exactly once. Anytime the knight was at an edge of the grid, it would simply wrap around to the other side of the grid to complete its movement. Unfortunately, I believe this example only works for

http://mathforum.org/te/exchange/hosted/suzuki/chani.welch.html Go DEC JAN JUN 17 2006 2007 2013
6 captures
17 Jan 2007 - 21 Jul 2016
About this capture

```
upon by De La Hire, is one of the simplest arithmetic methods I've
seen so far.  For this example I will use a 5x5 magic square,
although this method works for even squares as well:
      First, construct an NxN matrix, using numbers from 1 to N in
the following pattern:
(5x5) ----->   1  2  3  4  5   Now constuct a   20 15 10 5  0
N = 5          2  3  4  5  1   matrix using     0  20 15 10 5
               3  4  5  1  2   multiples of N   5  0  20 15 10
               4  5  1  2  3   (5x5) ---->      10 5  0  20 15
               5  1  2  3  4                    15 10 5  0  20

Now, add these two matrices                21 17 13 9  5
together, and you get an NxN ------>       2  23 19 15 6
(in this case, 5x5) magic                  8  4  25 16 12
square.                                    14 10 1  22 18
                                           20 11 7  3  24
```

There are many other ways of constructing magic squares, and many new geometric developments involving magic squares like magic cubes, magic pentagons, magic squares in circles, magic squares in borders, etc. Since I do not have the time to go into any of these new methods in depth, however, I will conclude with the following exercise:

Construct an odd magic square of 9x9 or larger OR construct an even magic square of 8x8 or larger using a pattern different from those given in the handout.

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Back to Suzuki's Magic Squares

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Please mail comments and suggestions to Suzanne Alejandre.

http://www.grogono.com/magic/index.php Go
171 captures
25 Jul 2003 - 2 May 2019
OCT JAN FEB
04
2005 2006 2007
About this capture

Grogono Magic Squares Home Page

Home Page
Make Your Own
Choose by Size
How Many?
The Formula
Magic Carpets
Analysis
Magic Cubes
History
References
Contact
Downloads
Links
Glossary
Grogono Home

Revision:
Features in Recent Revisions

Same Author:
Acid-Base
Animated Knots
Stereo Art

Introduction.

A Magic square is intriguing; its complexity challenges the mind. For order 4 and above the number of different magic squares is astonishing - and the number remains large even if we limit consideration to Pan-Magic squares. This website reflects my own fascination with these large numbers and presents techniques aimed at explaining and reducing the huge numbers by showing how this abundance can be reduced to a small number of underlying patterns or Magic Carpets.

Recent Addition

Do it yourself! Make your own magic square of any size up to 97x97.

Discoveries.

The development of this website was associated with several intriguing discoveries. Please look at the pages for the Order 4, Order 5, Order 6 magic squares.

Dedication.

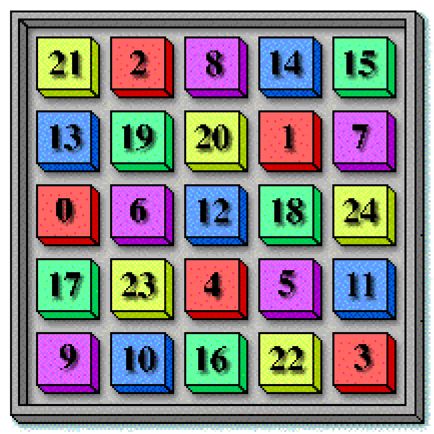
This Magic Square website is dedicated to my father E.B. Grogono (1909 - 1999) and was originally created at his bedside during his last illness. My fondest memories of him, from my earliest childhood to the final days of his life, center on his ability to transmit his love for, and fascination with, mathematics and science.

Revision

This revision uses up to date technology to make the website easier to manage and the material has been re-arranged to make it more accessible. A glossary has been added and the index system has been revised.

Now, Belatedly, Welcome!

Visit, play, learn about Magic Squares and Magic Carpets, make your Own Magic squares, and explore the techniques devised to understand pan-magic squares.



Glossary

If you want to check on the meaning of the terms used on this website, please review the Glossary

Pan-Magic Squares.

The Main focus of this website is Pan-Magic squares where even the broken diagonals add up to the Magic Sum, e.g., 60 in the square above 60 (diagonal 13, 2, 16, 5, 24). Pan-magic squares have also been called Pan-Diagonal and Nasik.

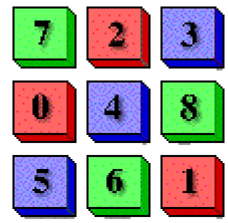
Why start Magic Squares using zero?

A glib answer might be because I like to and this is my site. A mathematical answer is that analysis (and construction) of magic squares is more logical, and the results easier to analyze, when the smallest number is 0. This is particularly true when the Magic Carpet approach is used to analyze or construct a magic square, e.g., to construct an order four magic square, four magic carpets would be required using: 8 & 0; 4 & 0; 2 & 0; and 1 & 0.

- **Traditional Magic Squares**, start at one, probably because magic squares were discovered first and analyzed later. Early counting systems didn't include either zero or negative numbers, so number one must have seemed a pretty good starting place.

http://www.grogono.com/magic/index.php Go OCT JAN FEB
04
2005 2006 2007
171 captures
25 Jul 2003 - 2 May 2019
About this capture

I am frequently asked to provide the Formula for Magic Squares. At the risk of spoiling some teacher's classwork assignments I have worked out a satisfactory answer and have devoted a page to this topic. (Thank you Danny Lawrence for making me do this and for sitting with me while I worked it out.) Two formulae are included, one for the prime-number orders, e.g., 5, 7, 11, 13, etc., and one for an order 4 square.



How Many Squares?

My fascination with magic squares grew from experimental attempts to count the total number of possible squares when squares which, apparently different, were really identical when appropriately reflected or rotated. A separate page lists the Number of Pan-Magic Squares for the Prime Number Order squares.

Unique Identifiers.

The process of counting and comparing regular panmagic squares generated a need to identify squares to facilitate ranking and comparison. Out of this grew a scoring system to uniquely identify any order 4 or order 5 pan-magic square.

The method I developed assigns a Unique Identifier to each square and is applicable to regular panmagic squares of orders 4 and 5. It depends on summing defined cells which have been multiplied by successively higher powers of the square's order. Although the technique could be extended to larger squares, the length of the expression, and the resulting magnitude of the numbers, makes it too unwieldy.

By the Same Author

If you have found this website useful, you are invited to visit my one of my other teaching sites.

Two of these other sites are mounted on my main website but all three are treated as an independent website:

- **Acid-Base Tutorial**

  This website is aimed at physicians, physiologists, medical students, nurses, and other health care professionals. The Tutorial includes interactive diagrams and equations to make the material more interesting and more readily understood.

- **Animated Knots**

  This website is aimed at yachtsmen, scouts, climbers, fishermen and anyone else who needs to know how to tie Practical Safe Knots. Each animated knot "ties itself" automatically and can also be "tied" and "untied" slowly to reveal its structure.

- **Stereo Art**

  This website demonstrates how a vivid three-dimensional stereo image is created from a repeated stereo image pair. A collection of Stereo Art Images illustrates the technique.

Size: Index | 3x3 | 4x4 | 5x5 | 6x6 | 7x7 | 8x8 | 9x9 | 10x10 | 11x11 | 12x12 | 13x13

Copyright © 2004 Magic Squares Website Updated January 30th 2005

http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.wasan.html Go DEC JAN JUL
7 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009
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Mutsumi Suzuki
Magic Squares

A brief history of magic square in Japan

Japan was isolated from western society in the Edo erra (1603-1867). During those days Japanese mathematician created their own mathematical world. Many difficult problems were presented and solved. Most of the answers were dedicated to temples or shrines as beautiful pannels which were called "San-Gaku". Many of them were lost during the tide of modernization after the Meiji revolution. About nine hundred San-Gaku, howver, are seen nowadays in rural area of Japan. A few of them are collected for W.W.W. by Mr. Kotera.

Many books on the Japanese mathematics (called "Wa-San") were also published during the Tokugawa-Shogun's period. These mathematics are called "Wa-San" (old Japanese Math) in order to distinguish them from western mathematics. Beauty of the Wa-San was recently introduced to the western society by "Japanese Temple Geometry Problems" written by Mr. H. Fukagawa, published from Charles Babbage Research Centre (1989). Mr. Fukagawa wrote another book on Wa-San (not translated into English yet). Following short comments on the magic squares in Japan were seen in the book.

```
    2  1  3
    3  2  1
    1  3  2
```

Above magic square using 1 , 2 and 3 was seen in a book publised in 1743.

```
    6  1  8
    7  5  3
    2  9  4
```

This well known square was seen in another book published in 1840.

```
                      19

                      16

  17                  13                    18
          14                          15
                11                12
                       1
                 9                10
           6                          7
    3                  8                     4

                       5

                       2
```

This magic circle was reported in 1660.

Back to **Suzuki's Magic Squares**

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http://mathforum.org/te/exchange/hosted/suzuki/MagicSquare.wasan.html Go DEC JAN JUL
7 captures 17
17 Jan 2007 - 21 Jul 2016 2006 2007 2009 About this capture

The Math Forum is a research and educational enterprise of the Drexel School of Education.

Please mail comments and suggestions to Suzanne Alejandre.

http://mathworld.wolfram.com/MagicSquare.html Go
218 captures
16 Aug 2000 - 4 Apr 2019
JUN JUL AUG
16
2005 2006 2007
About this capture

Last updated:
12,610 entries
Sat Jul 15 2006

Created, developed, and nurtured by Eric Weisstein at Wolfram Research

Magic Square

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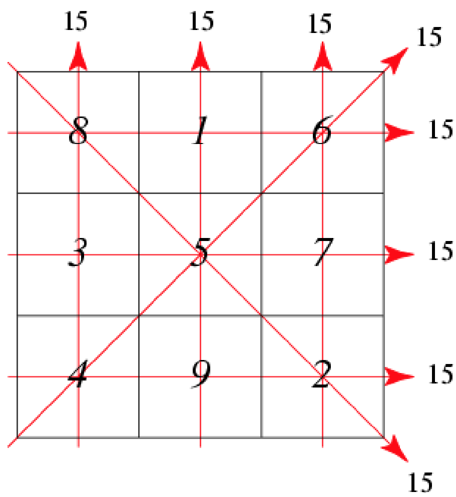


A magic square is a square array of numbers consisting of the distinct positive integers 1, 2, ..., n^2 arranged such that the sum of the n numbers in any horizontal, vertical, or *main* diagonal line is always the same number (Kraitchik 1952, p. 142; Andrews 1960, p. 1; Gardner 1961, p. 130; Madachy 1979, p. 84; Benson and Jacobi 1981, p. 3; Ball and Coxeter 1987, p. 193), known as the magic constant

$$M_2(n) = \frac{1}{n}\sum_{k=1}^{n^2} k = \tfrac{1}{2} n (n^2 + 1).$$

If every number in a magic square is subtracted from $n^2 + 1$, another magic square is obtained called the complementary magic square. A square consisting of consecutive numbers starting with 1 is sometimes known as a "normal" magic square.

8	1	6
3	5	7
4	9	2

16	3	2	13
5	10	11	8
9	6	7	12
4	15	14	1

17	24	1	8	15
23	5	7	14	16
4	6	13	20	22
10	12	19	21	3
11	18	25	2	9

32	29	4	1	24	21
30	31	2	3	22	23
12	9	17	20	28	25
10	11	18	19	26	27
13	16	36	33	5	8
14	15	34	35	6	7

30	39	48	1	10	19	28
38	47	7	9	18	27	29
46	6	8	17	26	35	37
5	14	16	25	34	36	45
13	15	24	33	42	44	4
21	23	32	41	43	3	12
22	31	40	49	2	11	20

64	2	3	61	60	6	7	57
9	55	54	12	13	51	50	16
17	47	46	20	21	43	42	24
40	26	27	37	36	30	31	33
32	34	35	29	28	38	39	25
41	23	22	44	45	19	18	48
49	15	14	52	53	11	10	56
8	58	59	5	4	62	63	1

The unique normal square of order three was known to the ancient Chinese, who called it the Lo Shu. A version of the order-4 magic square with the numbers 15 and 14 in adjacent middle columns in the bottom row is called Dürer's magic square. Magic squares of order 3 through 8 are shown above.

The magic constant for an nth order general magic square starting with an integer A and with entries in an increasing arithmetic series with difference D between terms is

$$M_2(n; A, D) = \tfrac{1}{2} n [2a + D(n^2 - 1)]$$

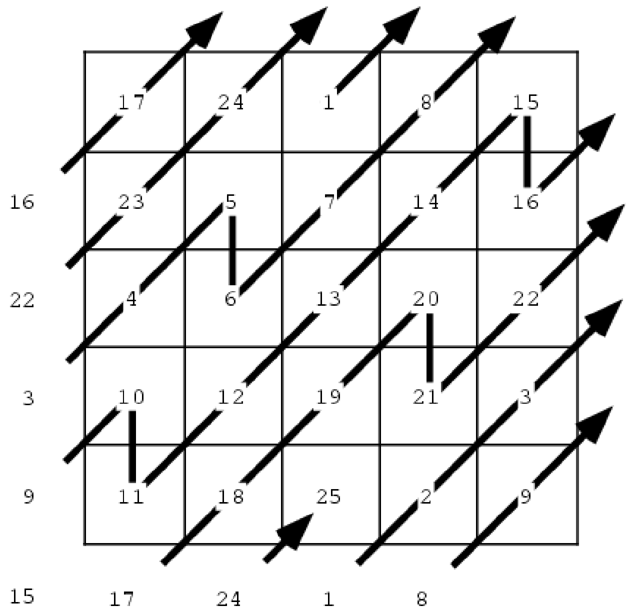
(Hunter and Madachy 1975).

http://mathworld.wolfram.com/MagicSquare.html Go JUN JUL AUG
218 captures 16
16 Aug 2000 - 4 Apr 2019 2005 2006 2007 About this capture

Bessy (1693), and are illustrated in Berlekamp *et al.* (1982, pp. 778-783). The number of 5×5 magic squares was computed by R. Schroeppel in 1973. The number of 6×6 squares is not known, but Pinn and Wieczerkowski (1998) estimated it to be $(1.7745 \pm 0.0016) \times 10^{19}$ using Monte Carlo simulation and methods from statistical mechanics. Methods for enumerating magic squares are discussed by Berlekamp *et al.* (1982) and on the MathPages website.

A square that fails to be magic only because one or both of the main diagonal sums do not equal the magic constant is called a semimagic square. If *all* diagonals (including those obtained by wrapping around) of a magic square sum to the magic constant, the square is said to be a panmagic square (also called a diabolic square or pandiagonal square). If replacing each number n_i by its square n_i^2 produces another magic square, the square is said to be a bimagic square (or doubly magic square). If a square is magic for n_i, n_i^2, and n_i^3, it is called a trimagic square (or trebly magic square). If all pairs of numbers symmetrically opposite the center sum to $n^2 + 1$, the square is said to be an associative magic square.

Squares that are magic under multiplication instead of addition can be constructed and are known as multiplication magic squares. In addition, squares that are magic under both addition *and* multiplication can be constructed and are known as addition-multiplication magic squares (Hunter and Madachy 1975).



Kraitchik (1942) gives general techniques of constructing even and odd squares of order n. For n odd, a very straightforward technique known as the Siamese method can be used, as illustrated above (Kraitchik 1942, pp. 148-149). It begins by placing a 1 in any location (in the center square of the top row in the above example), then incrementally placing subsequent numbers in the square one unit above and to the right. The counting is wrapped around, so that falling off the top returns on the bottom and falling off the right returns on the left. When a square is encountered that is already filled, the next number is instead placed *below* the previous one and the method continues as before. The method, also called de la Loubere's method, is purported to have been first reported in the West when de la Loubere returned to France after serving as ambassador to Siam.

A generalization of this method uses an "ordinary vector" (x, y) that gives the offset for each noncolliding move and a "break vector" (u, v) that gives the offset to introduce upon a collision. The standard Siamese method therefore has ordinary vector $(1, -1)$ and break vector (0, 1). In order for this to produce a magic square, each break move must end up on an unfilled cell. Special classes of magic squares can be constructed by considering the absolute sums $|u+v|$, $|(u-x)+(v-y)|$, $|u-v|$, and $|(u-x)-(v-y)| = |u+y-x-v|$. Call the set of these numbers the sumdiffs (sums and differences). If all sumdiffs are relatively prime to n and the square is a magic square, then the square is also a panmagic square. This theory originated with de la Hire. The following table gives the sumdiffs for particular choices of ordinary and break vectors.

Ordinary Vector	Break Vector	Sumdiffs	Magic Squares	Panmagic Squares
(1, -1)	(0, 1)	(1, 3)		none
(1, -1)	(0, 2)	(0, 2)	$6k \pm 1$	none
(2, 1)	(1, -2)	(1, 2, 3, 4)	$6k \pm 1$	none
(2, 1)	(1, -1)	(0, 1, 2, 3)	$6k \pm 1$	$6k \pm 1$
(2, 1)	(1, 0)	(0, 1, 2)	$2k + 1$	none
(2, 1)	(1, 2)	(0, 1, 2, 3)	$6k \pm 1$	none

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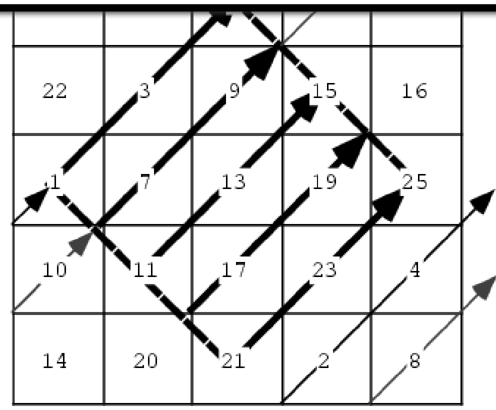
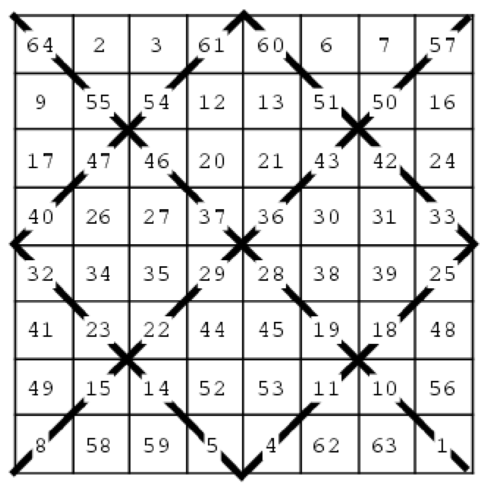
218 captures 16
16 Aug 2000 - 4 Apr 2019 2005 2006 2007
About this capture



A second method for generating magic squares of odd order has been discussed by J. H. Conway under the name of the "lozenge" method. As illustrated above, in this method, the odd numbers are built up along diagonal lines in the shape of a diamond in the central part of the square. The even numbers that were missed are then added sequentially along the continuation of the diagonal obtained by wrapping around the square until the wrapped diagonal reaches its initial point. In the above square, the first diagonal therefore fills in 1, 3, 5, 2, 4, the second diagonal fills in 7, 9, 6, 8, 10, and so on.



An elegant method for constructing magic squares of doubly even order $n=4m$ is to draw s through each subsquare and fill all squares in sequence. Then replace each entry on a crossed-off diagonal by or, equivalently, reverse the order of the crossed-out entries. Thus in the above example for , the crossed-out numbers are originally 1, 4, ..., 61, 64, so entry 1 is replaced with 64, 4 with 61, etc.

A very elegant method for constructing magic squares of singly even order with (there is no magic square of order 2) is due to J. H. Conway, who calls it the "LUX" method. Create an array consisting of rows of s, 1 row of Us, and

http://mathworld.wolfram.com/MagicSquare.html Go JUN JUL AUG
218 captures 16
16 Aug 2000 - 4 Apr 2019 2005 2006 2007 About this capture

That order is illustrated on the left side of the above figure, and the completed square is illustrated to the right. The "shapes" of the letters L, U, and X naturally suggest the filling order, hence the name of the algorithm.

Variations on magic squares can also be constructed using letters (either in defining the square or as entries in it), such as the alphamagic square and templar magic square.

Various numerological properties have also been associated with magic squares. Pivari associates the squares illustrated above with Saturn, Jupiter, Mars, the Sun, Venus, Mercury, and the Moon, respectively. Attractive patterns are obtained by connecting consecutive numbers in each of the squares (with the exception of the Sun magic square).

SEE ALSO: Addition-Multiplication Magic Square Alphamagic Square, Antimagic Square, Associative Magic Square, Bimagic Square, Border Square, Dürer's Magic Square, Euler Square, Franklin Magic Square, Gnomon Magic Square, Heterosquare, Latin Square, Magic Circles, Magic Constant, Magic Cube, Magic Hexagon, Magic Labeling, Magic Series, Magic Tesseract, Magic Tour, Multimagic Square, Multiplication Magic Square, Panmagic Square, Semimagic Square, Talisman Square, Templar Magic Square, Trimagic Square. [Pages Linking Here]

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218 captures 16
16 Aug 2000 - 4 Apr 2019 2005 2006 2007 About this capture

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291 captures 14
11 Jun 2002 - 20 Jan 2019 2005 2006 2007 About this capture

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Magic Squares

Suzanne's Math Lessons || Suzanne's Tessellation Lessons

Magic squares received their name because there are so many relationships between the sums of the numbers filling the squares.

Students often believe that "mathematics" was "written" by one person. In these pages you will find that the magic square **mathematical game** has existed throughout history and in many different parts of the world. Math is all around us and your mind will *see* it when you're ready!

What is a Magic Square?

Allan Adler defines and discusses some special properties of magic squares.

Magic Squares - History, Mathematics, Geography

Lo Shu Magic Square

The Back of the Divine Tortoise
Classroom Activity
China - the country of Lo Shu

Albrecht Dürer's Magic Square

Albrecht Dürer - Engraving of Melancholia
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More about Albrecht Dürer
Classroom Activity
Germany - the country of Albrecht Dürer
GEOM ART RY - Ralph Martel

Benjamin Franklin's 8x8 Magic Square

The World of Benjamin Franklin - the Franklin Institute
Classroom Activity
Pennsylvania, U.S.A. - Benjamin Franklin's State

http://mathforum.org/alejandre/magic.square.html Go JUN JUL OCT
291 captures 14
11 Jun 2002 - 20 Jan 2019 2005 2006 2007
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- **Where's the Math? - with Allan Adler**
  - **Classroom activities: multiplying magic squares**

    Constructing magic squares
    Defining the magic square; special properties
    Exploring the math
    Review: Squaring a magic square

- **Mike Morton's Magic Square Java Applet**

- **Updated Magic Square Java Applet by Pavel Safronov and Michael McKelvey**

- **Dubi Kaufmann's Magic Square Puzzle**

- **H. B. Meyer's 5 x 5 Magic Square Generator**

- **Special magic square unit by Neil Abrahams**
  - **The Franklin Square**

    Background and Lesson Information
    Construction Algorithm
    Observations and Proofs: Rows
    Columns and General Observations
    Columns and General Observations, cont.
    Questions, Suggestions & References

- **Other Magic Square Links**
  - **Mutsumi Suzuki's Magic Square Page**
  - Magic Squares, Magic Stars & Other Patterns by Harvey D. Heinz
  - Fabrizio Pivari's Simple Magic Square png maker
  - Grog's Magic Squares
  - Interactive Magic Square by Lee-Anne Grunwald
  - MathWorld: Magic Squares by Eric W. Weisstein
  - Multimagic Squares by Christian Boyer
  - Solving Magic Squares by Kevin Brown

- **Mutsumi Suzuki's Magic Stars**
  - What is a Magic Star?
  - Magic Star Sets
  - Transforming Magic Stars
  - Combining Exchange Rules

http://mathforum.org/alejandre/magic.square.html Go JUN JUL OCT
291 captures 14
11 Jun 2002 - 20 Jan 2019 2005 2006 2007 About this capture

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174 captures
7 Oct 1999 - 18 Feb 2019
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27
2005 2006 2007
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Magic Squares, Magic Stars & Other Patterns

Welcome

I hope you enjoy these examples from my collection of number patterns.

This site has three sections, with pages on magic squares, magic stars (a lot of original material) and miscellaneous number patterns. This site should be of interest to middle and high school students and teachers, and anyone interested in recreational mathematics.

Wherever there is number, there is beauty. __ Proclus (410-485 A.D.)

NEW **Star Updates** A new page containing additions to the magic stars site. It also contains links to three new pages of material from Simon Whitechapel, Jon Wharf, and Andrew Howroyd. All three have contributed significantly to magic star knowledge, including confirming total solution counts.

NEW **Cube Site Map** Feb. 22, 2005, I added links to the 41 pages of my cube site to this site map. Also, I corrected some links and minor cosmetic changes to a number of pages.

NEW **Search Engine** Dec. 17, 2004. I installed a search engine service for help in locating objects on my Geocities and Shaw Web sites. The index for both sites is combined, so entering a search term will supply a combined list of hits from both sites.

NEW **Magic Cubes site** In Sept. 2003, I added another button to the top of each page in this site. It points to a new site of 30 + pages discussing the history and many features of magic cubes. Jan. 3, 2004, I announced that this site was now virtually complete at 38 pages, and had a new summary page.

The Magic Square Lexicon : Illustrated is now in it's second print run!
And now a free PDF version of the first one-quarter of the book.

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Contents

Introduction A brief introduction to number patterns and these pages.

http://www.geocities.com/~harveyh/ Go FEB APR MAY
174 captures 27
7 Oct 1999 - 18 Feb 2019 2005 2006 2007 About this capture

orders 12, 13 and 14. On this page I present some results of this study.
Also . . .
A new **definition** for magic stars.
Examples of all orders from 5 to 14, a total of 30 different patterns (graphs).
All minimum and consecutive solutions for orders 5, 6, 7, 8 prime magic stars
Interesting comparisons between the different orders.

Bibliography	More then 160 books, chapters of books or papers dealing with magic squares, etc.
Downloads	Some of my Word, Excel and Basic program files.
Glossary	Approximately 125 terms related to magic squares, cubes, tesseracts, stars, etc.
Other Number Patterns	A hodge-podge of miscellaneous patterns from my collection. Included are number patterns, interesting numbers, magic graphs, etc.
All about Credits	My policy on these pages, about giving credit where credit is due.
Similar web sites	Links to other Magic Square, Magic Star and recreational mathematics web sites.
Site Map	Shows the organization of this site, complete with direct links to over 40 pages.
Talk to me. . .	Suggestions, criticism, share your favorite number patterns, etc. I would really appreciate any comments you wish to make in regard to these pages, number patterns in general and magic stars in particular, or for that matter, any aspect of recreational mathematics.

Introduction?

What?

* This WWW site is about numbers and the patterns that can be made from them.
* Most patterns shown here should be understandable to anyone with about grade 5 math but will hopefully be of interest also to persons with advanced education..
* **The section on Magic Stars** is mostly original work & includes material on Orders 5 to 14, a total of 30 patterns.
* This site represents a very small proportion of the material I have in my notes. I hope to be adding to it frequently so please stay tuned.

http://www.geocities.com/~harveyh/ Go FEB APR MAY 27 2005 2006 2007
174 captures
7 Oct 1999 - 18 Feb 2019
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To demonstrate that mathematics can be enjoyed by persons regardless of their education level.

To further the appreciation of mathematics and the understanding of number relationships.

Who?

Who will enjoy this site?
Anyone who loves mathematics in general and numbers in particular.
Teachers looking for enrichment material for their math classes.

Who designed the patterns?
Probably most of these patterns have been around for many years and the original author is unknown. Some are of recent origin, and if the author is known has been credited here. And some are of my own original design (at least as far as I know).
Most of the Magic Star patterns and material shown here are my work.

Who am I?
I am a retired bookbinder and have no training in mathematics beyond high school.
I have been fascinated by number patterns and have been collecting them since I was a teenager.
For the last several years I have been researching magic stars and have made many interesting discoveries.
More information about myself and my family are on my Personal Home-page.
(Also more Magic Stars & Magic Squares)

Who are you?
Presumably, because you are looking at this site, you too are interested in recreational mathematics.
Help explore the mysteries of magic stars. So far, I have been concentrating mostly on the relationships between the different orders. Aside from order-6, very little is known about the features of the individual orders.
If you too find this subject interesting, I would love to hear from you.
Tell me about yourself, your special interests, and your favorite number patterns.

Top

All about Credits

A Note regarding credits

My policy on all the pages of this WWW site is
If I know of only one source for a pattern, acknowledge it (if possible, obtain permission to use it).
If I have multiple sources for a pattern with no indication of the original source, consider it public domain.

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174 captures
7 Oct 1999 - 18 Feb 2019
FEB APR MAY
27
2005 2006 2007
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I may reconsider my acknowledgment.

Links to similar web sites

John R. Hendricks now has a website showing Perfect & Inlaid magic tesseracts, as well as other math topics.
Aale de Winkel is compiling an Encyclopedia of magic terms, which is also well worth visiting.
Christian Boyer has constructed tetramagic and pentamagic squares. His site has much information on multimagic squares and cubes.
Mutsumi Suzuki's excellent MAGIC SQUARES is now back - hosted by MathForum
Walter Trump has a great page on self-similar pandiagonal magic order-7 squares. He also discusses counting.
Abhinav Soni has a new site on magic cubes that features a hyper magic cube generator.
Kanji Setsuda has a large site and much information on magic squares. His English pages are here.
Eric W. Weisstein's Magic Squares - part of Eric's Treasure Trove Of Math, a very comprehensive work
Holger Danielsson's attractive Magic Squares site features online magic square generators and Hendricks work.
Francis Gaspalou has an excellent site dealing with methods and tools for enumeration of magic squares.
Magic Squares by "Grog" - theory of Pandiagonal magic squares. Also a good history of magic squares.
Suzanne Alejandre: Magic Squares - this attractive page presents magic squares as a way of teaching math
Fabrizio Pivari's Strange Magic Squares - a different way of looking at magic squares.
Robert W. Wilke's Nested Magic Squares - simple inlaid Magic squares. Samples. Some theory.
Shin, Kwon Young's Magic Squares - history, methods of solution, samples (up to 30 x 30).
Anti-Magic Squares by John Cormie & Vaclav Linek presents an extensive investigation of this subject.
saMagicSquares is a magic squares generating program written by Richard W. Bogosian.
Charles Kelly has a Java applet to generate magic squares and hypercubes.
Want to see some BIG! magic squares? Visit Bogdan Golunski's Web page to see the biggest! 10001 x 10001.
Simon Whitechapel has solutions for 1 pattern of each order magic star from 15 to 20. Also articles on other math subjects.
Cambridge University has an interesting site on Secondary School Math Enrichment.
Paul C. Pasles has pages on Franklin and other OLD magic squares.
Donald Morris has an excellent new page (2005) on **Franklin** squares and methods of construction.
Mark Swaney has a detailed history of magic squares .
Mark Farrar's page on magic squares includes several applets and a **subscription link to a magic squares group**.
To see what can be done with art and magic squares, visit Paul Heimbach's Web site.
G. D. Mutch's Natural Matrix Law is a large site which discusses practical (?) applications of magic squares.
See the Antimagic Square Project of John Cormie and V�clav Linek at the University of Winnipeg .
Magic Squares Newsgroup at http://uk.groups.yahoo.com/group/magicsquares/
Magic Cubes Newsgroup at http://groups.yahoo.com/group/magiccubes/

Some other sites on Mathematics

The Math Forum - The premier source on the Web for educational mathematics. All about math, for the student or hobbyist
Eric's Treasure Trove of Mathematics - covers a very wide range of material - a big site
Patrick De Geest's World of Numbers- is a very attractive and informative site
Carlos B. Rivera's site, Prime Puzzles and Problems, has lots of food for thought
Mike Keith – has lots of good material on interesting numbers
Keven Brown - has a great site on a variety on mathematic subjects.
Harry J.Smith's Fun With Mathematics - a variety of programs and subjects on recreational mathematics
Dr. Michael Ecker's Recreational and Educational Computing newsletter about recreational mathematics and

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FEB APR MAY
27
2005 2006 2007
174 captures
7 Oct 1999 - 18 Feb 2019
About this capture

mathematics
For a list of all PPDI's in bases 2 to 10, visit Dr. Lionel E. Deimel's site
Chris Caldwell has a large site dealing with Prime numbers as http://primes.utm.edu/
G. L. Honaker, Jr 's & Chris Caldwell's Prime Curios page has many fascinating facts about individual prime #
A great mathematics site for students is http://www.aaamath.com/
Charles Ashbasher's site has information about the Journal of Recreational Mathematics.
Reg Brooks has a page on Patterns in Numbers which includes the geometry of DNA. Also an interesting paper on Butterfly Primes.
The World of Trotter Math parades the work of dedicated mathematics teacher Terry Trotter.
Shyam Sunder Gupta discusses RARE and EPORNS numbers (and other numbers).
Walter Schneider has an informative site dealing with digit-related-numbers.
Charles-�. Jean has a good Dictionary of recreational mathematics (in French).
Peter Aleff has an excellent site and some eBooks on Prime Number Patterns at Recovered Science.
A prime spiral arranged as a circle is thoroughly discussed and illustrated at Rom Sacks http://www.numberspiral.com/
Math for Kids at http://www.allmath.com is an entry point to many web sites with interesting mathematical content.

Top

Site Map

- Magic Star, Squares, & Other Number Patterns (Geocities server)
  - Magic Squares
    - A Deluxe Magic Square
    - More Magic Squares
    - Material from REC
    - Unusual Magic Squares
    - John Hendricks - Cubes
    - Prime Number Magic Squares
    - Quadrant Magic Squares
      - Order-13 Quadrant Magic Squares
      - Order-17 Quadrant Magic Squares
    - Type 2 Order-3 Magic Squares
    - Anti-magic Squares
    - Self-similar Magic Squares
    - Most-perfect Magic Squares
    - Magic square Models
    - Transformations & Patterns
      - More Order-4 Transformations
      - Transformations Summary
      - Fellows Transformations
    - Order-4 Lists
      - Order4 #1 to 200
      - Order4 #201 to 400
      - Order4 #401 to 600
      - Order4 #601 to 880
    - Pandiagonal 5x5
    - Franklin squares
    - Multimagic Squares
  - Magic Stars
    - Magic Star Definitions
    - Magic Star Examples
      - Magic Star Examples - 2
      - Big Magic Stars
    - Order-5 Magic Stars

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FEB APR MAY
27
2005 2006 2007
174 captures
7 Oct 1999 - 18 Feb 2019
About this capture

Order-8 Magic Stars
Order-9 Magic Stars
Order-10 Magic Stars
Order-11 Magic Stars
Prime Number Magic Stars
Prime Number Magic Stars - 2
Unusual Magic Stars
Isomorphic-like magic Stars
3-D Magic Stars
Trenkler Stars
Magic Star Puzzles
Star Updates
Simon Whitechapel
Jon Wharf
Andrew Howroyd
Number Patterns
Prime Patterns
More Prime Patterns
Narcissistic Numbers
Palindromes
Glossary
Bibliography
Book for Sale
Downloads

Magic Cubes - Introduction (Shaw server- but connected by Button Bar)
Magic Cubes - The Basics
Magic Cube - Definitions
Perfect Magic Hypercubes
Magic Cubes - the Road to Perfect
The Early Cubes
A. H. Frost's Magic Cubes
F. A. P. Barnard's Magic Cubes
Magic Cubes - Order 3
Magic Cubes - Order 4
Magic Cubes - Order 5
Magic Cubes - Order 6
Magic Cubes - Order 7
Magic Cubes - Order 8
Magic Cubes - Order 9
Magic Cubes - Order 10
Magic Cubes - Order 11
Magic Cubes - Order 12
Magic Cubes - Order 13
Arnoux's Perfect Cube
Arnoux Patterns
Modulo Magic Cubes
Multimagic Cubes
Monster Cubes
Boyer's Bimagic 16 Cube
Boyer's Bimagic 32 Cube
Magic Cube Groups
Prime Number Magic Cubes
Magic Cubes - Multiply
Composition Magic Cubes
Hendricks Inlaid Magic Cubes
The Heinz X6 Magic Cube
Self-similar Magic Cubes
Magic Cubes - Pan and Semi-pan
Unusual Magic Cubes
Magic Cube Bibliography

http://www.geocities.com/~harveyh/ Go
174 captures
7 Oct 1999 - 18 Feb 2019
FEB APR MAY
27
2005 2006 2007
About this capture

Cube Update-3

Top

Thanks for the visit and I hope to see you again soon.

Highlighted in the MathForum
Math Forum Internet News

Please send me Feedback about my Web site!

Harvey Heinz harveyheinz@shaw.ca
This page last updated March 11, 2006
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http://www.grogono.com/magic/ Go
JUN DEC AUG
15
2005 2006 2007
379 captures
2 Dec 1998 - 17 Apr 2019
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Grogono Magic Squares Home Page

Revision: Features in Recent Revisions

Same Author: Acid-Base Animated Knots Stereo Art

- Home Page
- Make Your Own
- Choose by Size
- How Many?
- The Formula
- Magic Carpets
- Analysis
- Magic Cubes
- History
- References
- Contact
- Downloads
- Links
- Glossary
- Grogono Home

Introduction.

A Magic square is intriguing; its complexity challenges the mind. For order 4 and above the number of different magic squares is astonishing - and the number remains large even if we limit consideration to Pan-Magic squares. This website reflects my own fascination with these large numbers and presents techniques aimed at explaining and reducing the huge numbers by showing how this abundance can be reduced to a small number of underlying patterns or Magic Carpets.

Recent Addition

Do it yourself! Make your own magic square of any size up to 97x97.

Discoveries.

The development of this website was associated with several intriguing discoveries. Please look at the pages for the Order 4, Order 5, Order 6 magic squares.

Dedication.

This Magic Square website is dedicated to my father E.B. Grogono (1909 - 1999) and was originally created at his bedside during his last illness. My fondest memories of him, from my earliest childhood to the final days of his life, center on his ability to transmit his love for, and fascination with, mathematics and science.

Revision

This revision uses up to date technology to make the website easier to manage and the material has been re-arranged to make it more accessible. A glossary has been added and the index system has been revised.

Now, Belatedly, Welcome!

Visit, play, learn about Magic Squares and Magic Carpets, make your Own Magic squares, and explore the techniques devised to understand pan-magic squares.

21	2	8	14	15
13	19	20	1	7
0	6	12	18	24
17	23	4	5	11
9	10	16	22	3

Glossary

If you want to check on the meaning of the terms used on this website, please review the Glossary

Pan-Magic Squares.

The Main focus of this website is Pan-Magic squares where even the broken diagonals add up to the Magic Sum, e.g., 60 in the square above (diagonal 13, 2, 16, 5, 24). Pan-magic squares have also been called Pan-Diagonal and Nasik.

Why start Magic Squares using zero?

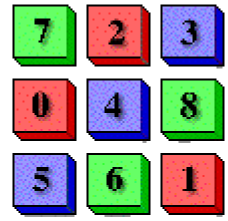
A glib answer might be because I like to and this is my site. A mathematical answer is that analysis (and construction) of magic squares is more logical, and the results easier to analyze, when the smallest number is 0. This is particularly true when the Magic Carpet approach is used to analyze or construct a magic square, e.g., to construct an order four magic square, four magic carpets would be required using: 8 & 0; 4 & 0; 2 & 0; and 1 & 0.

- **Traditional Magic Squares**, start at one, probably because magic squares were discovered first and analyzed later. Early counting systems didn't include either zero or negative numbers, so number one must have seemed a pretty good starting place.

http://www.grogono.com/magic/ Go
379 captures
2 Dec 1998 - 17 Apr 2019
JUN DEC AUG
15
2005 2006 2007
About this capture

I am frequently asked to provide the Formula for Magic Squares. At the risk of spoiling some teacher's classwork assignments I have worked out a satisfactory answer and have devoted a page to this topic. (Thank you Danny Lawrence for making me do this and for sitting with me while I worked it out.) Two formulae are included, one for the prime-number orders, e.g., 5, 7, 11, 13, etc., and one for an order 4 square.

How Many Squares?



My fascination with magic squares grew from experimental attempts to count the total number of possible squares when squares which, apparently different, were really identical when appropriately reflected or rotated. A separate page lists the Number of Pan-Magic Squares for the Prime Number Order squares.

Unique Identifiers.

The process of counting and comparing regular panmagic squares generated a need to identify squares to facilitate ranking and comparison. Out of this grew a scoring system to uniquely identify any order 4 or order 5 pan-magic square.

The method I developed assigns a Unique Identifier to each square and is applicable to regular panmagic squares of orders 4 and 5. It depends on summing defined cells which have been multiplied by successively higher powers of the square's order. Although the technique could be extended to larger squares, the length of the expression, and the resulting magnitude of the numbers, makes it too unwieldy.

By the Same Author

If you have found this website useful, you are invited to visit my one of my other teaching sites.

Two of these other sites are mounted on my main website but all three are treated as an independent website:

- **Acid-Base Tutorial**

  This website is aimed at physicians, physiologists, medical students, nurses, and other health care professionals. The Tutorial includes interactive diagrams and equations to make the material more interesting and more readily understood.

- **Animated Knots**

  This website is aimed at yachtsmen, scouts, climbers, fishermen and anyone else who needs to know how to tie Practical Safe Knots. Each animated knot "ties itself" automatically and can also be "tied" and "untied" slowly to reveal its structure.

- **Stereo Art**

  This website demonstrates how a vivid three-dimensional stereo image is created from a repeated stereo image pair. A collection of Stereo Art Images illustrates the technique.

Size: Index | 3x3 | 4x4 | 5x5 | 6x6 | 7x7 | 8x8 | 9x9 | 10x10 | 11x11 | 12x12 | 13x13

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http://user.chol.com/~brainstm/MagicSquare.htm Go
13 captures
14 Nov 2004 - 31 May 2015
OCT NOV MAR
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2003 2004 2007
About this capture

The Perfect Solution For the MAGIC - SQUARE

. ...KOREAN(ÇÑ±¹¾î·Î)... . *Since July 1997*

-- Yes, you can make all Magic Squares !! --

Stories

- **History of Magic Square**
  Suzanne Alejandre's Lo Shu Magic Square homepage shows a detail legend of Lo Shu in China. Magic squares have been around for over 3,000 years..

- **What's a Magic Square?**
  The following definition is a quote from Allan Adler's What is a Magic Square? homepage.

  A magic square is an arrangement of the numbers from **1** to **n^2** (n-squared) in an **n**x**n** matrix, with each number occurring exactly once, and such that the sum of the entries of any row, any column, or any main diagonal is the same. It is not hard to show that this sum must be **n(n^2+1)/2.**

- **What I'm saying is.. .**
  When I was young I saw a 3x3 magic square. It was just a kind of puzzle for me. As time passed, I saw the solution for magic squares of odd-series and some multiples of four, and I changed my mind. I started to find out the solution for all numbers. I tried to look for any books written on magic squares, but I could not find a regular solution for n=6,10,14,.. at anywhere. Even somebody said 'It's an unsolved mystery'. But, I found out the principle of constructing squares for other sizes and checked that sums are correct by using a computer. Perhaps a man I don't know has already solved this mystery. I hope that more information and news are exchanged at this site. Anyway, I am content to have solved it by myself. Now, the magic square is no more an unsolved mystery. What I'm saying here is "**It's Not Impossible!!**".

Solutions for the 3 types of Magic Square

If you remember solutions down here, You can construct any magic square(n>2).

- **The odd number series**(n=3,5,7,9,...)
  This solution that I'm going to demonstrate is just one of the common things that many people know.

- **A multiple of 4 series**(n=4,8,12,...)
  This solution is known, also. I have another method that is more simple and general, because this idea applies to the solution of the other sizes(n=6,10,...) more easily than other methods

- **The other sizes series**(n=6,10,14,...)

http://user.chol.com/~brainstm/MagicSquare.htm Go
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14 Nov 2004 - 31 May 2015
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2003 2004 2007
About this capture

Cheerio, GijsjebertiX introduces the solution.

Even though I don't explain the principle in detail, You can understand the idea well enough. If you have comments and suggestions, please mail to *Kwon Young Shin*.

Samples

- **The source program** in C-language
  This is a source program that I compiled and checked the Magic Squares using turbo-c 2.0 on PC. If you change some source code, You can create more magic squares even on other computers.
- **Magic Square samples**(n=11,12,14,16,18,22,26,30)

Other Magic Square links

- Mutsumi Suzuki's Magic Square Page
- Suzanne Alejandre's Magic Square Page

Back to Shin's homepage.

Thanks to Julianna Oh for helping me.
Shin, Kwon Young - brainstm@chollian.net
Last Update : 24 Jan 1998

http://rec-puzzles.org/sol.pl/arithmetic/magic.squares Go
15 captures
6 Dec 2002 - 29 Jul 2012
OCT DEC JUL
09
2003 2004 2009
About this capture

Solution to the /arithmetic/magic.squares problem

These are called magic squares. A magic square of order n (integers from 1 to n*n) has only one possible sum: (n*n+1)*n/2.

Odd and even order squares must be constructed by different approaches. For odd orders, the most common algorithm is a recursive scheme devised by de la Loubere about 300 years ago. For even orders, one procedure is the Devedec algorithm, which treats even orders not divisible by 4 slightly differently from those which are divisible by 4 (doubly even).

For squares with odd-length sides, the following algorithm builds a magic square:

Put 1 in the middle box in the upper row. From then on, if it's possible to put the next number one box diagonally up and to the right (wrapping around if the edge of the grid is reached), do so, otherwise, put it directly below the last one.

```
17 24  1  8 15
23  5  7 14 16
 4  6 13 20 22
10 12 19 21  3
11 18 25  2  9
```

...or even

```
47 58 69 80  1 12 23 34 45
57 68 79  9 11 22 33 44 46
67 78  8 10 21 32 43 54 56
77  7 18 20 31 42 53 55 66
 6 17 19 30 41 52 63 65 76
16 27 29 40 51 62 64 75  5
26 28 39 50 61 72 74  4 15
36 38 49 60 71 73  3 14 25
37 48 59 70 81  2 13 24 35
```

See archive entry knight.tour for magic squares that are knight's tours.

To get a 4x4 square, write the numbers in order across each row, filling the square...

```
1  2  3  4
5  6  7  8
9  10 11 12
13 14 15 16
```

then use the following pattern as a mask:

```
.  X  X  .
X  .  .  X
X  .  .  X
.  X  X  .
```

Everywhere there is an X, complement the number (subtract it from n*n+1). For the 4x4 you get:

```
1  15 14 4
12 6  7  9
```

http://rec-puzzles.org/sol.pl/arithmetic/magic.squares Go
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2003 2004 2009
15 captures
6 Dec 2002 - 29 Jul 2012
About this capture

Make an initial magic square by writing an n/2 magic square four times (the same one each time). Now, although this square adds up right we have the numbers 1 to n*n/4 written four times each. To fix this, simply add to it n*n/4 times one of the following magic squares:

if n/2 is odd (example: n/2=7),

```
3 3 3 0 0 0 0 2 2 2 2 2 1 1   (there are int(n/4) 3s, int(n/4-1) 1s on each
3 3 3 0 0 0 0 2 2 2 2 2 1 1    row)
3 3 3 0 0 0 0 2 2 2 2 2 1 1
0 3 3 3 0 0 0 2 2 2 2 2 1 1   (this is row int(n/4)+1.  It starts with just
3 3 3 0 0 0 0 2 2 2 2 2 1 1    the one 0)
3 3 3 0 0 0 0 2 2 2 2 2 1 1
3 3 3 0 0 0 0 2 2 2 2 2 1 1
0 0 0 3 3 3 3 1 1 1 1 1 2 2   (the lower half is the same as the upper half
0 0 0 3 3 3 3 1 1 1 1 1 2 2    with 3<->0 and 1<->2 swapped.  This guarantees
0 0 0 3 3 3 3 1 1 1 1 1 2 2    that each number 1-n*n will appear in the
3 0 0 0 3 3 3 1 1 1 1 1 2 2    completed square)
0 0 0 3 3 3 3 1 1 1 1 1 2 2
0 0 0 3 3 3 3 1 1 1 1 1 2 2
0 0 0 3 3 3 3 1 1 1 1 1 2 2
```

if n/2 is even (example: n/2=4),

```
0 0 3 3 2 2 1 1  (there are n/4 of each number on each row)
0 0 3 3 2 2 1 1
0 0 3 3 2 2 1 1
0 0 3 3 2 2 1 1
3 3 0 0 1 1 2 2
3 3 0 0 1 1 2 2
3 3 0 0 1 1 2 2
3 3 0 0 1 1 2 2
```

References:

"Magic Squares and Cubes"
W.S. Andrews
The Open Court Publishing Co.
Chicago, 1908

"Mathematical Recreations"
M. Kraitchik
Dover
New York, 1953

E-mail | to the index | to Arlet's home page | Powered by Linux/Apache.

... ``follow me,'' the wise man said, but he walked behind...

http://users.aol.com/themazeman/perf-mag.html Go OCT DEC FEB
44 captures 01
6 Dec 1998 - 30 Jul 2016 2000 2001 2003 About this capture

Click here to sign our Address Book and earn at least three free personalized puzzles
see full details at <www.MAZES.com> but hurry ... this offer expires Saturday July 1, 2000

MAGIC SQUARES

© '96 THE MAZE MAN John Knoderer

MAZE MAN PUZZLE SERVICES - 101 Main Street SE - P O Box 744 - Gravette, AR 72736-0744

The numbers in a magic square add up to the same sum in several ways:

- Every row adds up to the same number
- Every column adds up to that same number
- Both diagonals add up to that number
- The four corners add up to that number
- The four middle squares add up to that number
- The four squares in the top left corner add up to that number
- The four squares in the top right corner add up to that number
- The four squares in the bottom left corner add up to that number
- The four squares in the bottom right corner add up to that number

Each number in the list will only be used once, and every number will be used. In the puzzles below, there is only one solution to each set of numbers. A magic square is NOT NECESSARILY a perfect square.

This is a magic square:

Magic Square

7	6	12	9	10	11	5	8	13	16	2	3	4	1	15	14

Just in case your browser doesn't support tables, here's a second copy of the above:

```
+--+--+--+--+
| 7| 6|12| 9|
+--+--+--+--+
|10|11| 5| 8|
+--+--+--+--+
|13|16| 2| 3|
+--+--+--+--+
| 4| 1|15|14|
+--+--+--+--+
```

PERFECT SQUARES

The numbers in a perfect square add up to the same sum in many ways:

- Every row, every column, and every diagonal add up to that number
- The four corners add up to that number
- Every neighboring four numbers (in a 2x2 block) add up to that number

http://users.aol.com/themazeman/perf-mag.html Go
44 captures
6 Dec 1998 - 30 Jul 2016
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2000 2001 2003
About this capture

Perfect Square

1	15	6	12	8	10	3	13	11	5	16	2	14	4	9	7

Just in case your browser doesn't support tables, here's a second copy of the above:

```
+--+--+--+--+
| 1|15| 6|12|
+--+--+--+--+
| 8|10| 3|13|
+--+--+--+--+
|11| 5|16| 2|
+--+--+--+--+
|14| 4| 9| 7|
+--+--+--+--+
```

Find these MAGIC SQUARES

Here are nine more MAGIC SQUARES to find:

(if you are given a list of sequential numbers, but not the sum, the sum will be equal to (first+last)*2, or in the case of the first puzzle, (83+98)*2=362, in the case of the second puzzle, (5+35)*2=80.)

three easy MAGIC SQUARE puzzles

Only a calculator will be needed for easy puzzles

```
1. Use every number    2. Use every odd number  3. Use every fourth #
   from 83 to 98          from 5 to 35             from 28 to 88
   (all sums are 362)     (all sums are 80)        (all sums are ???)

   +--+--+--+--+          +--+--+--+--+            +--+--+--+--+
   |89|  |  |  |          |33|15|  |  |            |48|40|  |76|
   +--+--+--+--+          +--+--+--+--+            +--+--+--+--+
   |92|93|  |  |          |  | 5|  |  |            |84|  |  |56|
   +--+--+--+--+          +--+--+--+--+            +--+--+--+--+
   |  |98|84|  |          |  |35|  |  |            |  |52|  |  |
   +--+--+--+--+          +--+--+--+--+            +--+--+--+--+
   |86|  |  |  |          | 7|  |  |31|            |  |  |  |  |
   +--+--+--+--+          +--+--+--+--+            +--+--+--+--+
```

three harder MAGIC SQUARE puzzles

some thinking or trial-and-error may be required

```
4. Use every number   5. Use every third #     6. Use every fourth #
   from 61 to 76          from 10 to 55            from 21 to 81
   +--+--+--+--+          +--+--+--+--+            +--+--+--+--+
   |  |  |  |66|          |25|  |  |34|            |  |  |  |  |
   +--+--+--+--+          +--+--+--+--+            +--+--+--+--+
   |  |  |  |  |          |  |  |  |  |            |53|37|33|  |
```

http://users.aol.com/themazeman/perf-mag.html Go
OCT DEC FEB
01
2000 2001 2003
44 captures
6 Dec 1998 - 30 Jul 2016
About this capture

```
  +---+---+---+---+        +---+---+---+---+        +---+---+---+---+
```

three hardest MAGIC SQUARE puzzles

the most thinking will be required for these hardest puzzles

```
7. Use every even #     8. Use every fifth #     9. Use every ?? number
   from 32 to 62           from ?? to ??            from ?? to ??
   (all sums = ???)        (all sums = 230)         (all sums = 270)
   +---+---+---+---+       +---+---+---+---+        +---+---+---+---+
   |42 |62 |32 |   |       |80 |   |   |   |        |68 |   |   |   |
   +---+---+---+---+       +---+---+---+---+        +---+---+---+---+
   |   |   |   |   |       |   |65 |   |   |        |   |   |   |   |
   +---+---+---+---+       +---+---+---+---+        +---+---+---+---+
   |   |   |   |   |       |   |   |   |   |        |   |   |   |   |
   +---+---+---+---+       +---+---+---+---+        +---+---+---+---+
   |   |38 |   |   |       |25 |95 |   |   |        |71 |60 |   |65 |
   +---+---+---+---+       +---+---+---+---+        +---+---+---+---+
```

Find these PERFECT SQUARES

Here are nine more PERFECT SQUARES to find:

three easy PERFECT SQUARE puzzles

```
1. Use every fourth #   2. Use every number      3. Use every number
   from 21 to 81           from 72 to 87            from 18 to 33
   (all sums are 362)      (all sums are ???)       (all sums are ???)
   +---+---+---+---+       +---+---+---+---+        +---+---+---+---+
   |   |   |   |29 |       |   |   |   |   |        |   |   |   |   |
   +---+---+---+---+       +---+---+---+---+        +---+---+---+---+
   |25 |45 |   |   |       |   |73 |   |   |        |   |   |   |30 |
   +---+---+---+---+       +---+---+---+---+        +---+---+---+---+
   |61 |   |33 |   |       |   |78 |83 |72 |        |   |22 |   |19 |
   +---+---+---+---+       +---+---+---+---+        +---+---+---+---+
   |   |   |   |   |       |   |   |   |86 |        |   |   |26 |24 |
   +---+---+---+---+       +---+---+---+---+        +---+---+---+---+
```

three harder PERFECT SQUARE puzzles

```
4. Use every third #    5. Use every even #      6. Use every fourth #
   from 37 to 82           from 18 to 48            from 5 to 65
   +---+---+---+---+       +---+---+---+---+        +---+---+---+---+
   |   |   |   |   |       |   |   |   |24 |        |   |   |   |13 |
   +---+---+---+---+       +---+---+---+---+        +---+---+---+---+
   |   |76 |46 |61 |       |   |32 |38 |26 |        |   |   |   |   |
   +---+---+---+---+       +---+---+---+---+        +---+---+---+---+
   |   |   |   |82 |       |   |   |   |   |        |   |57 |   |37 |
   +---+---+---+---+       +---+---+---+---+        +---+---+---+---+
   |   |   |   |   |       |   |   |   |   |        |   |   |49 |   |
   +---+---+---+---+       +---+---+---+---+        +---+---+---+---+
```

http://users.aol.com/themazeman/perf-mag.html Go
44 captures
6 Dec 1998 - 30 Jul 2016
OCT DEC FEB
01
2000 2001 2003
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```
from 32 to 62          from ?? to ??            from ?? to ??
(all sums = ???)       (all sums = 230)         (all sums = 270)
+--+--+--+--+          +--+--+--+--+            +--+--+--+--+
|  |  |  |  |          |  |  |21|  |            |  |  |  |22|
+--+--+--+--+          +--+--+--+--+            +--+--+--+--+
|48|  |42|  |          |  |45|  |  |            |  |  |28|  |
+--+--+--+--+          +--+--+--+--+            +--+--+--+--+
|  |45|  |  |          |  |  |33|  |            |  |  |  |40|
+--+--+--+--+          +--+--+--+--+            +--+--+--+--+
|  |  |  |  |          |  |  |  |  |            |  |  |  |  |
+--+--+--+--+          +--+--+--+--+            +--+--+--+--+
```

http://members.aol.com/robertw653/magicsqr.html Go
30 captures
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About this capture

Nested Magic Squares

by Robert C. Wilke

5 x 5 Nested Magic Square

Traditionally, a magic square consists of a set of consecutive numbers such that the rows, columns, and diagonals add up to the same number. A nested magic square is defined as magic square which contains a magic square of smaller order. For example,

A	B	C	D	E
F	G	H	I	J
K	L	M	N	O
P	Q	R	S	T
U	V	W	X	Y

If the above square is magic and nested then the square with the corners G, I, Q, S, will also be magic. Since the nested square has certain properties, then the outer ring, A, B, C, D, E, J, O, T, Y, X, W, V, U, P, K, F can be worked on independently from the inner magic square, greatly reducing the number of calculations required to determine the total number of nested magic 5 x 5 squares.

Choosing the proper value of the 3 x 3 magic square which will be nested in a 5 x 5 magic square turns out to be quite easy.

The 5 x 5 magic square by definition consists of the numbers 1 through 25, the sum of those numbers equals 325. In selecting the nested 3 x 3 magic square by definition, the smallest magic 3 x 3 square would consist of the numbers 1 to 9, and the largest 3 x 3 magic square would consist of the numbers 17 through 25 because of the consecutive number constraints imposed by the 5 x 5 magic square. It is possible to construct the following chart for the 5 x 5 magic square which only lists whole number solutions to the problem.

Whole Number Solutions 5 x 5 Nested Magic Square

Sum Total 5 x 5 Square	Sum of Nested 3 x 3 Square	Sum of One Ros of Nested 3 x 3 Square	5 x 5 Sum Minus 3 x 3 Sum	Difference Divided by Eight	Sum of One Row 3 x 3 and One Pair of Numbers 5 x 5
325	45	15	280	35	50
325	69	23	256	32	55
325	93	31	232	29	60
325	117	39	208	26	65

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27 Apr 1999 - 24 Nov 2018
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325	189	65	156	17	80

Reading across the first row of this chart you can see that the sum total of the 5 x 5 magic square will be 325. Assuming sum total for the 3 x 3 magic square equals 45 (a magic square with the number 1 through 9), then if you divide by 3 (the number of rows), you find that the sum of one row will be 15. If the sum for the 3 x 3 magic square of 45 is subtracted from the sum of the 5 x 5 magic square which has to be 325, the remaining balance is equal to 280. Since the 3 x 3 square is magic, then the eight sums, (A+Y, B+V, C+W, D+X, E+U, F+J, K+O, P+T) must all be equal. Therefore if you divide 280 by 8, you get the value of the sum of any of the two numbers which in this case is equal to 35. Therefore, A+Y = 35 and G+M+S = 15, so the sum of any row will be equal to 50. This is an obvious contradiction since the sum of all rows, columns and diagonals for a 5 x 5 must equal 325 divided by 5 or 65. Hence from the table it is obvious that for all nested 5 x 5 magic squares, the 3 x 3 magic square must have a row, column and diagonal total of 39.

There is only one 3 x 3 magic square which meets these conditions and also is made up of consecutive numbers. (Note: There are actually 26 magic squares whose row, column, and diagonal total equals 39, however there is only one which consists of consecutive numbers.)

10	17	12
15	13	11
14	09	16

There are only ten rings which can be calculated, which will give you a nested 5 x 5 magic square using this 3 x 3 magic square base. The following nested magic squares have been ordered in the following way in order to eliminate the possibility of confusion. The magic square is written so that the lowest corner number is always placed in the upper left hand corner. Next the magic square is rotated on the diagonal A-Y so that the next smallest corner number is located in the upper right hand side. The remaining numbers in the top row are ordered in increasing value at the same time ordering the numbers in the bottom row in decreasing value such that B<C<D and V>W>X. Finally the remaining numbers on the left hand side are ordered so that F<K<P and J>O>T. Confusion and duplication will be avoided if the nested 5 x 5 magic squares are ordered in this manner.

01	18	21	22	03
02	10	17	12	24
19	15	13	11	07
20	14	09	16	06
23	08	05	04	25

01	19	20	22	03
02	10	17	12	24
18	15	13	11	08
21	14	09	16	05
23	07	06	04	25

02	07	23	25	08
04	10	17	12	22
20	15	13	11	06
21	14	09	16	05
18	19	03	01	24

03	06	24	25	07
04	10	17	12	22
18	15	13	11	08
21	14	09	16	05
19	20	02	01	23

03	08	22	25	07
02	10	17	12	24
20	15	13	11	06

04	07	23	25	06
02	10	17	12	24
18	15	13	11	08

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26
2004 2005 2008
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04 08 23 24 06	05 04 22 23 07
01 10 17 12 25	03 10 17 12 23
19 15 13 11 07	18 15 13 11 08
21 14 09 16 05	20 14 09 16 06
20 18 03 02 22	19 22 04 01 21
05 06 23 24 07	06 04 23 24 08
01 10 17 12 25	01 10 17 12 25
18 15 13 11 08	19 15 13 11 07
22 14 09 16 04	21 14 09 16 05
19 20 03 02 21	18 22 03 02 20

Each one of these 10 rings defines a family of nested 5 x 5 magic squares. When looking at the rows of numbers you will notice that if B-C, and V-W are both switched, a different unique magic square will be formed. B,C,D and V,W,X can all be switched independently giving 6 permutations. In addition F,K,P and J,O,T can also be switched independently in the same way giving 6 x 6 or 36 permutations - unique magic squares. Additionally, the 3 x 3 nested magic square can be rotated and flipped on a diagonal and rotated into 8 different positions on each of the independent permutations so that each ring allows for 6 x 6 x 8 = 288 unique magic squares. Since there are 10 rings there are a total of 2880 unique nested 5 x 5 magic squares.

---

7 x 7 Nested Magic Squares

Using the same methods of calculation it is also possible to quantify the total number of 7 x 7 nested magic squares. The total number of 7 x 7 rings possible is 1291. Permutations on the top and bottom row total a possible 120, and permutations on the left and right side rows also total 120. Additionally, the nested 5 x 5 magic square possibilities 2880 each can be rotated and flipped eight different ways. Therefore the total number of unique 7 x 7 nested magic squares equals 1291 x 120 x 120 x 2880 x 8 = 428,322,816,000. Below are the smallest, and largest possible 7 x 7 nested magic squares, which have been ordered in the manner described above for the 5 x 5 nested magic squares.

01 02 38 42 43 16 03	10 09 11 43 44 16 12
05 13 30 33 34 15 45	01 18 16 35 36 20 49
06 14 22 29 24 36 44	02 13 22 29 24 37 49
37 31 27 25 23 19 13	37 31 27 25 23 19 13
39 32 26 21 28 18 11	42 33 26 21 28 17 08
40 35 20 17 16 37 10	45 30 34 15 14 32 05
47 48 12 08 07 04 49	38 41 39 07 06 04 40

---

9 x 9 Nested Magic Squares

Using the same methods of calculation it is also possible to quantify the total number of 9 x 9 nested magic squares. The total number of 9 x 9 rings possible is 3567. Permutations on the top and bottom row total a

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3467 x 5040 x 5040 x 428,322,816,000 x 8 = 310,474,101,077,200,000,000,000. Below are the smallest, and largest possible 9 x 9 nested magic squares, which have been ordered in the manner described above for the 5 x 5 nested magic squares.

01	02	04	69	71	72	73	74	03	14	10	11	12	75	76	77	78	16
05	17	18	54	58	59	62	19	77	01	26	25	27	59	60	62	28	81
06	21	29	46	49	50	31	61	76	02	17	34	32	51	52	36	65	80
07	22	30	38	45	40	52	60	75	03	18	29	38	45	40	53	64	79
66	53	47	43	41	39	35	29	16	67	53	47	43	41	39	35	29	15
67	55	48	42	37	44	34	27	15	69	58	49	42	37	44	33	24	13
68	56	51	36	33	32	53	26	14	73	61	46	50	31	30	48	21	09
70	63	64	28	24	23	20	65	12	74	54	57	55	23	22	20	56	08
79	80	78	13	11	10	09	08	81	66	72	71	70	07	06	05	04	68

Numerical Relationships - Nested Magic Squares

The following relationships exists for all odd numbered nested magic squares.

Center Square C = ((n*n)+1)/2)

Sum of Nested 3 x 3 Row = 3 * C Sum of Nested 3 x 3 Square = 3 * 3 * C

Sum of Nested 5 x 5 Row = 5 * C Sum of Nested 3 x 3 Square = 5 * 5 * C

Sum of Nested 3 x 3 Row = 7 * C Sum of Nested 3 x 3 Square = 7 * 7 * C

Sum of Nested 3 x 3 Row = 9 * C Sum of Nested 3 x 3 Square = 9 * 9 * C

....

Sum of Nested 3 x 3 Row = n * C Sum of Nested 3 x 3 Square = n * n * C

For example with a 3 x 3 nested magic square:

n = 3 then C = 5, Sum of a row = 3 * 5 = 15, Sum of the square = 3 * 3 * 5 = 45

It follows that with a 5 x 5 nested magic square:

n = 5 then C = 13, Sum of a row = 5 * 13 = 65, Sum of the square = 5 * 5 * 13 = 325,

Also,

the Sum of a row of the 3 x 3 nested square = 3 * 13 = 39 and

the Sum of the nested 3 x 3 magic square = 3 * 3 * 13 = 117.

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Also,

the Sum of a row of the 3 x 3 nested square = 3 * 25 = 75 and

the Sum of the nested 3 x 3 magic square = 3 * 3 * 25 = 225.

the Sum of a row of the 5 x 5 nested square = 5 * 25 = 125 and

the Sum of the nested 5 x 5 magic square = 5 * 5 * 25 = 625.

It follows that with a 9 x 9 nested magic square:

n = 9 then C = 41, Sum of a row = 9 * 41 = 369, Sum of the square = 9 * 9 * 41 = 3321,

Also,

the Sum of a row of the 3 x 3 nested square = 3 * 41 = 123 and

the Sum of the nested 3 x 3 magic square = 3 * 3 * 41 = 369.

the Sum of a row of the 5 x 5 nested square = 5 * 41 = 205 and

the Sum of the nested 5 x 5 magic square = 5 * 5 * 41 = 1025.

the Sum of a row of the 7 x 7 nested square = 7 * 41 = 287 and

the Sum of the nested 7 x 7 magic square = 7 * 7 * 41 = 2009.

If you have any questions or comments, please e-mail me at robertw653@aol.com

http://www.csc.fi/math_topics/Mail/NANET94/msg00831.html Go
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19
2005 2006 2007
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[Prev][Next][Index]

Magic Hexagon

- *From*: Jens Lorenz <lorenz@igpm.igpm.rwth-aachen.de>
- *Date*: Mon, 14 Nov 94 13:33:29 +0100
- *Subject*: Magic Hexagon

```
The following magical hexagon out of the first
19 integers has  sum 38 in each horizontal
and diagonal.


             10   12    16

           13    4    2    19

         15   8    5     7    3

           14    6    1    17

              9   11   18


I have this from my Highschool teacher, who says it
is due to a railroad engineer of the Old Wild West.

I wonder if someone has seen this before, knows about
its origin, or generalizations (except magic squares).
Please let me know.
```

Jens Lorenz
Numerische Mathematik
RWTH Aachen
Templergraben 55
Germany

lorenz@igpm.rwth-aachen.de

- Prev: --- NA Digest V. 94, # 47
- Next: Least Squares Problems with Identical Hessians
- Index: Numerical Analysis Digest 1994

http://www.comm.toronto.edu/~frank/hexagon/index.html Go
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13
2005 2006 2008
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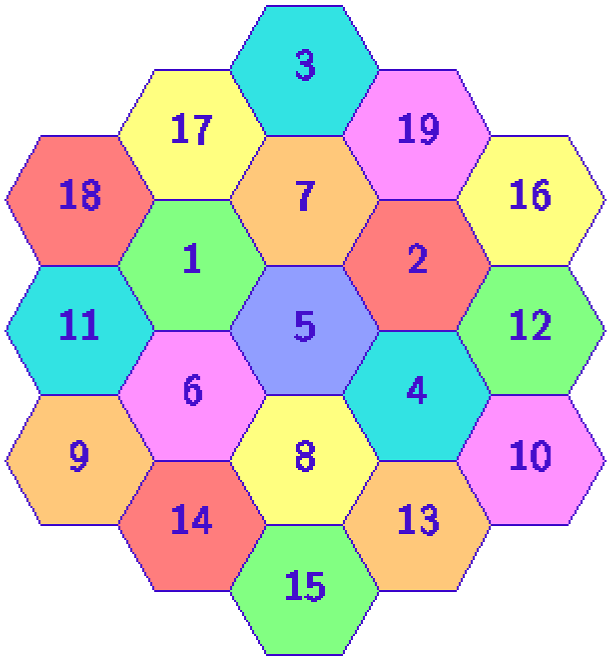
The Magic Hexagon



This is a diameter-5 magic hexagon. Each integer from 1 to 19 appears exactly once, and the sum of the numbers along any column or diagonal is the same. It is easy to prove that 1 and 5 are the only possible magic hexagon diameters, using the numbers from 1 to the hexagon size. The diameter-1 magic hexagon is trivial, and the diameter-5 magic hexagon is essentially unique. (There are 12 variations which arise by rotating and reflecting the hexagon under the action of the dihedral group of order 12).

For information on the history of the magic hexagon visit Eric W. Weisstein's World of Mathematics page.

Phil J. Taylor (xptaylor at hotmail dot com) writes:

```
Hi Professor Kschischang,
   Thank you for posting information about the Magic Hexagon problem. I have played with the
problem for several years and I have attached the simplest C program that I've been able to
create that solves the problem. You are welcome to post it or pass it along to others who might
be interested.

Cheers,
-Phil J. Taylor
```

I have posted Phil's program here. Thank you, Phil!

Frank R. Kschischang, April 6, 2004.

http://www.inetworld.net/~houlton/ Go
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NOV DEC FEB
17
2000 2001 2003
About this capture

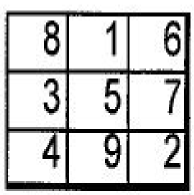
Magic Figures:

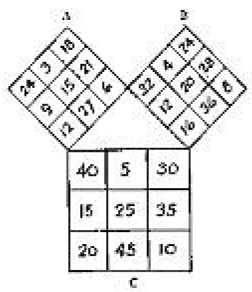
Magic Squares, Magic Triangles, Magic Cubes, and Magic Hypercubes

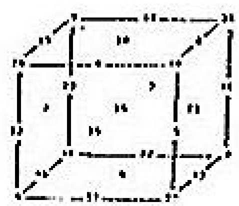
by Meredith Houlton

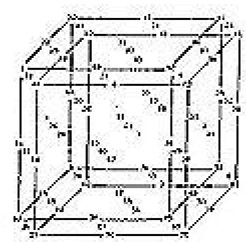
G.E.N.O.

A *G*eneral *E*xpression for *N*-dimensional *O*dd-ordered Magic Figures--
No such expression has been created before!
Calculates the numbers that fill the positions of odd-ordered magic figures of any spacial dimension.









Magic Squares

Magic Triangles

Magic Cubes

Magic Hypercubes

Author's Projects
References
Acknowledgments
e-mail the author

http://olympiads.win.tue.nl/ioi/ioi94/contest/day1prb3/problem.html Go
68 captures
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APR JUN SEP
13
2004 2006 2007
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IOI'94 - Day 1 - Problem 3: The Primes

```
|---|---|---|---|---|
| 1 | 1 | 3 | 5 | 1 |
|---|---|---|---|---|
| 3 | 3 | 2 | 0 | 3 |
|---|---|---|---|---|
| 3 | 0 | 3 | 2 | 3 |
|---|---|---|---|---|
| 1 | 4 | 0 | 3 | 3 |
|---|---|---|---|---|
| 3 | 3 | 3 | 1 | 1 |
|---|---|---|---|---|  (Figure 1)
```

Figure 1 shows a square. Each row, each column and the two diagonals can be read as a five digit prime number. The rows are read from left to right. The columns are read from top to bottom. Both diagonals are read from left to right. Using the data in the `INPUT.TXT` file, write a program that constructs such squares.

- The prime numbers must have the same digit sum (11 in the example).
- The digit in the top left-hand corner of the square is pre-determined (1 in the example).
- A prime number may be used more than once in the same square.
- If there are several solutions, all must be presented.
- A five digit prime number cannot begin with zeros, ie 00003 is NOT a five digit prime number.

Input Data

The program reads data from the `INPUT.TXT` file. First the digit sum of prime numbers and then the digit in the top left-hand corner of the square. The file contains two lines. There will always be a solution to the given test data. In our example:

```
11
1
```

Output Data

In the `OUTPUT.TXT` file, write five lines for each solution found, where each line in turn consists of a five digit prime number. The above example has 3 solutions which means that the `OUTPUT.TXT` file contains the following (the empty lines are optional):

```
11351
14033
30323
53201
13313

11351
33203
30323
14033
33311
```

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http://www.pivari.com/squaremaker.html Go
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21
2005 2006 2007
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Design your Magic Square

This application can live with publicity incomings
by Fabrizio Pivari© 2004-2006 http://www.pivari.com/

Introduce your Magic Square (every number separated by ,)

```
5,31,35,60,57,34,8,30
19,9,53,46,47,56,18,12
16,22,42,39,52,61,27,1
63,37,25,24,3,14,44,50
26,4,64,49,38,43,13,23
41,51,15,2,21,28,62,40
54,48,20,11,10,17,55,45
36,58,6,29,32,7,33,59
```

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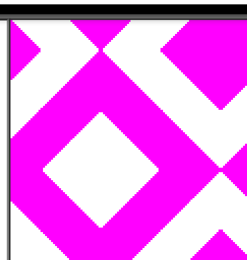
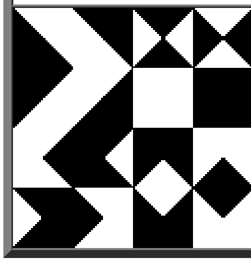
Puzzle Page



Patterns and Magic Squares (1)
Patterns and Magic Squares (2)
Polyomino Patterns



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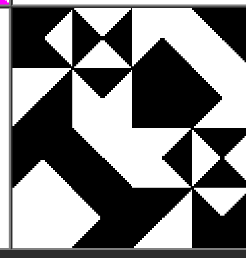

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Me & My Interests

Magic

Northamptonshire Magicians' Club

Magic Squares

Mnemonics

Mumbles (Our Chief Bear)

Paw Print Press

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In this puzzle the goal is to have the total of each row and column to be equal to 30. Click on a piece to pick it up and click again to drop it.

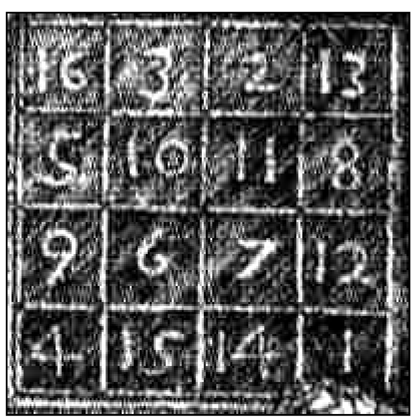
This puzzle has been conceived and executed by Dubi Kaufmann
contact math@dubster.com for information or try FAQ

Highlighted in the MathForum
Math Forum Internet News

http://www-groups.dcs.st-and.ac.uk/~history/Miscellaneous/Durer/Melancholia.h Go AUG MAY JAN
36 captures 05
3 Mar 2000 - 31 Jul 2017 2004 2006 2007 About this capture

Melancholia

This engraving, made in 1514 shows a Magic Square whose bottom numbers have been arranged to give the date.
An enlarged version of the square is shown below



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JOC/EFR August 1999

http://www.markfarrar.co.uk/msqpht01.htm Go
42 captures
6 Oct 2003 - 21 Oct 2018
DEC FEB DEC
2004 17 2005 2006
About this capture

8	1	6
3	5	7
4	9	2

Magic Square Photographs

This page is intended to show photographs of Magic Squares found in real life.

If anybody finds any other Magic Squares and would like to let me have a photograph of them, I would be very grateful.

Shown below is the first photograph of a Magic Square that I have obtained (from a friend). This particular photograph was taken at Gaudi's cathedral in Barcelona, and you will notice (if you have exceptionally good eyesight) that the "Magic Total" is 33, which is popularly acknowledged as the age at which Jesus Christ died.

For those of you whose eyesight is less than perfect, the Magic Square is reproduced here:

1	14	14	4
11	7	6	9
8	10	10	5
13	2	3	15

This photograph of the same Magic Square was taken by **Gordon Brindle** whilst on holiday in Barcelona to celebrate his wife's birthday.

Finally, there is an **interesting article** by **George Zimmerman** on this Subirachs Magic Square.

http://www.markfarrar.co.uk/msqpht01.htm Go DEC FEB DEC
42 captures 17
6 Oct 2003 - 21 Oct 2018 2004 2005 2006 About this capture

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38 captures 21
25 Apr 2001 - 17 Oct 2018 2005 2006 2008
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Unusual Magic Squares

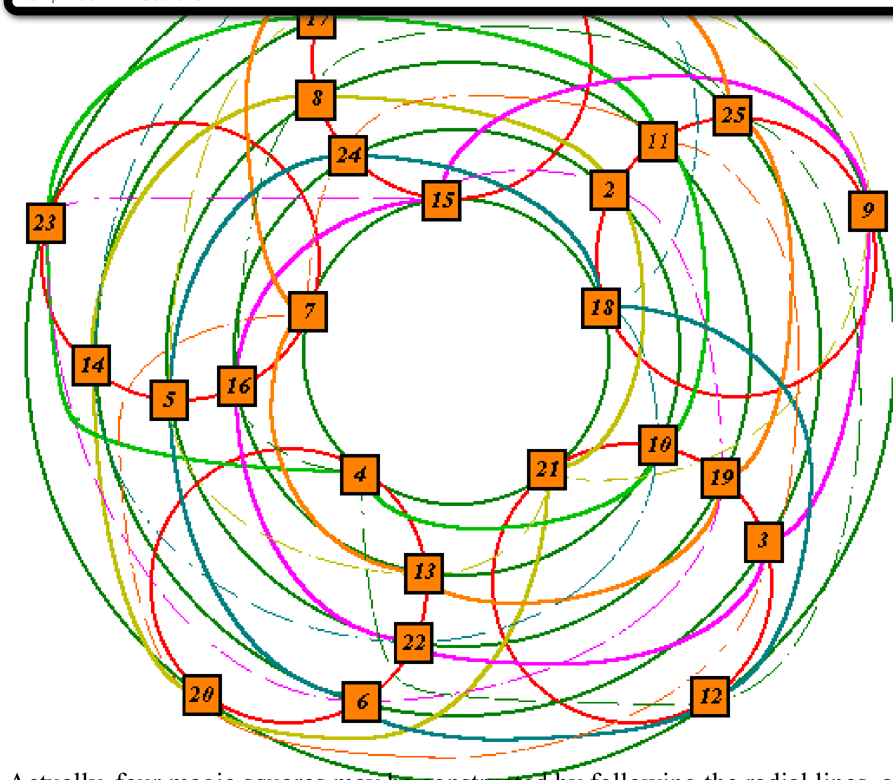
Welcome to this page of unusual magic squares. New material will be added here as it becomes available and time permits. Enjoy!

A Pandiagonal Torus	This pattern generates 50 order-5 pandiagonal magic squares.
Magic Circles	Two diagrams show characteristics of order-4.
Square with Special Numbers	Commemorates my Dad's 90th birthday.
Prime Heterosquare	Rivera's prime # squares have each line summing different.
Double HH	Ed Shineman constructed this order-16 with HH embedded.
Shineman's Magic Diamonds	Two magic diamond patterns with special numbers.
Square with Embedded Star	Arto Heino's order-8 contains a magic hexagon.
Square to Star	Heino's order-4 magic square converts to an order-8 star.
Franklin's Order-8	Benjamin Franklin's order-8 semi-magic square.
A Beastly Magic Square	Patrick De Geest's Order-6 magic square sums to 666.
Millennium Magic Square	Shineman's order-16 pandiagonal with inlaid 2000.
Sagrada Familia Magic Square	A beautiful Spanish cathedral's magic square sums to 33.

A Pandiagonal Torus

This pattern, which is a torus drawn in two dimensions may be used as an order-5 pandiagonal magic square generator.

http://www.geocities.com/~harveyh/unususqr.htm Go FEB APR FEB
38 captures
25 Apr 2001 - 17 Oct 2018
2005 21 2006 2008
About this capture



Start at number 2, and follow the big circles, to generate the columns of the **B** magic square.

25 different pandiagonal magic squares can be formed this way by starting with each of the 25 numbers on the model.
Another 25 different magic squares can be constructed by forming the rows and columns with the numbers along the spiral lines. See Magic square **C**, below.

Actually, four magic squares may be constructed by following the radial lines, and another four by following the spiral lines, in either direction around the torus. However, three of these magic squares are just disguised versions of the fourth one, because they are rotations or reflections.

1	**9**	**12**	**20**	**23**
17	**25**	**3**	**6**	**14**
8	**11**	**19**	**22**	**5**
24	**2**	**10**	**13**	**16**
15	**18**	**21**	**4**	**7**

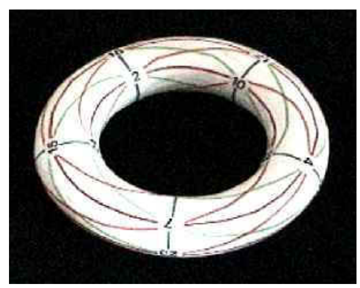
A.

2	**11**	**25**	**9**	**18**
10	**19**	**3**	**12**	**21**
13	**22**	**6**	**20**	**4**
16	**5**	**14**	**23**	**7**
24	**8**	**17**	**1**	**15**

B.

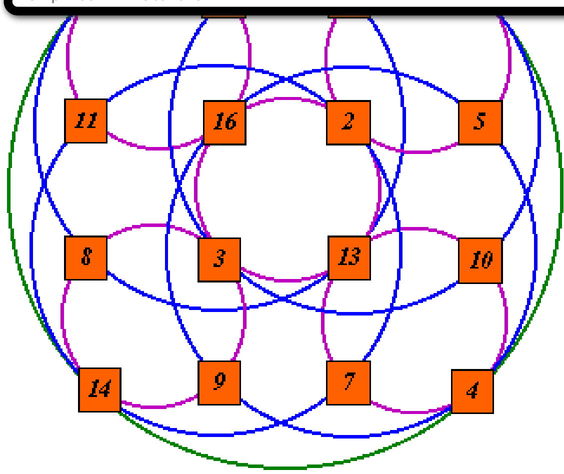
1	**25**	**19**	**13**	**7**
14	**8**	**2**	**21**	**20**
22	**16**	**15**	**9**	**3**
10	**4**	**23**	**17**	**11**
18	**12**	**6**	**5**	**24**

C.

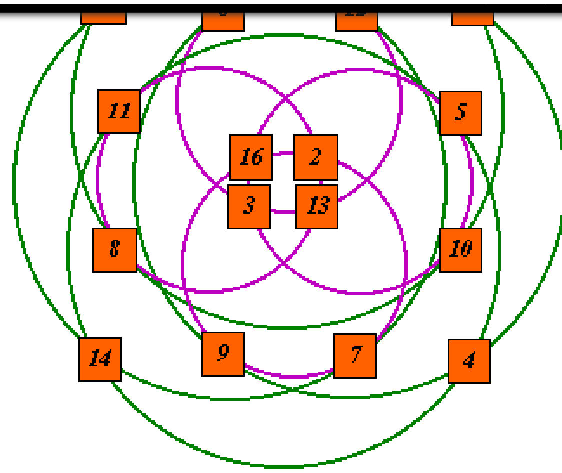

A 3-D model

Magic Circles

http://www.geocities.com/~harveyh/unususqr.htm Go
FEB APR FEB
21
2005 2006 2008
38 captures
25 Apr 2001 - 17 Oct 2018
About this capture



A.



B.

These two diagrams, between them, illustrate some relationships in this order-4 magic square.

	A.	**B.**
1 6 12 15		
11 16 2 5	1 + 15 + 4 + 14 -- biggest circle	1 + 15 + 10 + 8 -- 1 of 4 big circles
8 3 13 10	1 + 12 + 13 + 8 -- 1 of 4 medium circles	11 + 2 + 13 + 8 -- 1 of 4 small circles
14 9 7 4	1 + 6 + 16 + 11 -- 1 of 5 small circles	

Thanks for the idea to W. S. Andrews, *Magic Squares and Cubes, Dover, 1960.*

Pandiagonal with Special Numbers.

32	4	23	3	28
17	12	49	5	7
22	8	1	26	33
10	47	6	25	2
9	19	11	31	20

I designed this pandiagonal magic square to commemorate my Dad's 90th birthday. The three center numbers in the top row are his birth date, April 23/03. The 5 rows, 5 columns, the 2 main diagonals and the 10 broken diagonal pairs all sum to 90.

Because this is also an Associative magic square, the corners of twenty-five 3 x 3 and twenty-five 5 x 5 squares, along with the center square in each case (including wrap-around) also all sum to 90.

There is still more! Corners of 25 2 x 2 rhombics along with the center cell of each. Example: 17 + 4 + 49 + 8 + 12 = 90. Also 25 3 x 3, 4 x 4, and 5 x 5 rhombics (including wrap-around). An example of a 5 x 5 rhombic; 32 + 7 + 28 + 20 + 3 = 90. It is easier to visualize wrap-around if you lay out multiple copies of the magic square like a magic carpet.

For still more patterns summing to 90, see my Deluxe magic square, although not all those patterns are possible because this is not a pure magic square.

Top

Prime Number Heterosquares

http://www.geocities.com/~harveyh/unususqr.htm Go
38 captures
25 Apr 2001 - 17 Oct 2018
FEB APR FEB
2005 21 2006 2008
About this capture

	17	3	47	67
	7	83	11	101
23	29	127	71	227

	53	59	61	173
	67	43	47	157
167	151	139	149	439

The Order-3 heterosquare on the left consists of 9 prime numbers. The 3 rows, 3 columns and the 2 main diagonals all sum to different prime numbers. The sum of all 9 cells is also a prime number.
Is this the square with the smallest possible total with eighteen unique primes (including the totals)?

The Square on the right has identical features, but in addition consists of consecutive primes.
Is this the square with the smallest possible total with nine consecutive primes?

These squares designed by Carlos Rivera, Sept. 98. See his Web page on Prime Puzzles & Problems at http://www.sci.net.mx/~crivera/

Double HH

98	79	178	95	162	63	194	47	210	255	2	239	18	143	114	159
158	179	78	163	94	195	62	211	46	3	254	19	238	115	142	99
100	77	180	93	164	61	196	45	212	253	4	237	20	141	116	157
155	182	75	166	91	198	59	214	43	6	251	22	235	118	139	102
101	76	181	92	165	60	197	44	213	252	5	236	21	140	117	156
153	184	73	168	89	200	57	216	41	8	249	24	233	120	137	104
103	74	183	90	167	58	199	42	215	250	7	234	23	138	119	154
151	186	71	170	87	202	55	218	39	10	247	26	231	122	135	106
105	72	185	88	169	56	201	40	217	248	9	232	25	136	121	152
149	188	69	172	85	204	53	220	37	12	245	28	229	124	133	108
107	70	187	86	171	54	203	38	219	246	11	230	27	134	123	150
148	189	68	173	84	205	52	221	36	13	244	29	228	125	132	109
110	67	190	83	174	51	206	35	222	243	14	227	30	131	126	147
146	191	66	175	82	207	50	223	34	15	242	31	226	127	130	111
112	65	192	81	176	49	208	33	224	241	16	225	32	129	128	145
160	177	80	161	96	193	64	209	48	1	256	17	240	113	144	97

This is an Order-16 pandiagonal pure magic square so uses the consecutive numbers from 1 to 256.
Each of the 16 rows, columns, and diagonals sum to the constant 2056
The E. S. each also sum to 2056 and the H. H. each sum to 2056 x 2.

Constructed in Sept./98 by E.W. Shineman, Jr. for myself. Thanks Ed.

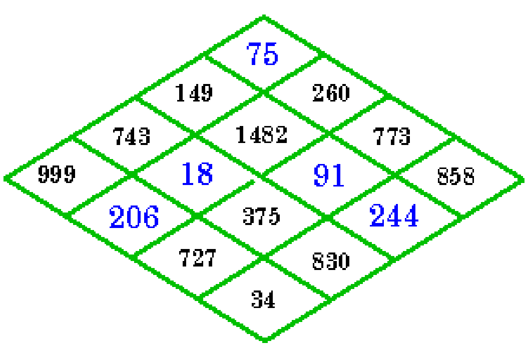
http://www.geocities.com/~harveyh/unususqr.htm Go FEB APR FEB
38 captures 21
25 Apr 2001 - 17 Oct 2018 2005 2006 2008 About this capture

S/2.
The word ‘All’ with no qualifier means that the pattern may be started at ANYof the 256 cells of the magic square.

All rows of 16 cells.
All columns of 16 cells.
All rows of 8 cells starting on EVEN columns
All columns of 8 cells starting on rows 8 & 16
All rows of 4 cells starting on EVEN columns
All columns of 4 cells starting on rows 2 & 10
All rows of 2 cells starting on EVEN columns
All 16 cell diagonals
All 2x2 square arrays
Corners of all even squares
All 16 cell small patterns (fully symmetrical within a 6x6 or 8x8 square array)
All 16 cell midsize patterns (fully symmetrical within a 10 or 12 square array)
All 16 cell large patterns (fully symmetrical within a 14 or 16 square array)
All horizontal 2-cell segment bent-diagonals
All vertical 2-cell segment bent-diagonals, R, L starting on ODD rows
All vertical 2-cell segment bent-diagonals, L, R starting on EVEN rows
All horizontal 4-cell segment bent-diagonals starting in column 4, 8, 12 and 16
All vertical 4-cell segment bent-diagonals starting in column 2, 6, 10, 14
NO 8-cell segment (regular) bent-diagonals
All knight-move horizontal 8-cell segment, bent-diagonals
All knight-move vertical 8-cell segment, bent-diagonals

See more on the Franklin page

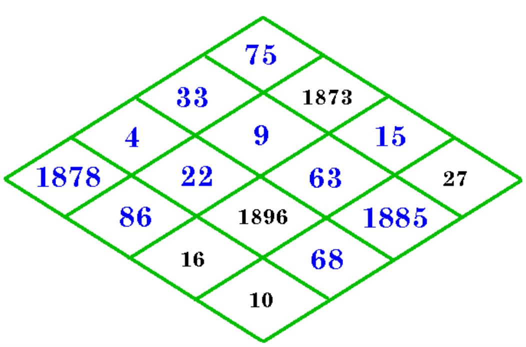
Shineman's Magic Diamonds



Constructed by E. W. Shineman, Jr. , treasurer, to commemorate his company's 75th (Diamond) Anniversary in 1966. It contains 5 special numbers.

75 The anniversary.
18 & 91 1891 The year the company was founded.
206 Net sales in 1966 (millions of dollars).
244 Net earnings (cents per share).

24 combinations of 4 numbers sum to 1966.



Also constructed by E. W. Shineman, Jr., this in 1990 for his 75th birthday. This one contains 11 special numbers.
75 Age on reaching diamond anniversary.
33 (1933) Year graduated from high school.
4-9-15 Date of birth.
1878 Year father was born.
22 Age when graduated from college
86 (1886) Birthyear of Father-in-law & mother-in-law
1885 Year mother was born.
63 & 68 (1963 &1968) Years of career milestones

http://www.geocities.com/~harveyh/unususqr.htm Go FEB APR FEB
38 captures 21
25 Apr 2001 - 17 Oct 2018 2005 2006 2008
About this capture

Order-8 with embedded star

9	14	4	7	1	10	8	15
8	11	5	10	16	13	3	2
1	6	12	15	5	4	14	11
16	3	13	2	12	7	9	6
16	1	8	9	11	16	5	2
3	12	13	6	8	1	12	13
10	7	2	15	9	14	7	4
5	14	11	4	6	3	10	15

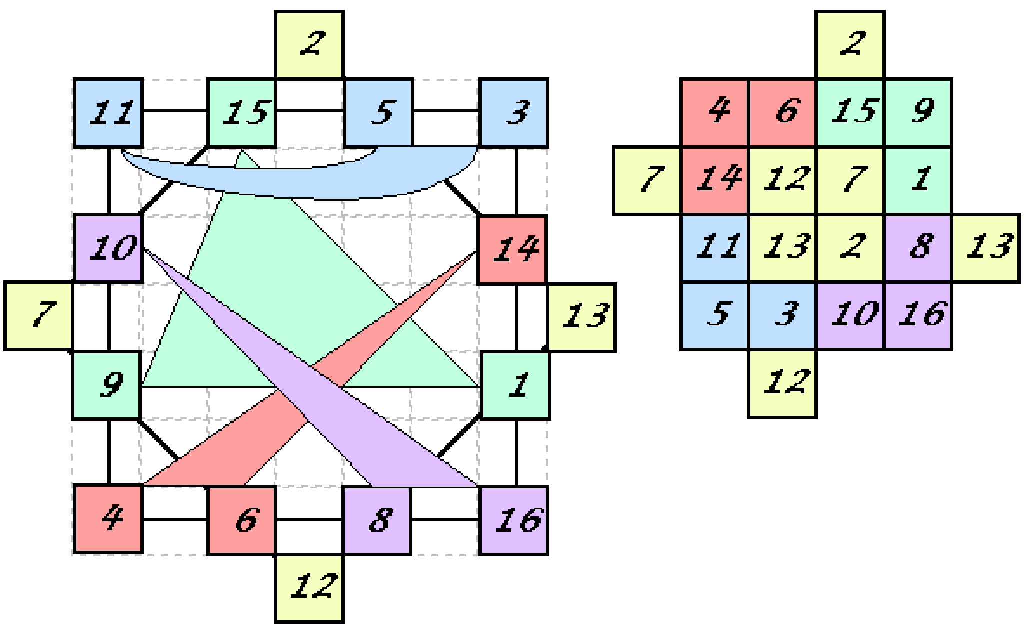
This order-8 magic square is composed of four order-4 pure magic squares. The embedded magic star is index # 16 and is super-magic (the points also sum to the constant 34).
The index numbers of the magic squares are:
upper left # 390 equivalent upper right # 142 the basic solution
lower left # 724 equivalent lower right # 271 equivalent
The equivalent solutions require rotations and/or reflections in order to match the basic solution # shown.

Fr�nicle, assigned these magic square index numbers about 1675, when he published a list of all 880 basic solutions for the order-4 magic square. For more information, see
Benson & Jacoby, *New Recreations with Magic Squares, Dover Publ., 1976.*

The **magic star index numbers** were designed and assigned by me and a full description appears at Magic Star Definitions.

Thanks to Arto Juhani Heino who e-mailed me this pattern on Jul. 15/98.

Order-4 square to order-8 star.



This diagram shows some relationships between an order-8B magic star and an order-4 magic square.
Both patterns are basic solutions. The star is index # 57 (Heinz) and the square is index # 666 (Fr�nicle).

Thanks to Arto Juhani Heino for this design.

Franklin 8 x 8 Magic Square

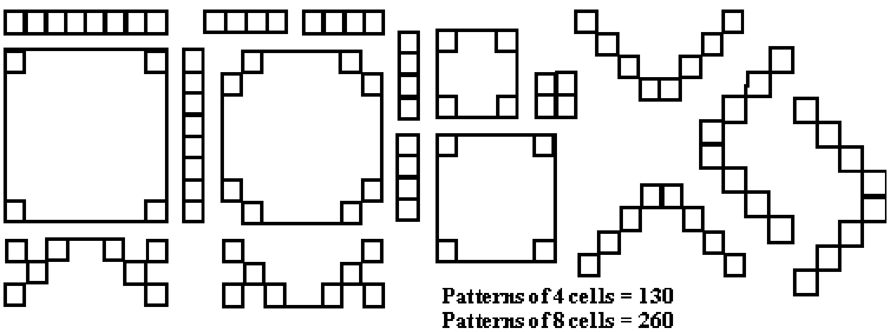
http://www.geocities.com/~harveyh/unusussqr.htm Go FEB APR FEB
38 captures 21
25 Apr 2001 - 17 Oct 2018 2005 2006 2008 About this capture

53	60	5	12	21	28	37	44
11	6	59	54	43	38	27	22
55	58	7	10	23	26	39	42
9	8	57	56	41	40	25	24
50	63	2	15	18	31	34	47
16	1	64	49	48	33	32	17

following cell patterns.

Because the square is continuous, (wraps around), each pattern is repeated 64 times (8 in each direction).

However, because the main diagonals do not sum correctly (one totals 260 - 32 & the other 260 + 32), it is not a true magic square.



Franklin also constructed an order-16 magic square with similar properties.

It also has the property that any 4 by 4 square sums to the constant, 2056, as well as some other combinations.

See my Franklin page for more on all of Ben Franklin squares (and his magic circle)

A Beastly Magic Square

This order-6 magic square is constructed from
the first 36 multiples of 6, and has a magic sum
of 666.

66	108	78	174	216	24
96	84	72	204	30	180
90	60	102	198	168	48
120	162	132	12	54	186
150	138	126	42	192	18
144	114	156	36	6	210

I received this beastly square from Patrick De Geest on Dec. 7, 1998.
Well done Patrick!

This square contains many hidden 3-digit palindromes (which I indicate here in blue).
The top left 3 by 3 square is magic with S = 252.
The bottom left 3 by 3 square is magic with S = 414.
The 3 row of 3 cells in top right corner sum to 414.
The 3 row of 3 cells in bottom right corner sum to 252.
The corners of the 3 squares working from the outside to the center, each sum to 444.
The 6 by 6 border cells sum to 2220 which equals 666 + 888 + 666.
The border cells of the central 4 by 4 square sum to 1332 which equals 666 + 666.
The top half of the right-hand column sums to 252 and the bottom half to 414.
The top half of the column next to it sums to 414 and the bottom half to 252.
By dividing each number in the magic square by 6, a new magic square is obtained, with S = 111.
What other features still await discovery?

Millennium Magic Square

http://www.geocities.com/~harveyh/unususqr.htm Go
38 captures
25 Apr 2001 - 17 Oct 2018
FEB APR FEB
2005 21 2006 2008
About this capture

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
246	20	230	116	134	100	150	181	69	165	85	197	53	213	37	04
03	231	19	135	115	151	99	70	180	86	164	54	196	38	212	247
244	22	228	118	132	102	148	183	67	167	83	199	51	215	35	06
05	229	21	133	117	149	101	68	182	84	166	52	198	36	214	245
242	24	226	120	130	104	146	185	65	169	81	201	49	217	33	08
07	227	23	131	119	147	103	66	184	82	168	50	200	34	216	243
241	25	225	121	129	105	145	186	64	170	80	202	48	218	32	09
10	224	26	128	122	144	106	63	187	79	171	47	203	31	219	240
239	27	223	123	127	107	143	188	62	172	78	204	46	220	30	11
12	222	28	126	124	142	108	61	189	77	173	45	205	29	221	238
253	13	237	109	141	93	157	174	76	158	92	190	60	206	44	-03
-02	236	14	140	110	156	94	75	175	91	159	59	191	43	207	252
251	15	235	111	139	95	155	176	74	160	90	192	58	208	42	-01

from –3 to 253 with one number not used. (Can you find the missing number?)

Each row, column and diagonal, including the broken diagonal pairs, sum to 2000. In addition, the three groups of sixteen numbers (the zeros) each sum to 2000.
The large two, which contains 32 numbers, sums to 4000 (the magic sum x 2).
The double zero shown in the top left cell represents the new year.

NOTE: There is controversy as to whether the year 2000 is part of the 20th or the 21st century (and the 2nd or 3rd millennium). Here we consider it to be the latter.

Sagrada Familia Magic Square

The Sagrada Familia cathedral in Barcelona, Spain, contains the unusual magic square shown in the two pictures below. Both the number 10 and the number 14 are repeated twice and there is no 12 or 16. The magic sum is 33.
Does anyone know the significance of this magic square? Many people have speculated that 33 signifies Jesus Christ's age at the time of his crucifixion.

These pictures were taken by Jorge Posada and are dedicated to his girlfriend **Maite**. Thank you Jorge, for the pictures and for drawing this item to my attention.

The picture below shows the placement in the cathedral but is of unknown origin.

Alex Cohn (e-mail July 15/01) points out that this square also appears multiple times on the main facade of the incompleted church.

The Sagrada Familia cathedral is the most important work of Gaudi, a spanish architect considered as a true genius. He worked on this building from 1882 until his death in 1926. Although it is not completed yet, it is the most important and amazing building in

http://www.geocities.com/~harveyh/unususqr.htm Go FEB APR FEB
38 captures 21
25 Apr 2001 - 17 Oct 2018 2005 2006 2008
About this capture

Lee Sallows (July12,2001) points out that magic squares with a magic sum of 33 may be constructed without using duplicate integers.
Here is one (of several he provided) that uses the integers 0 to 16, but without the 4.

0	**5**	**12**	**16**
15	**11**	**6**	**1**
10	**3**	**13**	**7**
8	**14**	**2**	**9**

Please send me Feedback about my Web site! Top

Harvey Heinz harveyheinz@shaw.ca
This page last updated October 06, 2005
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http://mathforum.org/te/exchange/hosted/suzuki/Magic.Mail.html Go
JUN JUL JUN
24
2008 2009 2013
4 captures
24 Jul 2009 - 21 Jul 2016
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Mutsumi Suzuki
[Magic Squares]

Mails come from all over the world

Followings are mails from many Magic Square Manias.

- Seamus Bellows finally calculated the total number of 5x5 semimagic squares. (Dec. 18 , 1997)

  #########(begins)
  Hello Everyone

  I have computed what I think is the total number of 5 by 5 semimagic squares.

  Using the first 25 integers the total number is 3 872 768 400 000 giving 486 096 050 000 unique ones.

  The computing time was about 50 hours on a 486 machine using 66 MegaHertz.

  I considered the following squares:

  ```
  1 a b c d
  e * * * *
  f * * * *
  g * * * *
  h * * * *
  ```

  It was sufficient to consider the corner as 1 since there are 25 choices for this. The following conditions were also considered:

  ```
  a < b < c < d ( giving 24 possibilities )
  e < f < g < h ( giving 24 possibilities )
  e > a ( giving 2 possibilities )
  ```

  My computation resulted in 134 471 125 possibilities

  Then 134 471 125 x 2 x 24 x 24 x 25 resulted in 3 872 768 400 000 squares.

  Seamus Bellew
  North West Institute
  ########(end)

- Mail from Dr. Younan Lu
  #########(begins)
  Hi Dr. msuzuki,

  In the September issue of Scientific American (page 94) the author states: the existance of 8*8 complete magic square has neither been proved nor disproved. I am not so sure if this statement is correct or not. I looked at your data base on the

http://mathforum.org/te/exchange/hosted/suzuki/Magic.Mail.html Go JUN JUL JUN 24 2008 2009 2013
4 captures
24 Jul 2009 - 21 Jul 2016
About this capture

intellectual recreations. I finally solved this problem. I got a complete 8*8 magic square. Would you be interested to see it?

Regards,

Dr. Younan Lu

(Thu, 11 Sep 1997)

==========My answer is===============

Thank you for your interesting mail. The following clasification is known for the existence and algorithm of the complete magic squares.

```
                  N = 3n  type  ............ exist
     odd N  <
                  N is not 3n  type.........exist

                                 odd m   ....exist
                  N = 4m   type <
     even N <                    even m  ....exist
                  N = 4m+2 type.............not exist
```

However, the known algorithm and yielded squares are limited to very special case.
The total number of complete magic squares is not known.

In anyway, I am very interested into your 8x8 square. Please show me the result.

Mutsumi Suzuki
#########(end)

- Question from a school
  #########(begins)
  Subject: math problem for grade seven kid

  We looked through your 1800+ squares and can't find the one we need.We have some filled in with the rest blanks I don't know if they fit the pattern of yours but here it is anyway.

```
11 ? 7 ? 3
 4 12? ? ?
 ?  5? ? 9
10 ? ? ? ?
 ? ? ? ? ?
```

  Please send the anwser to the address of: xxxxxx
  Thanks Alot.

  (Tue, 9 Sep 1997)

http://mathforum.org/te/exchange/hosted/suzuki/Magic.Mail.html Go
JUN JUL JUN
24
2008 2009 2013
4 captures
24 Jul 2009 - 21 Jul 2016
About this capture

```
Dear sir;
(1)
 11 19  7 25  3
  4 12 20  8 21
 22  5 13 16  9
 10 23  1 14 17
 18  6 24  2 15

(2)
 11 20  7 24  3
  4 12 18  8 23
 21  5 13 17  9
 10 22  2 15 16
 19  6 25  1 14

(3)
 11 24  7 20  3
  4 12 25  8 16
 17  5 13 21  9
 10 18  1 14 22
 23  6 19  2 15

(4)
 11 25  7 19  3
  4 12 23  8 18
 16  5 13 22  9
 10 17  2 15 21
 24  6 20  1 14
```

I think it is too difficult for kids. I had to use my computer.

Mutsumi Suzuki
#########(end)

- Mail from **Dave Harper** (dharper@idirect.com)
  #########(begins)
  Hi, I enjoyed your pages about Magic Squares - I found them when I was searching for other sites to reference in the WEB site I'm developing as part of a course that I'm taking...

  I took the liberty of putting links to your sites in my 'reference' page.

  If you have time, I would appreciate it if you could take a look at the site I'm developing:

  http://web.idirect.com/~recmath/

  Although the focus will be on Recreational Maths in general, I wanted the first topic to be about Magic Squares - a subject that I've been interested in for many years.

  Thanks, Dave.
  (19 Aug 1997)

http://mathforum.org/te/exchange/hosted/suzuki/Magic.Mail.html Go JUN JUL JUN
4 captures 24
24 Jul 2009 - 21 Jul 2016 2008 2009 2013 About this capture

##########(begins)
Hello!

I am Kwon Young Shin. I'm a science teacher in Korea.
I made a homepage for the Magic Square.
It shows 'all' of the solution for the Magic Square and supports a source program.
Even if n=4*k+2 (n=6,10,14,...), Yes I can.
Please, come & see!

URL=> http://www.chollian.net/~brainstm/MagicSquare.htm

Thank you.

Shin, Kwon Young - brainstm@chollian.net
(30 Jul 1997)
##########(end)

- Mail from **Robert C. Wilke** (RobertW653@aol.com)
##########(begins)
Subject: Nested Magic Squares

Thought you might be interested in my page on Nested Magic Squares.

http://members.aol.com/robertw653/magicsqr.html

Thanks,
Bob

(18 Jul 1997)
##########(end)

- Mail from **Dietchi** (dieter.christ@student.uni-augsburg.de)
##########(begins)
hello!

The 5 times 5 square - number is 275305224.
Please refer to Journal:
Scientific American Nr. 234 (1976) January
page 118 - 122 from Richard Schroeppel.

Dietchi
(April 1, 1997)
##########(end)

I received about the same mail from Prof. Ohishi (Daido Inst. Tech., Japan) a week befor.

- Mail from **Seamus Bellew** (nwifhe@nwifhe.demon.co.uk)
##########(begins)
I have calculated the number of unique 5 by 5 magic squares and got the same result as Mr Matsumato of 275 305 224 this number was also obtained by Rich

http://mathforum.org/te/exchange/hosted/suzuki/Magic.Mail.html Go JUN JUL JUN
4 captures 24
24 Jul 2009 - 21 Jul 2016 2008 2009 2013
About this capture

- Mail from **Tony Richards**
  ##########(begins)
  My uncle has a silver tag which is rectangular in shape about 2" by 1" with the following magic square:

  ```
  4 14 15  1
  9  7  6 12
  5 11 10  8
  16 2  3 13
  ```

  At top and bottom of the rectangle are:
  +ELOHIM+ELOHI++
  ++ROGYEL+IOSEHIEL
  On the left and right sides of the rectangle are:
  ADONAL+
  ZEBAOTH+

  Do you know the significance of this tag? I was give your address by Mr Grogono.

  Thanks
  Tony Richards
  (Nov. 20, 1996)
  ##########(end)

- Mail from **Marian Trenkler** (Slovakia)
  ##########(begins)
  I send you two preprints about magic hypercubes in two formats HP-for laser printer and PS-post scriptum. Of couse you can include this resalts in your www-information.
  Sircerely Marian Trenkler
  (Nov. 18 , 1996)
  ##########(end)

  You can see the post-script files by clicking here(Magic Cube) and (Magic Hyper Cube)

- Mails from **Alvaro Ros** (Barcelona)
  ##########(begins)
  DO YOU KNOW IF EXISTING ANY SQUARE MAGIC 3 X 3 WICH ARE ALL FORMED
  FOR ONLY SQUARE NUMBERS ?
  (Oct. 12 , 1996)
  ---------(and)
  In my opinion there are not any 3 x 3 formed only for square numbers. but never read this demostration.
  (Oct. 16, 1996)
  ##########(end)

- **Ralf Laue** (Leipzig) sent his four programs to me.
  ##########(begins)

http://mathforum.org/te/exchange/hosted/suzuki/Magic.Mail.html Go
JUN JUL JUN
24
2008 2009 2013
4 captures
24 Jul 2009 - 21 Jul 2016
About this capture

I have used this algorithm for four programs, written in C, Basic, Fortran and Pascal. For the record I used a program based on the same algorithm but with a little more comfort.
(Oct. 11, 1996)
##########(end)

- **Fabrizio Pivari**(San Donato) wrote;
##########(begins)
Hi,
I'm glad to announce the version 3.3 of Simple Magic Square checker and gif maker. With this simple form you can create on the fly a magic square gif or a table.
....
Here it is
http://www.agip.it/~pivari/squaremaker.html
After saving your Magic Square you can use the gif to create a magic square Texture Map in VRML with http://www.agip.it/~pivari/VRML.html.
....
Bye
(Oct. 8, 1996)
##########(end)

- **Enver Haase** (Berlin)wrote to me his doubt on the total number 880 of order 4 squares;
##########(begins)
Hi there!
Did I get you right saying that there are 220 "fundemantal" Squares that you can multiplay by 4 (which is trivial since you can turn it 4 times: 0,90,180,270 degrees) and get 880 different ones?!
I mean, you did not consider the resulting ones "pan" or "complete" or otherwise special.
I attached a gzip'd list of the non-special magic squares of degree 4 I have found - they are more than 880 and as far as I can see there are no doubles. Did not prove it until now, though.
Hope to hear from you - will see your page in a few days or so again when I am not bound to a costy phone line.
(Oct, 7, 1996)
##########(I wrote an answer to him, and he wrote to me again that;)
.... I want to make sure that there are really to doubles; guess there have to be when you all say it is only 880 - and now I got an idea WHY my program could behave so - same reason why you can solve Rubik's Cube in more than only one way, too. .....
(Oct. 8, 1996)
##########(end)

- Question from **Meredith Houlton**(San Diego) to MSMSM;
##########(begins)
I am interested to know if anyone has made a 14x14x14, 18x18x18, and 22x22x22 (4n+2) magic cube. I have made magic squares from 3x3 to 23x23 and magic cubes from 3x3x3 to 23x23x23 with those exceptions. The number 23 comes from

http://mathforum.org/te/exchange/hosted/suzuki/Magic.Mail.html Go
JUN JUL JUN
24
2008 2009 2013
4 captures
24 Jul 2009 - 21 Jul 2016
About this capture

Hi,
I also am interested in that. As long as I know, I can mention the followings:
(1) 4n-type cube has general algorithm (at least reported by Andrew.)
(2) I have an algorithm to construct arbitrary prime order complete magic cube (N>6).
(3) My genric algorithm for m-dimensional (N^m) hyper magic cube covers arbitrary odd number order N except N=5 (as a paticular case m=3). (,which is reported in the last mail.)
(4) There is well known algorithm to construct 5x5x5 and 3x3x3 magic cube (reported by Andrew.)
(5) 6x6x6 complete magic cube and 10x10x10 magic cube are reported in japanese book.
Since (2) may have potentiality to exhaust listing up some category of (complete) magic cubes, it is important, but in order to give one magic cube, (2) is not necessary.
The algorithms (1), (2), (4) cover 4n type, 4n+1 type and 4n+3 type. So, your question still remains. We do not have 14x14x14, 18x18x18, 22x22x22, and 4n+2 type (thus, n>2) magic cubes.
(Oct. 2 , 1996)
##########(end)

- **Yoshihide Tamori**(La Jolla, CA) wrote a **generic algorithm** to create hyper magic cubes(3x3, 3x3x3, 3x3x3x3, 3x3x3x3x3, ...).
  ##########(begins)
  Hi folks,
  I found a generic algorithm to construct hyper magic cubes. In the definition, hyper magic cubes are natural extensions of magic squares and magic cubes toward higher dimension (thus 3x3, 3x3x3, 3x3x3x3, 3x3x3x3x3,...).
  Since my spare of time is limited recently, the explanation will be appear in the future, but as an evidence, I gave you the examples given by the algorithm in the following page:
  http://www.cnl.salk.edu/~yo/mathemusement/magic/cube/hypermagiccube.html
  In the page, I gave you the hyper magic cubes
  3x3x3x3
  3x3x3x3x3
  3x3x3x3x3x3 (To open this page, you need to expand the memory limit of your netscape.)
  Enjoy them.
  (Sept. 30, 1996)
  ##########(end)

- Qestion from **Yoshihide Tamori**(La Jolla, CA)
  ##########(begins)
  Subject: Question about De la Loubere
  Hello,
  I have a question to all.
  My algorithm in the last mail for magic cubes is based on the famous algorithm for odd ordered magic squares invented by De la Loubere. (c.f. see the following explanation
  http://sdcc14.ucsd.edu/~fillmore/blurbs/msquare.html
  for his algorithm.)

http://mathforum.org/te/exchange/hosted/suzuki/Magic.Mail.html Go JUN JUL JUN
4 captures 24
24 Jul 2009 - 21 Jul 2016 2008 2009 2013 About this capture

My question is whether or not the name De la Loubere in the different historycal facts is of the same person.
If you know something about the historical facts, please let me know.
Thanx,
(Sept. 28, 1996)
##########(end)

- Mail from **Ralf Laue**(Leipzig) on the Largest Magic Square
##########(begins)
Hallo,
......
.....If you are interested in my information about the largest magic squares, just skip to:
http://www.imn.htwk-leipzig.de/~saxonia/records/magic.html
Of course, I would be glad if you could add a link to this URL to your pmagic square pages.

  Very Best Wishes,
  Ralf Laue
  (21/Sept/1996)
  ##########(end)

- **Robert Wilke** pointed out that all pan-magic squares are also complete
##########(begins)
You may want to retire the category of Ultra Super Masic Squares. Using Alan Grogono's "Magic Carpet" on "Completeness: that is the Sum of the five numbers of all small squares and the centers" --

```
X * X * *
* X * * *
X * X * *
* * * * *
* * * * *
```

  If this pattern is laid anywhere on the "Magic Carpet" the sum can be shown to be 5 * (A+B+C+D+E) + (a+b+c+d+e) = 55
  In addition Rhonbohedral completeness

```
* X * * *
X X X * *
* X * * *
* * * * *
* * * * *
```

  If this pattern is laid anywhere on the "Magic Carpet" the sum can be shown to be 5 * (A+B+C+D+E) + (a+b+c+d+e) = 55
  Therefore all Pan-Magic Squares generated by Alan Grogono's "Magic Carpet" are also "Ultra Super Magic Squares" making the total of Ultra Super Magic Squares equals at least 57600.
  (Sept. 8 ,1996)
  ##########(Comments from Grogono);
  Maurice Kraitchik in his book on Mathematical Recreations (Dover Publications 1942).....

http://mathforum.org/te/exchange/hosted/suzuki/Magic.Mail.html Go JUN JUL JUN
4 captures 24
24 Jul 2009 - 21 Jul 2016 2008 2009 2013 About this capture

```
 x     x x
xxx     x        x x x        x
 x     x x
                   x        x     x
```

Grog (Sept. 10,1996)
##########(my comment);
I was very impressed by Grog's idea of spread sheet again. Because, as pointed out by Robert, it can be easily seen that 5x5 pan-magic squares have the "magic-constellation" patterns.
I can hardly understand the relation without using the spread sheet.
I think the name "ultra super magic square" was too sensational. I had to say "symmetrical(or self similar) pan-magic square".
Mutsumi
(Sept. 11,1996)
##########(end)

- **Professor Grogono** created a "magic carpet". He said that there is really only a single pattern which generates all the possible magic squares. (29/Aug/1996)
- **Fabrizio Pivari** made a simple form that can create on the fly a magic square gif or a table. You can find it by clicking here (29/Aug/1996)
- 80 data of the Magic Stars of David are listed in **Suzanne's page.** . (06/Aug/1996)
- **Fourier Ang Yong Hui** relocated his page address. From new cite, you can enjoy faster responce than before. Interesting chinese story on a magic square and 6x6 squares of prime numbers are presented. (03/Aug/1996)
- **Martin Henz** pointed out big errors in my database of 4n+2 type. I would like to rewrite the data sooner. (29/Jul/1996)
- **Dr. Tamori** wrote a www-page on a magic square decomposition method. He found that many pan-magic squares can be decomposed into very few elemental N-adic matrices. See above list. (25/Jul/1996)
- Professional mathematician **Allan Adler** wrote interesting notes on magic squares. See Suzanne's page. (19/Jul/1996)
- I found **Dr. Tamori** enjoining his Mathematical-Amusement in California. In his pages of "Friday afternoon math" he wrote a page on magic cubes. (9/Jul/1996)
- Math. teacher **Suzanne Alejandre** wrote wonderful pages on the magic squares. Her page is very attractive not only for her students but also for us grownups too old to re-study mathmematics. (24/Jun/1996)
- **Professor Grogono** has just discovered a new method to create 4x4 pan-magic square yesterday. His method is again simple and beautiful. (20/Jun/1996)
- I received a new method for 6x6 square from **Professor Grogono**. His simple and beautiful method is very exciting. I hope he will make his own home page soon. (18/June/1996)
- **Philip Lei** wrote me that he rewrote his home page. Please visit his page again and see the new version. (14/June/1996)

Back to **Suzuki's Magic Squares**

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http://mathforum.org/te/exchange/hosted/suzuki/Magic.Mail.html Go JUN JUL JUN
4 captures 24
24 Jul 2009 - 21 Jul 2016 2008 2009 2013
About this capture

Please mail comments and suggestions to Suzanne Alejandre.

http://mathforum.org/te/exchange/hosted/suzuki/refference.html Go
6 captures
21 Jul 2009 - 12 Mar 2017
JUN JUL OCT
2008 21 2009 2012
About this capture

Mutsumi Suzuki
[Magic Squares]

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21 Jul 2009 - 12 Mar 2017 About this capture

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EUC code is used for the Japanese Characters

http://mathforum.org/te/exchange/hosted/suzuki/refference.html Go JUN JUL OCT
6 captures 21 2008 2009 2012
21 Jul 2009 - 12 Mar 2017 About this capture

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About this capture

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Back to Suzuki's Magic Squares

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