HEXBOTS POST ALPHAGO

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computing UAlberta

2017 oct 2

THANK YOU

- invitation Yngi, Magnus
- solving 10×10 Hex joint with Jakub Pawlewicz
- builds on work with B Arneson, P Henderson
- machine Martin Müller
- photo courtesy MIT Museum, MIT, Cambridge MA
- Natural Sciences and Engineering Research Council of Canada

ALPHAGO: 2015 - 2017

https://gogameguru.com/i/2016/01/Fan-Hui-vs-AlphaGo.jpg Oct 2015

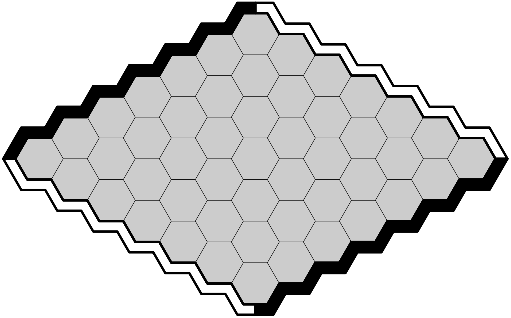
https://www.youtube.com/watch?v=l-GsfyVCBu0&t=77m40s Mar 2016

https://www.youtube.com/watch?v=0CevCII1zo0&t=1m23s Mar 2017

1942 HEX

RULES

- 2 players, alternate moves
- win: connect your two sides



1942 HEX

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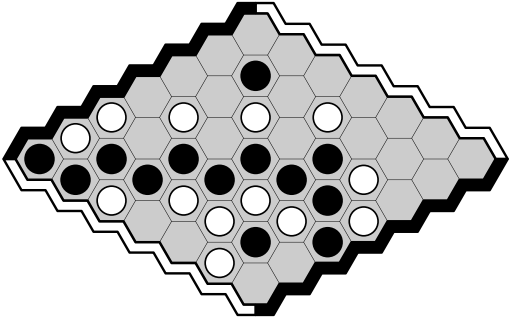
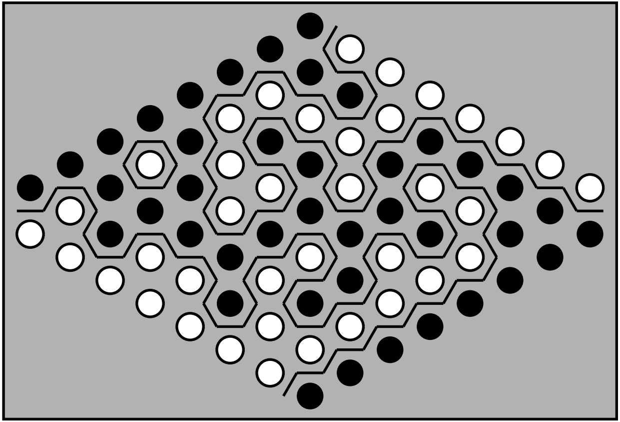


n x n Hex: 1st-player win

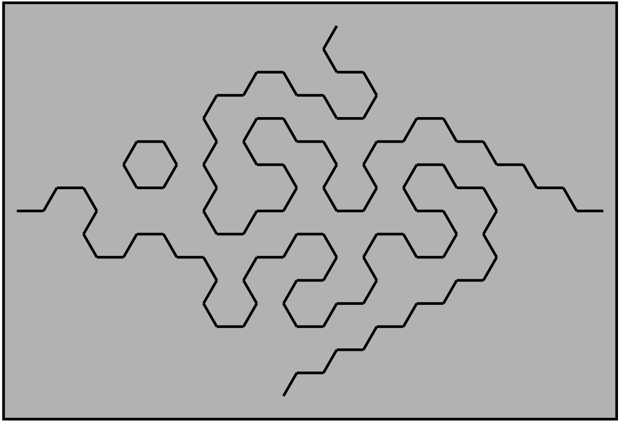
Proof

- lemma: extra X-cell ok for player X
- lemma: no draws
- suppose P2 has win strategy S2
- then P1 can move anywhere, forget move, and follow S2
- thus P1 has win strategy, contradiction □

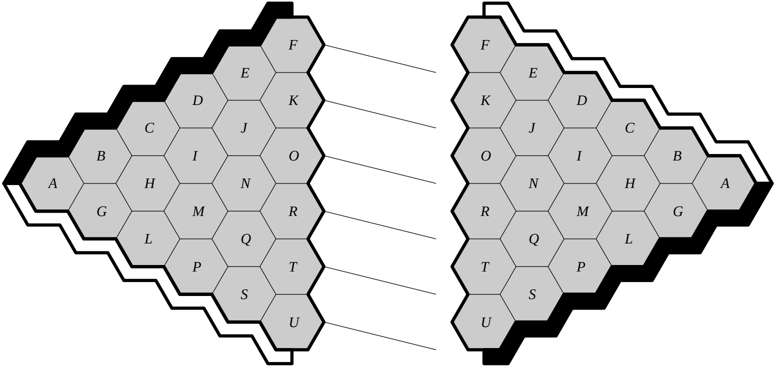
NO-DRAW



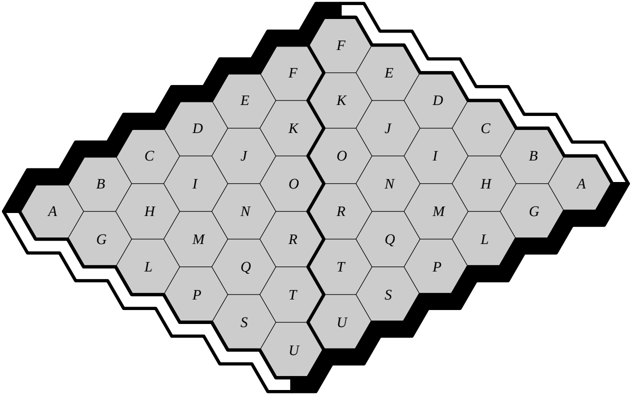
NO-DRAW



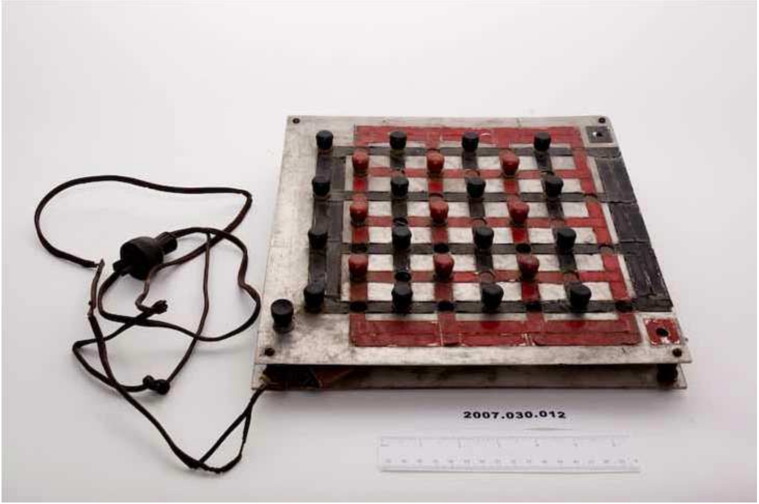
n x n+1 Hex: longer-side win



N X N+1 HEX: LONGER-SIDE WIN



1951 Shannon machine

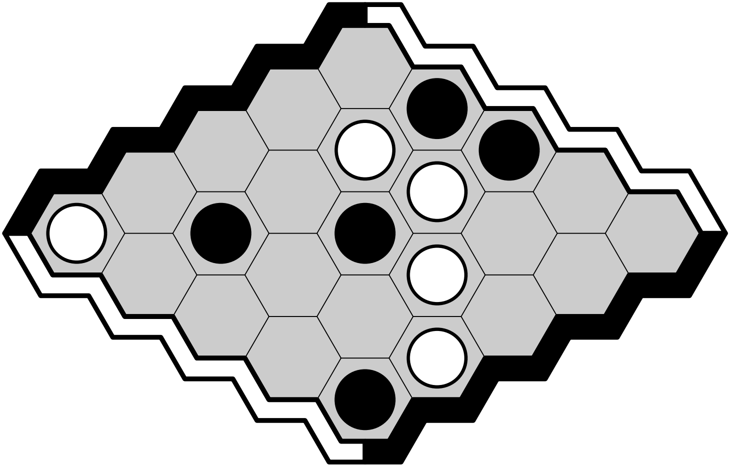


1951 Shannon machine

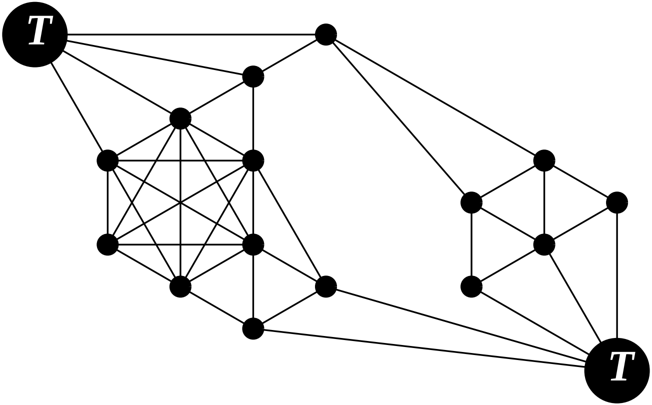
- play on any graph
- two marked vertices
- black move: 'short' any vertex (make nbrs clique)
- white move: 'cut' any vertex (delete)
- black wins iff two marked vertices are shorted (connected)

- generalizes Hex

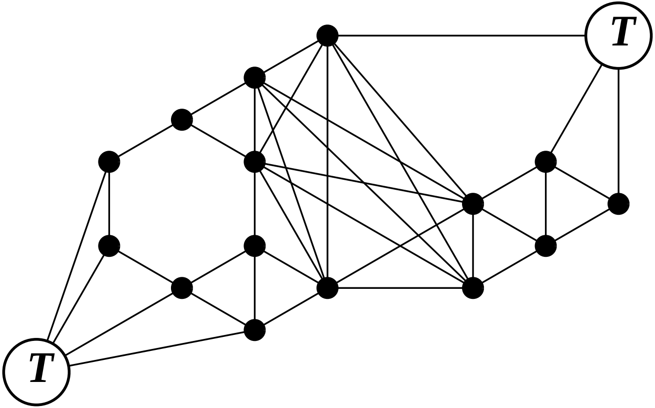
1951 Shannon machine



1951 Shannon machine



1951 Shannon machine



PROVABLY HARD

• 1975 Even & Tarjan	Shannon v-switching: PS-c
• 1981 Stefan Reisch	Hex: PS-c
• 2000 Clay Math Inst	P vs NP: $1 000 000

HUMANS

SOLVED OPENINGS

- 2001 Yang — 17/49 7x7
- 2002 Yang — 8x8
- 2003 Yang — 9x9
- 2004 Noshita — 7x7
- 2005 Noshita — 8x8
- 2006 Mishima — 8x8

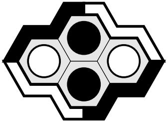
COMPUTERS

SOLVED OPENINGS

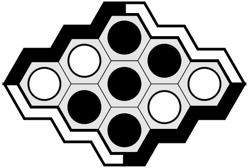
1995	Enderton		6x6
2000	van Rijswijck		6x6
2003	H Bjö Joh Kan Po vRij	5d	7x7
2007	Rasmussen et al.		7x7
2009	Arneson H Henderson	4d	8x8
2010	A H H	25d	some 9x9
2012	Pawlewicz H	110d x 24 thread	9x9
2013	Pawlewicz H	63d x 24 thread	centre 10x10

COMPUTERS

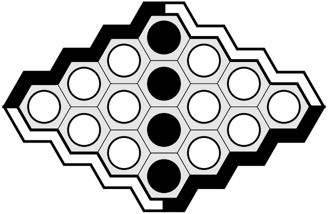
COMPUTERS



computers



COMPUTERS



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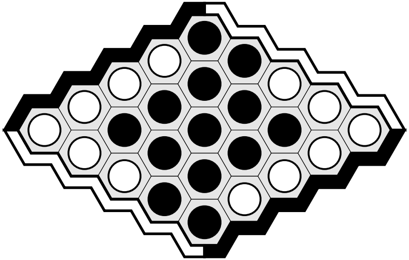

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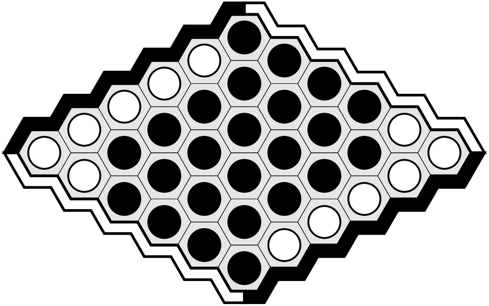

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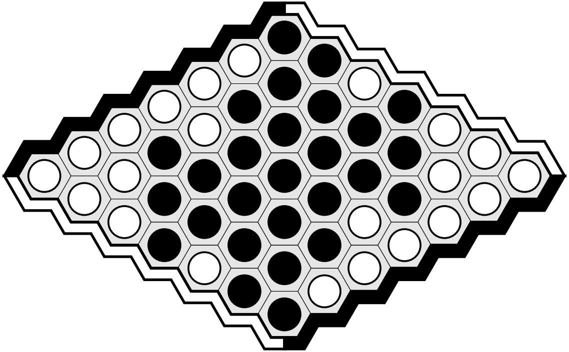

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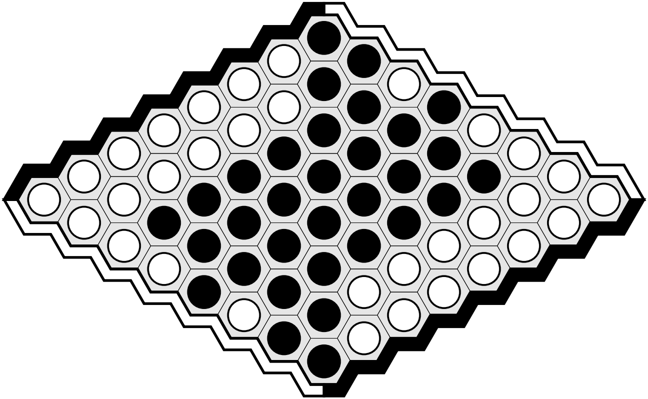

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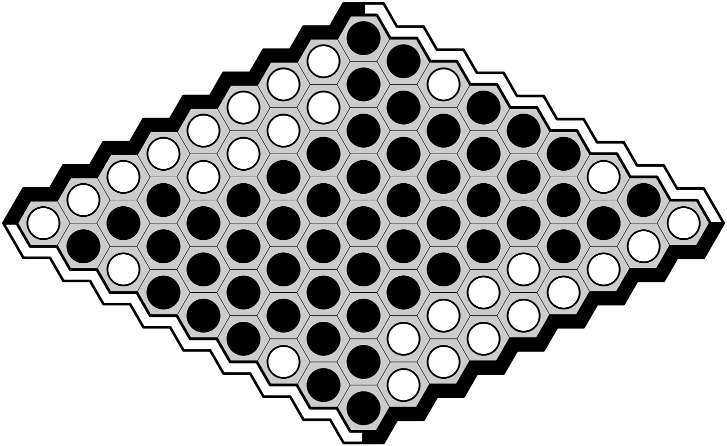
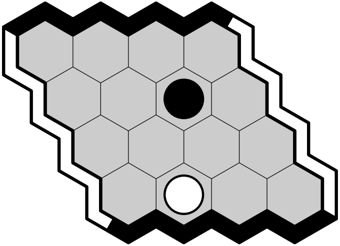


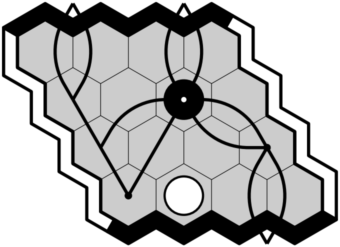
KNOWLEDGE

- virtual connections: combining rules, mustplay
- inferior cells: dead, captured, etc.

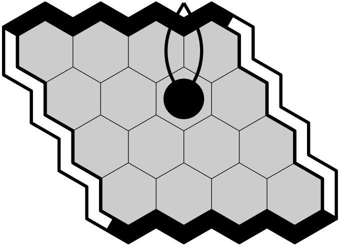
A VIRTUAL CONNECTION



A VIRTUAL CONNECTION



COMBINING RULE: AND (FULL)



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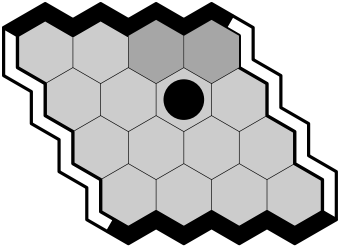

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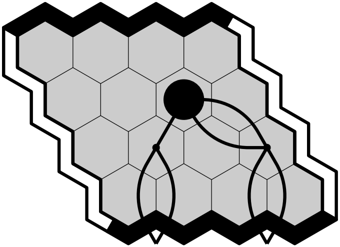

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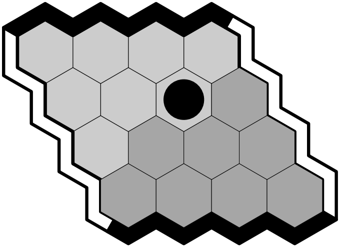

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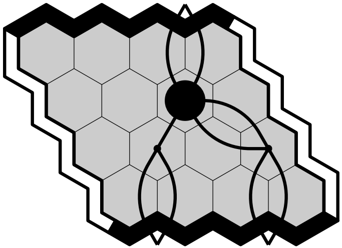
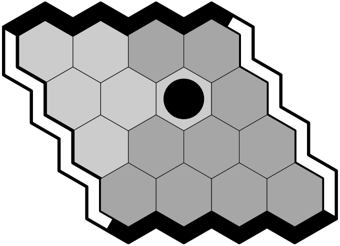
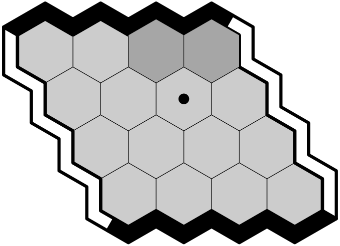


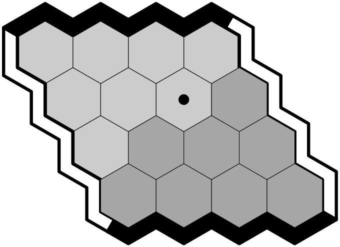
COMBINING RULE: AND (FULL)



COMBINING RULE: AND (SEMI)



COMBINING RULE: AND (SEMI)



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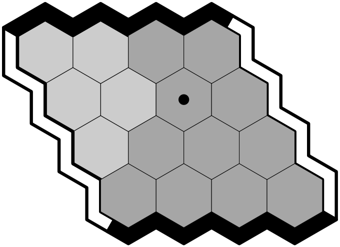
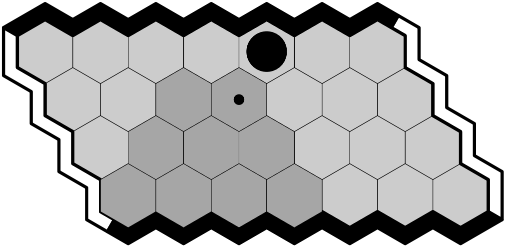


COMBINING RULE: OR



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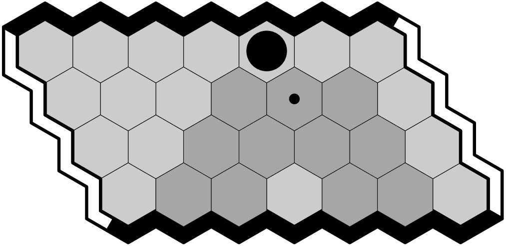

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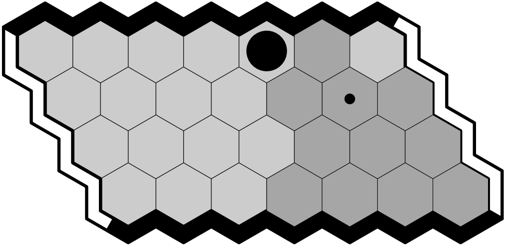

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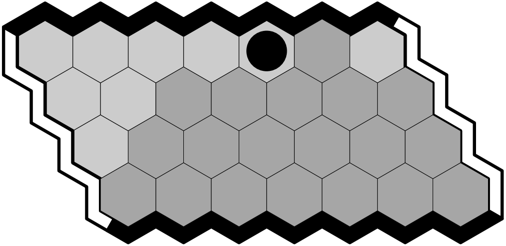
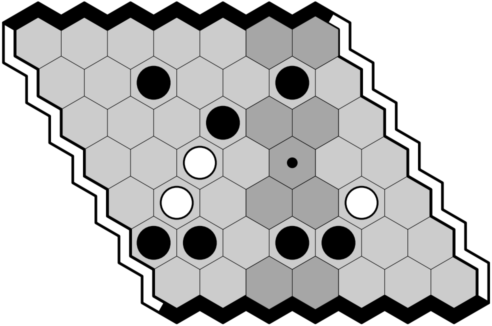


WHERE MUST WHITE PLAY?



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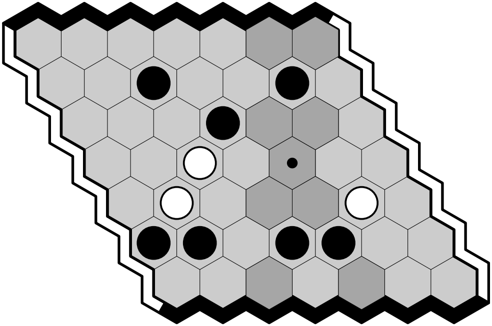

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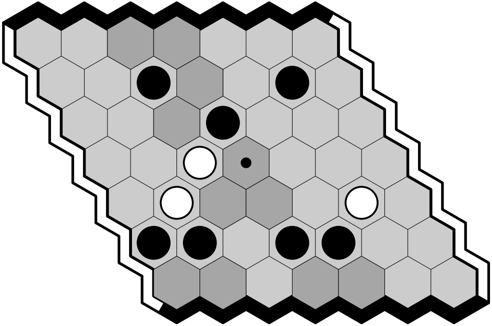

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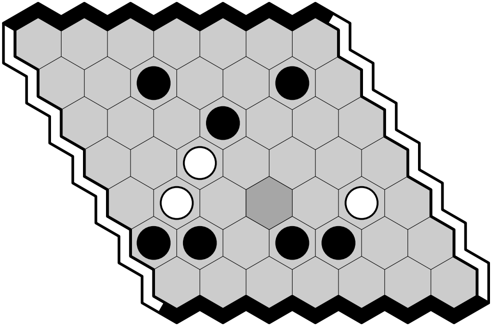
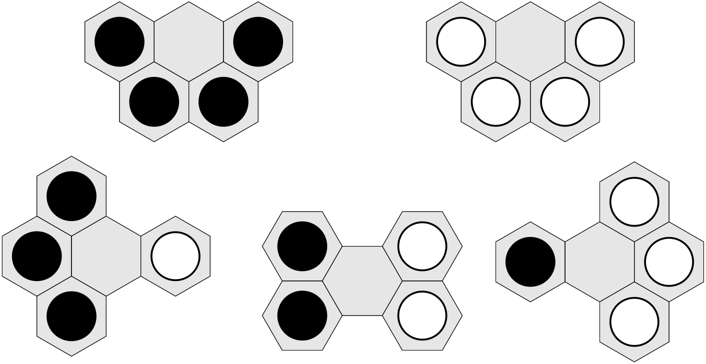
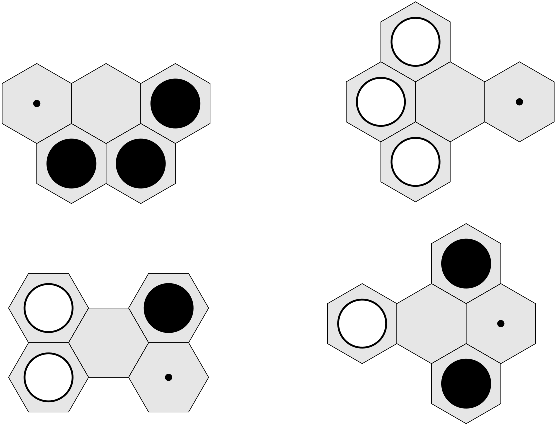


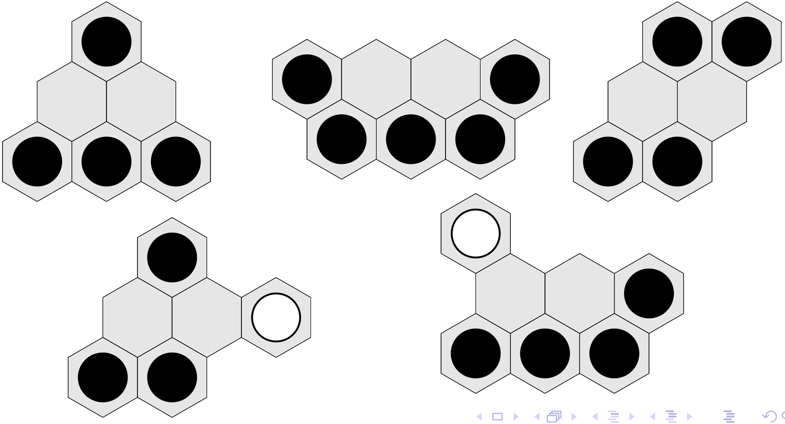
DEAD



BLACK-DOMINATED (DOT SUPERIOR)



BLACK-CAPTURED



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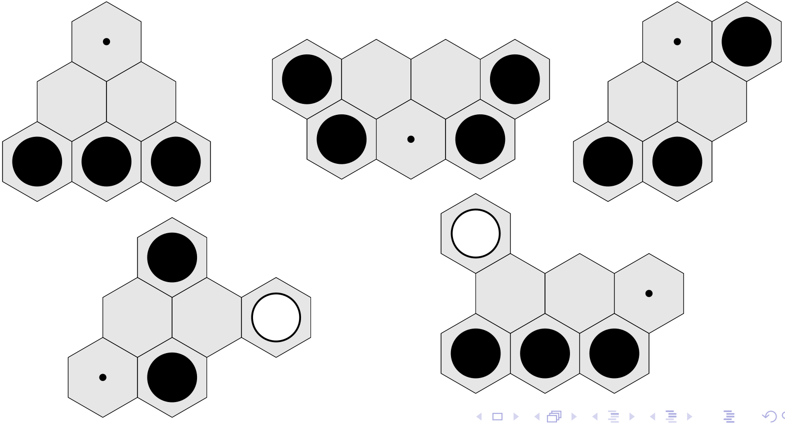
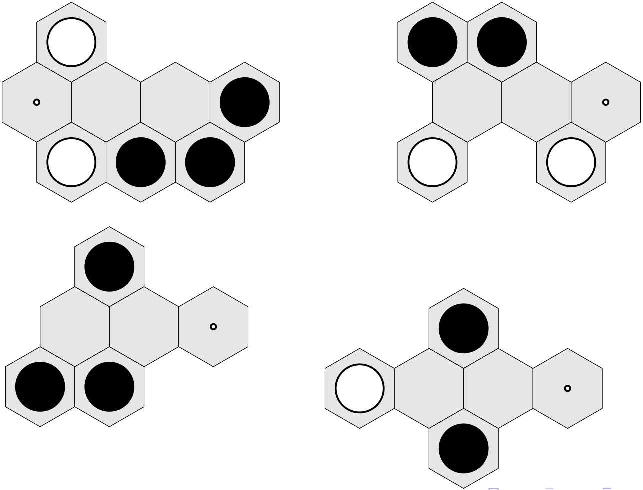
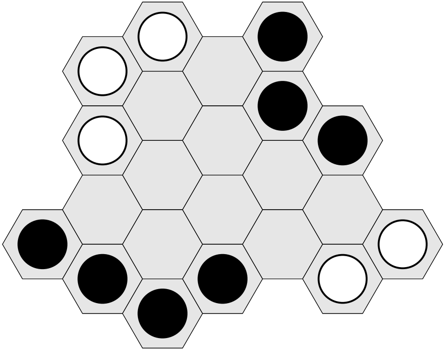


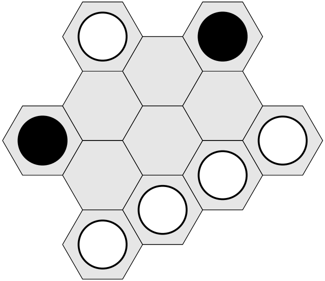
BLACK-CAPTURE-REVERSIBLE (TO WHITE DOT)



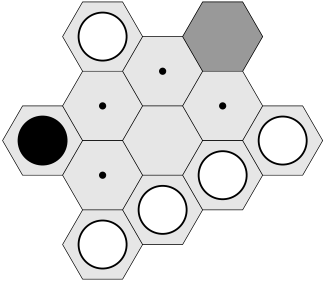
BLACK FILL DECOMPOSITION



STAR DECOMPOSITION

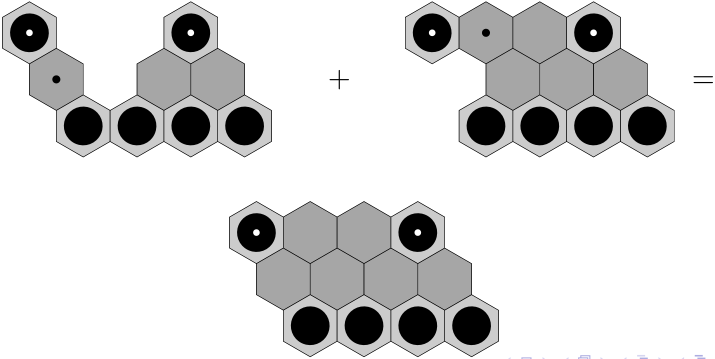


BLACK STAR DECOMP DOMINATION

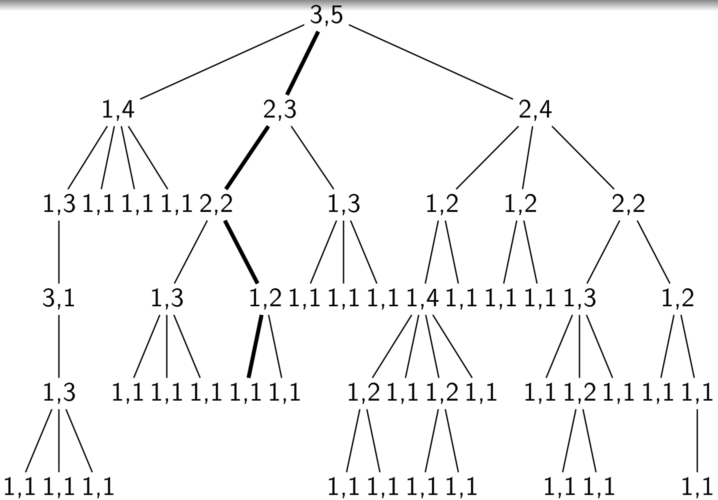


MODIFY H-SEARCH

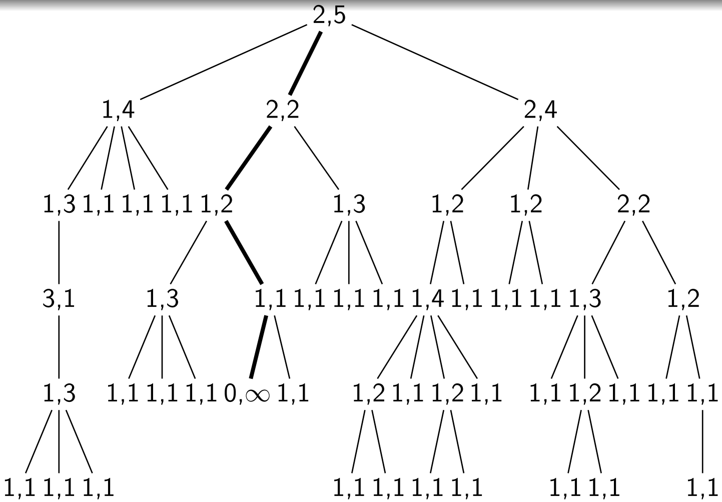
- and/or combining rules + capture



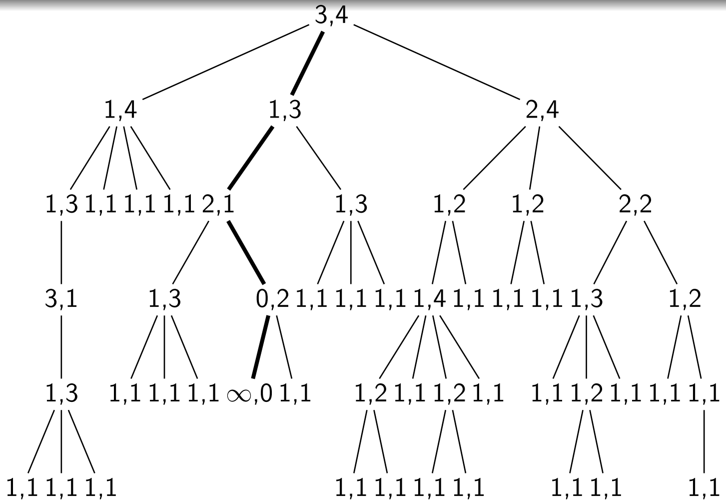
PROOF NUMBER SEARCH NEGAMAX P,D VALUES



PROOF NUMBER SEARCH



PROOF NUMBER SEARCH



F-DFPNS

- PNS Allis et al

F-DFPNS

- PNS Allis et al
- DFPNS Nagai

F-DFPNS

- PNS   Allis et al
- DFPNS   Nagai
- DFPNS in Hex ?

F-DFPNS

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- . . . requires non-incremental H-search :(

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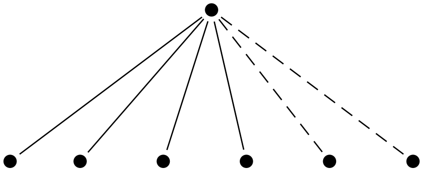
- . . . uniform branching factor :(

F-DFPNS

- PNS   Allis et al
- DFPNS   Nagai
- DFPNS in Hex ?
- . . . requires non-incremental H-search :(
- . . . uniform branching factor :(
- idea: move ordering + DFPNS = F-DFPNS

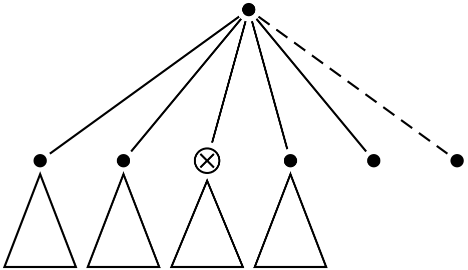
F-DFPNS (1)

- expand node
- consider first $b + \lceil f \times 6 \rceil = 4$ (of 6) live children



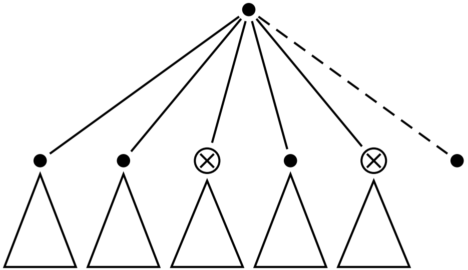
F-DFPNS (2)

- discover move 3 loses
- consider first $b + \lceil f \times 5 \rceil = 4$ (of 5) live children



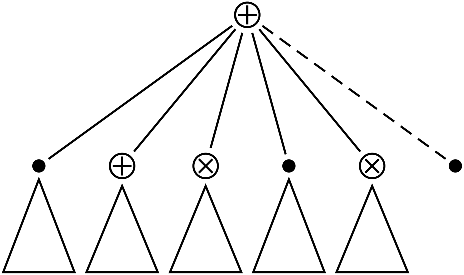
F-DFPNS (3)

- discover move 5 loses
- consider first $b + \lceil f \times 4 \rceil = 3$ (of 4) live children



F-DFPNS (4)

- discover move 2 wins, so . . .
- . . . root solved without exploring 6th move



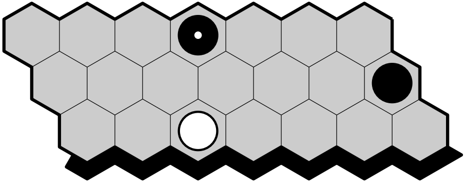
solving 10x10

- stronger VC computations
- scalable parallel DFPN S

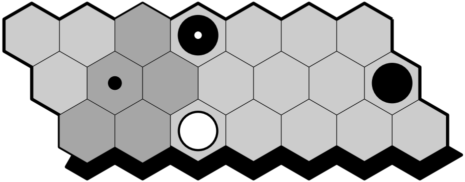
Pawlewicz: stronger VC computations

- faster and/or-rule VC computation
- limit form of new VCs, so never redundant
- find fewer VCs, but solve 2 to 10 times faster

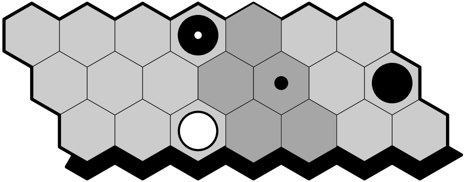
Example: VCS to side



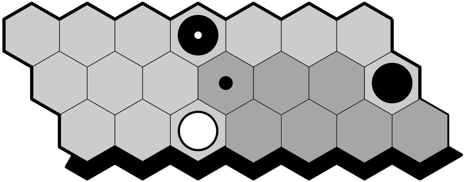
EXAMPLE: SEMIS



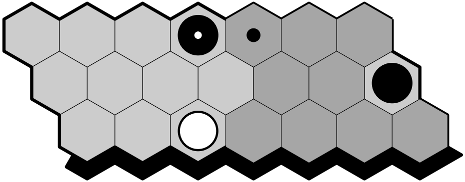
EXAMPLE: SEMIS



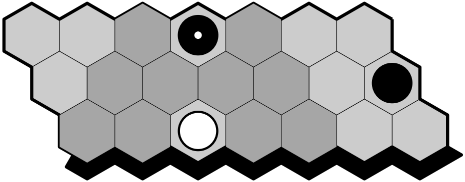
EXAMPLE: SEMIS



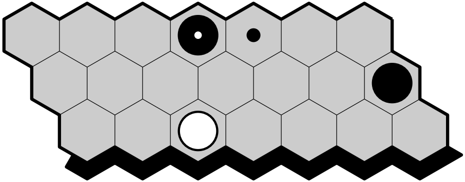
Example: semis



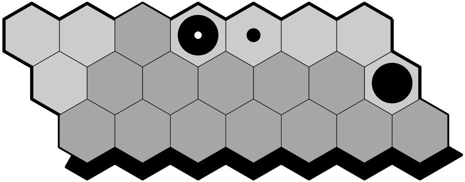
GREEDY UNION SEMIS TO GET FULL



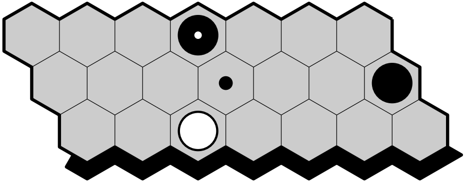
BLOCK CELL TO GET ANOTHER VC



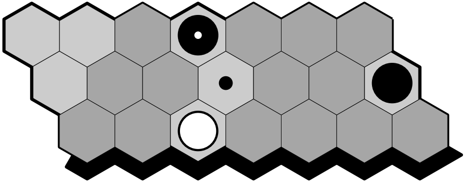
BLOCK CELL TO GET ANOTHER VC



Block cell to get another VC



BLOCK CELL TO GET ANOTHER VC



Pawlewicz: scalable parallel DFPNS

- parallel PNS: keep tree in memory? e.g. I-Chen Wu connect6
- Hex: leaf computations fast, so tree too big
- how to assign jobs to processors?
  - jobs too long: computation redundant
  - jobs too short: too much client/server traffic
  - solution: MaxWorkPerJob

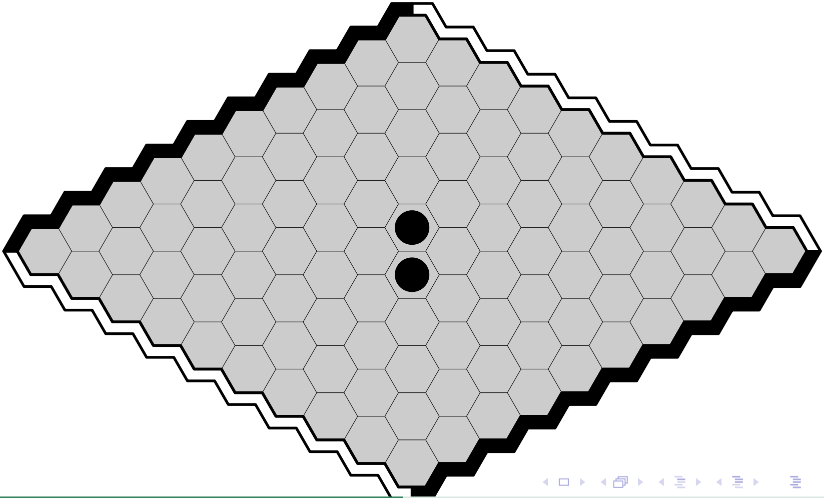
SP DFPN S FEATURES

- $1+\varepsilon$ variant of DFPN
- advanced TT resolution: upon collision, search next k (say 4) cells for empty location; if none found, overwrite location with smallest work job
- once node computation assigned to leaf, use virtual win/loss so new threads go elsewhere
- . . . so compute virtual (dis)proof numbers
- shared TT: many-read / 1-write locks
- tune MaxWorkPerJob
- for Hex: use Focussed DFPN S

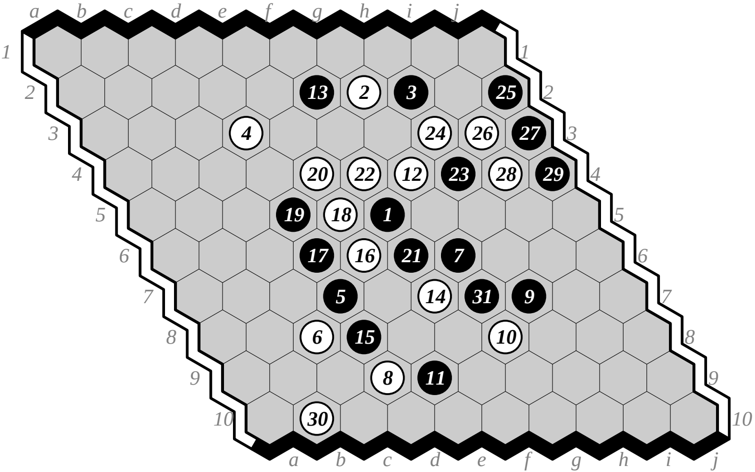
SP DFPN S performance

- speedup test: 8 hardest 8x8 openings, 8 11x11 positions
- speedup performance: 11.8 on 16 threads (.74)
- solved all 9x9 openings
- solved centre 10x10 opening

SP DFPN S performance



SP DFPN S PERFORMANCE



SP DFPN S PERFORMANCE

opening	#threads	time	winner
a2	8/24	68d09:40:18	black
a3	8	80d08:37:34	white
a4	8	33d14:06:03	black
a5	8	65d04:14:52	black
a6	24	110d14:35:06	black
a7	24	4d08:56:03	white
a8	24	6d14:21:30	black

SP DFPN S PERFORMANCE

opening	#threads	time	winner
b2	8	53d15:18:21	black
b4	8	29d23:53:14	black
b6	8	1d21:52:28	black
b7	8	4d17:19:13	black
c2	24	1d08:42:57	black
i1	24	6d00:51:25	black
10x10:f5	24	63d20:44:30	black

HOW LONG UNTIL 11x11 ?

	states (approx)	center cell: solver fn calls
2x2	9.0 e 0	0
3x3	5.5 e 1	0
4x4	7.6 e 5	0
5x5	4.0 e 9	0
6x6	4.0 e 14	2
7x7	1.5 e 20	68
8x8	1.0 e 27	19 554
9x9	2.7 e 34	912 352
10x10	1.2 e 43	5 821 097 789
11x11	2.2 e 52	??? ??? ??? ??? ???

UAlberta connection

- Martin Müller, Rich Sutton: David Silver
- Martin Müller, Ryan Hayward: Aja Huang
- Csaba Szepesvari
- Michael Bowling

ALPHAGO ETC

http://webdocs.cs.ualberta.ca/~hayward/670gga/jem/go.html

computer go

https://gogameguru.com/i/2016/01/Fan-Hui-vs-AlphaGo.jpg AG-FH 5-0

https://www.youtube.com/watch?v=l-GsfyVCBu0&t=77m40s shoulder hit

https://www.youtube.com/watch?v=0CevCII1zo0&t=1m23s Ke Jie moment

https://webdocs.cs.ualberta.ca/~hayward/talks/hex.deepQ.pdf

https://webdocs.cs.ualberta.ca/~hayward/talks/hex.cnnfdfpns.pdf

THANK YOU

- invitation Yngi, Magnus
- solving 10×10 Hex joint with Jakub Pawlewicz
- builds on work with B Arneson, P Henderson
- machine Martin Müller
- photo courtesy MIT Museum, MIT, Cambridge MA
- Natural Sciences and Engineering Research Council of Canada