Clouded Thoughts

Air Quality & Cognitive Performance

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January 23, 2019

Question: How does air quality affect the decision-making of individuals performing high level of inductive reasoning?

Motivation

News headlines:

- “WHO reveals 7 million die from pollution each year [...]” – *The Telegraph*, May 2018
- “More than 95% of world’s population breathe dangerous air, major study finds” – *The Guardian*, Apr 2018

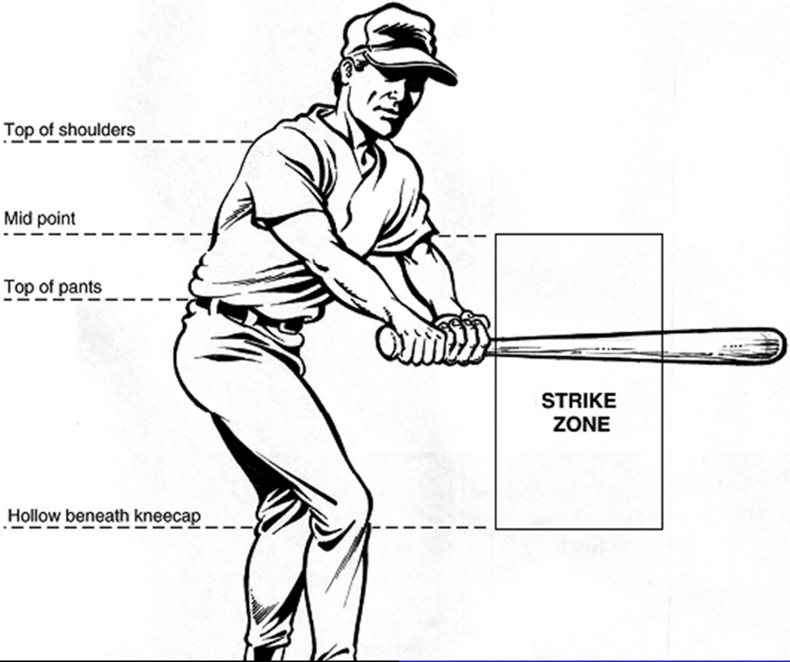
Report takeaway:

- 1990 Clean Air Act Amendments avert 160k deaths and 86k hospitalizations each year – EPA 2015

Motivation

Air pollution may adversely affect our life every day:

- Decreased productivity for fruit pickers in California [Graff Zivin and Neidell, AER 2012]
- Decreased productivity for call center workers in China [Chang et al., WP 2016]
- Increased ball/strike call error for MLB baseball umpires [Archsmith, Heyes and Saberian, JAERE 2018]


Top of shoulders
Mid point
Top of pants
Hollow beneath kneecap
STRIKE ZONE

Research Question

Literature suggests air quality decreases some cognitive functions...

Research Question

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Question: How does air quality affect the decision-making of individuals performing high level of inductive reasoning?

Research Question

Question: How does air quality affect the decision-making of individuals performing high level of inductive reasoning?

Why

- High value jobs are cognitively demanding and often involve decisions
- Even modest impacts could add up if the affected cognitive skills are ubiquitous

Research Question

This talk:

- Estimating a *causal* effect of air pollution on the quality of decision-making for expert players of the game Go

game example

Why Go?

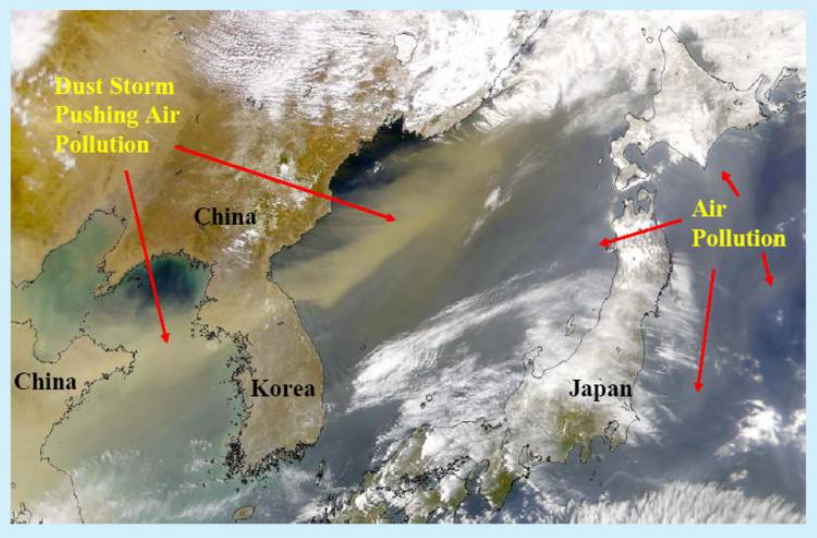
- Purely cognitive game demanding high level of inductive reasoning and concentration
- Played indoors, typically in "laboratorial" environment
- Age distribution of players is wide

age dist'n

Research Question

Why Go?

- Popular game in Japan and South Korea...
- ...Which are affected by **Asian dust** – source of exogenous spatial and time variation in air pollution



Asian dust storm and air pollution movement

Asian dust storm in Seoul

Research Question

Why Go?

- Popular game in Japan and South Korea...
- ...Which are affected by **Asian dust** – source of exogenous spatial and time variation in air pollution

Research Question

Why Go?

- Popular game in Japan and South Korea...
- ...Which are affected by **Asian dust** – source of exogenous spatial and time variation in air pollution
- Players' cognitive performance can be objectively measured using the **Leela Zero** Go-playing AI

Roadmap

1. Background & Data
2. Empirical Strategy
3. Results
4. Conclusion

Background – Asian dust

Asian dust storms

- Natural phenomena carrying dust particles from northern China to its neighbours
- Traces back to 174 A.D.
- Growing environmental concern in East Asia due to China's economic growth
- Under the radar of environmental authorities in Japan/Korea

Data – Asian dust

Strategy adopted by Japan/Korea: "Asian dust storm" warnings
Daily records:

- 81 weather stations in South Korea; 1961–today
- 59 weather stations in Japan; 1967–today

Methodology:

1. Verify dust occurrence in desert regions of northern China;
2. Track dust movements through weather maps/satellite imagery;
3. Confirm storm visually and issue dust warning when necessary

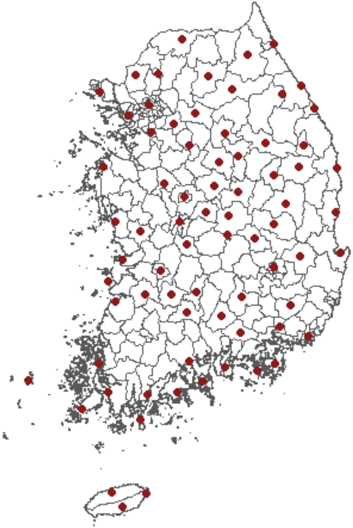
Data – Asian dust

Strategy adopted by Japan/Korea: "Asian dust storm" warnings
Daily records:

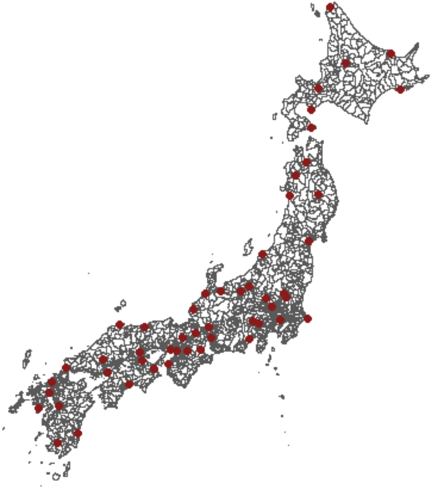
- 81 weather stations in South Korea; 1961–today
- 59 weather stations in Japan; 1967–today

.

- Match dust records with air pollution data from NIER
- Korea: 24hr-avg of PM_{10} O_3 SO_2 and, CO (2001-2017)
- Japan: 24hr-avg of SPM $PM_{2.5}$ SO_2 and, CO (2009-2016)



Dust-detecting stations in South Korea



Dust-detecting stations in Japan

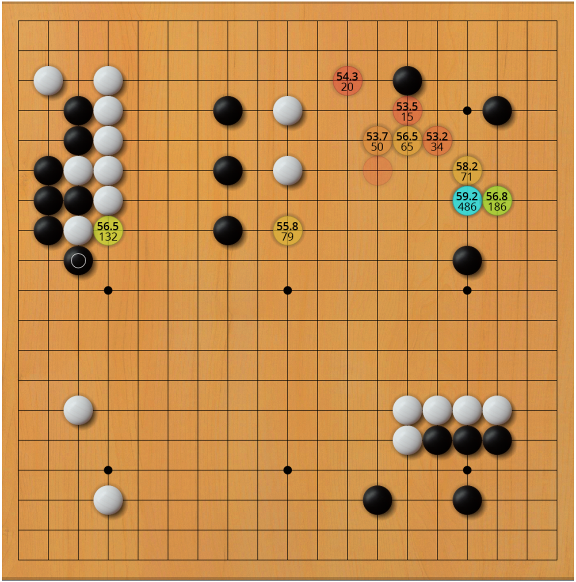
Background – Go

What is Leela Zero?

- AI modeled after Google Deepmind's Alpha Go Zero
- Reinforcement learning: "trained" Go exclusively with self-play
- Currently stronger than any human

How it works?

1. Given a board configuration, Leela Zero computes choice probabilities for each possible move
2. She then performs Monte Carlo Tree Search (MCTS) a large number of times, drawing from these choice probabilities
3. In the end, Leela Zero picks the move with highest "value," derived from choice probabilities plus Monte Carlo wins



54.3
20
53.5
15
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50
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65
53.2
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71
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486
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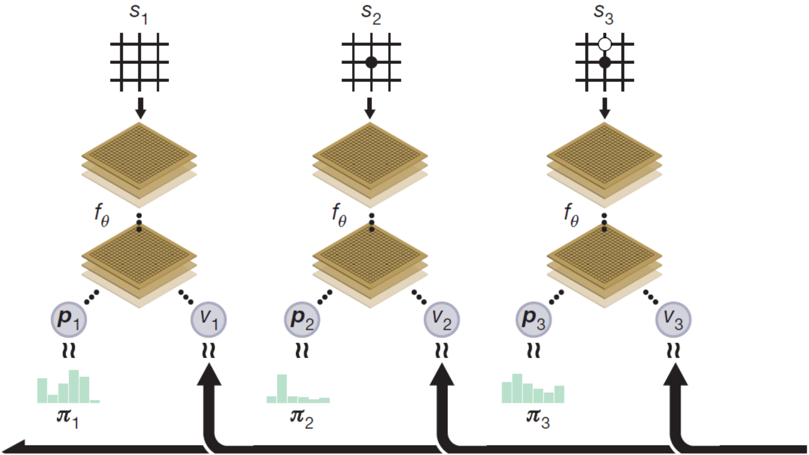
186
56.5
132
55.8
79

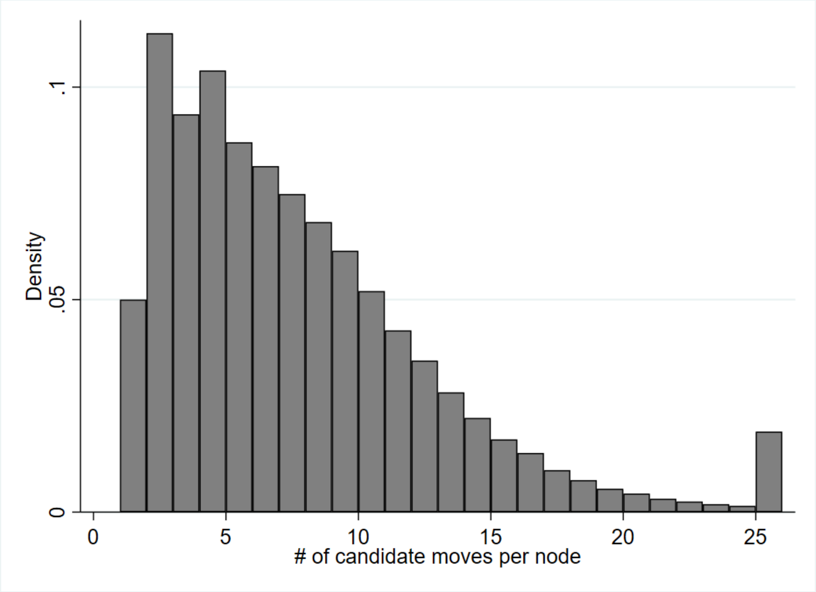


Alpha Go Zero's Neural Network

Data – Go

Move evaluations:

- Ask Leela Zero to analyze a subset of mid-game moves of each game (moves 100-120)
- In each state s_t, Leela Zero outputs a value representation $v(a_t)$ for each action a_t visited in the MCTS simulations
- The move played in the actual game can be classified as:
  - **Strong**, if it equals the preferred move outputted by Leela Zero
  - Acceptable if it belongs to the set of moves visited in the MCTS step (but is not the preferred move)
  - **Blunder**, otherwise


Density
0
.05
.1
0
5
10
15
20
25
# of candidate moves per node

Data – Go

Game records:

- GoGoD: Internet archive of historical Go games sourced from printed and online media
- Each record includes metadata about the game
- I lookup player names on a database of player biographies and a database of player elo ratings
- Final games dataset comprises 22,213 games played between 1980 and 2018, with 60% of games coming from major Go tournaments

Property name	Description
Player Name	name of player
Rank	rank of player at game date
Elo	elo rating of player at game date
Age	age of player at game date
Gender	gender of player
# of Moves	number of moves played in game
Date	date of game
Place	place where game was played
Event Name	name of game event

Variables from Game Records, Bios, and Elo database

	tournaments	games	avg duration	% high dan	Prize(USD)
Bacchus	36	328	364	69	unknown
Fujitsu	26	591	224	92	130,000
Gosei	41	1,139	366	97	70,000
GS Caltex	15	273	166	79	60,000
Honinbo	86	1,516	311	89	280,000
Judan	40	1,145	476	97	130,000
Kisei	60	1,382	393	87	400,000
Kiseong	25	290	382	72	unknown
Kuksu	61	473	157	67	unknown
LG	24	607	241	78	60,000
Meijin	79	1,635	350	93	300,000
Myeongin	53	598	201	72	90,000
NEC	37	226	211	98	unknown
Nongshim†	19	256	182	80	440,000
Oza	42	791	425	95	120,000
Paedal	9	80	158	72	unknown
Paewang	26	240	199	81	unknown
Samsung	23	734	151	82	175,000
Siptan	9	266	136	68	unknown
Taewang	15	145	258	77	unknown
Tengen	45	1,246	419	96	125,000
Tong Yang	11	162	235	90	unknown
	782 (Sum)	14,123 (Sum)	273 (Mean)	83 (Mean)	

Summary of tournaments in data

Data – Combined

Final dataset:

- Match recorded Go games with Asian dust + air quality data by city and date
- Compute percent of **strong** and **blunder** moves for each player in each game

Empirical Strategy

Main specification at game level:

$$Y_{pjt} = \alpha + \delta Dust_{jt} + \beta Fem_p + \gamma Dan_{pt} + \psi_j + \eta_{ym(t)} + \phi_p + \varepsilon_{pjt}$$

where
Y_{pjt} is the performance metric of player p in city j and day t
$Dust_{jt}$ indicates Asian dust events in city j and day t
Fem_p equals 1 if player is Female
Dan_{pt} is the Dan ranking of player p on day t
$\psi_j, \eta_{ym(t)}, \phi_p$ are city, year-month, and player FE respectively.

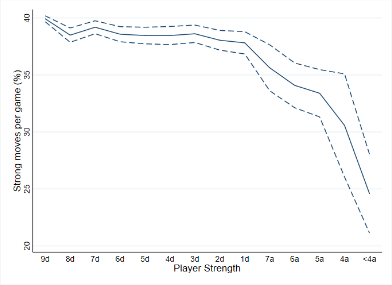
δ: effect of an Asian dust day on quality of decision-making.

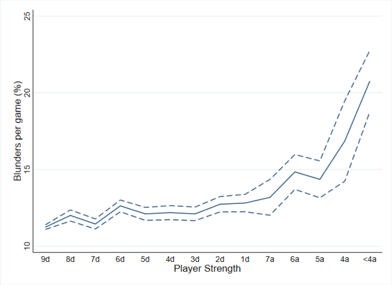
Empirical Strategy

Does Y_{pjt} actually measure cognitive performance?

Empirical Strategy

Does Y_{pjt} actually measure cognitive performance?



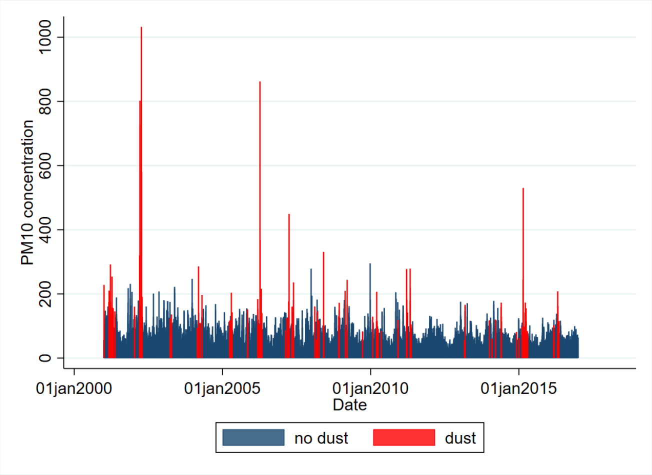


Checks: elo logit

Empirical Strategy

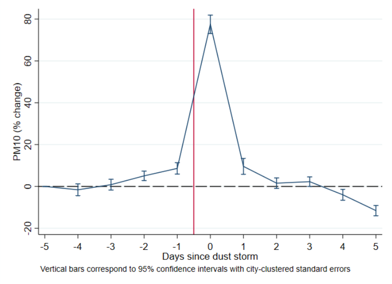
Does $Dust_{jt}$ actually induce air pollution shock?

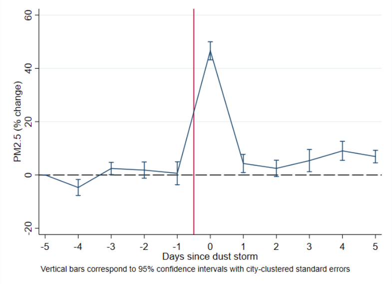
Does $Dust_{jt}$ actually induce air pollution shock? e.g. Seoul

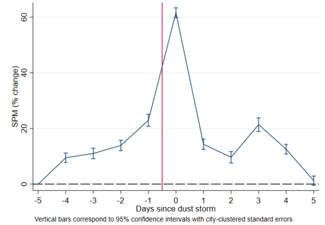


Empirical Strategy

Does $Dust_{jt}$ actually induce air pollution shock?







Results

Dep. Var: Strong moves per game (%)	(1)	(2)	(3)	(4)
Dust event	-0.219	-0.173	-0.166	-0.229
	(0.471)	(0.533)	(0.543)	(0.675)
Controls	Fem	Fem	Fem,Dan	Fem,Dan
Fixed Effects	Y-M	Y-M,City	Y-M,City	All
Observations	43755	43755	43755	43755
R^2	0.016	0.023	0.024	0.056

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Effect of air pollution on % strong moves elo

Dep. Var: Blunder moves per game (%)	(1)	(2)	(3)	(4)
Dust event	1.227***	1.235***	1.233**	1.041*
	(0.362)	(0.361)	(0.373)	(0.457)
Controls	Fem	Fem	Fem,Dan	Fem,Dan
Fixed Effects	Y-M	Y-M,City	Y-M,City	All
Observations	43755	43755	43755	43755
R^2	0.013	0.017	0.018	0.065

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Effect of air pollution on % blunders elo

Dep. Var: Strong moves per game (%)	(1)	(2)	(3)	(4)
Panel A				
Below median age (30 yrs)				
Dust event	-0.130	0.025	0.006	-0.260
	(0.558)	(0.652)	(0.673)	(0.866)
Controls	Fem	Fem	Fem,Dan	Fem,Dan
Fixed Effects	Y-M	Y-M,City	Y-M,City	All
R^2	0.030	0.040	0.041	0.080
Observations	21427	21427	21427	21427
	(1)	(2)	(3)	(4)
Panel B				
Above median age (30 yrs)				
Dust event	-0.952	-1.191	-1.155	-1.207
	(0.835)	(0.845)	(0.836)	(0.825)
Controls	Fem	Fem	Fem,Dan	Fem,Dan
Fixed Effects	Y-M	Y-M,City	Y-M,City	All
R^2	0.027	0.037	0.038	0.077
Observations	21427	21427	21427	21427

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Effect of air pollution on % strong moves (age split) elo

Dep. Var: Blunder moves per game (%)	(1)	(2)	(3)	(4)
Panel A				
Below median age (30 yrs)				
Dust event	0.650	0.735	0.751	0.637
	(0.824)	(0.788)	(0.817)	(1.001)
Controls	Fem	Fem	Fem,Dan	Fem,Dan
Fixed Effects	Y-M	Y-M,City	Y-M,City	All
R^2	0.024	0.032	0.034	0.083
Observations	21427	21427	21427	21427
	(1)	(2)	(3)	(4)
Panel B				
Above median age (30 yrs)				
Dust event	2.204***	2.185***	2.153***	1.836**
	(0.547)	(0.554)	(0.555)	(0.643)
Controls	Fem	Fem	Fem,Dan	Fem,Dan
Fixed Effects	Y-M	Y-M,City	Y-M,City	All
R^2	0.024	0.032	0.033	0.093
Observations	21427	21427	21427	21427

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Effect of air pollution on % blunders (age split) elo

Conclusion

Conclusion

This research:

- Documents air pollution shocks induced by Asian dust storms
  - PM_{10}: $\uparrow 75\%$, $PM_{2.5}$: $\uparrow 45\%$
  - Other pollutants: ambiguous/small change
- Constructs measures of cognitive performance in Go based on move evaluations from an AI which outperforms humans
  - % of **strong** moves – same move as suggested by Leela Zero
  - % of **blunders** – move outside of Leela Zero's consideration set

Conclusion

This research:

- Exploits Asian dust storms and documents effect of air pollution on quality of decision-making in Go
  - Find no significant effect on players' ability to play **strong** moves
  - Find overall $\approx 7\%$ increase in **blunders**
- Uncovers some heterogeneity:
  - Effects are driven by older players (i.e. insignificant for younger ones)

Key takeaway: Air quality increases propensity of human error in a mentally taxing task, yet it does not appear to affect cognitive skill of inductive reasoning.

What's next?

Strong and **Blunder** are extreme cases.

What's next?

Strong and **Blunder** are extreme cases.

Can move choices, in general, reveal something about the thought process of players?

Kramnik vs Anand 2008 WCH Game 3: Stockfish centipawn values at various depths

	Depth →																		
Move	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Nd2	103	093	087	093	027	028	000	000	056	-007	039	028	037	020	014	017	000	006	000
Bxd7	048	034	-033	-033	-013	-042	-039	-050	-025	-010	001	000	-009	-027	-018	000	000	000	000
Qg8	114	114	-037	-037	-014	-014	-022	068	-008	-056	042	-004	-032	000	-014	-025	-045	-045	-050
...																			
Nxd4	-056	-056	-113	-071	-071	-145	-020	-006	077	052	066	040	050	051	-181	-181	-181	-213	-213

Kramnik vs Anand 2008 WCH Game 3:
Stockfish centipawn values at various depths

	Depth →																		
Move	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Nd2	103	093	087	093	027	028	000	000	056	-007	039	028	037	020	014	017	000	006	000
Bxd7	048	034	-033	-033	-013	-042	-039	-050	-025	-010	001	000	-009	-027	-018	000	000	000	000
Qg8	114	114	-037	-037	-014	-014	-022	068	-008	-056	042	-004	-032	000	-014	-025	-045	-045	-050
...																			
Nxd4	-056	-056	-113	-071	-071	-145	-020	-006	077	052	066	040	050	051	-181	-181	-181	-213	-213

Classify moves as:

- Swing-up if move becomes a better choice if we think "deeply"
- Swing-down if move becomes a worse choice instead

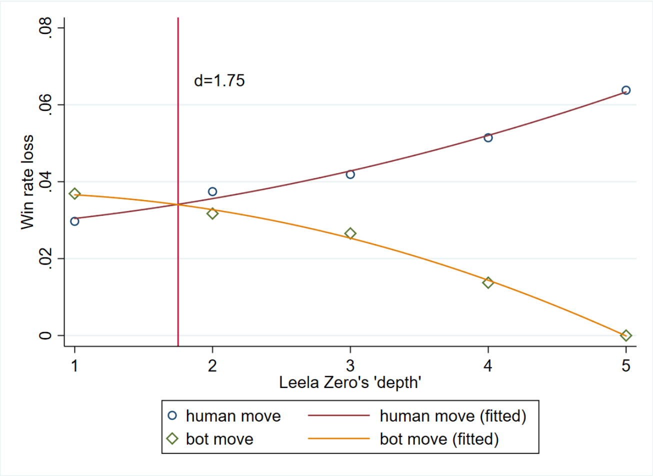
Shimako vs Hirohisa 7th Shinjin-O
Leela Zero win rate values at various depths

	Depth →					
Move	1	2	3	4	5	swing
G2	10.32	11.15	12.25	11.15	12.60	5.96
N11	10.32	12.75	13.22	12.89	12.49	1.21
J14	10.30	10.30	10.30	10.30	11.21	4.07
O11	11.97	12.17	11.50	11.53	10.88	-3.22
L13	10.02	12.35	11.37	11.48	10.02	-4.71
J13	7.60	7.60	7.60	8.14	7.60	-0.11

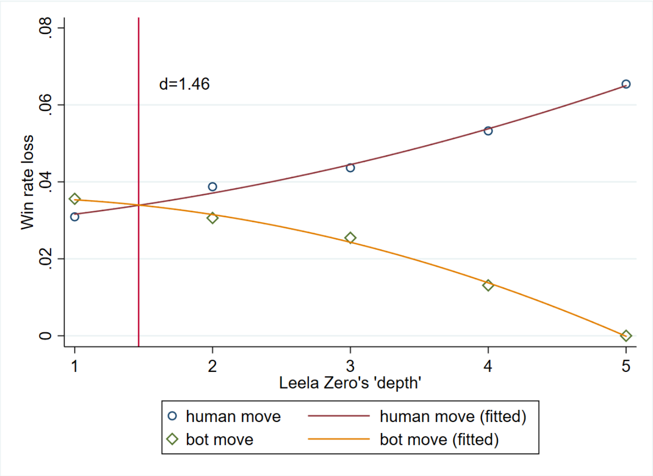
where

$$\mathrm{swing}(m) = \sum_{d=1}^{D} \delta_d(m) - \delta_D(m)$$

$\delta_d(m)$ is the difference from optimality of move m at depth d.



Average error of swing-down moves and AI moves vs depth
High ranked players (5-dan and above)

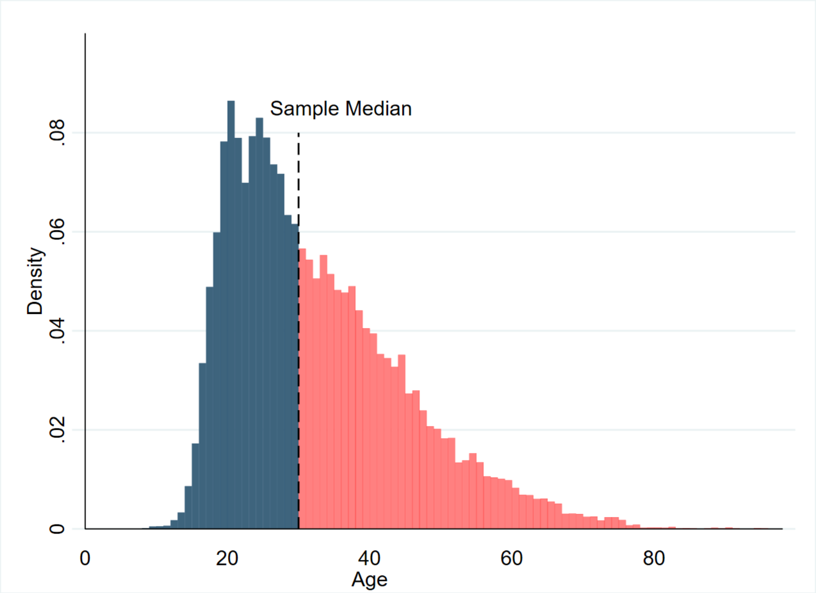


Average error of swing-down moves and AI moves vs depth
Low ranked players (4-dan and below) swing-up case

How do decisions and thought process revealed from Go players transport to other life situations?

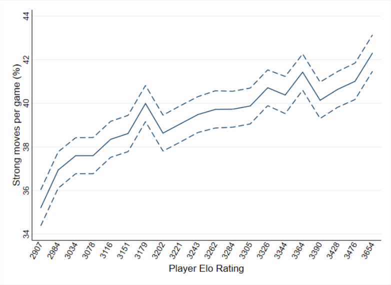
Thank you!

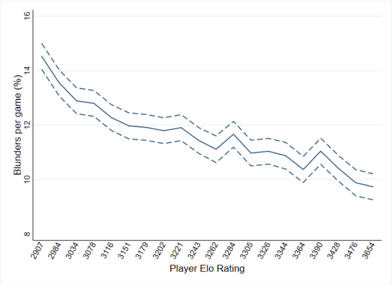
Have suggestions on how to refine this research?
Contact me! anova0515@gmail.com



Age distribution of Go players in the data back

Does Y_{pjt} actually measure cognitive performance?





back

Empirical Strategy

Dep. Var: Pr(Black wins)	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta strong > 0$	1.504***	1.507***	1.510***			
	(14.70)	(14.65)	(14.68)			
$\Delta blunder < 0$				2.677***	2.624***	2.613***
				(35.40)	(34.46)	(34.20)
$\Delta rank < 0$		1.101***	1.124***		1.093***	1.114***
		(18.48)	(21.13)		(16.61)	(19.16)
$\Delta age > 10$			0.659***			0.670***
			(-12.74)			(-11.95)
Observations	22165	22165	22165	22165	22165	22165

Exponentiated coefficients; t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

back

Empirical Strategy

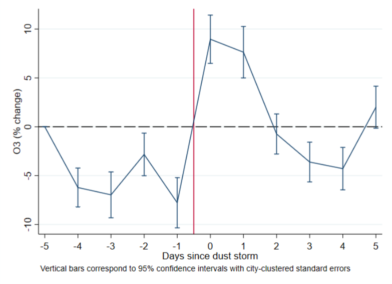
Logistic models from previous slide:

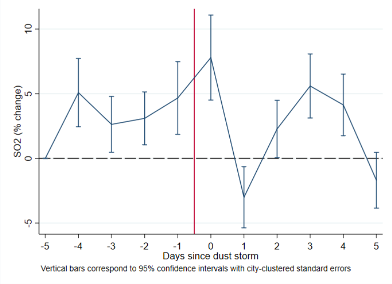
$$F\left[Pr(Black\ wins)\right] = \beta_0 + \beta_1 \mathbb{1}(\Delta strong > 0) + \beta_2 \mathbb{1}(\Delta rank < 0) + \beta_3 \mathbb{1}(\Delta age > 10)\}$$

$$F\left[Pr(Black\ wins)\right] = \beta_0 + \beta_1 \mathbb{1}(\Delta blunder < 0) + \beta_2 \mathbb{1}(\Delta rank < 0) + \beta_3 \mathbb{1}(\Delta age > 10)\}$$

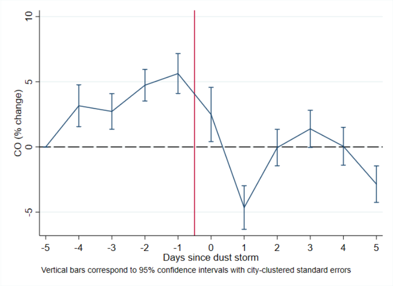
where $F[x] = ln\frac{x}{1-x}$

Does $Dust_{jt}$ actually induce air pollution shock?



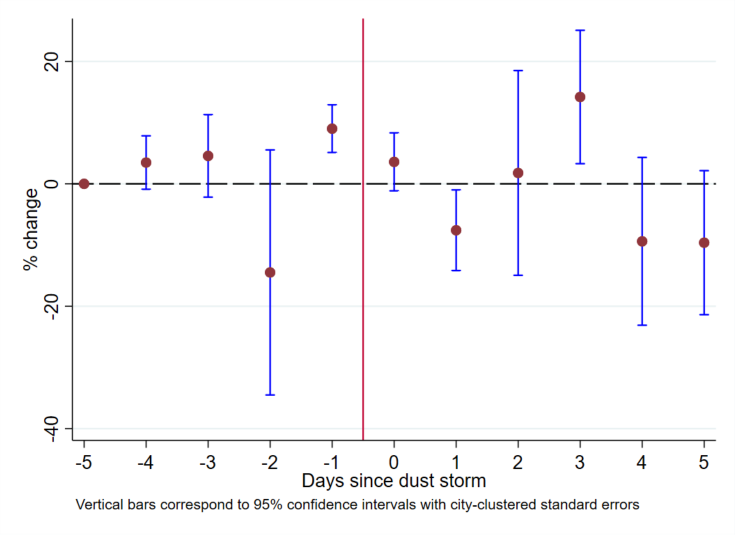


Does $Dust_{jt}$ actually induce air pollution shock?



model #games

Empirical Strategy



back

Dep. Var: Strong moves per game (%)	(1)	(2)	(3)	(4)
Panel A				
Low/Amateur-Dan				
Dust event	0.841	0.570	0.678	-0.092
	(0.939)	(0.746)	(0.673)	(0.737)
Controls	Fem	Fem	Fem,Age	Fem,Age
Fixed Effects	Y-M	Y-M,City	Y-M,City	All
R^2	0.061	0.071	0.076	0.182
Observations	8540	8540	8178	8178
	(1)	(2)	(3)	(4)
Panel B				
High Dan				
Dust event	-0.332	-0.324	-0.260	-0.340
	(0.626)	(0.669)	(0.688)	(0.783)
Controls	Fem	Fem	Fem,Age	Fem,Age
Fixed Effects	Y-M	Y-M,City	Y-M,City	All
R^2	0.018	0.026	0.026	0.053
Observations	35215	35215	34686	34686

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Effect of air pollution on % strong moves (rank split)

Dep. Var: Blunder moves per game (%)	(1)	(2)	(3)	(4)
Panel A				
Low/Amateur-Dan				
Dust event	1.369	1.717*	1.714*	2.150**
	(0.967)	(0.769)	(0.749)	(0.720)
Controls	Fem	Fem	Fem,Age	Fem,Age
Fixed Effects	Y-M	Y-M,City	Y-M,City	All
R^2	0.056	0.063	0.068	0.189
Observations	8540	8540	8178	8178
	(1)	(2)	(3)	(4)
Panel B				
High Dan				
Dust event	1.233***	1.259***	1.159***	1.008**
	(0.260)	(0.270)	(0.264)	(0.351)
Controls	Fem	Fem	Fem,Age	Fem,Age
Fixed Effects	Y-M	Y-M,City	Y-M,City	All
R^2	0.015	0.020	0.021	0.061
Observations	35215	35215	34686	34686

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Effect of air pollution on % blunders (rank split)

robust

Dep. Var: Strong moves per game (%)	(1)	(2)	(3)	(4)
Dust event	-0.219	-0.173	-0.261	-0.482
	(0.471)	(0.533)	(0.719)	(0.750)
Controls	Fem	Fem	Fem,Elo	Fem,Elo
Fixed Effects	Y-M	Y-M,City	Y-M,City	All
Observations	43755	43755	41213	41213
R^2	0.016	0.023	0.028	0.052

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Effect of air pollution on % strong moves

back

Dep. Var: Blunder moves per game (%)	(1)	(2)	(3)	(4)
Dust event	1.227***	1.235***	1.088*	0.916
	(0.362)	(0.361)	(0.536)	(0.561)
Controls	Fem	Fem	Fem,Elo	Fem,Elo
Fixed Effects	Y-M	Y-M,City	Y-M,City	All
Observations	43755	43755	41213	41213
R^2	0.013	0.017	0.027	0.060

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Effect of air pollution on % blunders back

Dep. Var: Strong moves per game (%)	(1)	(2)	(3)	(4)
Panel A				
Below median age (30 yrs)				
Dust event	-0.130	0.025	-0.156	-0.407
	(0.558)	(0.652)	(0.767)	(0.938)
Controls	Fem	Fem	Fem,Elo	Fem,Elo
Fixed Effects	Y-M	Y-M,City	Y-M,City	All
R^2	0.030	0.040	0.044	0.079
Observations	21427	21427	19936	19936
	(1)	(2)	(3)	(4)
Panel B				
Above median age (30 yrs)				
Dust event	-0.952	-1.191	-1.411	-1.568
	(0.835)	(0.845)	(1.034)	(1.019)
Controls	Fem	Fem	Fem,Elo	Fem,Elo
Fixed Effects	Y-M	Y-M,City	Y-M,City	All
R^2	0.027	0.037	0.043	0.069
Observations	21427	21427	20514	20514

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Effect of air pollution on % strong moves back

Dep. Var: Blunder moves per game (%)	(1)	(2)	(3)	(4)
Panel A				
Below median age (30 yrs)				
Dust event	0.650	0.735	0.782	0.615
	(0.824)	(0.788)	(0.950)	(1.106)
Controls	Fem	Fem	Fem,Elo	Fem,Elo
Fixed Effects	Y-M	Y-M,City	Y-M,City	All
R^2	0.024	0.032	0.040	0.084
Observations	21427	21427	19936	19936
	(1)	(2)	(3)	(4)
Panel B				
Above median age (30 yrs)				
Dust event	2.204***	2.185***	1.886***	1.634**
	(0.547)	(0.554)	(0.503)	(0.605)
Controls	Fem	Fem	Fem,Elo	Fem,Elo
Fixed Effects	Y-M	Y-M,City	Y-M,City	All
R^2	0.024	0.032	0.045	0.083
Observations	21427	21427	20514	20514

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Effect of air pollution on % blunders

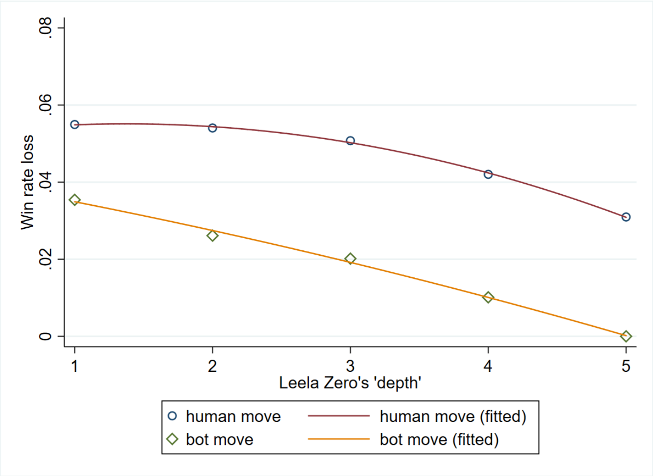
back

Sample:	(1) Full	(2) Younger	(3) Older	(4) Low/Amateur-Dan	(5) High-Dan
Strong (%)	-0.373	-0.861	-1.105	-0.677	-0.492
	(0.699)	(0.776)	(0.896)	(0.591)	(0.845)
Blunder (%)	0.931*	0.801	1.501*	2.681***	0.739**
	(0.398)	(0.828)	(0.636)	(0.662)	(0.273)
N	28785	13190	15302	3256	25236

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Column (4) of results tables w/o untreated players back



Average error of swing-up moves and AI moves vs depth
High ranked players (5-dan and above) back

A model of Go [from Silver et al. 2017; Igami 2018]

A model of Go [from Silver et al. 2017; Igami 2018]
Discrete time: $t = 0, 1, 2, ...$
Two players: $i = 1, 2$ alternating moves a_t
Deterministic state transition: $s_{t+1} = f(s_t, a_t)$; $f()$ and s_0 given
Action space in period t is the finite set of legal moves: $a_t \in \mathcal{A}(s_t)$
After a_t is played, the game either continues in period $t + 1$ or concludes. Thus, the state space consists of

$$s_t \in \mathcal{S} = \mathcal{S}_{cont} \cup \mathcal{S}_{win} \cup \mathcal{S}_{lose}$$

Model (cont'd)

Payoff of player 1 in each period t is

$$u_1(s_t) = \begin{cases} 1, & \text{if } s_t \in \mathcal{S}_{win} \\ -1, & \text{if } s_t \in \mathcal{S}_{lose} \\ 0, & \text{if } s_t \in \mathcal{S}_{cont} \end{cases}$$

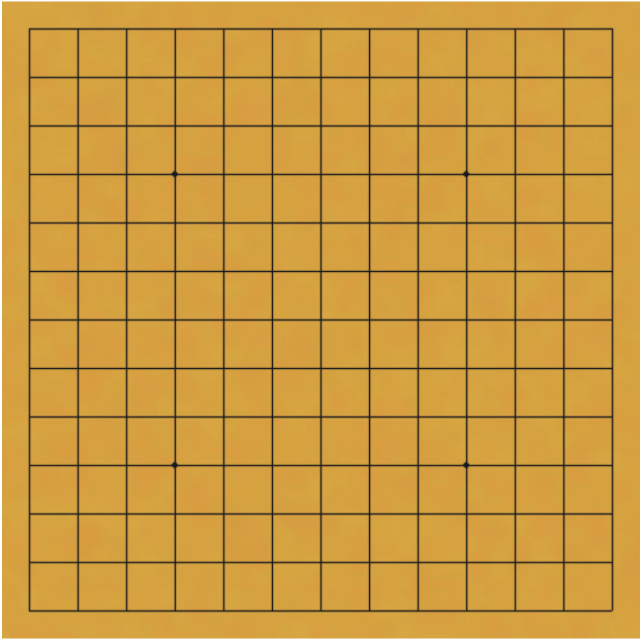
$u_2(s_t)$ is similarly defined with payoffs flipped.

Model (cont'd)

Go players (and AIs) choose a move at each turn by searching for a_t^* that maximizes an evaluation function $V()$ in some future period $t+K$ given parameters θ

$$a_t^* = \arg\max_{a_t \in \mathcal{A}(s_t)} \{V(s_{t+K};\theta)\}$$

AGZ



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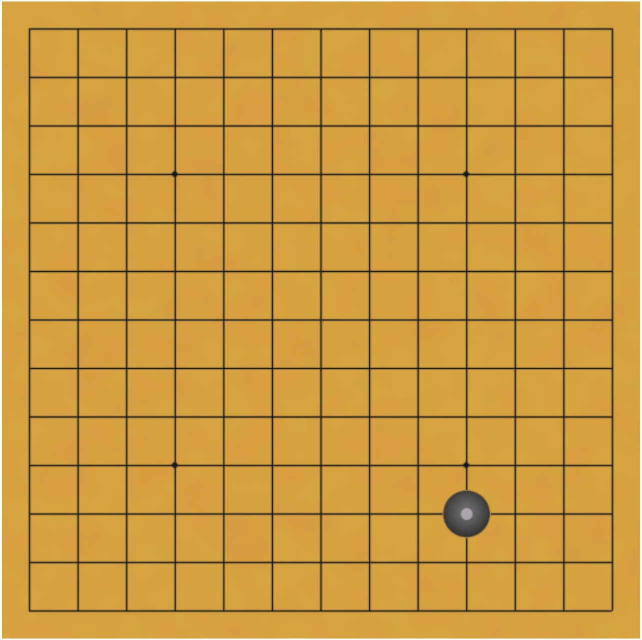

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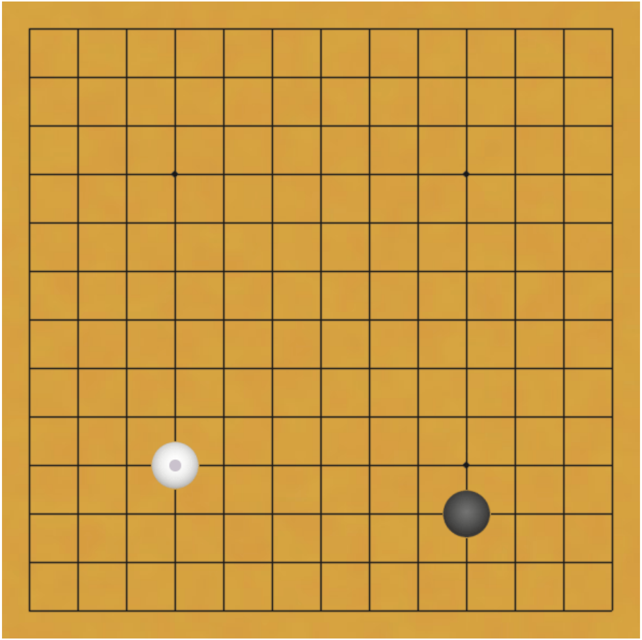

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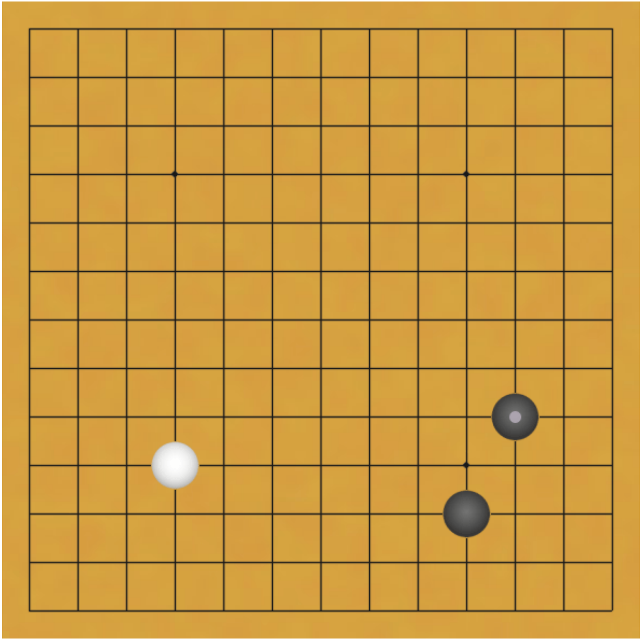

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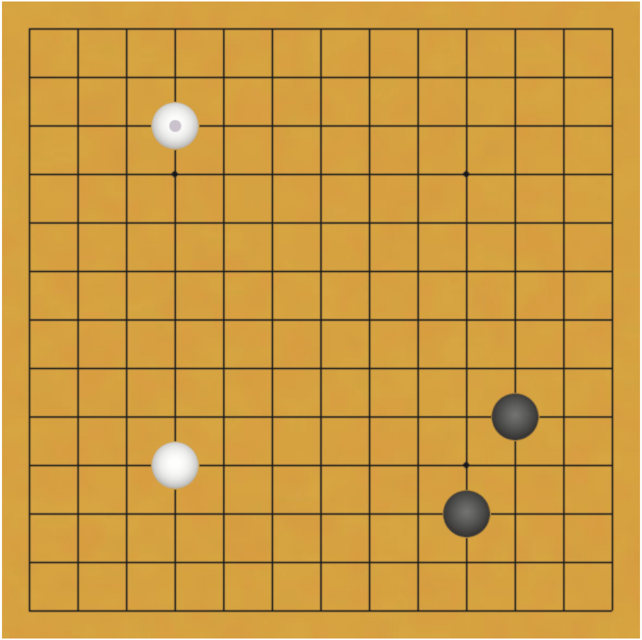

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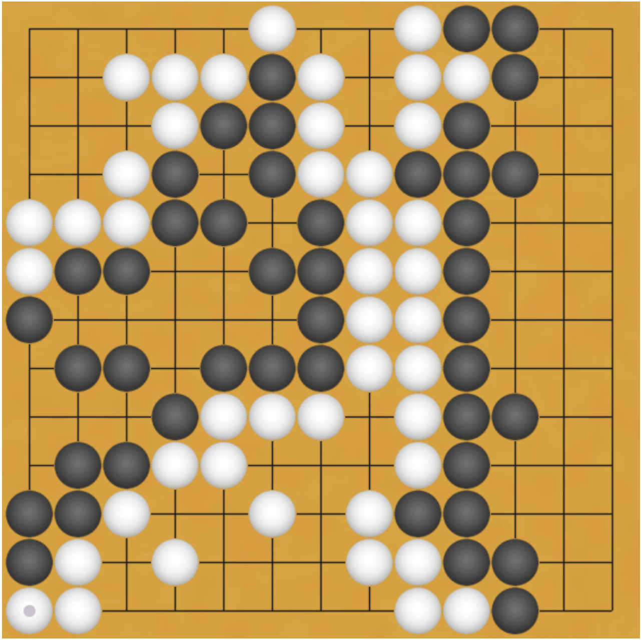

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