

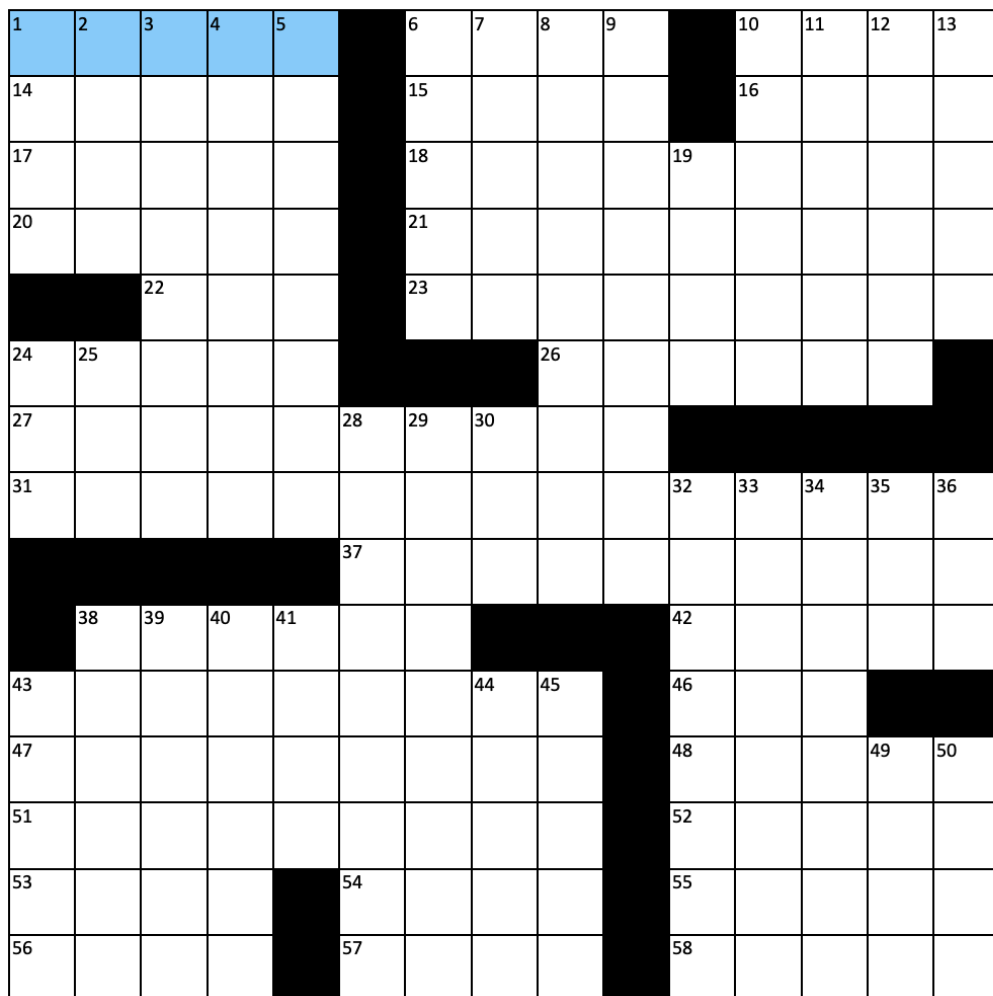
Automated Crossword Solving



Eric Wallace*, Nicholas Tomlin*, Albert Xu*, Kevin Yang*,
Eshaan Pathak*, Matthew L. Ginsberg, Dan Klein



Example Crossword



Across

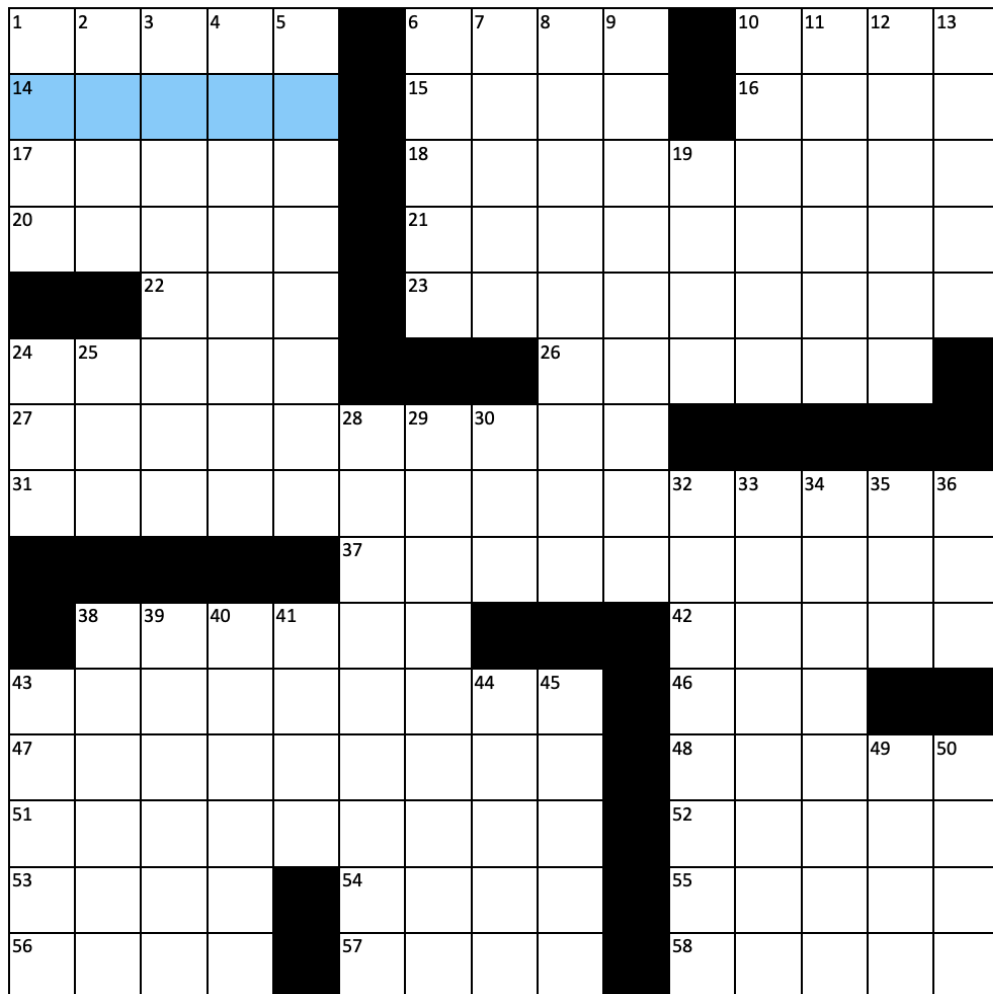
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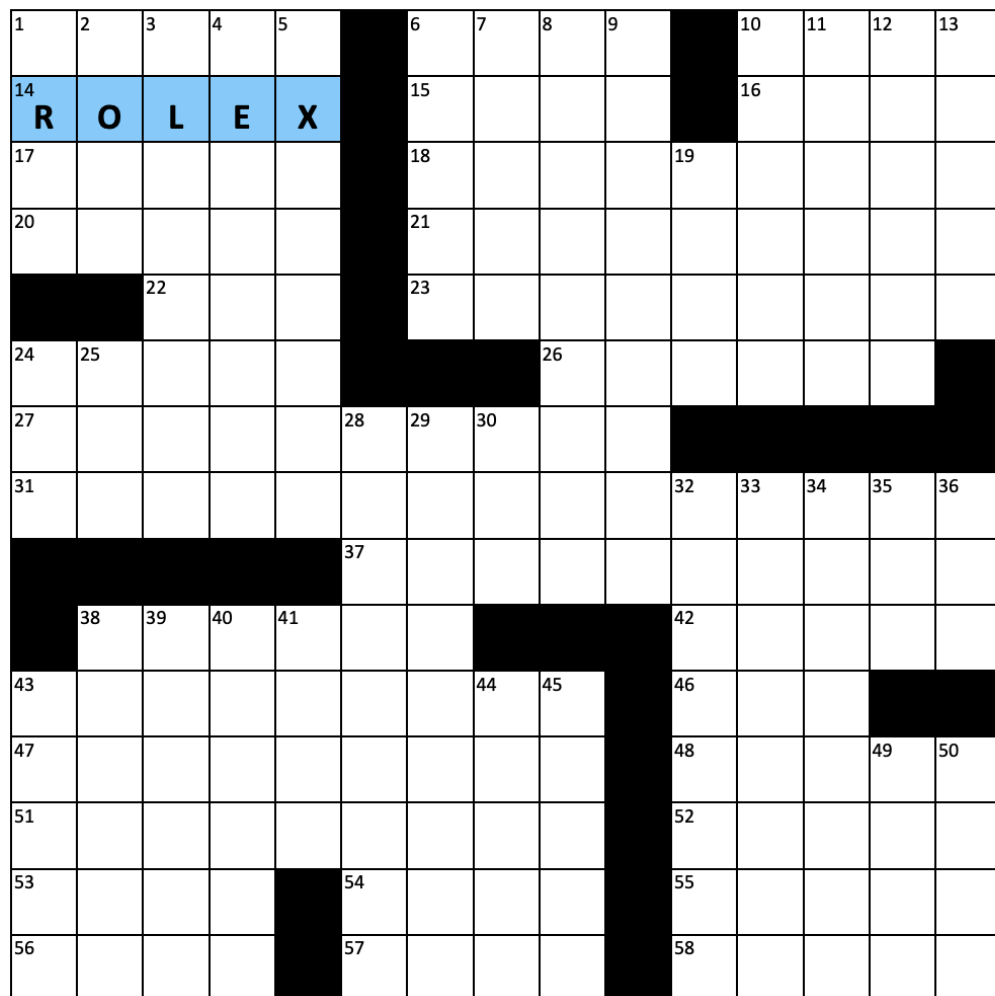
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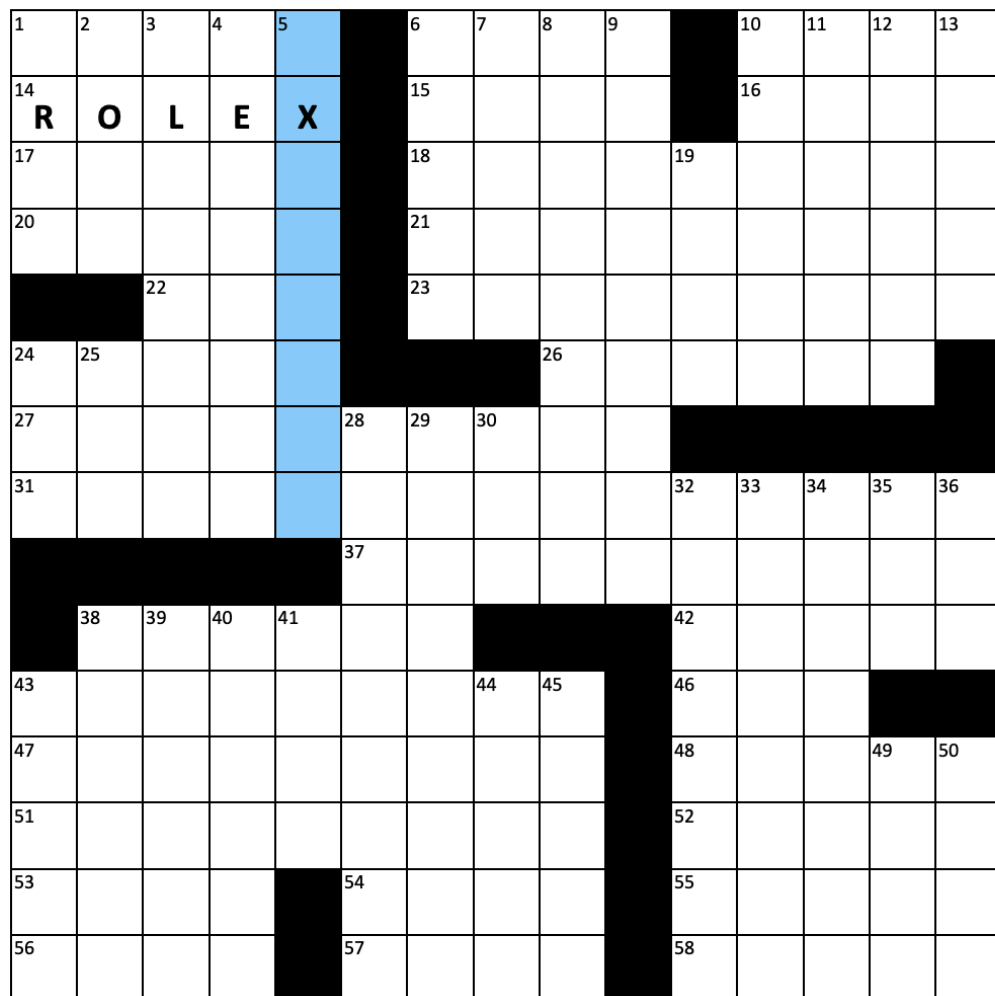
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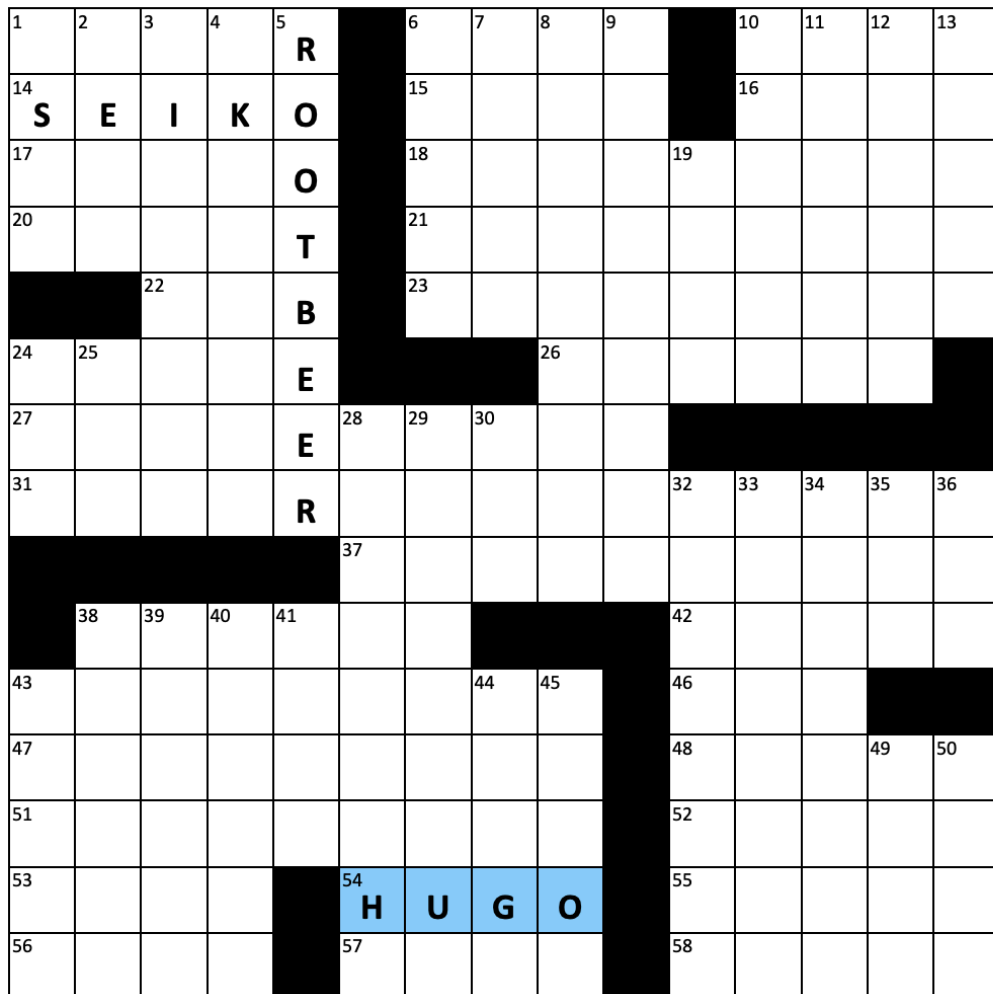
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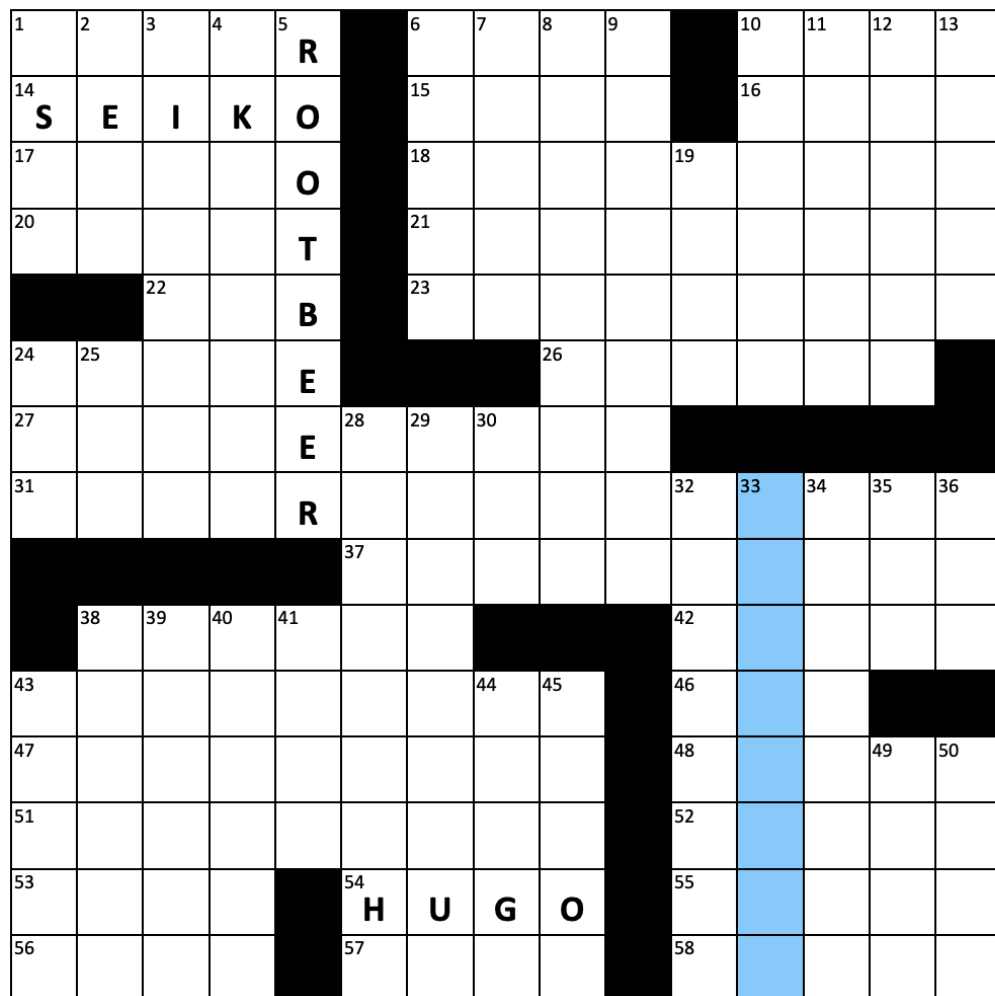
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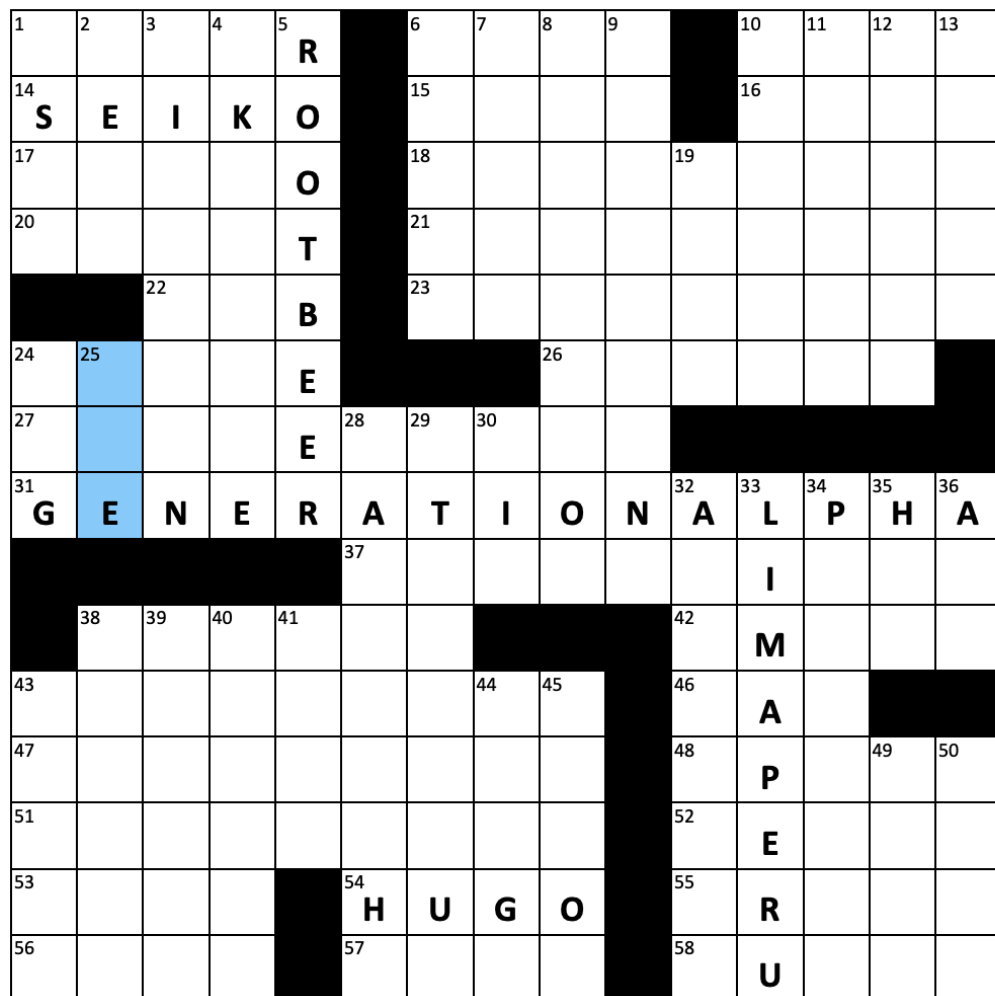
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- 37 They might cut to the chase
- 38 Electrically balanced, in chemistry
- 42 Leaders at the Kaaba
- 43 "Things are going great for me!"
- 46 Muscle worked in rowing exercises, for short
- 47 Portmanteau coinage for the uneducated and uncultured
- 48 Touches, e.g.
- 51 Special pawn move in chess
- 52 Many a Madrileño
- 53 Enemy of Wonder Woman
- 54 Best Picture-nominated 2011 film based on a children's book

Down

- 3 "I wanna know all the details"
- 4 Start of a modern inquiry
- 5 Drink similar to sarsaparilla
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- 24 Assignment for an anchor
- 25 "____ noticed ..."
- 28 Great Hindu sage
- 29 Late-Triassic flier
- 30 It can be found right on a clock
- 32 "100 Years ... 100 Stars" and others, in brief



Across

27 Sci-fi enemy collective, perhaps

54 Best Picture-nominated 2011 film based on a children's book

32 "100 Years ... 100 Stars" and others, in brief



Across

54 Best Picture-nominated 2011 film based on a children's book

32 "100 Years ... 100 Stars" and others, in brief



Example Crossword

1	2	3	4	5		6	7	8	9		10	11	12	13		
		F		R												
14	S	E	I	K	O						16					
17			L		O					19						
20			L		T											
			22													
		M		B												
24	25								26							
	I	E		E												
27	E	V	I	L	E	28	29	30								
					M	P		I	R	E						
31	G	E	N	E	R	A	T		I	O	N	32	33	34	35	36
									I							
						37							I			
		38	39	40	41						42		M			
43								44	45		46		A			
47											48		P		49	50
51											52		E			
53						54					55		R			
56						57					58		U			

Across

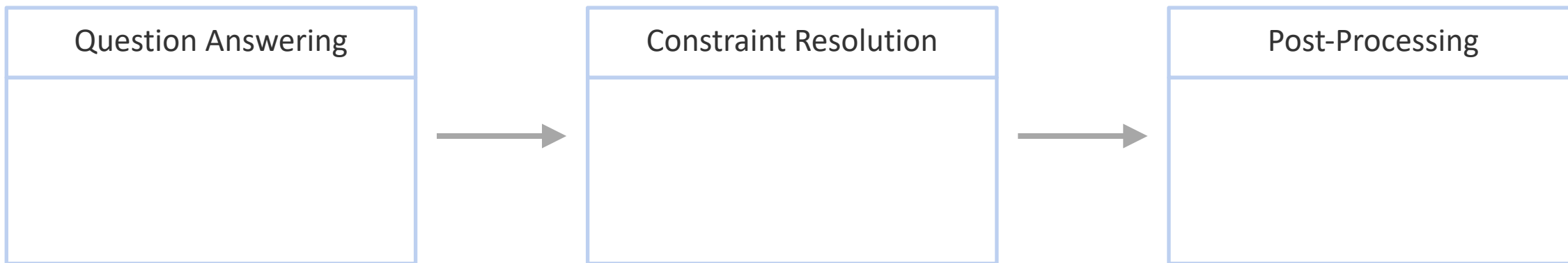
- 22 ___ rule
- 23 They don't hold water
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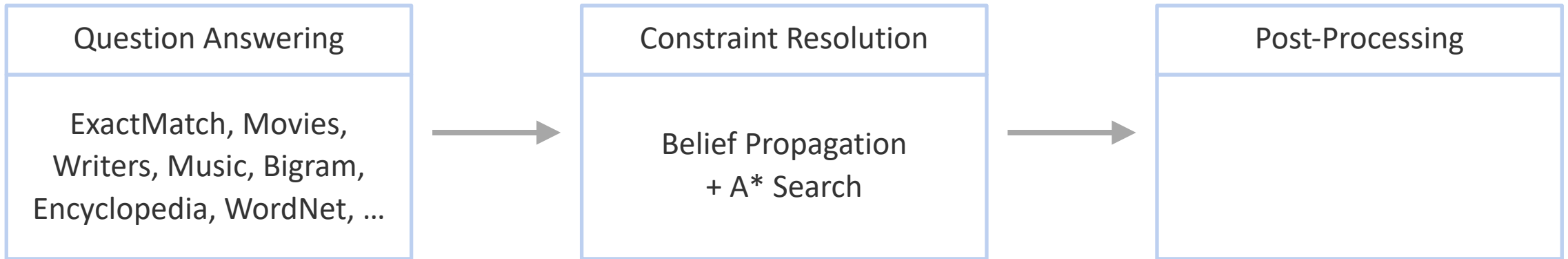
General Framework





Previous Work

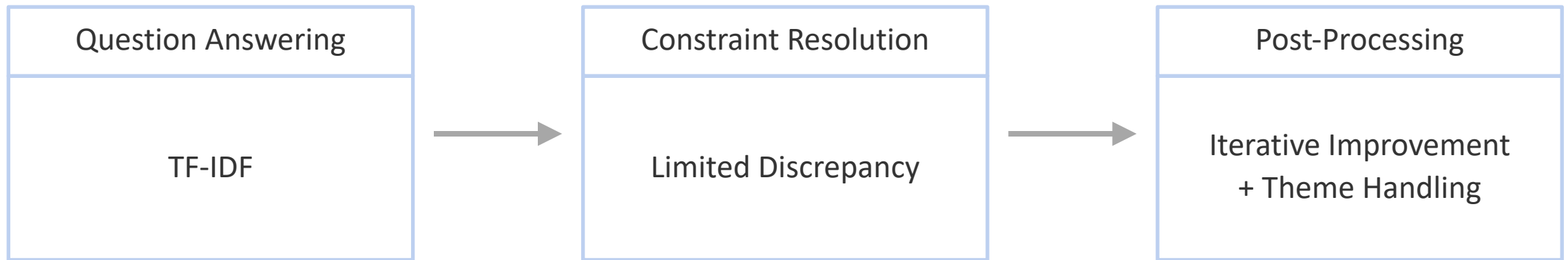
Proverb [Littman et al., 2002]





Previous Work

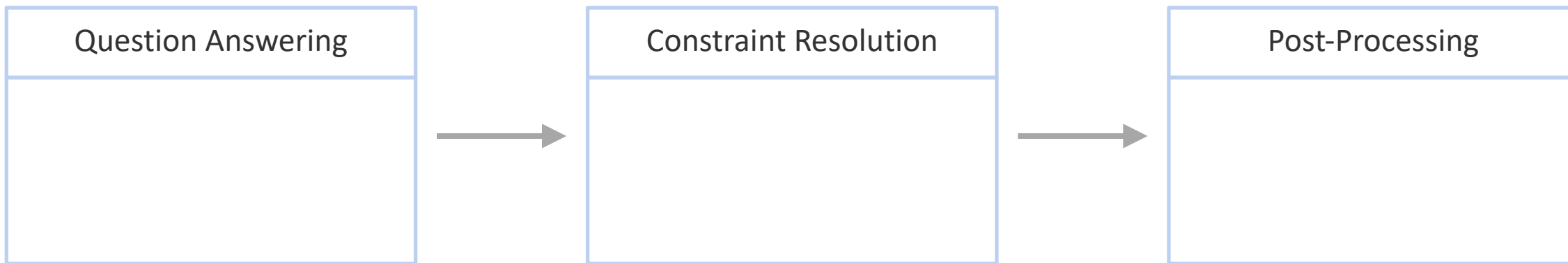
Dr. Fill [Ginsberg, 2011]





Our Approach

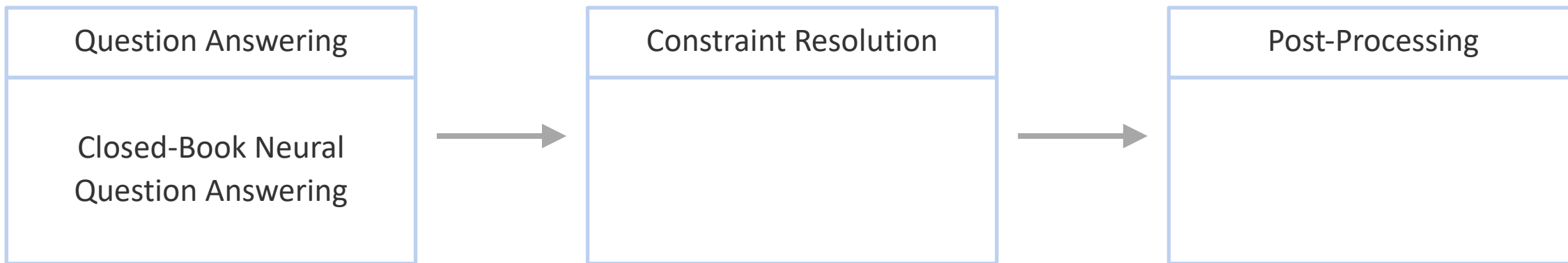
The Berkeley Crossword Solver





Our Approach

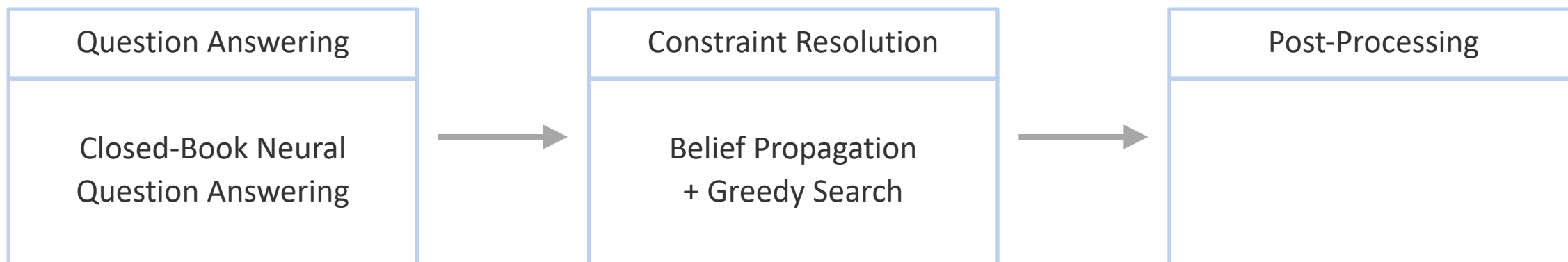
The Berkeley Crossword Solver





Our Approach

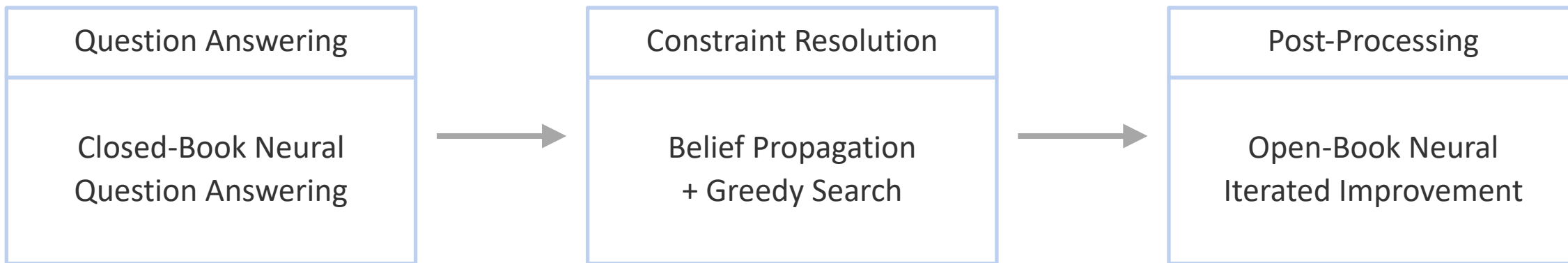
The Berkeley Crossword Solver





Our Approach

The Berkeley Crossword Solver





Our Approach

The Berkeley Crossword Solver





Closed-Book QA

14. Omega competitor





Closed-Book QA

14. Omega competitor



¹⁴
A B A S E

¹⁴
A B A T E

¹⁴
A B B E Y

¹⁴
A B I D E

¹⁴
A B O U T

¹⁴
A B Y S S

⋮

¹⁴
Z O O M S

Vocabulary



Closed-Book QA

14. Omega competitor



¹⁴
R O L E X

¹⁴
S E I K O

¹⁴
A L P H A

¹⁴
W A T C H

¹⁴
A P P L E

¹⁴
E N E M Y

⋮

¹⁴
S K U N K

Predictions



Closed-Book QA

14. Omega competitor



¹⁴
A B A S E

¹⁴
A B A T E

¹⁴
A B B E Y

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A B I D E

¹⁴
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⋮

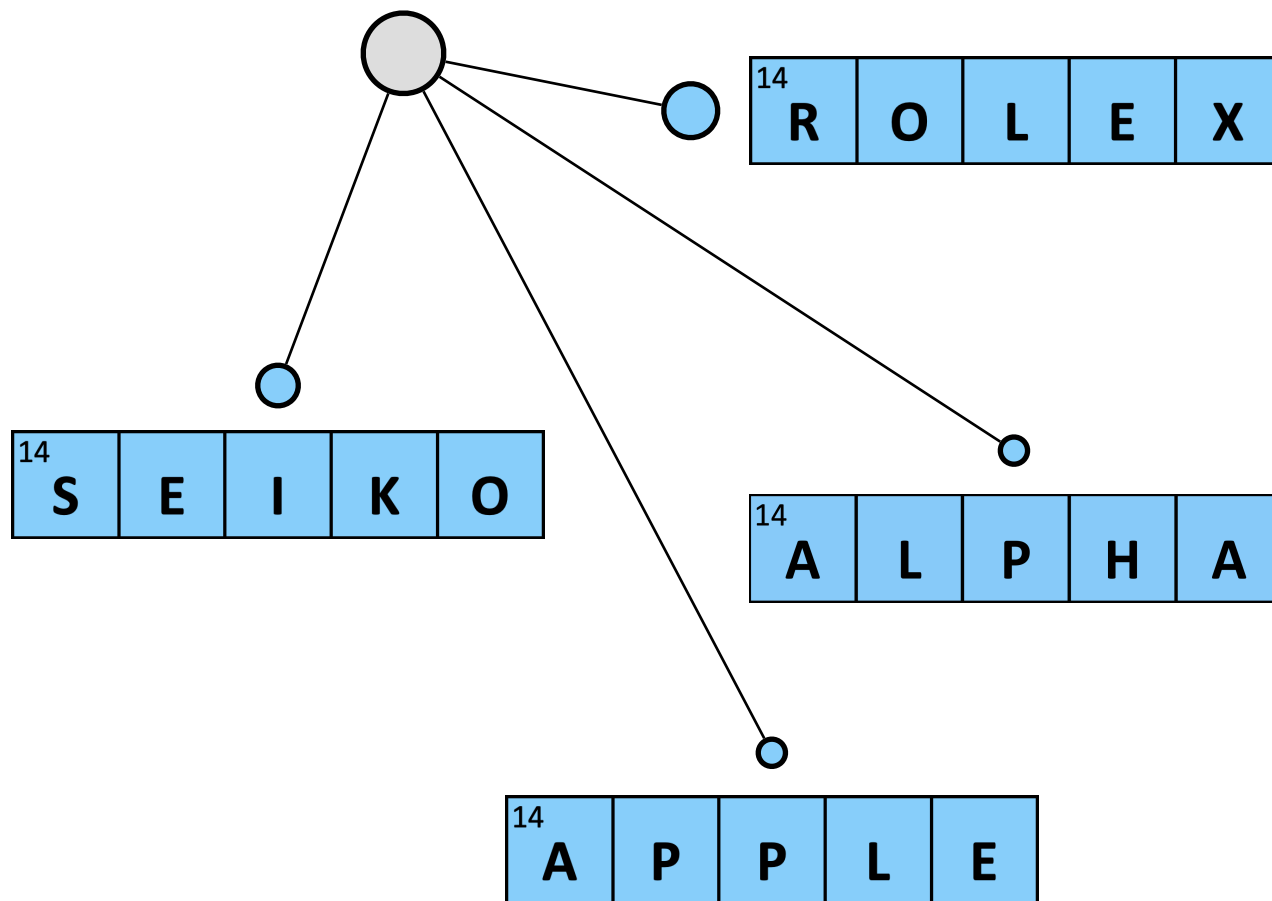
¹⁴
Z O O M S

Vocabulary



Closed-Book QA

14. Omega competitor



14 A B A S E

14 A B A T E

14 A B B E Y

14 A B I D E

14 A B O U T

14 A B Y S S

...

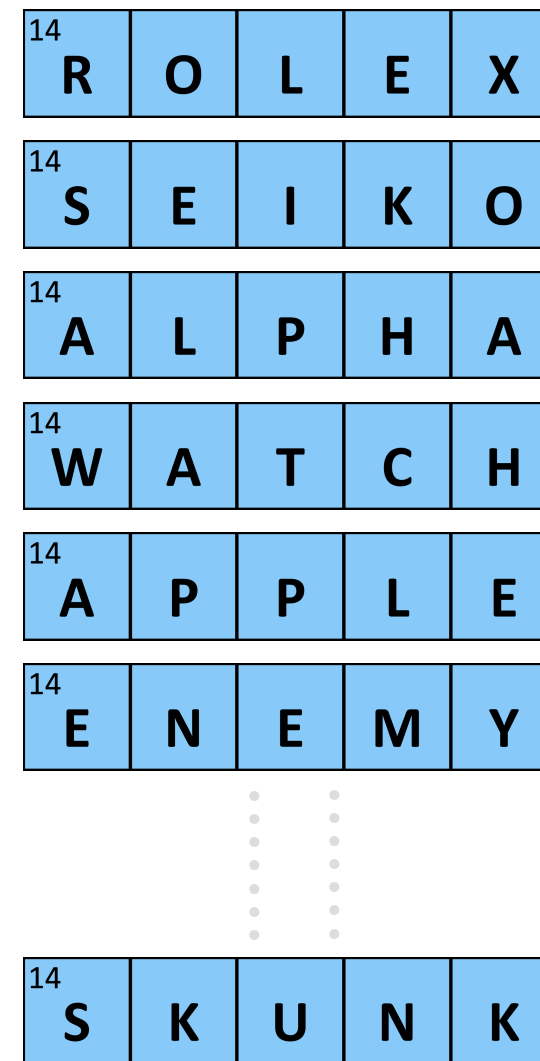
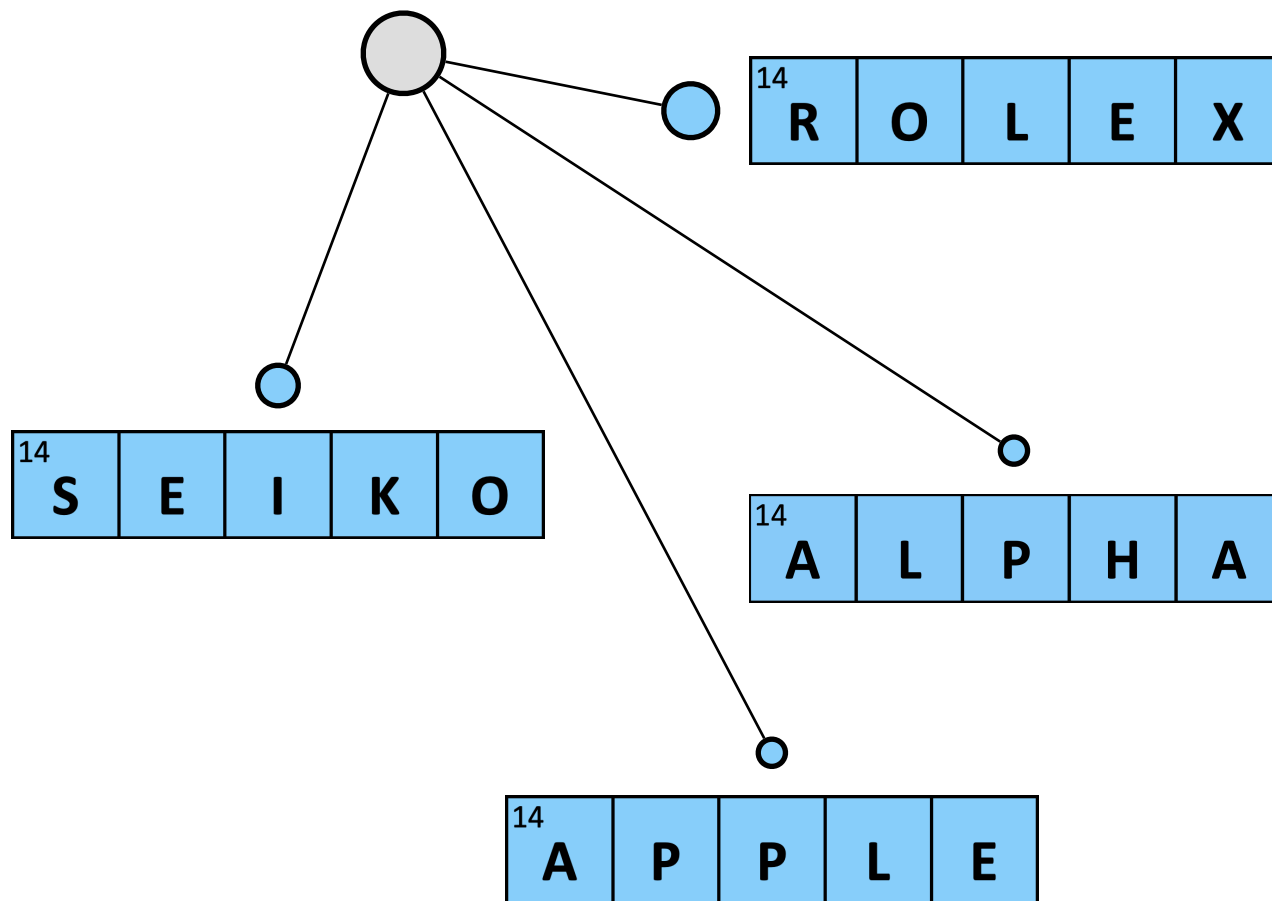
14 Z O O M S

Vocabulary



Closed-Book QA

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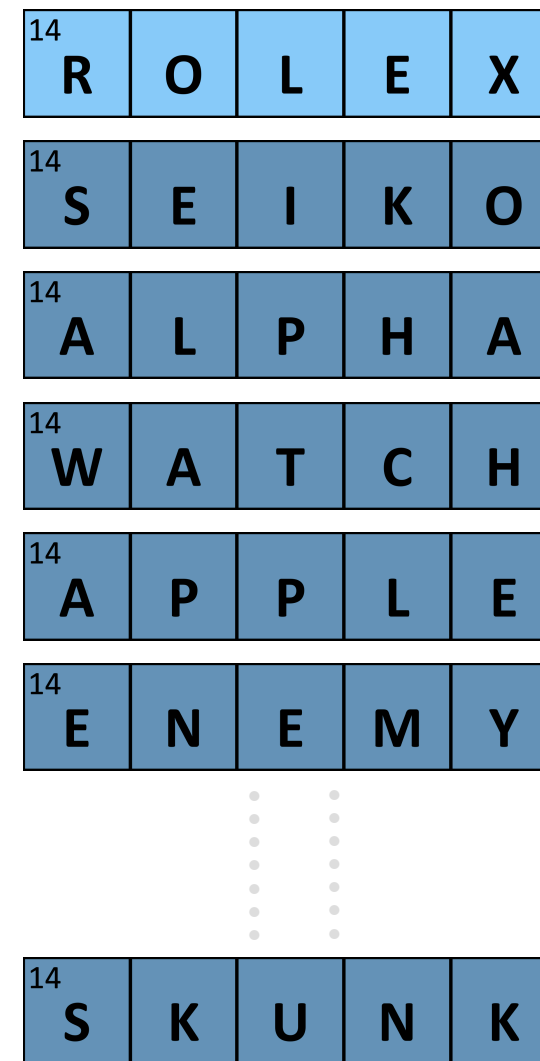
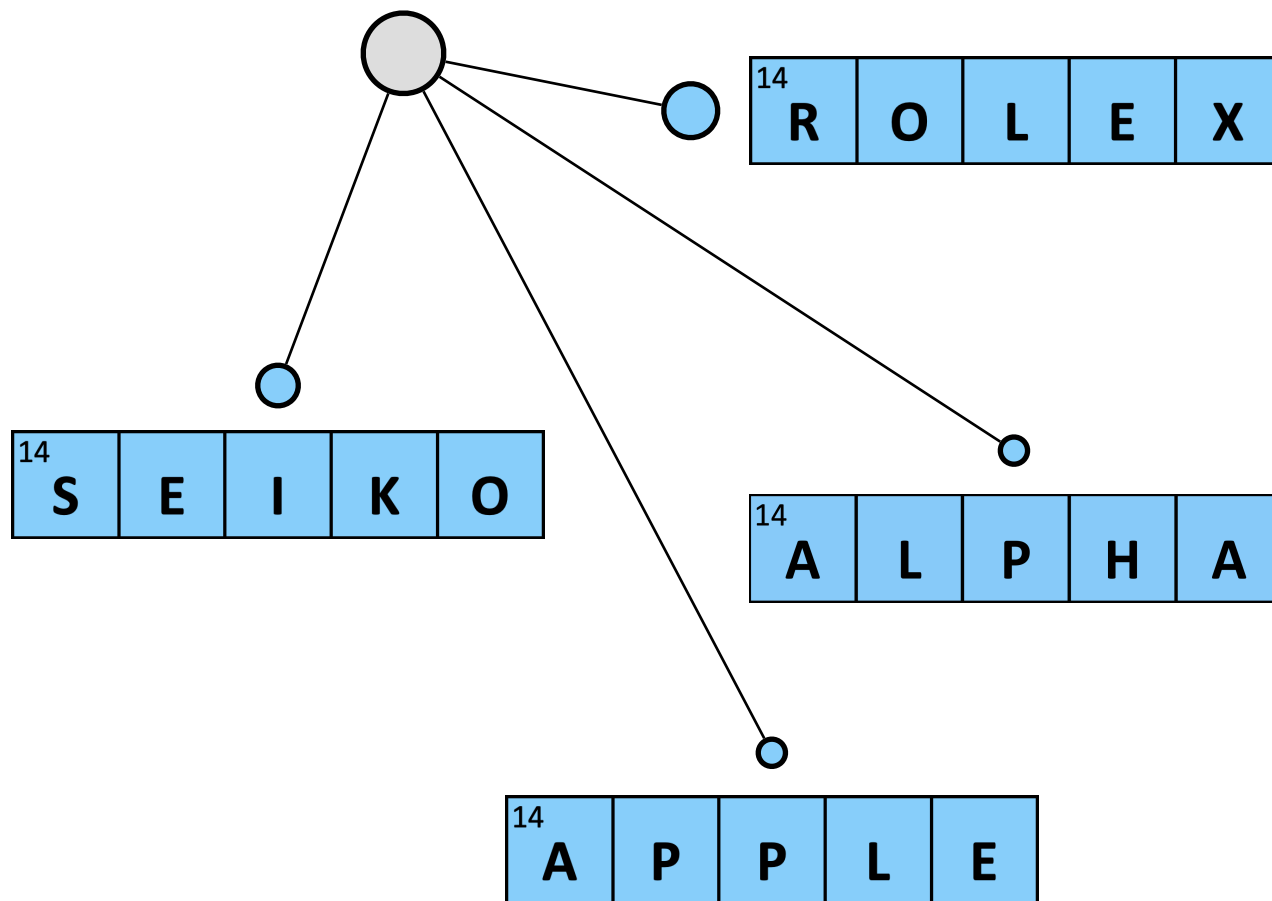


Predictions



Closed-Book QA

14. Omega competitor



Predictions



Handling Ambiguous Clues

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

Across

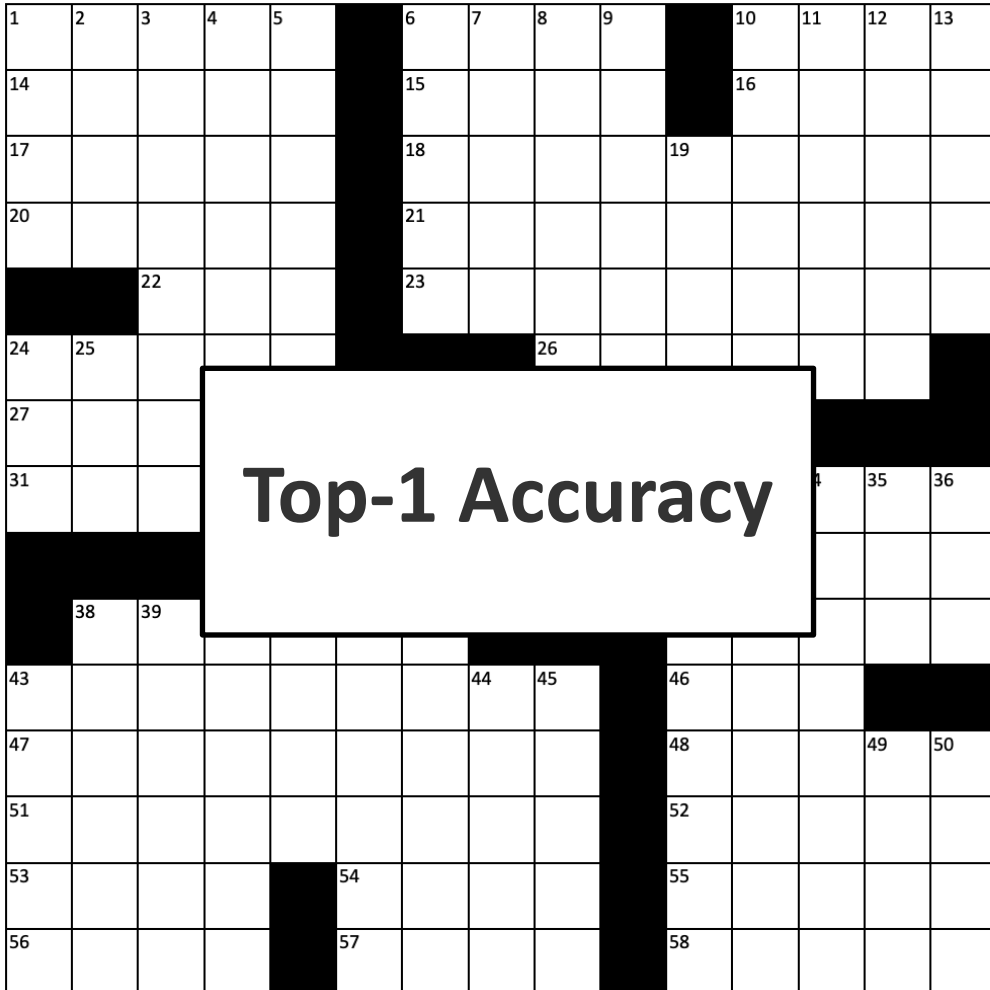
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Handling Ambiguous Clues



Across

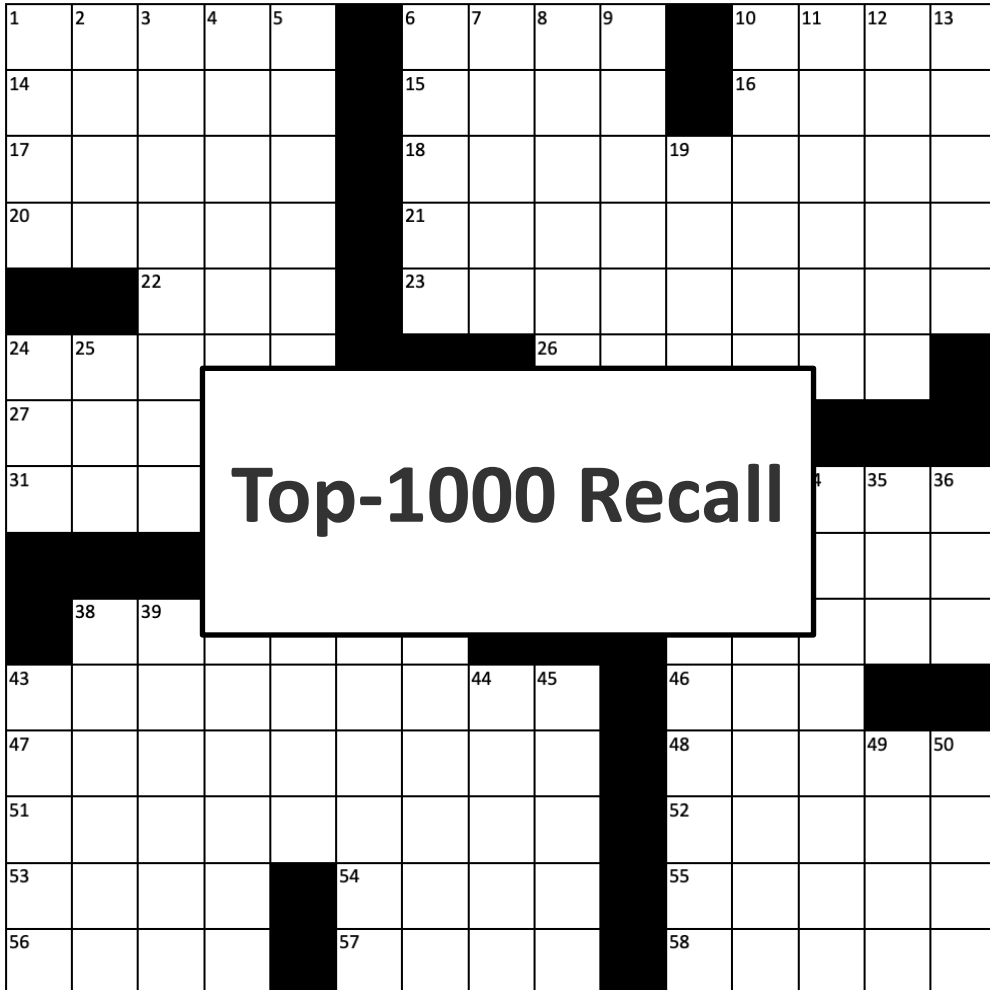
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Handling Ambiguous Clues



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Our Approach

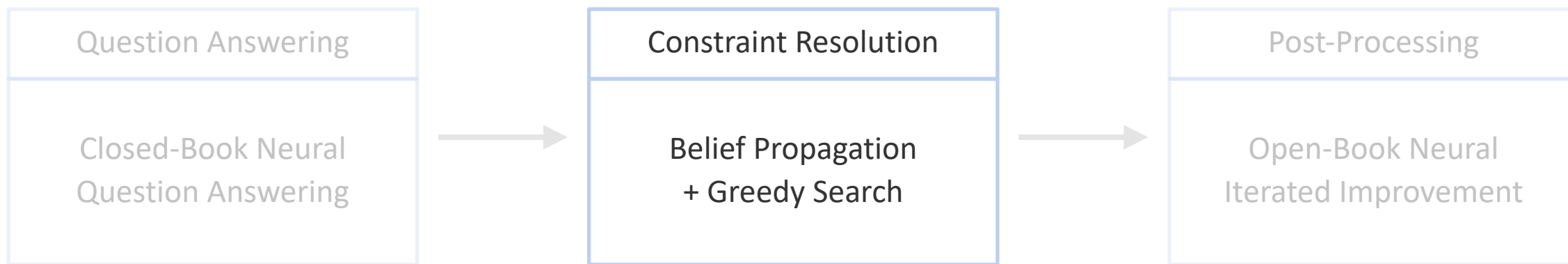
The Berkeley Crossword Solver





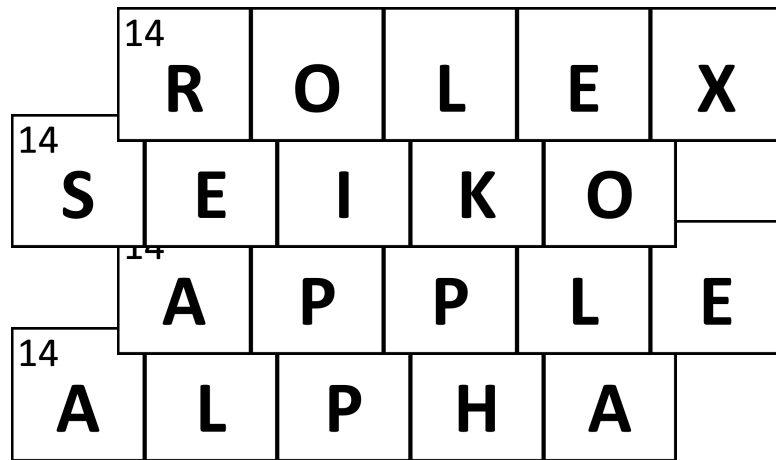
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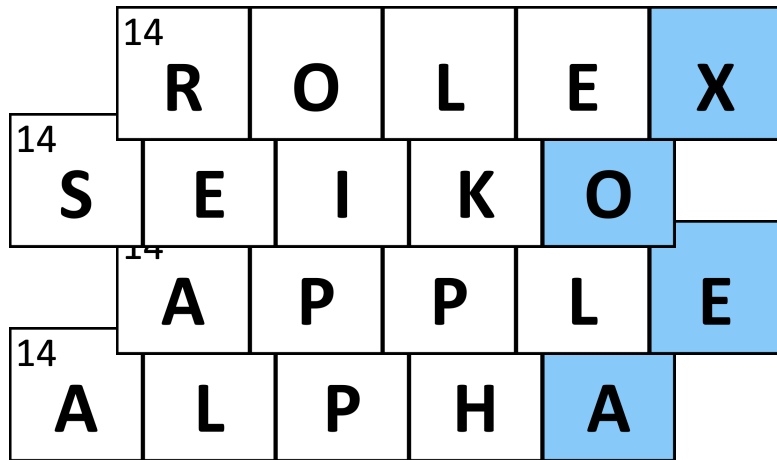


Loopy Belief Propagation



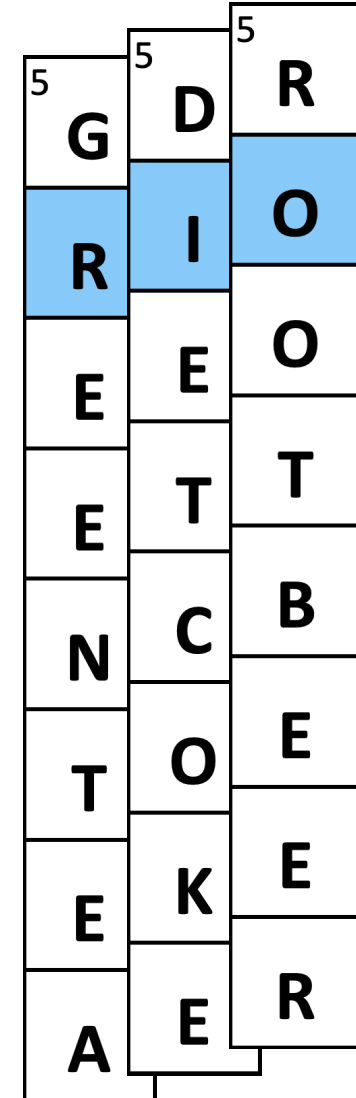
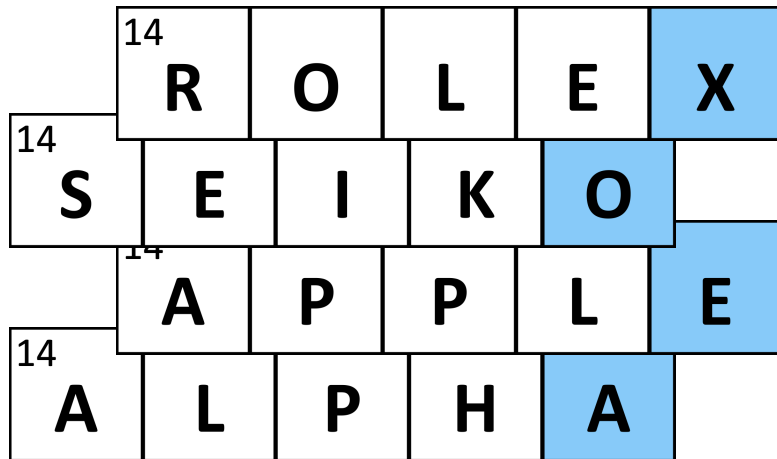


Loopy Belief Propagation



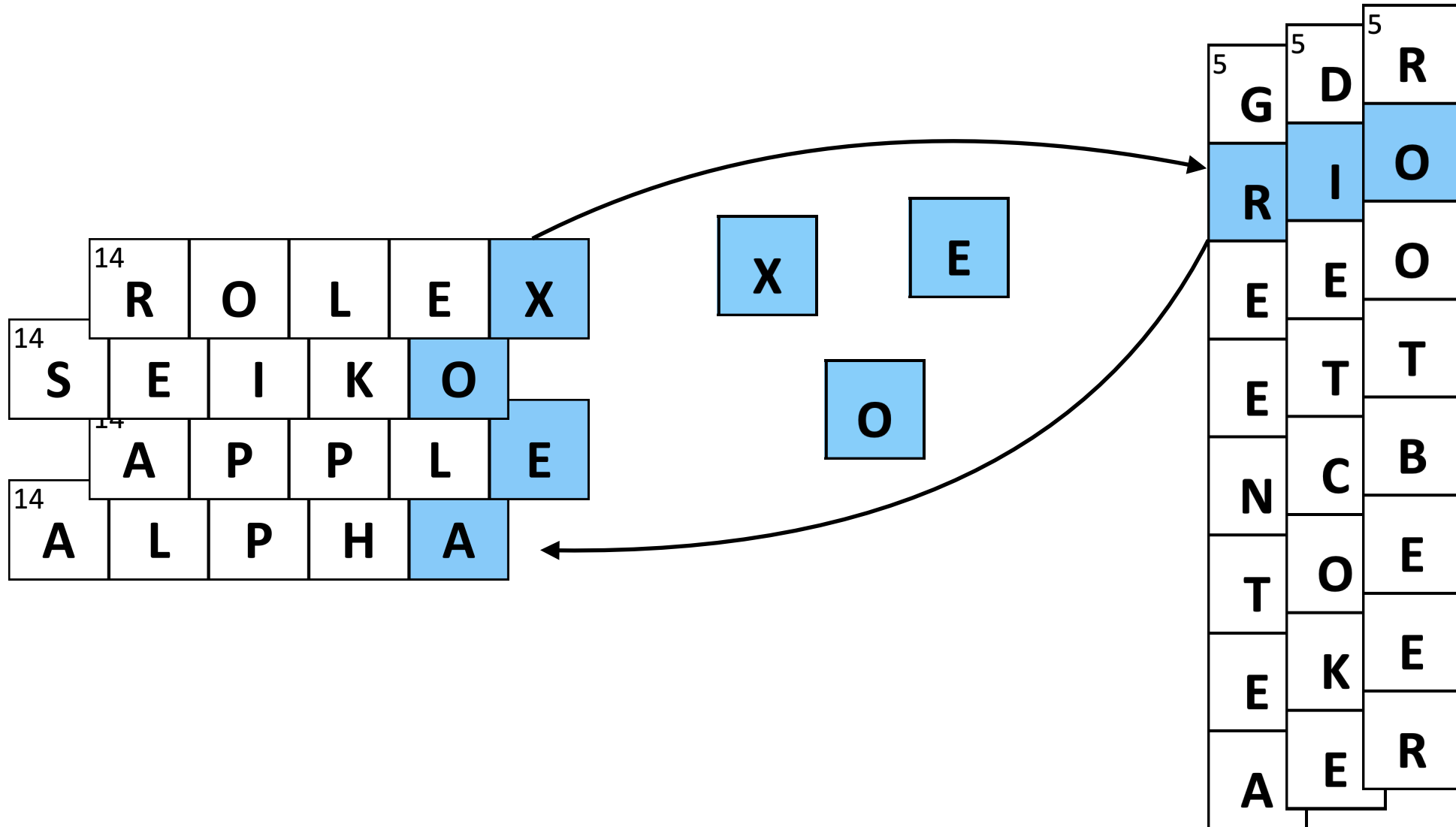


Loopy Belief Propagation



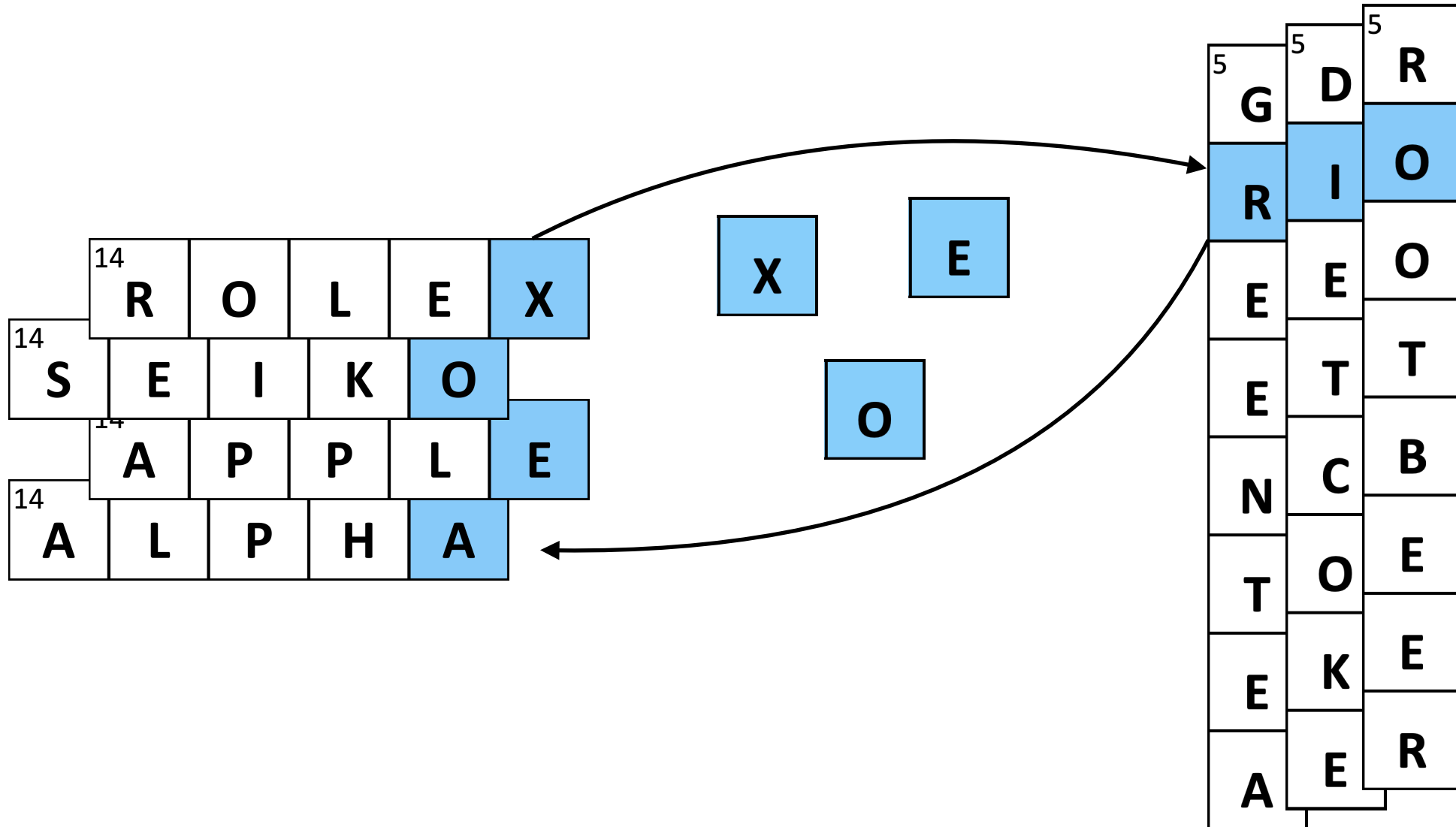


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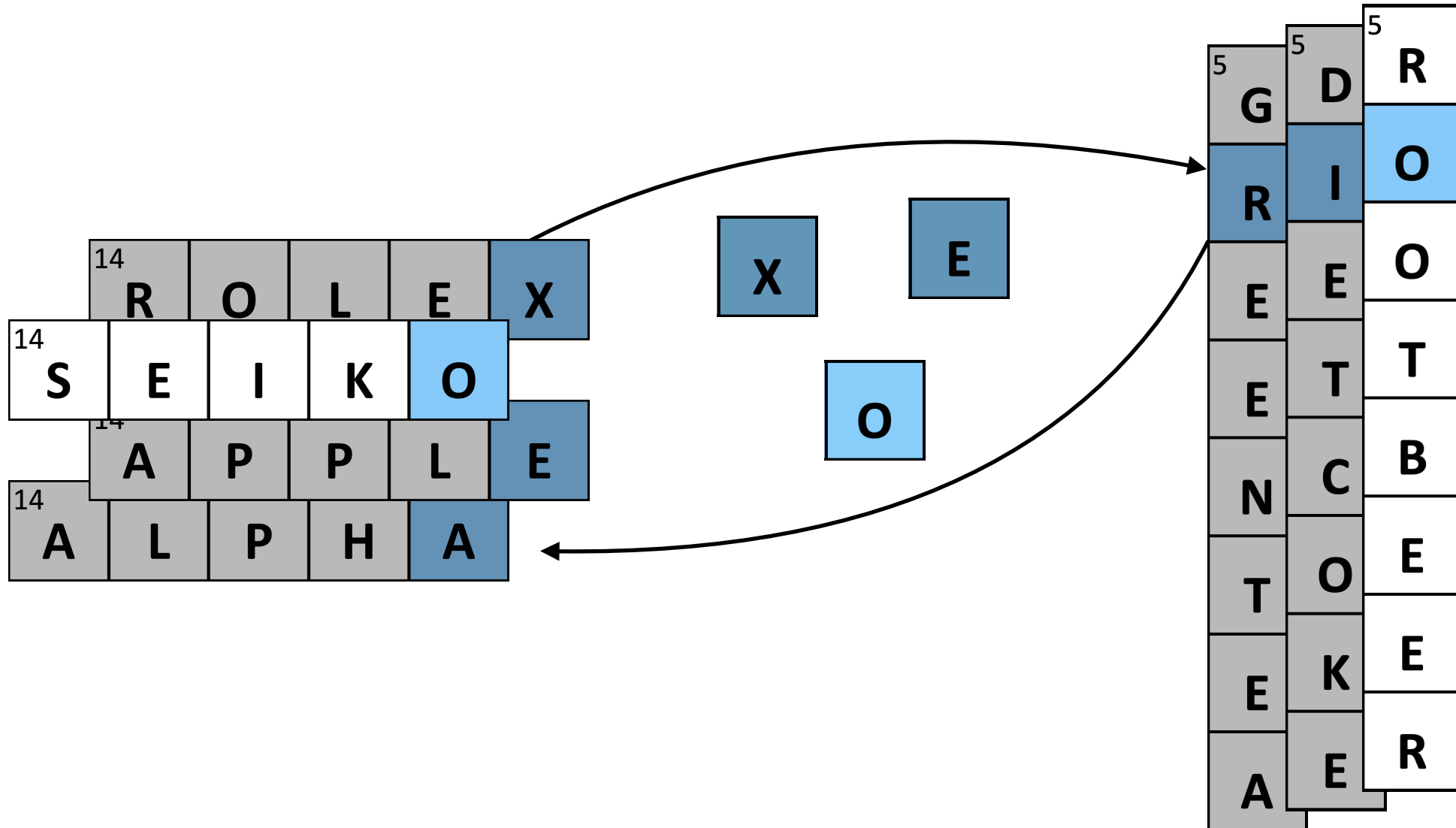


Loopy Belief Propagation





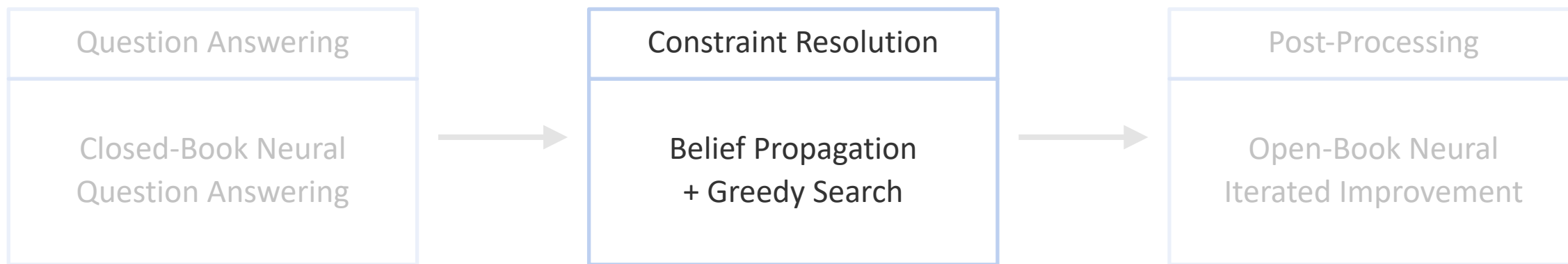
Loopy Belief Propagation





Our Approach

The Berkeley Crossword Solver





Our Approach

The Berkeley Crossword Solver





Open-Book Improvement

1	H	2	A	3	H	4	I	5	D		6	S	7	N	8	A	9	P		10	E	11	D	12	S	
13	A	M	O	R	E					14	C	A	N	I					15	V	E	T		16	S	
17	M	O	T	E				18	N	I	S	T	S					19	I	C	E	E				
20	M	E	T			21	A	C	E				22	I	M	A					O	N	E			
		24	B	A	25	R	T	O	N				26	O	D	E	D	O	N							
27	C	O	K	I	E			28	T	29	S	30	P		31	D	Y	E	S							
32	D	I	E	D				33	S	I	T	U	34	A	T	E										
35	C	D	S			36	Y	E	S	O	R	N	O				37	M	38	F	39	R				
				40	T	A	S	T		B	G	A	S			41	A	R	E	A						
		42	A	43	C	H	Y		44	S	A	A		45	B	I	P	E	D							
46	P	R	O	A	M	S					48	G	49	A	O	L	E	D								
50	D	E	G		E	E	51	S			52	A	U	G			53	A	B	54	E					
55	A	N	N	A			56	T	U	57	R	N	S	I	G	N	A	L								
59	S	T	A	D			60	I	M	A	C			61	E	A	U	C	I							
		62	I	C	S			63	N	O	P	E			64	S	I	T	K	A						

Across

- 1 Beloved, in Arabic
- 6 [Make it quick!]
- 10 Masthead listings, for short
- 13 Italian herbal liqueur
- 14 "Please, please, please?"
- 15 People calling the shots at the zoo?
- 17 Not radical
- 19 Drink with a dome-shaped lid
- 20 Where to find the Egyptian Temple of Dendur, with "the"
- 21 Crush, as a test
- 22 Cry from a survivor
- 24 Clara in the National Women's Hall of Fame
- 26 Stuffed oneself with, facetiously
- 27 Newswoman Roberts
- 28 Recipe amt.
- 31 Doesn't stay natural?
- 32 Fell off, as laughter
- 33 Place

Down

- 1 Soccer star on a 1999 Wheaties box
- 2 Bloblike
- 3 Ill-advised opinions
- 4 Fury
- 5 Feeling on a lo-o-ong car trip
- 6 Lab workers
- 7 Performer with the hit 2006 album "Hip Hop Is Dead"
- 8 Voting no
- 9 ____ Beach, Calif.
- 10 Satan, with "the"
- 11 Crack, as a secret message
- 12 Shorthand writers, for short
- 16 Dated
- 18 Cpl. or sgt.
- 23 Expand
- 25 Purge (of)
- 27 Atlanta-based health org.
- 29 Long fur scarfs



Open-Book Improvement

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13	A	M	O	R	E					14	C	A	N	I						15	V	E	T		16	S
17	M	O	D	E				18	N	I	S	T	S							19	I	C	E	E		
20	M	E	T			21	A	C	E				22	I	M	A						O	N	E		
		24	B	A	25	R	T	O	N					26	O	D	E	D	O	N						
27	C	O	K	I	E			28	T	29	S	30	P		31	D	Y	E	S							
32	D	I	E	D			33	S	I	T	U	34	A	T	E											
35	C	D	S			36	Y	E	S	O	R	N	O				37	M	38	F	39	R				
				40	C	A	S	T		41	B	A	S				41	A	R	E	A					
		42	A	43	C	H	Y			44	S	A	A			45	B	I	P	E	D					
46	P	R	O	A	M	S						48	H	49	A	I	L	E	D							
50	D	E	G			E	E		51	S			52	A	U	G			53	A	B	E	54			
55	A	N	N	A				56	T	U	R	N	S			58	I	G	N	A	L					
59	S	T	A	D				60	I	M	A	C				61	E	L	U	C	I					
		62	I	C	S			63	N	O	P	E				64	S	I	T	K	A					

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13	A	M	A	R	E					14	C	A	N	I					15	V	E	T		16	S	
17	M	O	D	E		18	N	I	S	T	S			19	I	C	E	E								
20	M	E	T		21	A	C	E			22	I	M	A			O	N	E							
	24	B	A	25	R	T	O	N			26	O	D	E	D	O	N									
27	C	O	K	I	E		28	T	29	S	30	P		31	D	Y	E	S								
32	D	I	E	D		33	S	I	T	U	34	A	T	E												
35	C	D	S		36	Y	E	S	O	R	N	O			37	M	38	F	39	R						
				40	C	A	S	T	B	L	E	S		41	A	R	E	A								
	42	A	43	C	H	Y		44	S	A	C		45	B	I	P	E	D								
46	P	R	O	A	M	S				48	H	49	A	I	L	E	D									
50	D	E	G		E	E	51	S		52	A	U	G		53	A	B	E								
55	A	N	N	A		56	T	U	57	R	N	S	I	58	G	N	A	L								
59	S	T	A	D		60	I	M	A	C			61	N	A	U	C	I								
	62	I	C	E		63	N	O	P	E			64	S	I	T	K	A								

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13	A	M	A	R	O		C	A	N	I		V	E	T	S
17	M	O	D	E		N	I	S	T	S		I	C	E	E
20	M	E	T		A	C	E		I	M	A		O	N	E
		B	A	R	T	O	N				O	D	E	D	O
27	C	O	K	I	E		T	S	P		D	Y	E	S	
32	D	I	E	D		S	I	T	U	A	T	E			
35	C	D	S		Y	E	S	O	R	N	O		M	F	R
				C	A	S	T	L	E	S		A	R	E	A
		A	C	H	Y		S	I	C		B	I	P	E	D
46	P	R	O	A	M	S			H	A	I	L	E	D	
50	D	E	G		E	E	S		A	U	G		A	B	E
55	A	N	N	A		T	U	R	N	S	I	G	N	A	L
59	S	T	A	D		I	M	A	C		N	A	U	C	I
		I	C	E		N	O	P	E		S	I	T	K	A

Across

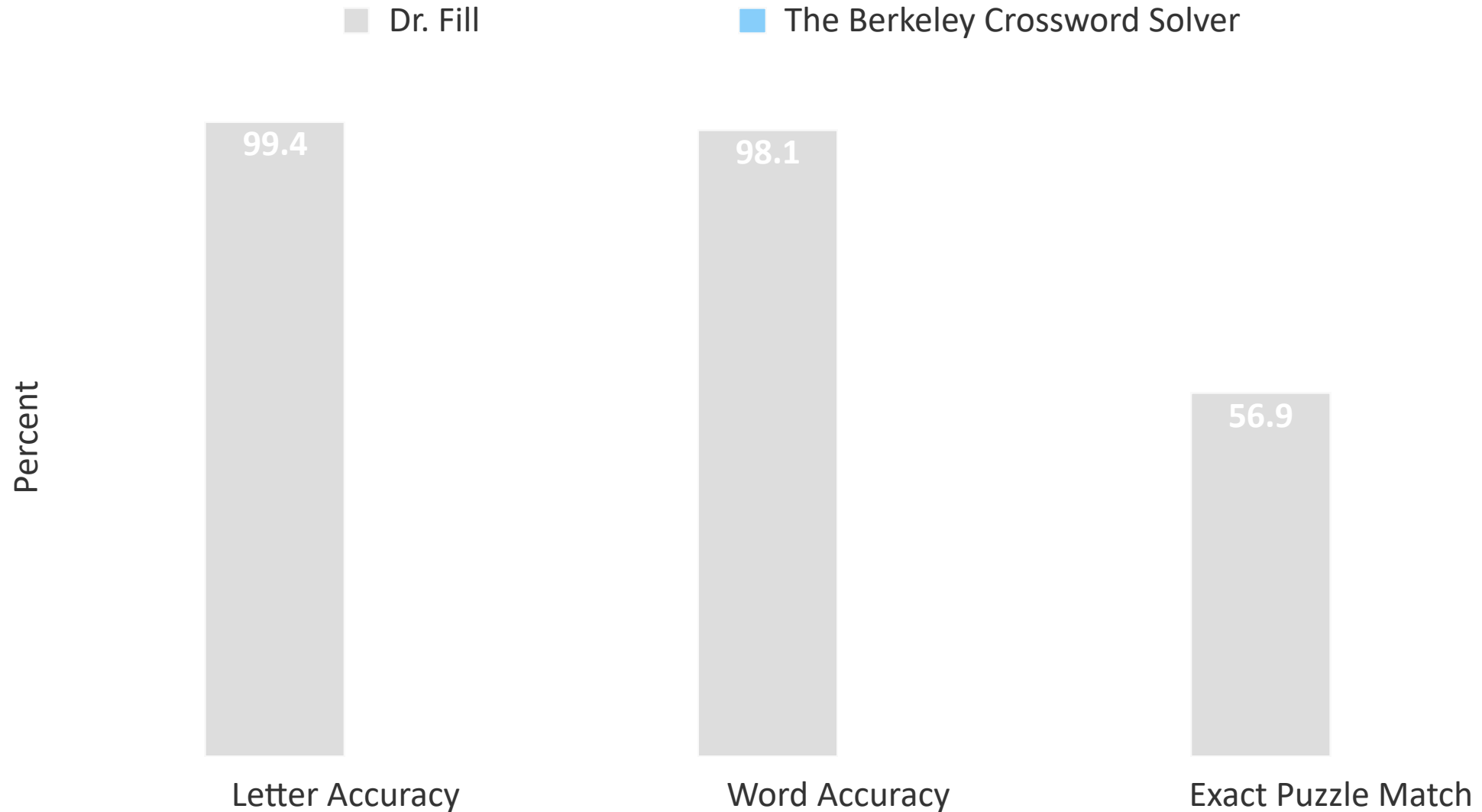
- Beloved, in Arabic
- [Make it quick!]
- Masthead listings, for short
- Italian herbal liqueur
- "Please, please, please?"
- People calling the shots at the zoo?
- Not radical
- Drink with a dome-shaped lid
- Where to find the Egyptian Temple of Dendur, with "the"
- Crush, as a test
- Cry from a survivor
- Clara in the National Women's Hall of Fame
- Stuffed oneself with, facetiously
- Newswoman Roberts
- Recipe amt.
- Doesn't stay natural?
- Fell off, as laughter
- Place

Down

- Soccer star on a 1999 Wheaties box
- Bloblike
- Ill-advised opinions
- Fury
- Feeling on a lo-o-ong car trip
- Lab workers
- Performer with the hit 2006 album "Hip Hop Is Dead"
- Voting no
- ___ Beach, Calif.
- Satan, with "the"
- Crack, as a secret message
- Shorthand writers, for short
- Dated
- Cpl. or sgt.
- Expand
- Purge (of)
- Atlanta-based health org.
- Long fur scarfs

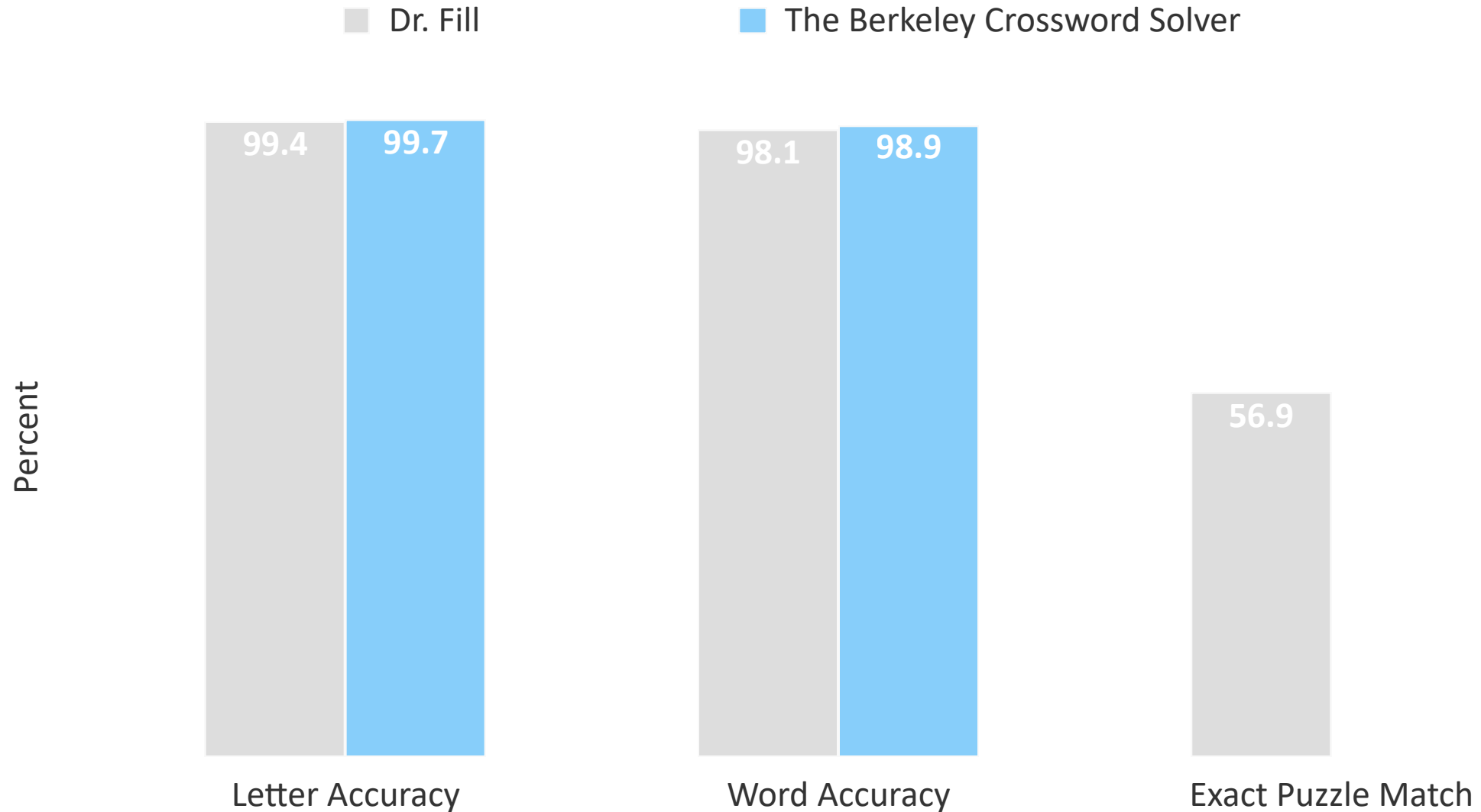


Results: The New York Times



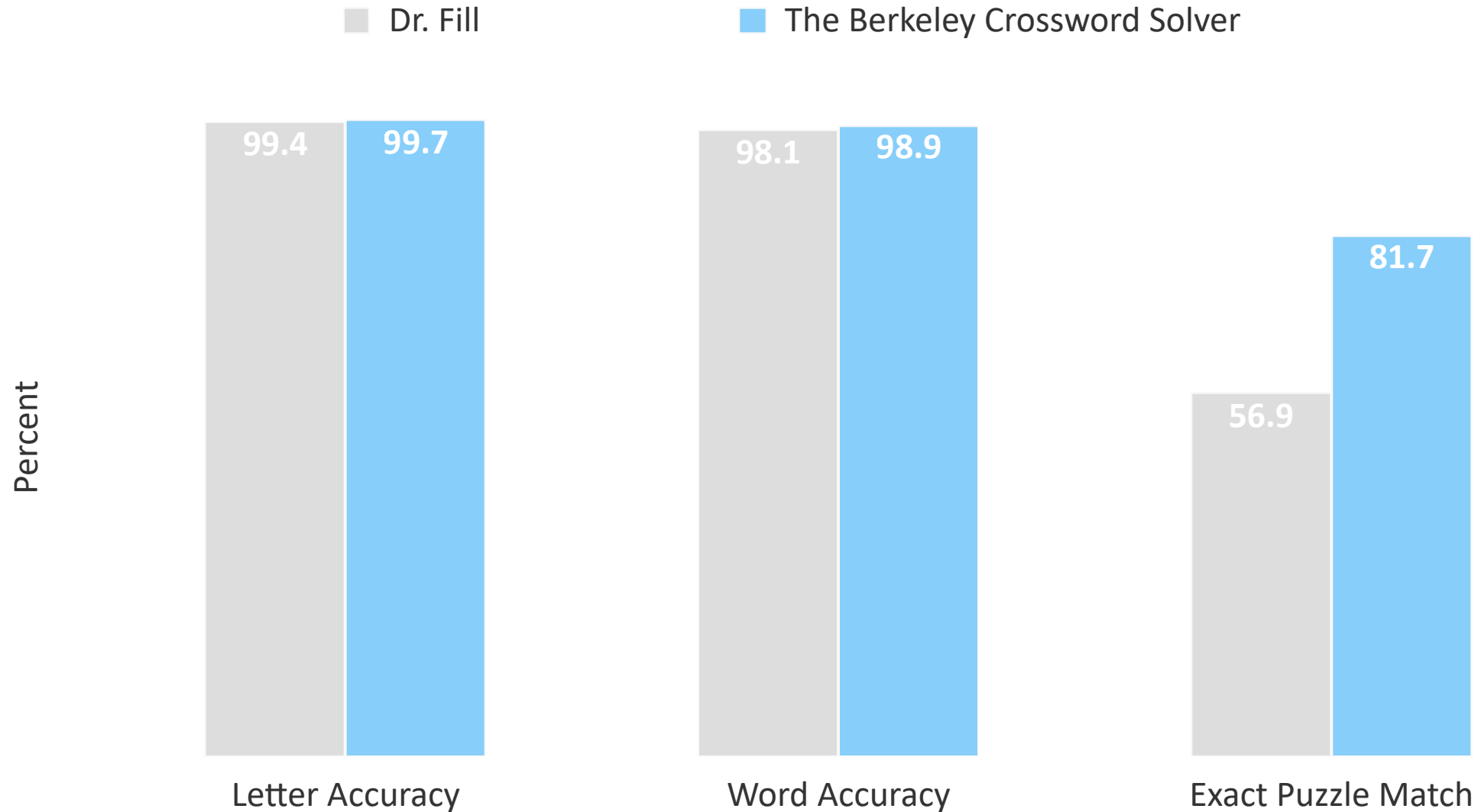


Results: The New York Times





Results: The New York Times





American Crossword Puzzle Tournament

Top Human Competitor



Median Human



Proverb (1998)

Dr. Fill (2012)

DF + BCS (2021)

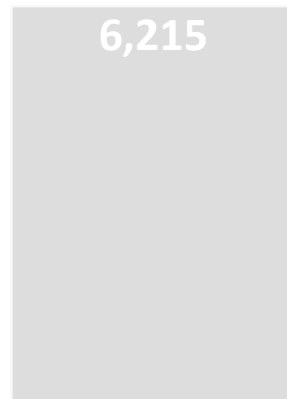


American Crossword Puzzle Tournament

Top Human Competitor



Median Human



6,215

Proverb (1998)

Dr. Fill (2012)

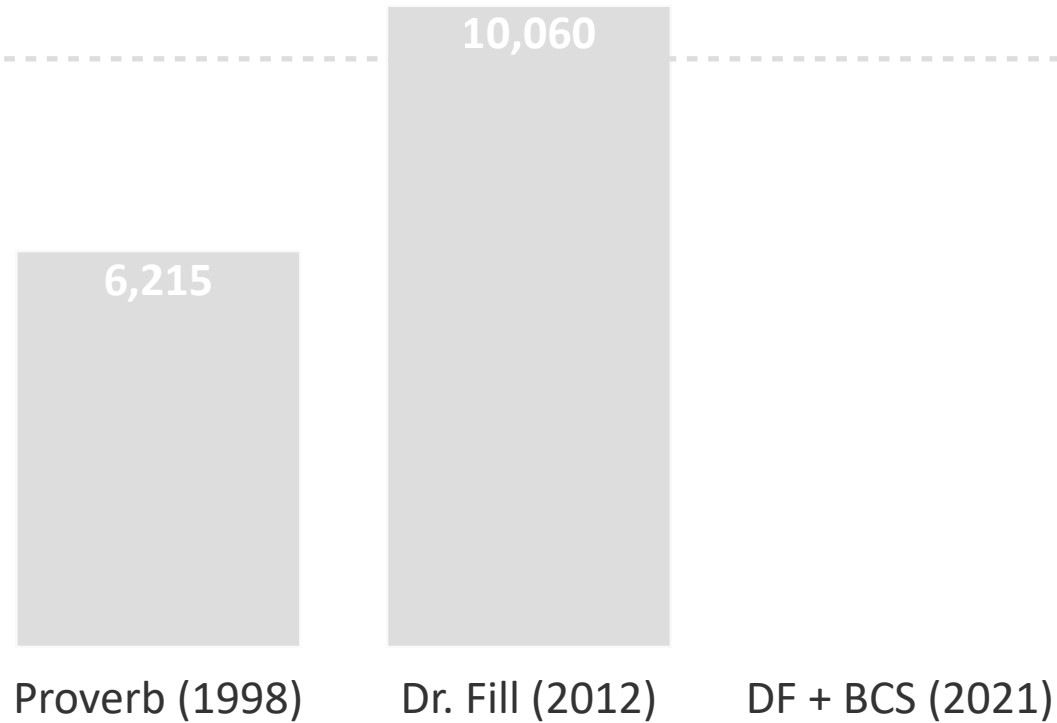
DF + BCS (2021)



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Median Human

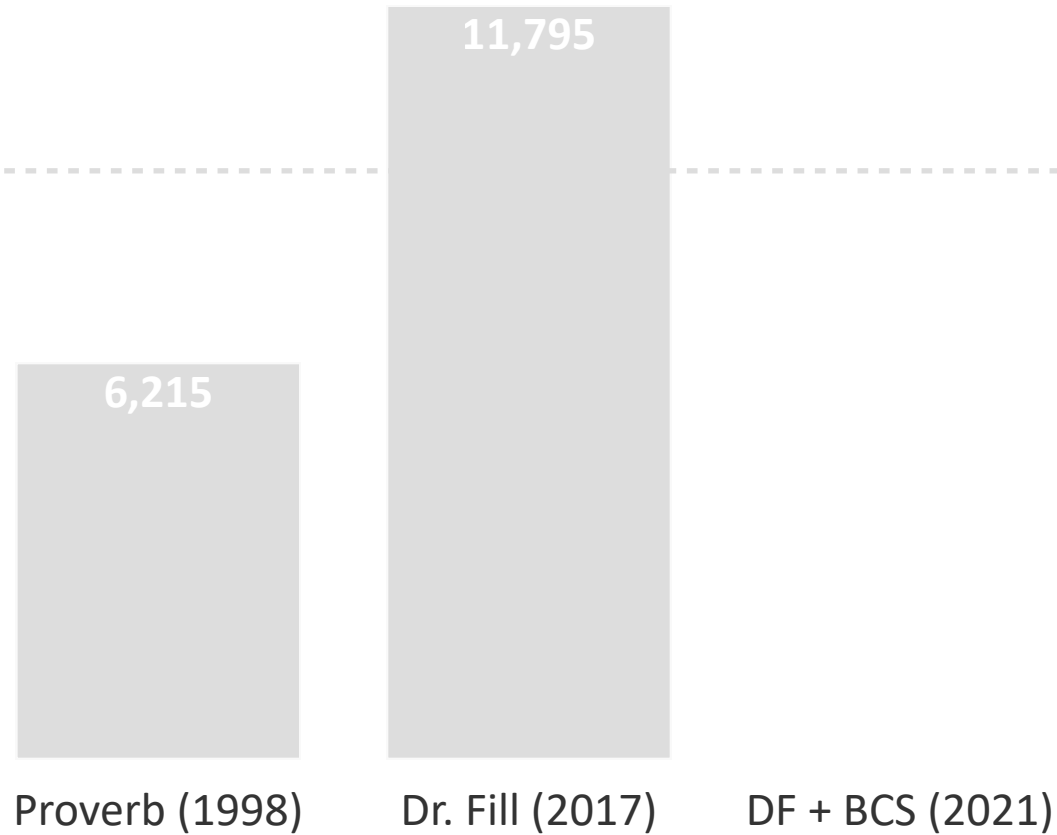




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Median Human

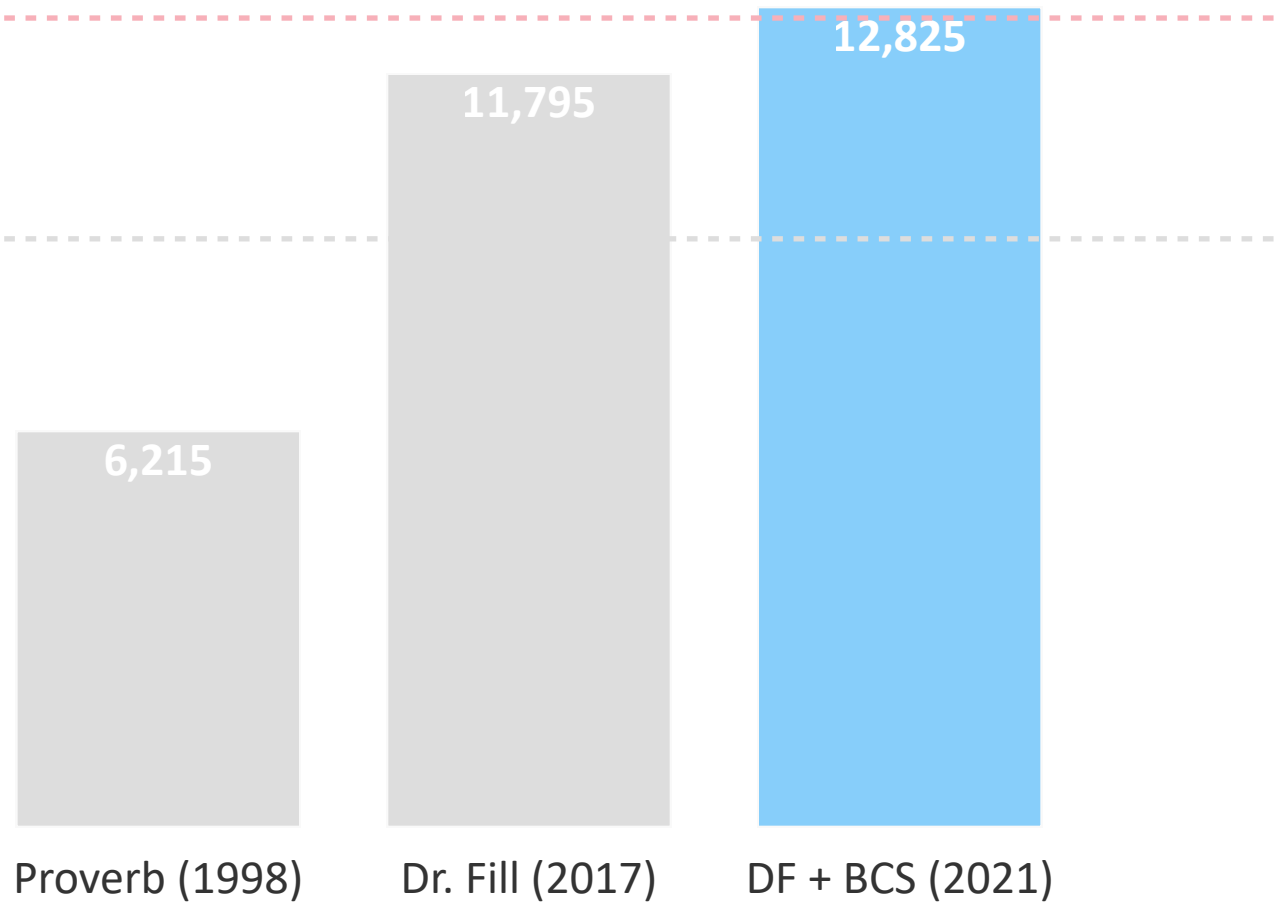




American Crossword Puzzle Tournament

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Median Human

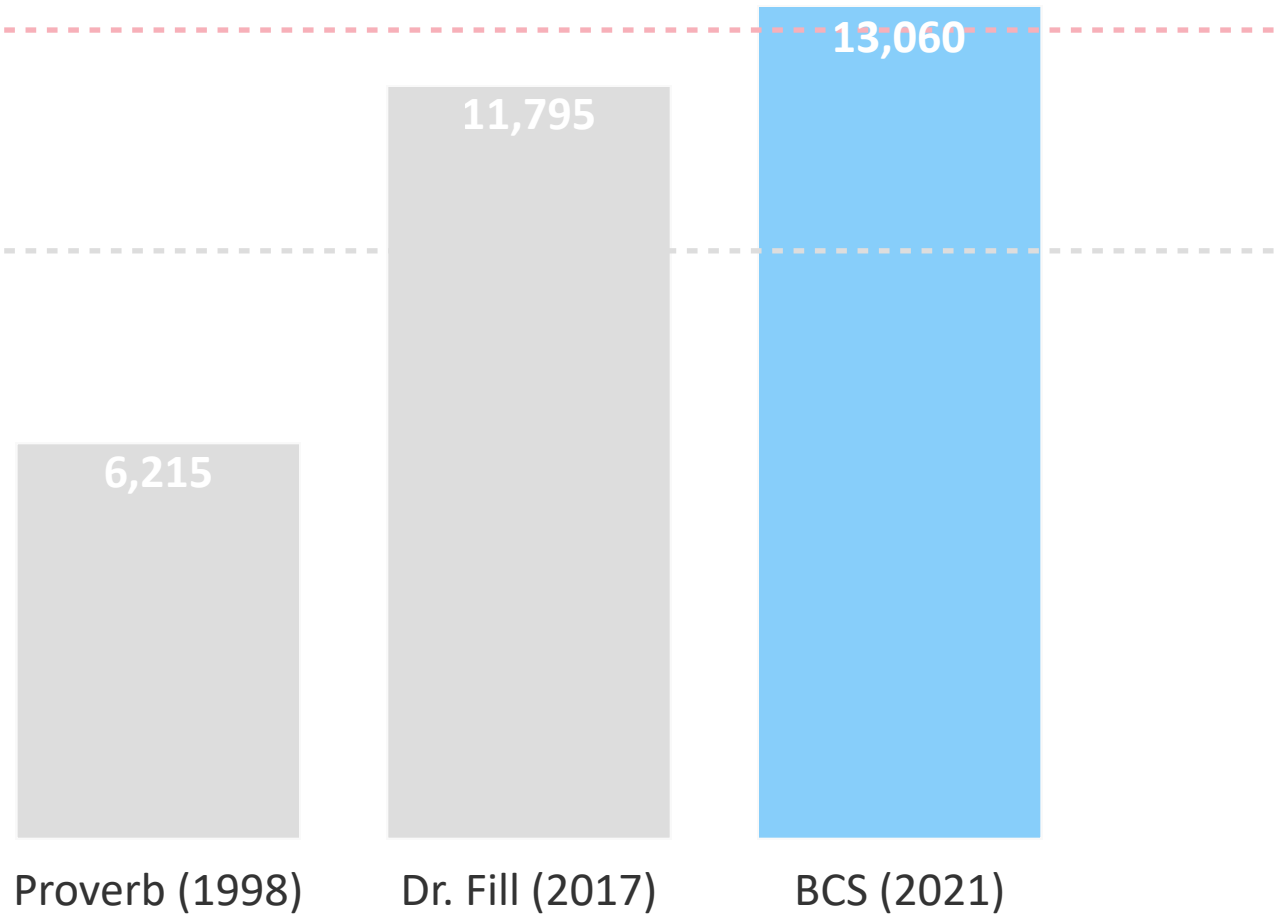




American Crossword Puzzle Tournament

Top Human Competitor

Median Human





Demo

1	2	3	4	5		6	7	8	9		10	11	12	13
14						15					16			
17						18				19				
20						21								
			22			23								
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27						28	29	30						
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						37								
	38	39	40	41						42				
43								44	45					
47										48			49	50
51										52				
53						54				55				
56						57				58				

Across

- 1 Regarding
- 6 Take back, in a way
- 10 Start of an aside
- 14 Omega competitor
- 15 Something hitting a nerve?
- 16 Papyrus, e.g.
- 17 "Take me with you!"
- 18 Begin flirting with someone, so to speak
- 20 Assign
- 21 Hoth, in "Star Wars"
- 22 ___ rule
- 23 They don't hold water
- 24 Feudal figure
- 26 Panegyric, e.g.
- 27 Sci-fi enemy collective, perhaps
- 31 Ones born beginning in the early 2010s
- 37 They might cut to the chase
- 38 Electrically balanced, in chemistry
- 42 Leaders at the Kaaba

Down

- 1 Home to 41-Down
- 2 Convince
- 3 "I wanna know all the details"
- 4 Start of a modern inquiry
- 5 Drink similar to sarsaparilla
- 6 Co-star of 1984's "Ghostbusters"
- 7 Right on
- 8 Aces with aces?
- 9 Like some households
- 10 Designer with an eponymous hotel in the Burj Khalifa
- 11 Currency units in West Africa
- 12 Grievous
- 13 "Golden Boy" playwright
- 19 Actress Shawkat of "Arrested Development"
- 24 Assignment for an anchor
- 25 "___ noticed ..."
- 28 Great Hindu sage
- 29 Late-Triassic flier



Dataset Release, Code, and Demo

We're publicly releasing a dataset of 6.4M question-answer pairs collected from 65+ years of published crossword data.

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Thanks for listening!