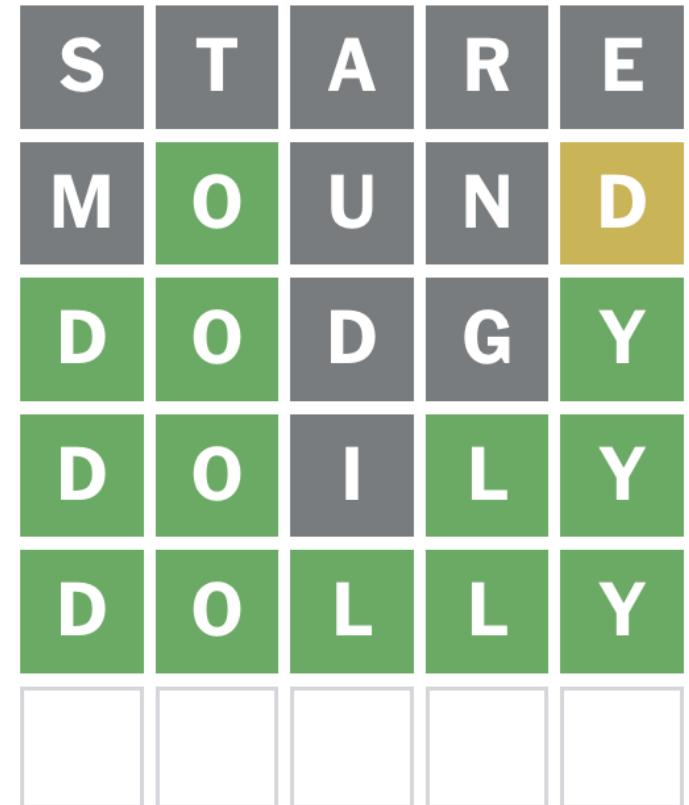


# Warmup: Wordle as a CSP

- Guess the 5-letter word in 6 tries
- What are the:
  - Variables?
  - Domain?
  - Constraints?



## Examples

W E A R Y

W is in the word and in the correct spot.

P I L L S

I is in the word but in the wrong spot.

# CS 188: Artificial Intelligence

## Constraint Satisfaction Problems



Summer 2024: Eve Fleisig & Evgeny Pobachienko

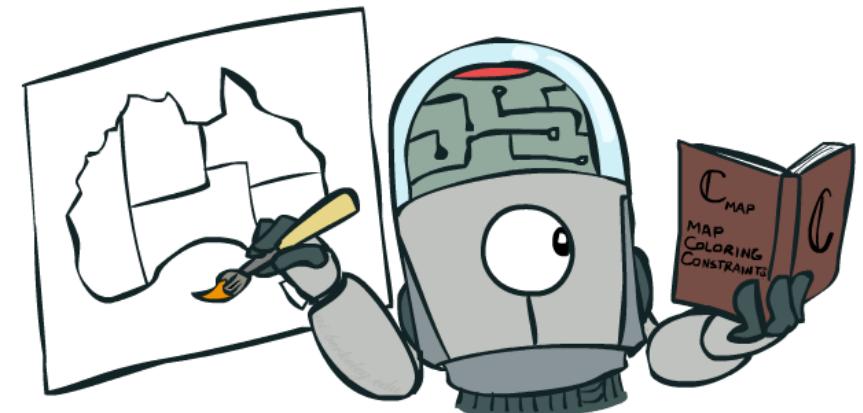
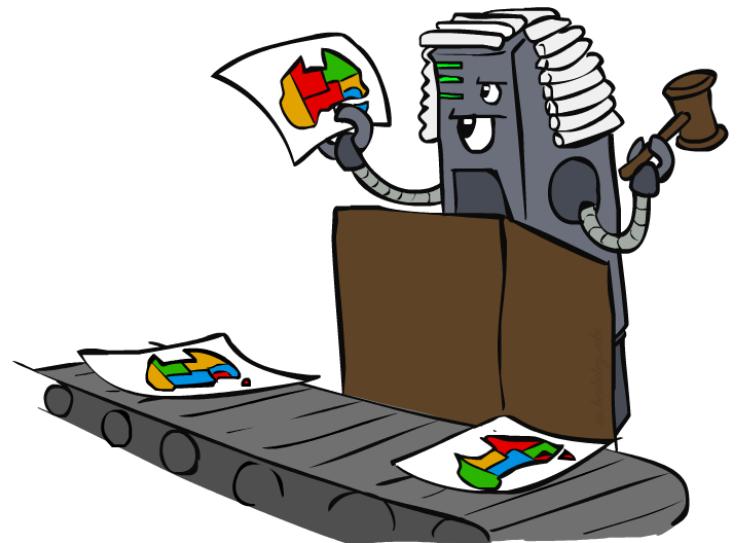
University of California, Berkeley

[Slides adapted from Nicholas Tomlin, Dan Klein, Pieter Abbeel, and Anca Dragan]

# Reminder: CSPs

---

- CSPs:
  - Variables
  - Domains
  - Constraints
    - Implicit (provide code to compute)
    - Explicit (provide a list of all legal tuples)
    - Unary / Binary / N-ary
- Goals:
  - Here: find any solution
  - But also: find all solutions, best solution, etc.



# Backtracking Search

---

```
function BACKTRACKING-SEARCH(csp) returns solution/failure
    return RECURSIVE-BACKTRACKING({ }, csp)
function RECURSIVE-BACKTRACKING(assignment, csp) returns soln/failure
    if assignment is complete then return assignment
    var  $\leftarrow$  SELECT-UNASSIGNED-VARIABLE(VARIABLES[csp], assignment, csp)
    for each value in ORDER-DOMAIN-VALUES(var, assignment, csp) do
        if value is consistent with assignment given CONSTRAINTS[csp] then
            add {var = value} to assignment
            result  $\leftarrow$  RECURSIVE-BACKTRACKING(assignment, csp)
            if result  $\neq$  failure then return result
            remove {var = value} from assignment
    return failure
```

# Improving Backtracking

- General-purpose ideas bring huge gains in speed
  - ...but it's all still NP-hard
- Filtering: can we detect inevitable failure early?
- Ordering:
  - Which variable should be assigned next?
  - In what order should its values be tried?
- Structure: can we exploit the structure of the problem/constraint graph?



# Reminder: Forward Checking

- Filtering: Keep track of domains for unassigned variables and cross off bad options
  - Forward checking: Cross off values that violate a constraint when added to the existing assignment



WA

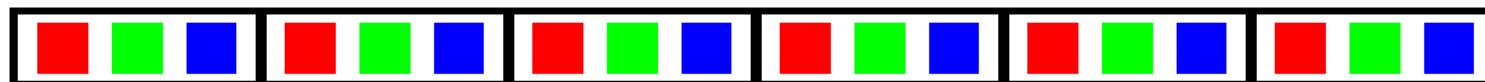
NT

Q

NSW

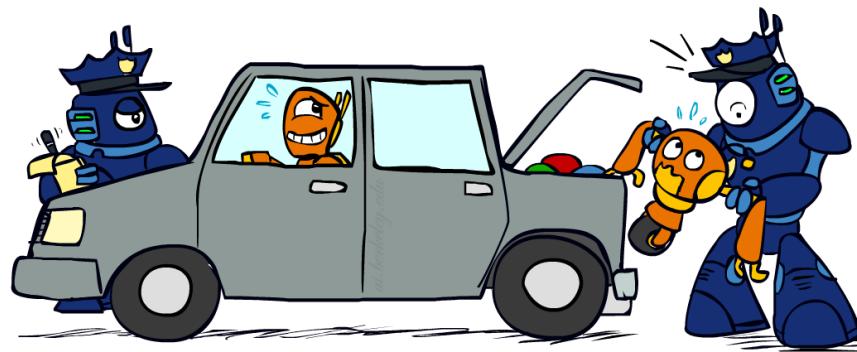
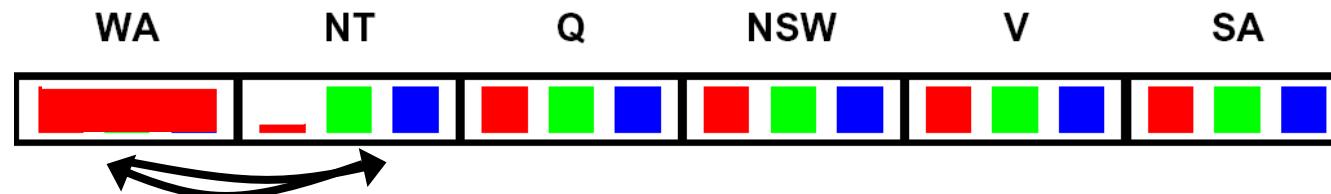
V

SA



# Reminder: Arc Consistency

- An arc  $X \rightarrow Y$  is **consistent** iff for *every*  $x$  in the tail there is *some*  $y$  in the head which could be assigned without violating a constraint



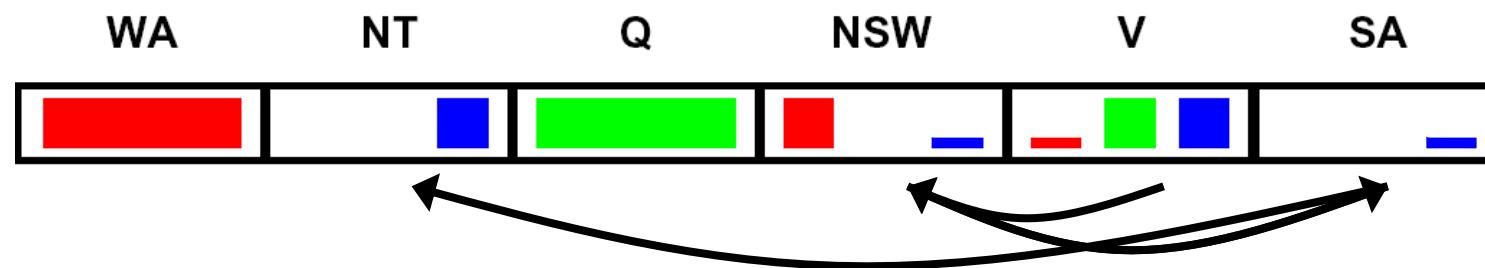
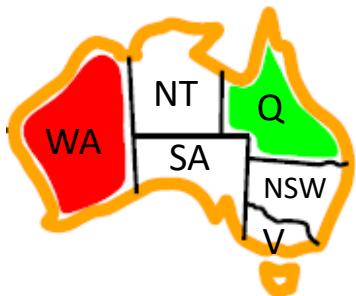
*Delete from the tail!*

Forward checking?

Enforcing consistency of arcs pointing to each new assignment

# Reminder: Arc Consistency

- A simple form of propagation makes sure **all** arcs are consistent:



- Important: If  $X$  loses a value, neighbors of  $X$  need to be rechecked!
- Arc consistency detects failure earlier than forward checking
- Can be run as a preprocessor or after each assignment
- What's the downside of enforcing arc consistency?

*Remember: Delete  
from the tail!*

# Ordering

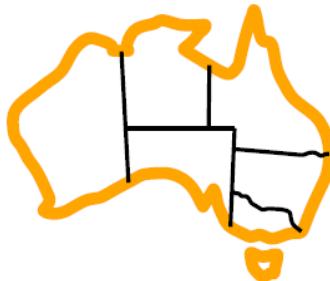
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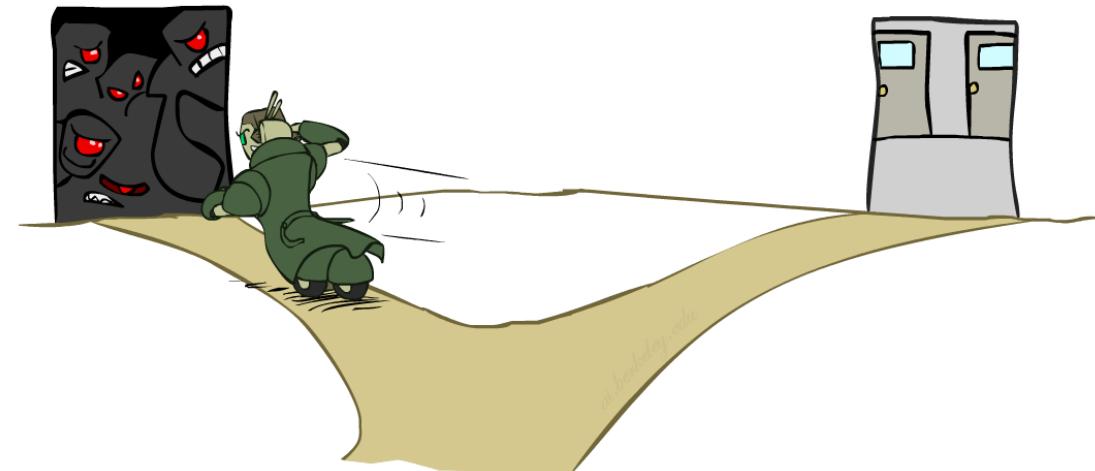
# Ordering: Minimum Remaining Values

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- Variable Ordering: Minimum remaining values (MRV):
  - Choose the variable with the fewest legal values left in its domain

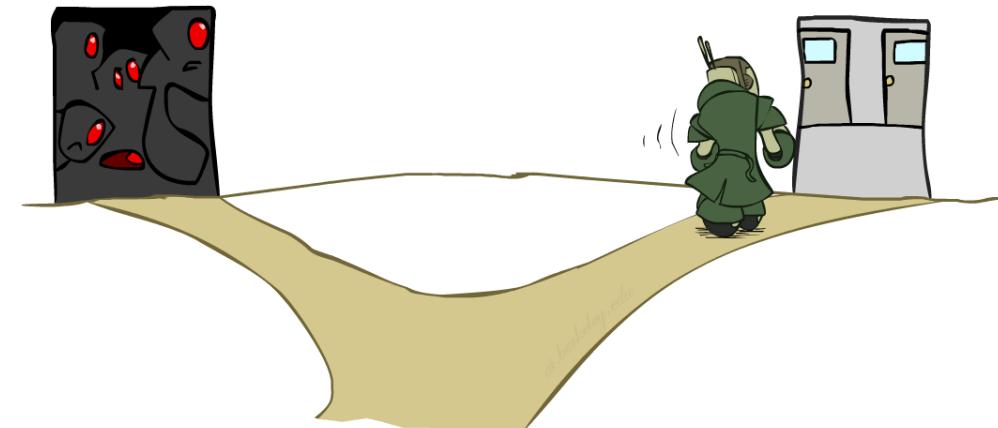
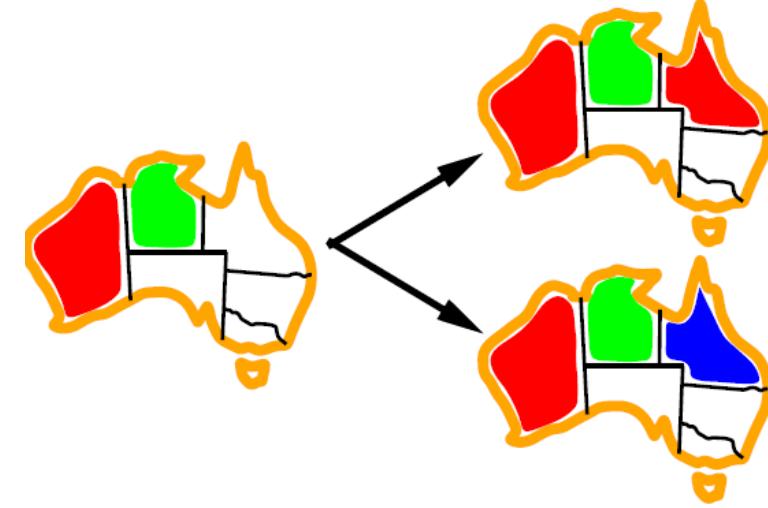


- Why min rather than max?
- Also called “most constrained variable”
- “Fail-fast” ordering



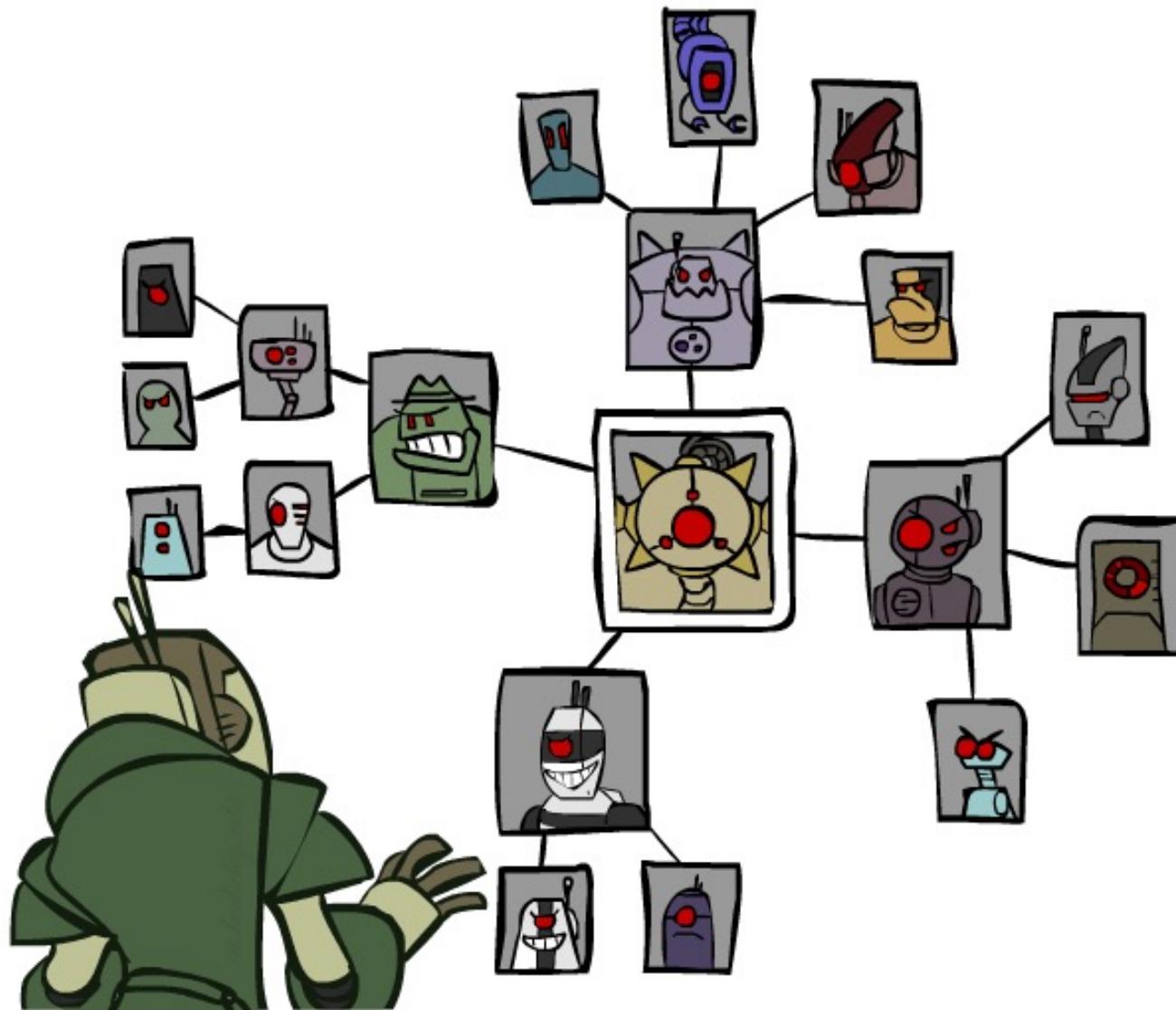
# Ordering: Least Constraining Value

- Value Ordering: Least Constraining Value
  - Given a choice of variable, choose the *least constraining value*
  - I.e., the one that rules out the fewest values in the remaining variables
  - Note that it may take some computation to determine this! (E.g., rerunning filtering)
- Why least rather than most?
- Combining these ordering ideas makes 1000 queens feasible



# Structure

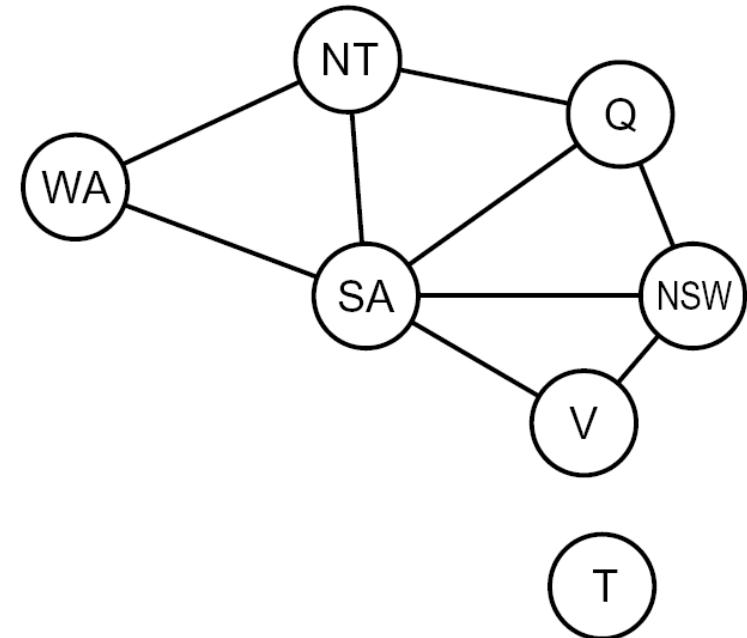
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# Problem Structure

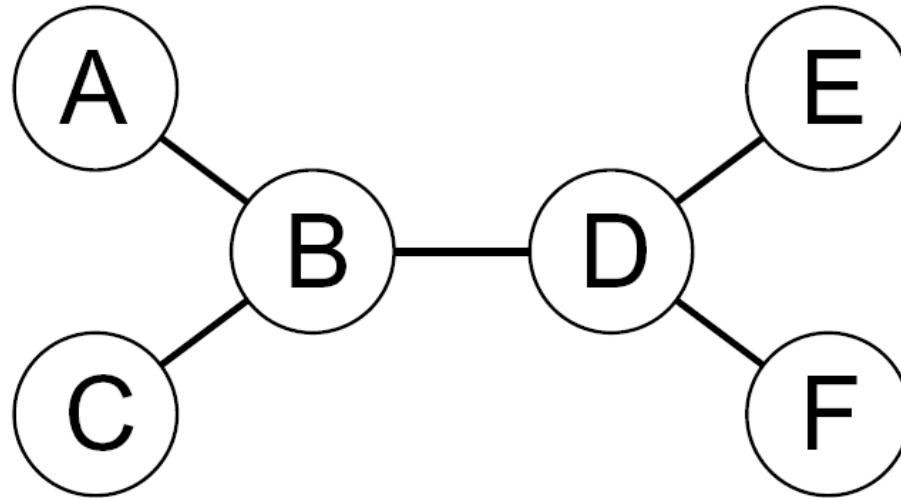
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- Extreme case: independent subproblems
  - Example: Tasmania and mainland do not interact
- Independent subproblems are identifiable as connected components of constraint graph
- Suppose a graph of  $n$  variables can be broken into subproblems of only  $c$  variables:
  - Worst-case solution cost is  $O((n/c)(d^c))$ , linear in  $n$
  - E.g.,  $n = 80$ ,  $d = 2$ ,  $c = 20$
  - $2^{80} = 4$
  - $(4)(2^{20}) = 0.4$  seconds at 10 million nodes/sec



# Tree-Structured CSPs

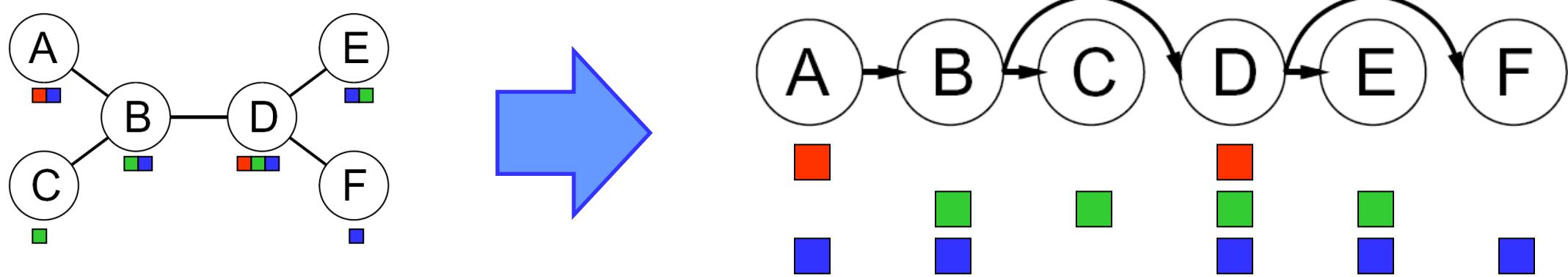
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- Theorem: if the constraint graph has no loops, the CSP can be solved in  $O(n d^2)$  time
  - Compare to general CSPs, where worst-case time is  $O(d^n)$
- This property also applies to probabilistic reasoning (later): an example of the relation between syntactic restrictions and the complexity of reasoning

# Tree-Structured CSPs

- Algorithm for tree-structured CSPs:
  - Order: Choose a root variable, order variables so that parents precede children

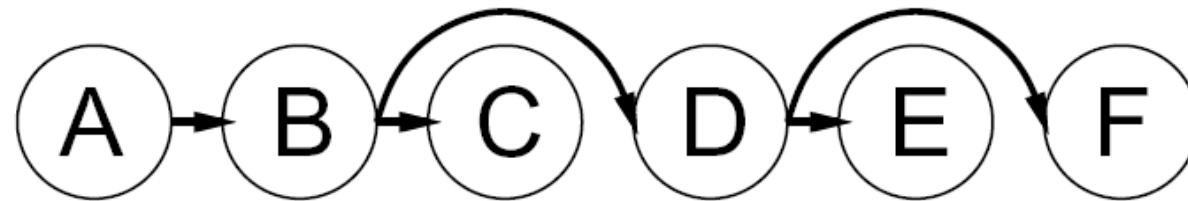


- Remove backward: For  $i = n : 2$ , apply RemoveInconsistent( $\text{Parent}(X_i), X_i$ )
- Assign forward: For  $i = 1 : n$ , assign  $X_i$  consistently with  $\text{Parent}(X_i)$
- Runtime:  $O(n d^2)$  (why?)

# Tree-Structured CSPs

---

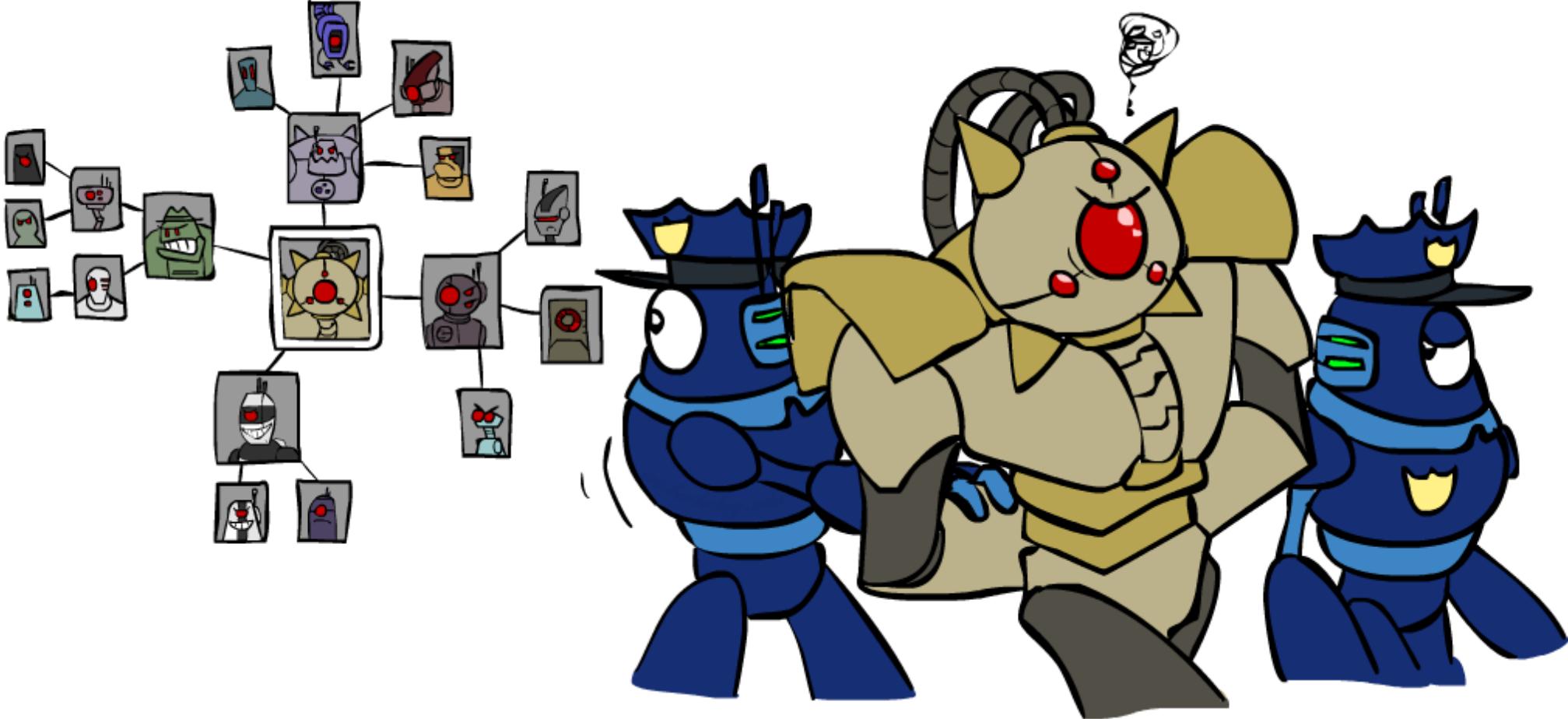
- Claim 1: After backward pass, all root-to-leaf arcs are consistent
- Proof: Each  $X \rightarrow Y$  was made consistent at one point and  $Y$ 's domain could not have been reduced thereafter (because  $Y$ 's children were processed before  $Y$ )



- Claim 2: If root-to-leaf arcs are consistent, forward assignment will not backtrack
- Proof: Induction on position
- Note: we'll see this basic idea again with Bayes' nets

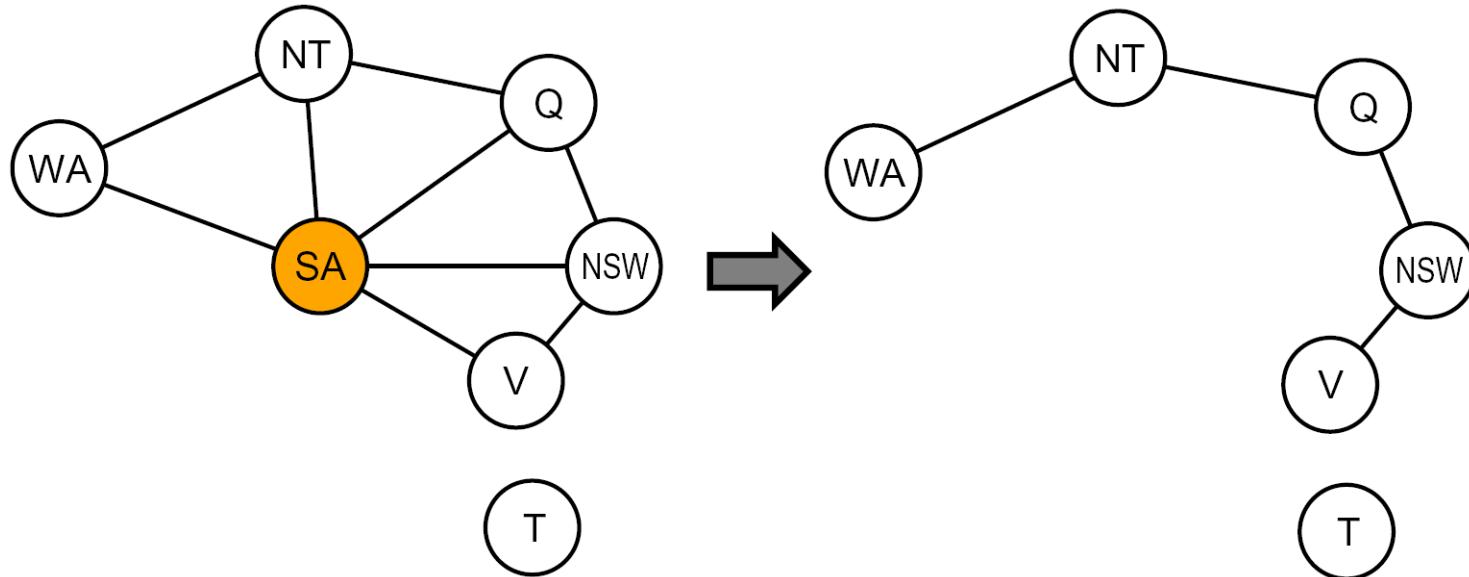
# Improving Structure

---



# Nearly Tree-Structured CSPs

---



- Conditioning: instantiate a variable, prune its neighbors' domains
- Cutset conditioning: instantiate (in all ways) a set of variables such that the remaining constraint graph is a tree
- Cutset size  $c$  gives runtime  $O( (d^c) (n-c) d^2 )$ , very fast for small  $c$

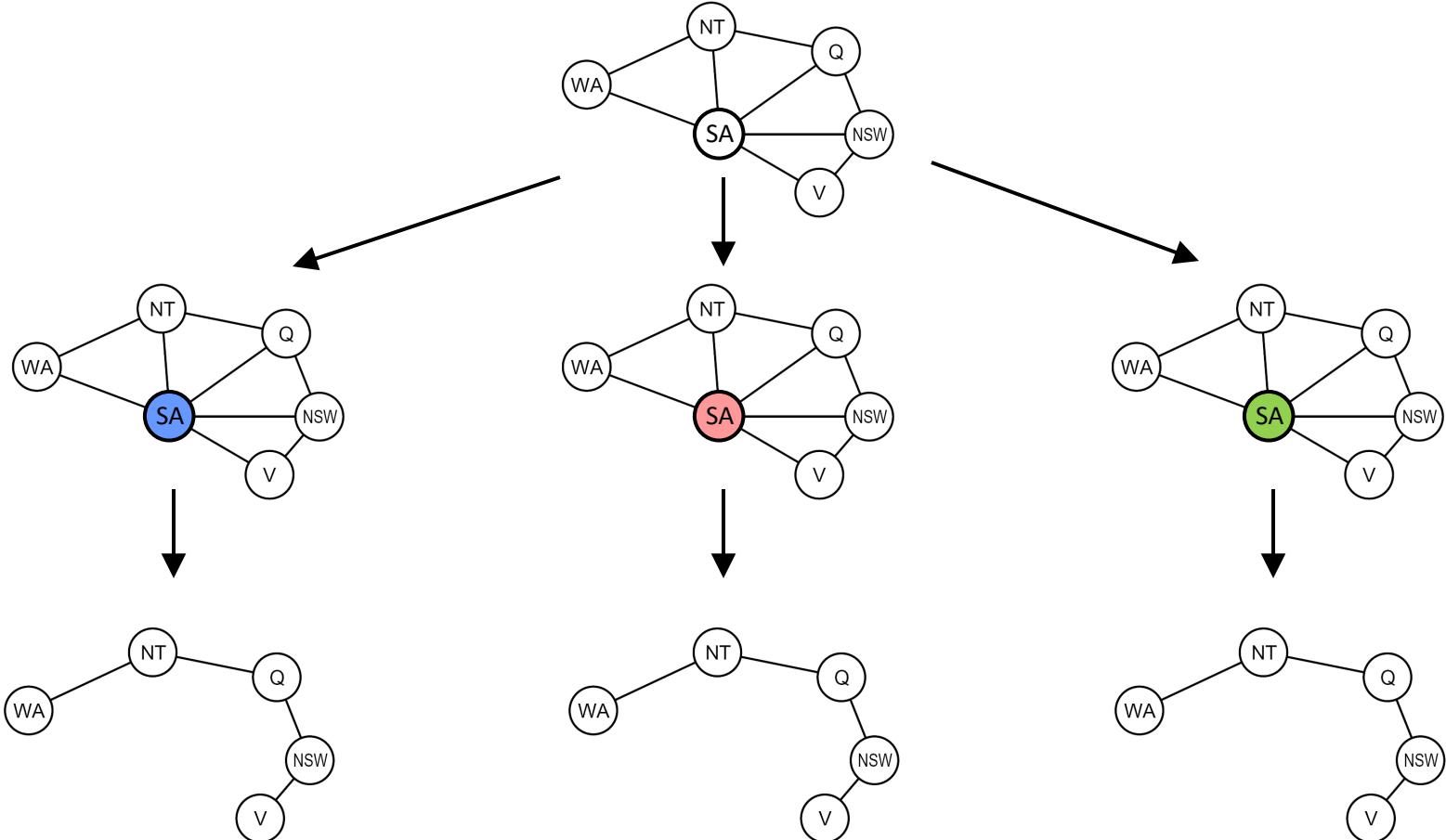
# Cutset Conditioning

Choose a cutset

Instantiate the cutset  
(all possible ways)

Compute residual CSP  
for each assignment

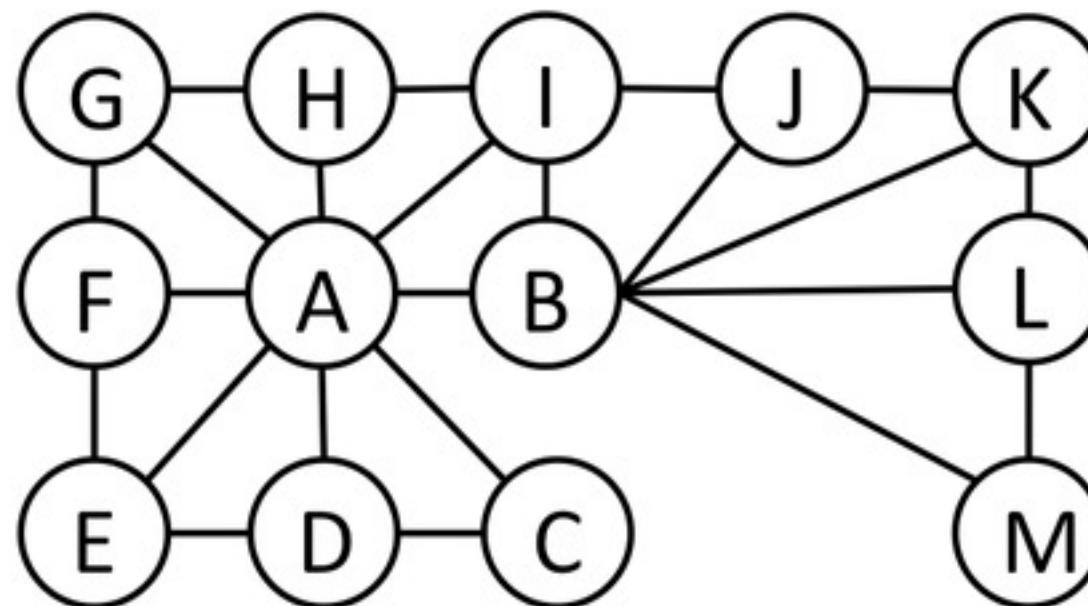
Solve the residual CSPs  
(tree structured)



# Cutset Quiz

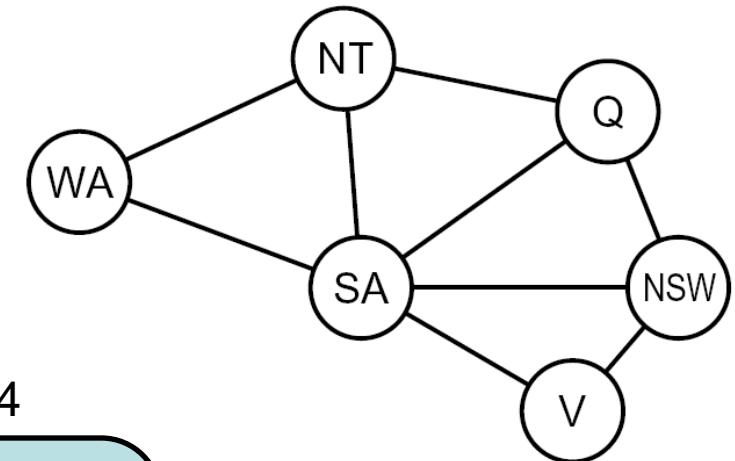
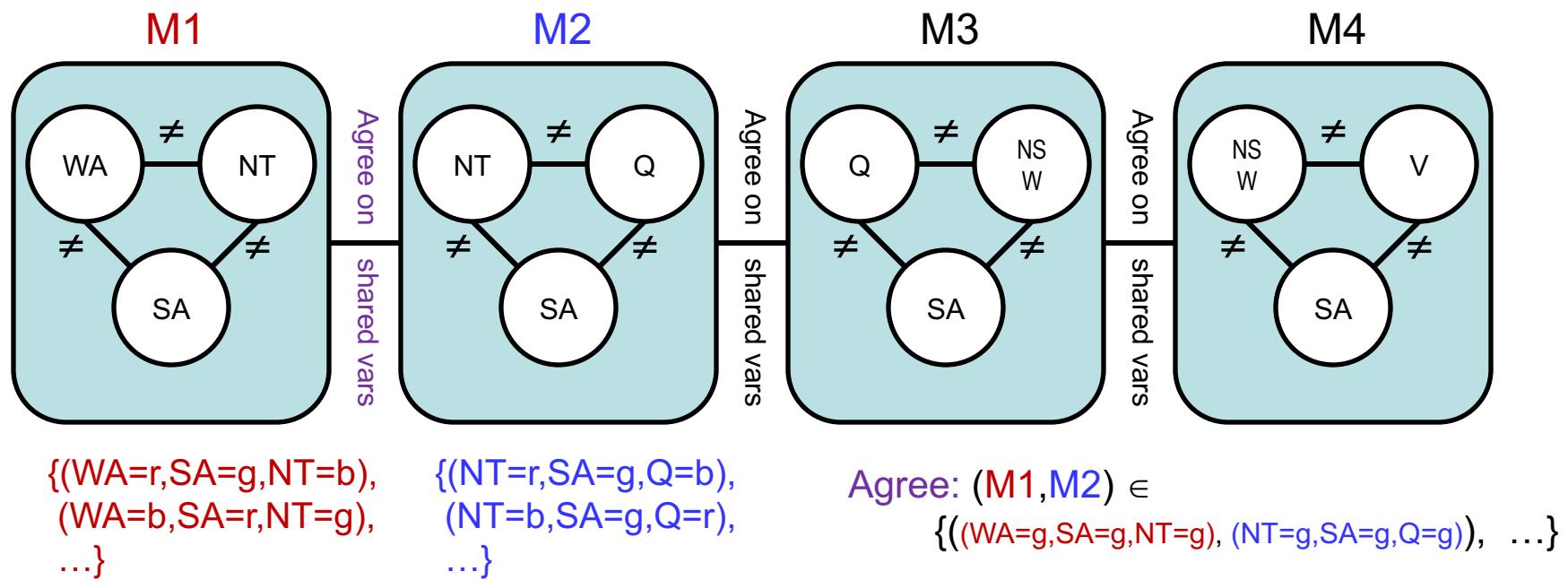
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- Find the smallest cutset for the graph below.



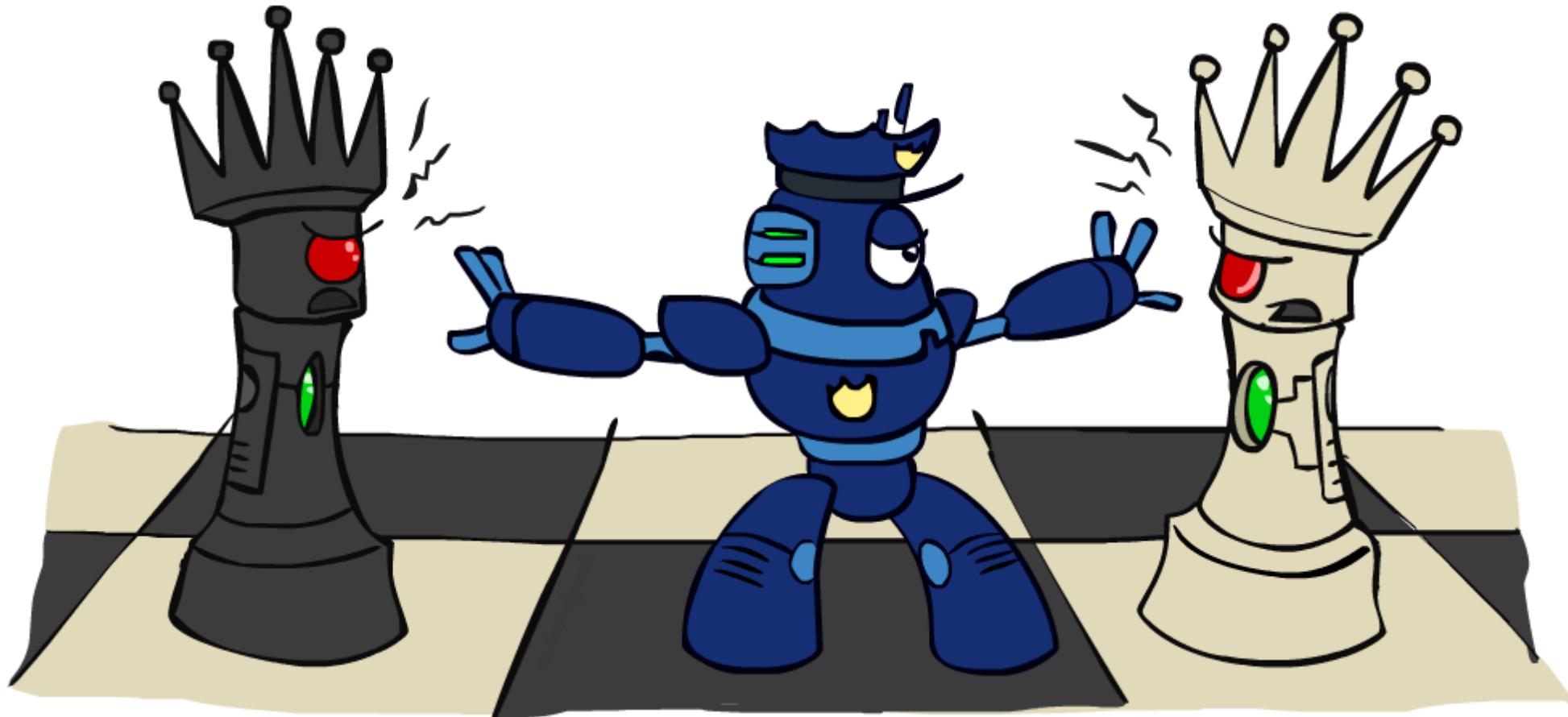
# Bonus: Tree Decomposition

- Idea: create a tree-structured graph of mega-variables
- Each mega-variable encodes part of the original CSP
- Subproblems overlap to ensure consistent solutions



# Iterative Improvement

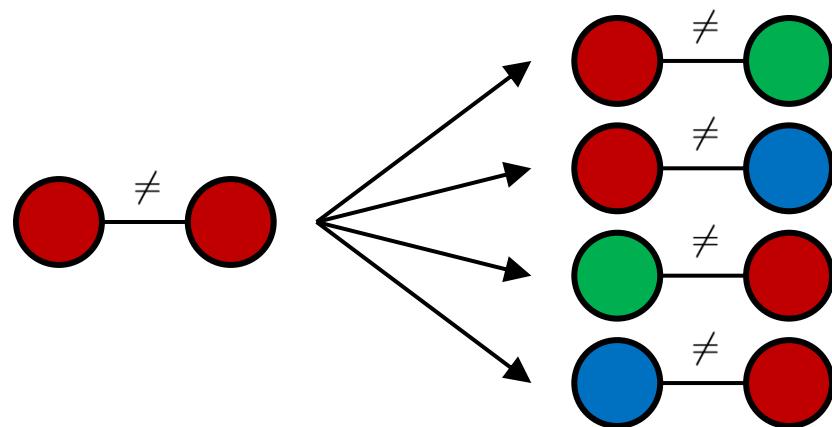
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# Local Search

---

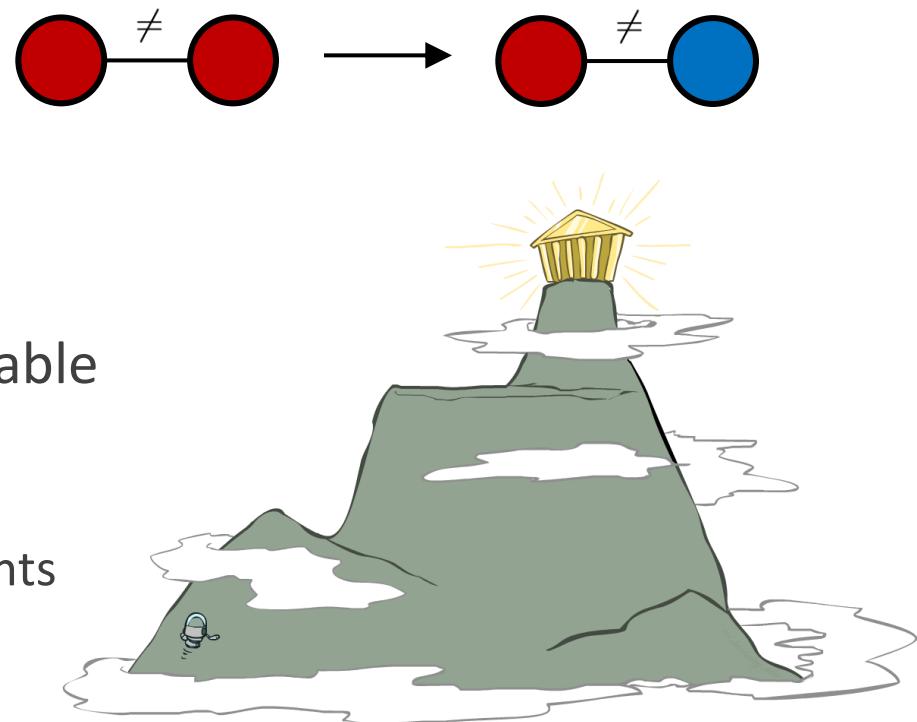
- Tree search keeps unexplored alternatives on the fringe (ensures completeness)
- Local search: improve a single option until you can't make it better (no fringe!)
- New successor function: local changes



- Generally much faster and more memory efficient (but incomplete and suboptimal)

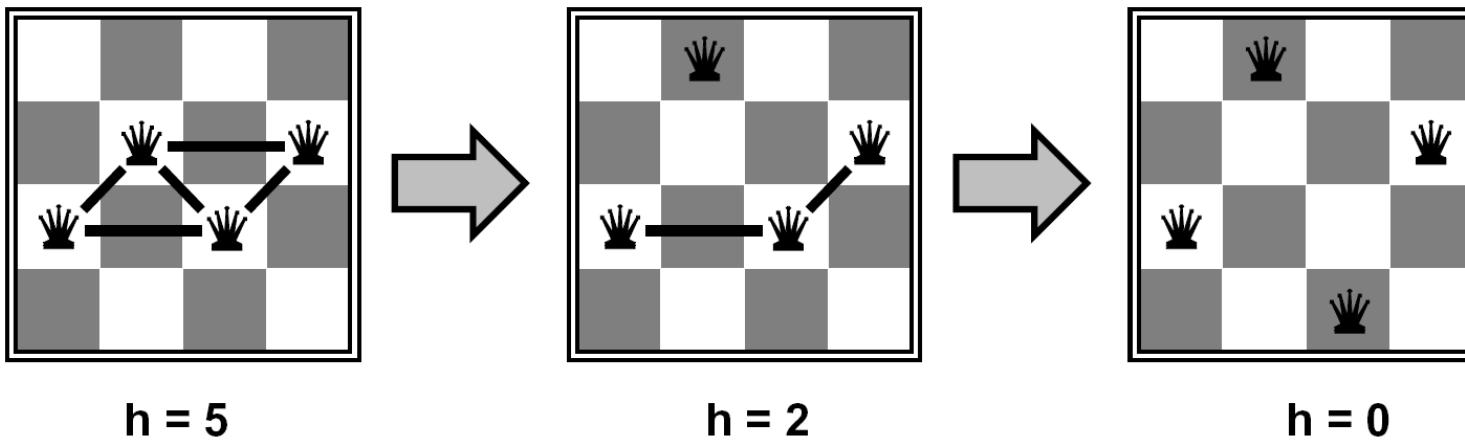
# Iterative Algorithms for CSPs

- Local search methods typically work with “complete” states, i.e., all variables assigned
- To apply to CSPs:
  - Take an assignment with unsatisfied constraints
  - Operators *reassign* variable values
  - No fringe! Live on the edge.
- Algorithm: While not solved,
  - Variable selection: randomly select any conflicted variable
  - Value selection: min-conflicts heuristic:
    - Choose a value that violates the fewest constraints
    - I.e., hill climb with  $h(x)$  = total number of violated constraints



# Example: 4-Queens

---

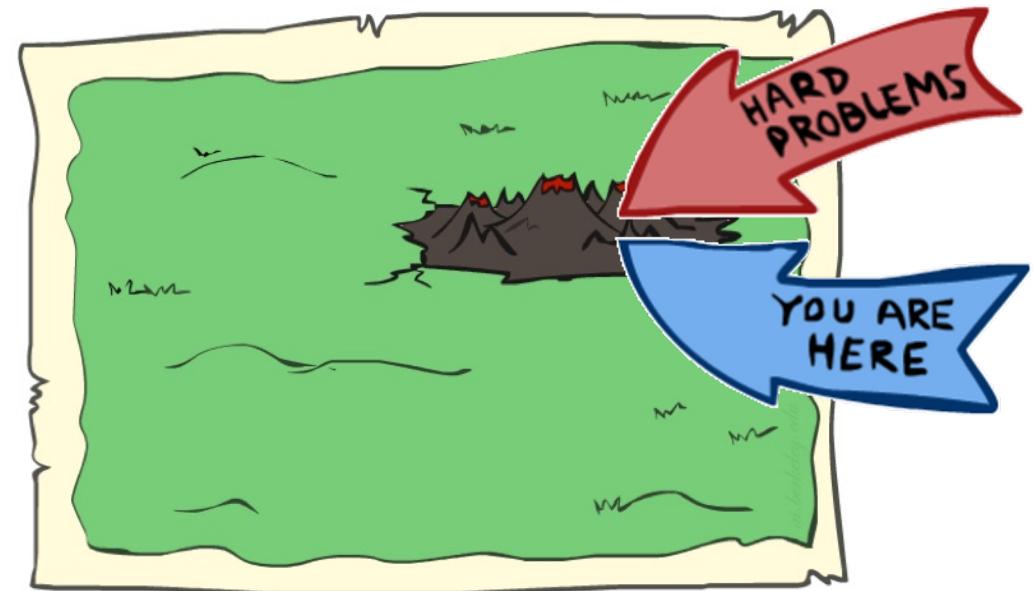
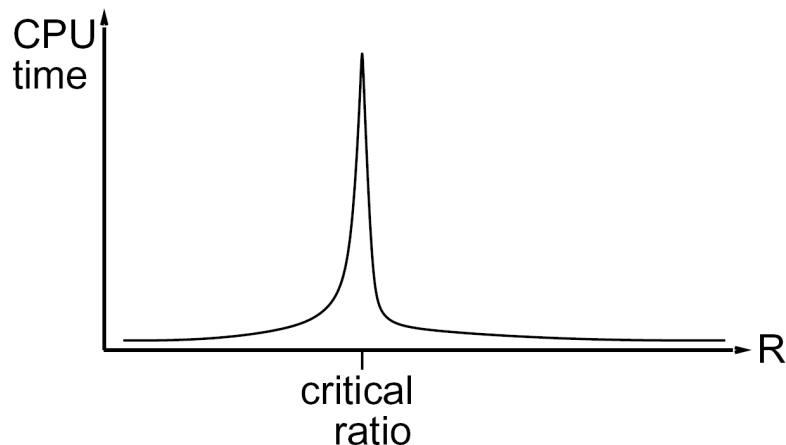


- States: 4 queens in 4 columns ( $4^4 = 256$  states)
- Operators: move queen in column
- Goal test: no attacks
- Evaluation:  $c(n) = \text{number of attacks}$

# Performance of Min-Conflicts

- Given random initial state, can solve n-queens in almost constant time for arbitrary n with high probability (e.g., n = 10,000,000)!
- The same appears to be true for any randomly-generated CSP *except* in a narrow range of the ratio

$$R = \frac{\text{number of constraints}}{\text{number of variables}}$$



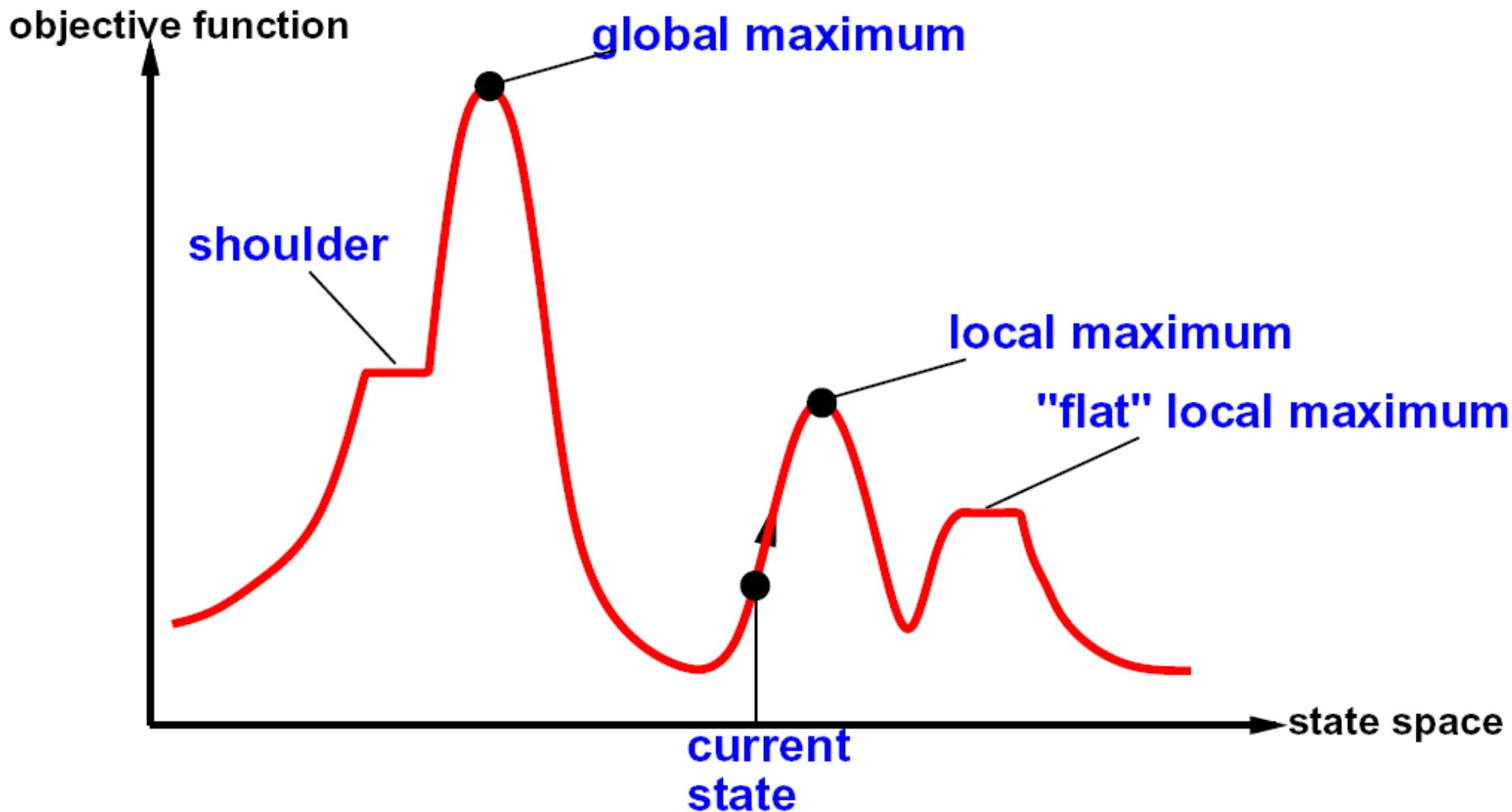
# Hill Climbing

---

- Simple, general idea:
  - Start wherever
  - Repeat: move to the best neighboring state
  - If no neighbors better than current, quit
- What's bad about this approach?
- What's good about it?

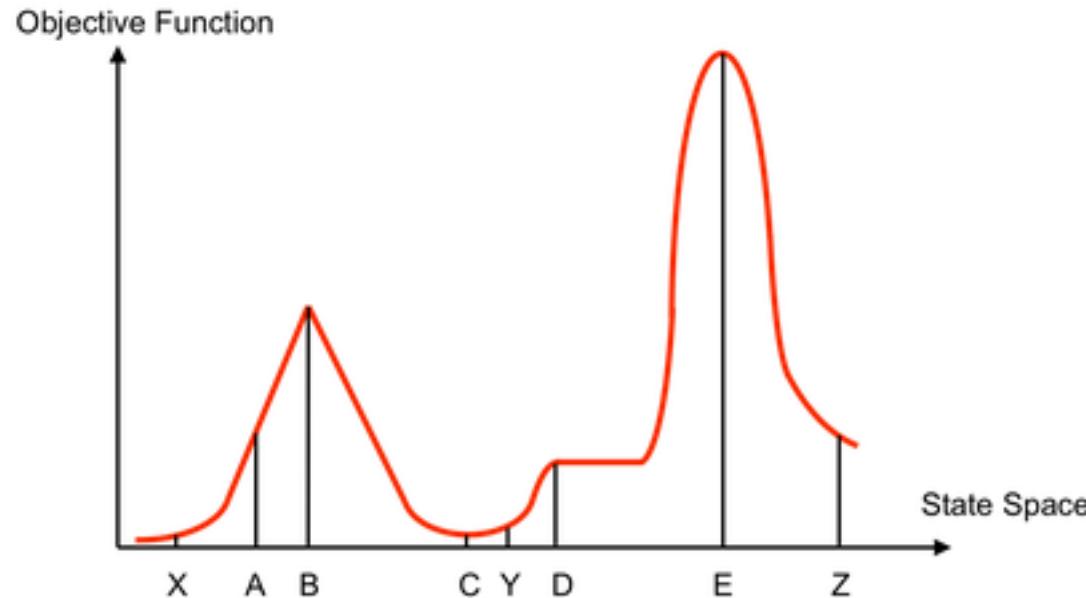


# Hill Climbing Diagram



# Hill Climbing Quiz

---



Starting from X, where do you end up ?

Starting from Y, where do you end up ?

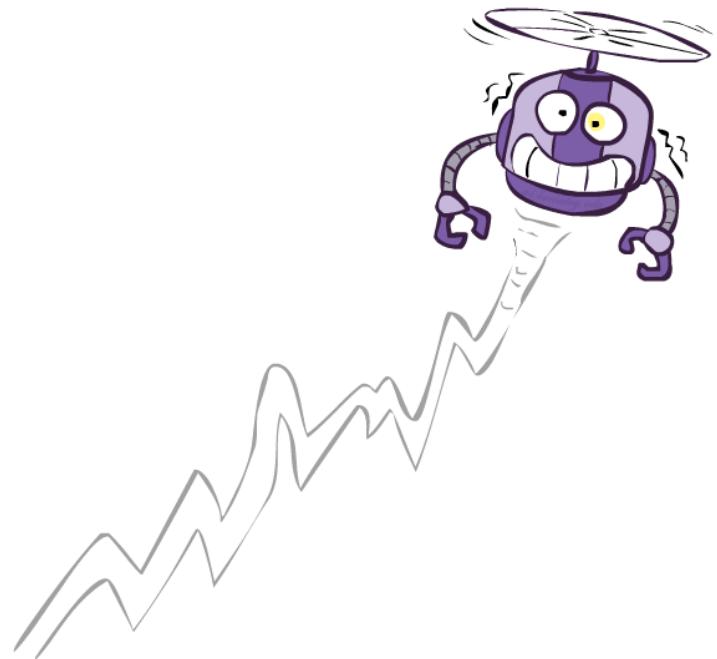
Starting from Z, where do you end up ?

# Simulated Annealing

- Idea: Escape local maxima by allowing downhill moves
  - But make them rarer as time goes on

```
function SIMULATED-ANNEALING(problem, schedule) returns a solution state
  inputs: problem, a problem
          schedule, a mapping from time to “temperature”
  local variables: current, a node
                    next, a node
                    T, a “temperature” controlling prob. of downward steps

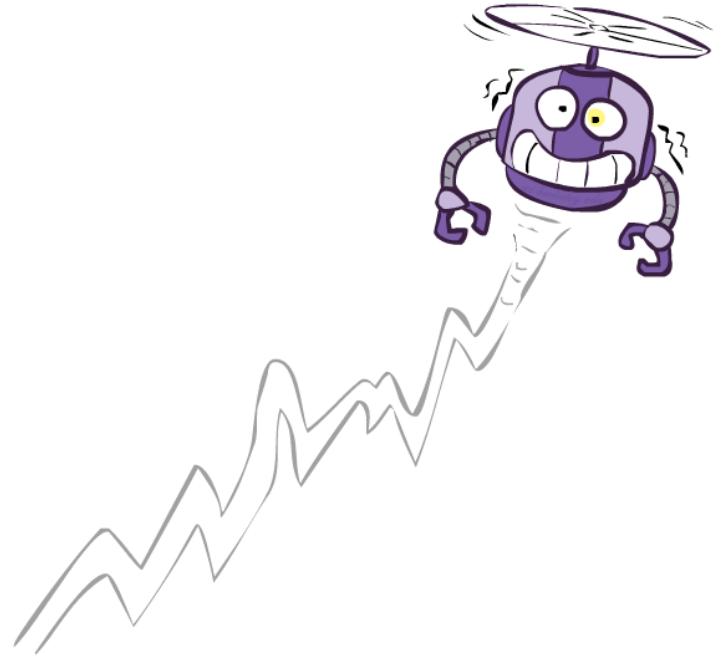
  current  $\leftarrow$  MAKE-NODE(INITIAL-STATE[problem])
  for t  $\leftarrow$  1 to  $\infty$  do
    T  $\leftarrow$  schedule[t]
    if T = 0 then return current
    next  $\leftarrow$  a randomly selected successor of current
     $\Delta E \leftarrow$  VALUE[next] - VALUE[current]
    if  $\Delta E > 0$  then current  $\leftarrow$  next
    else current  $\leftarrow$  next only with probability  $e^{\Delta E/T}$ 
```



# Simulated Annealing

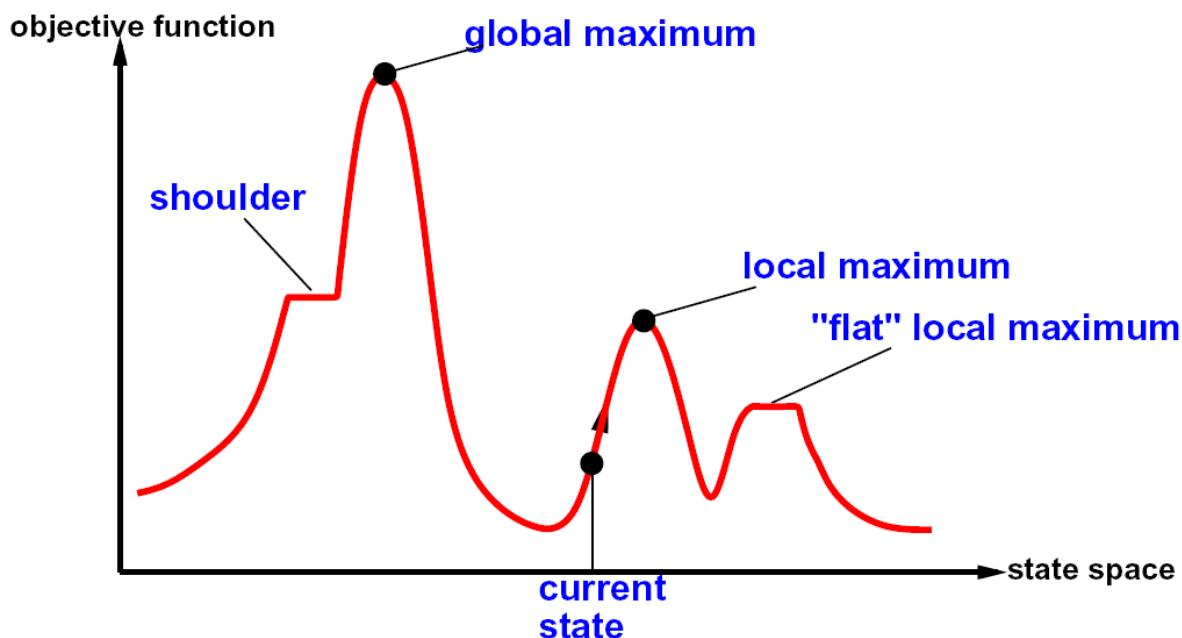
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- Theoretical guarantee:
  - Stationary distribution:  $p(x) \propto e^{\frac{E(x)}{kT}}$
  - If T decreased slowly enough,  
will converge to optimal state!
- Is this an interesting guarantee?
- Sounds like magic, but reality is reality:
  - The more downhill steps you need to escape a local optimum, the less likely you are to ever make them all in a row
  - People think hard about *ridge operators* which let you jump around the space in better ways



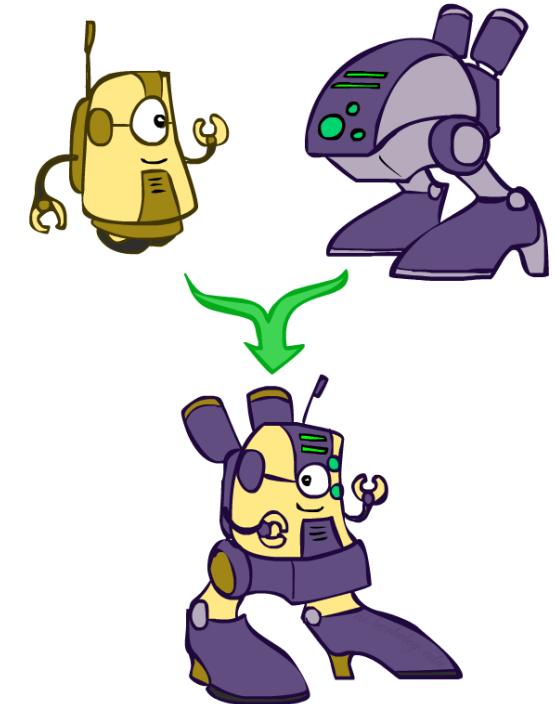
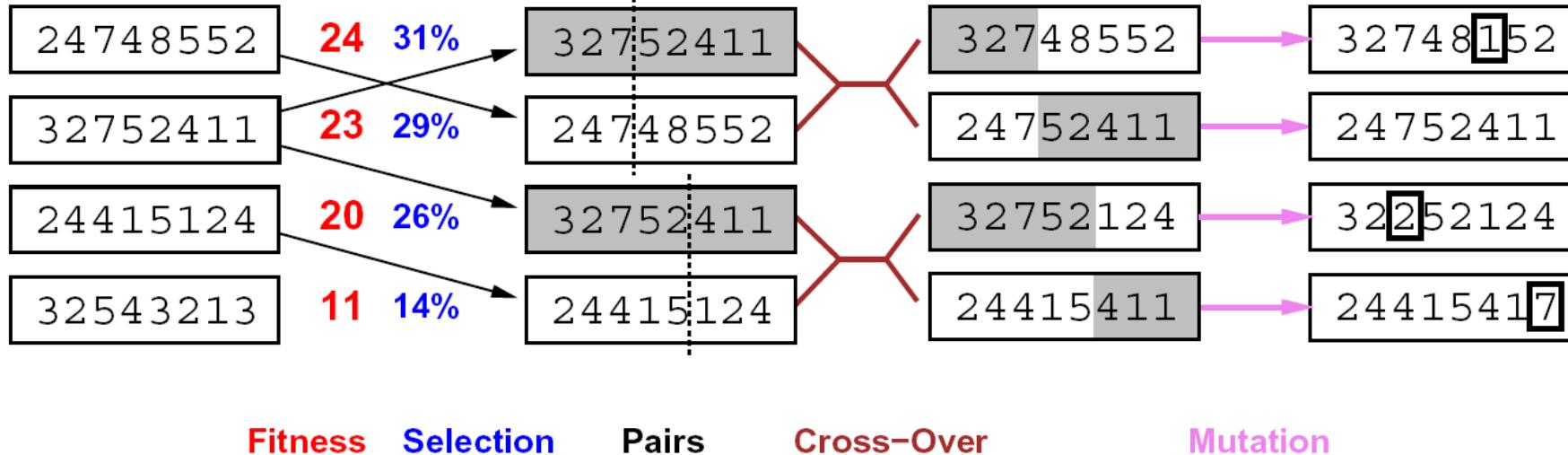
# Gradient Descent as Simulated Annealing

- Q: Can we do better than randomly guessing?
- A: Yes, if the function is continuous and differentiable.



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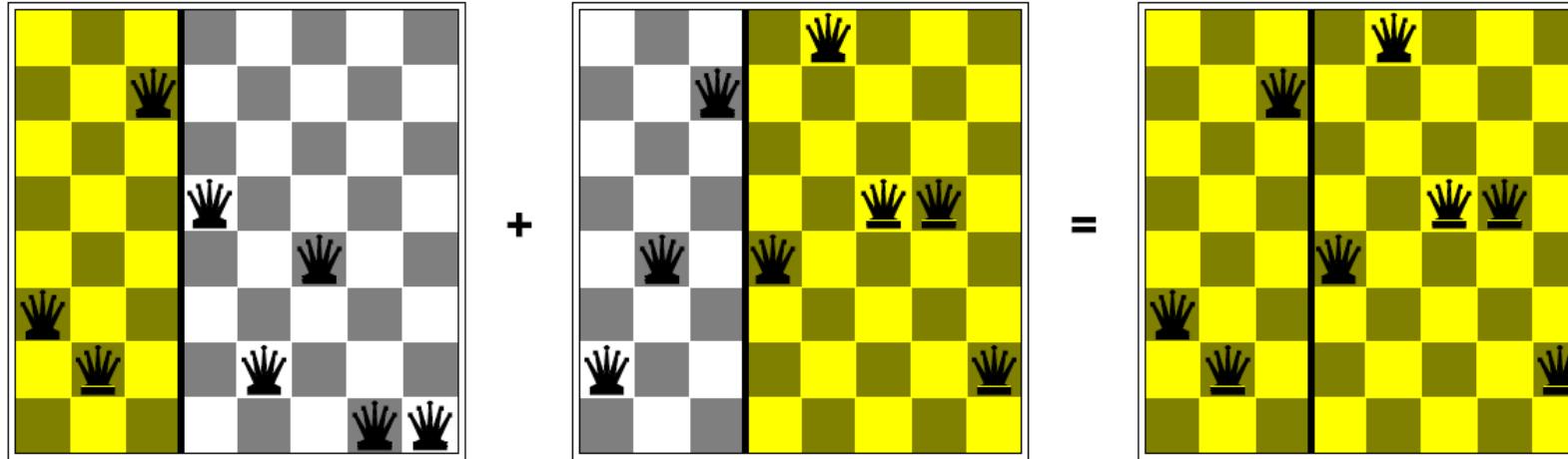
# Genetic Algorithms



- Genetic algorithms use a natural selection metaphor
  - Keep best N hypotheses at each step (selection) based on a fitness function
  - Also have pairwise crossover operators, with optional mutation to give variety
- Possibly the most misunderstood, misapplied (and even maligned) technique around

# Example: N-Queens

---



- Why does crossover make sense here?
- When wouldn't it make sense?
- What would mutation be?
- What would a good fitness function be?

# Bonus: Weighted CSPs

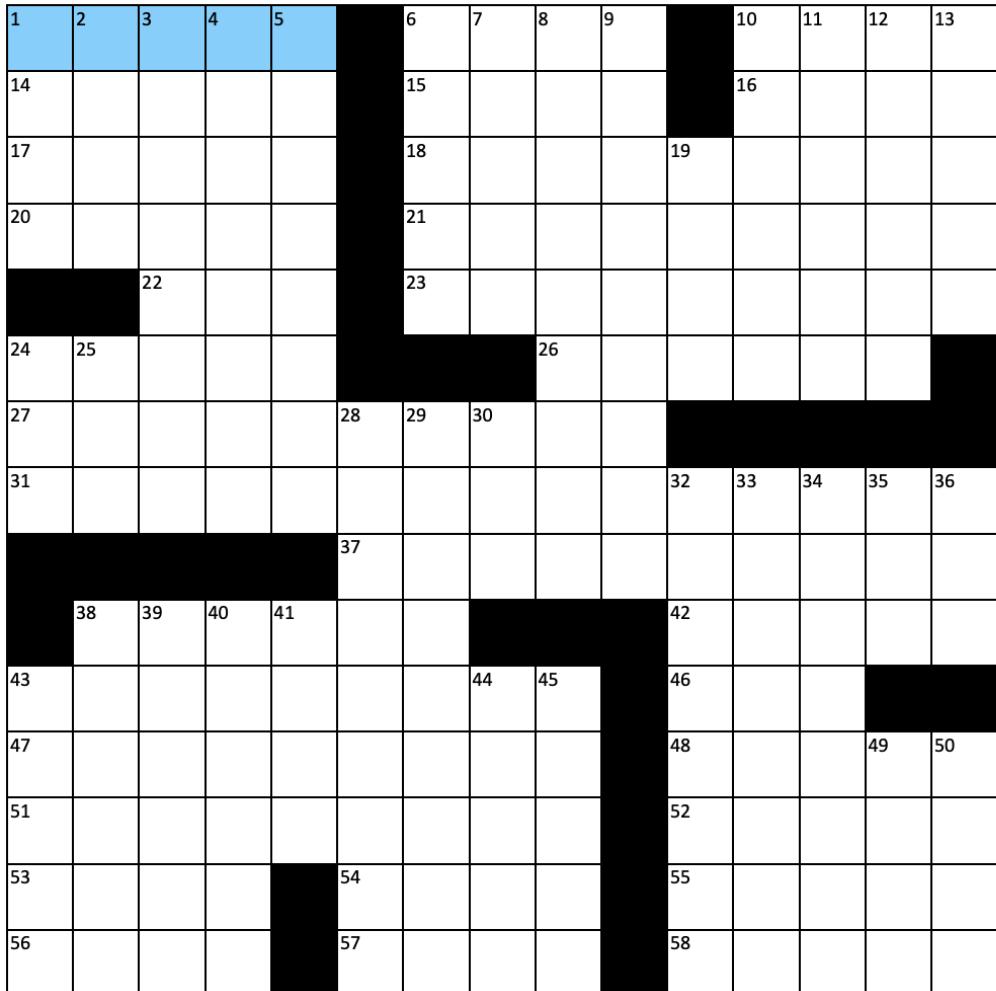
- In the real world, many constraints are soft:
  - Scheduling:
    - With enough people attending a meeting, no times will work
    - Solution: some conflicts are more important than others, make sacrifices where necessary
  - Travel planning:
    - Budget: would like to keep things cheap, but willing to spend more if it's worth it
    - Distance: want to avoid long walks, but can make exceptions for really interesting places
  - Running example: crosswords!
- Different set of algorithms often used for WCSPs



“Automated crossword solving.” Eric Wallace, Nicholas Tomlin, Albert Xu, Kevin Yang, Eshaan Pathak, Matthew Ginsberg, Dan Klein



# Example Crossword



## Across

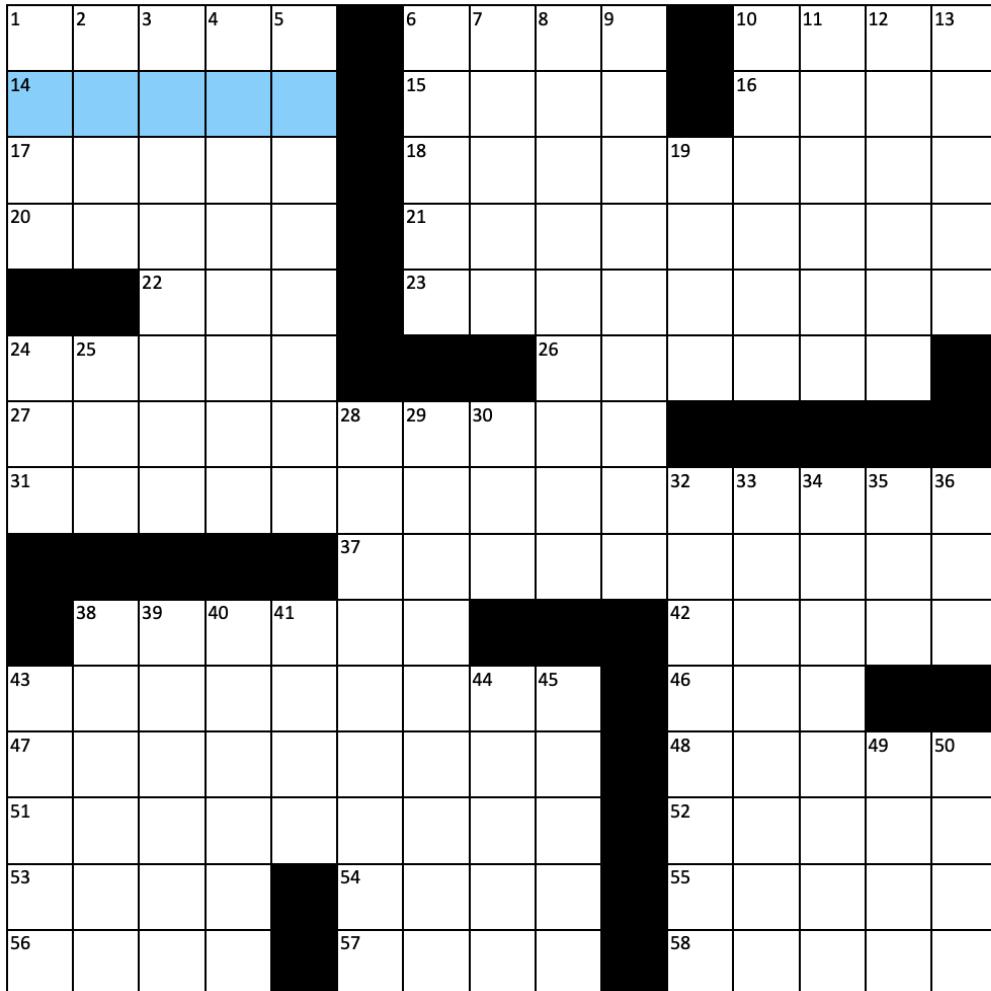
- 1 Regarding
- 6 Take back, in a way
- 10 Start of an aside
- 14 Omega competitor
- 15 Something hitting a nerve?
- 16 Papyrus, e.g.
- 17 "Take me with you!"
- 18 Begin flirting with someone, so to speak
- 20 Assign
- 21 Hoth, in "Star Wars"
- 22 \_\_\_ rule
- 23 They don't hold water
- 24 Feudal figure
- 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



# Example Crossword



## Across

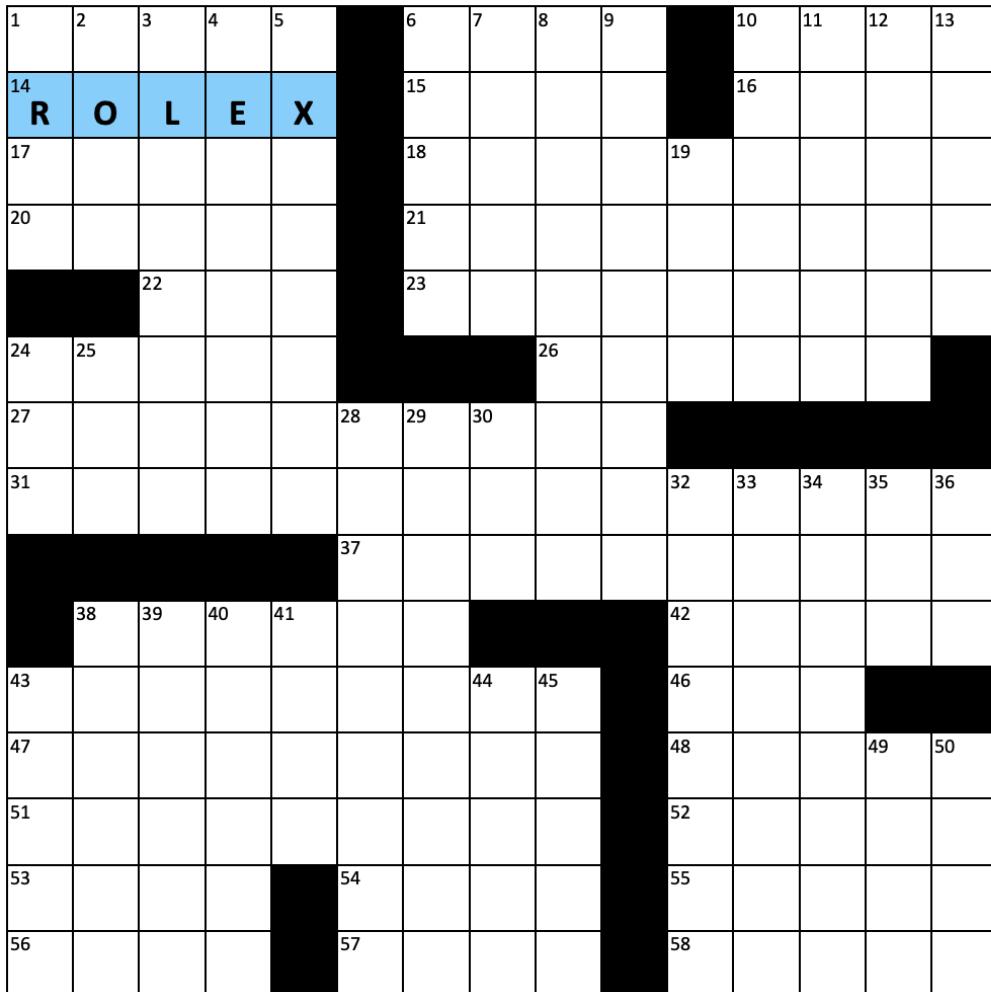
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# Example Crossword



## Across

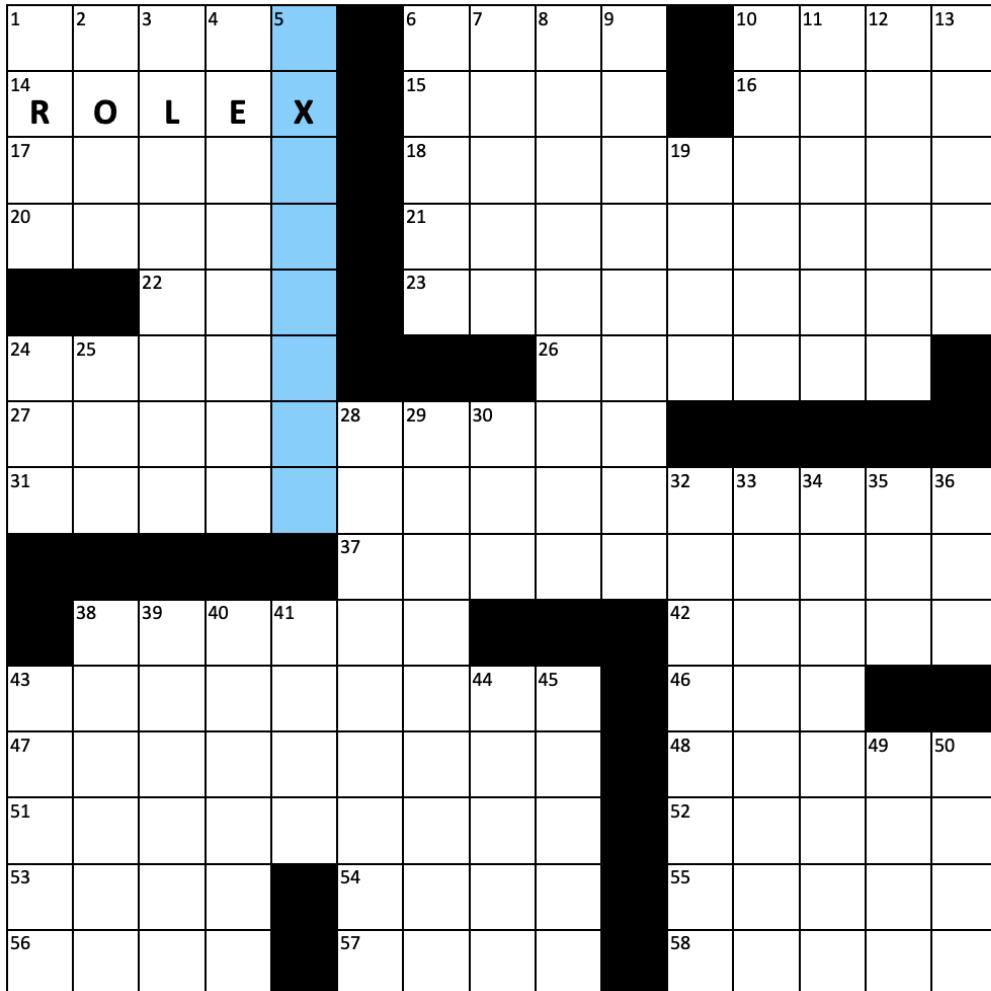
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# Example Crossword



## Across

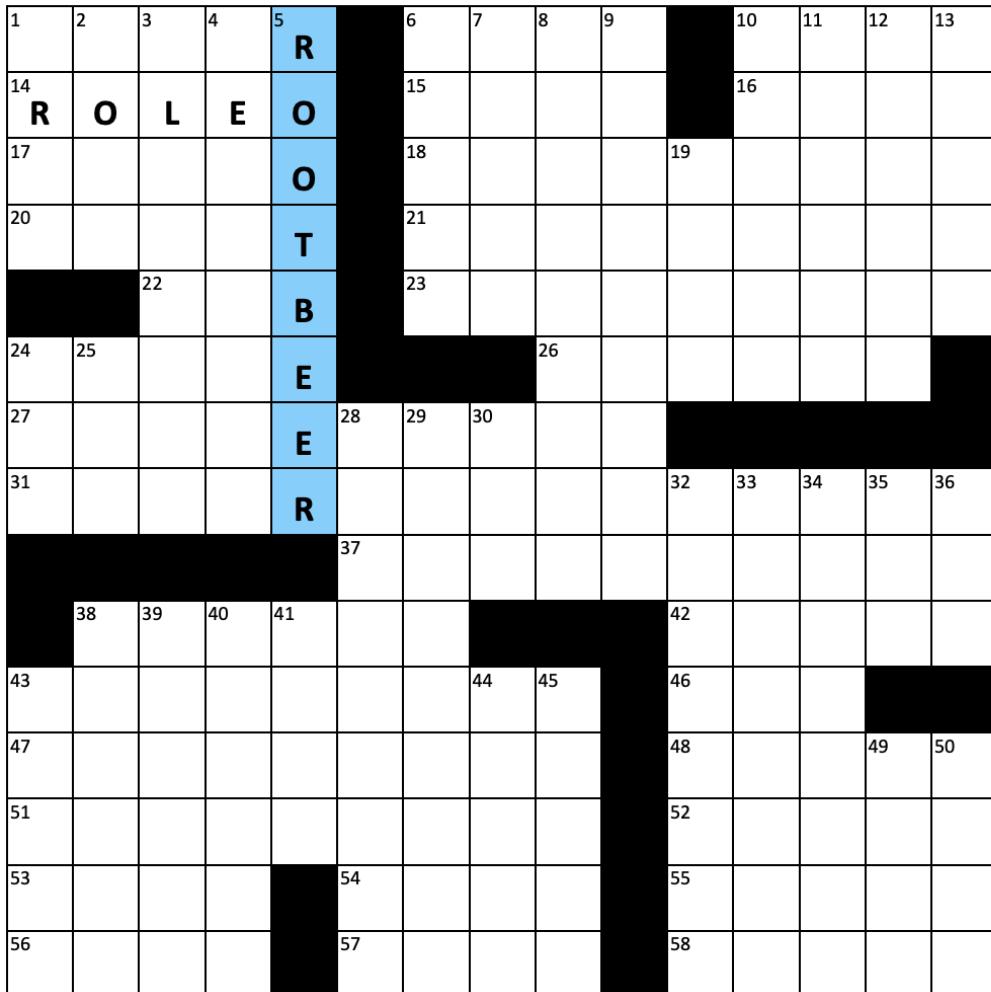
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# Example Crossword



## Across

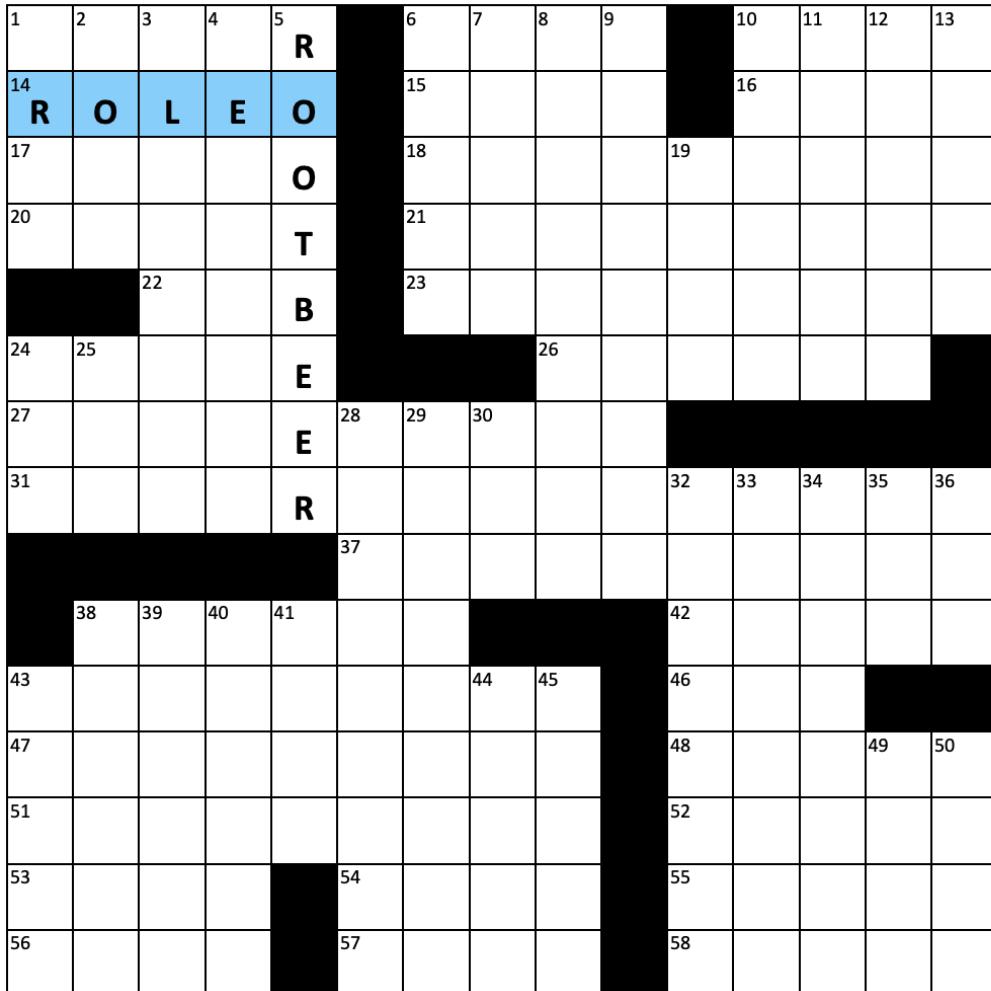
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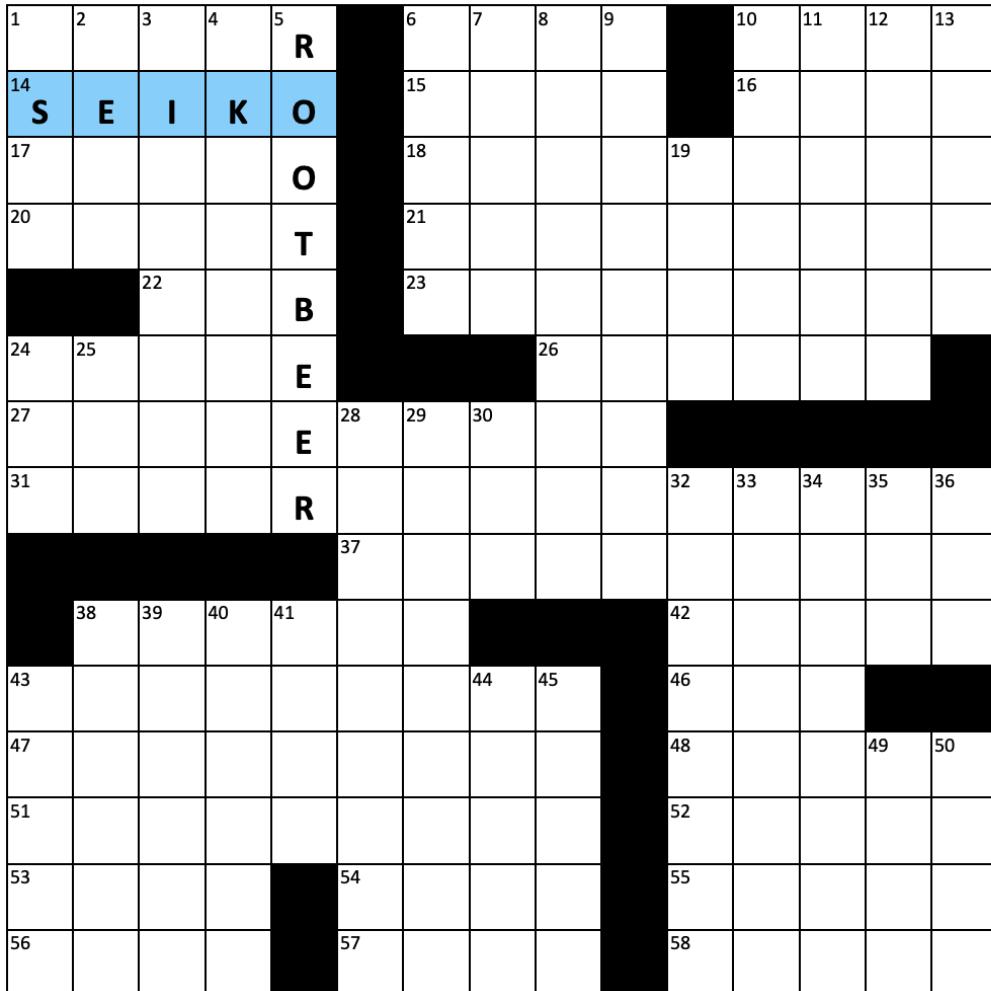
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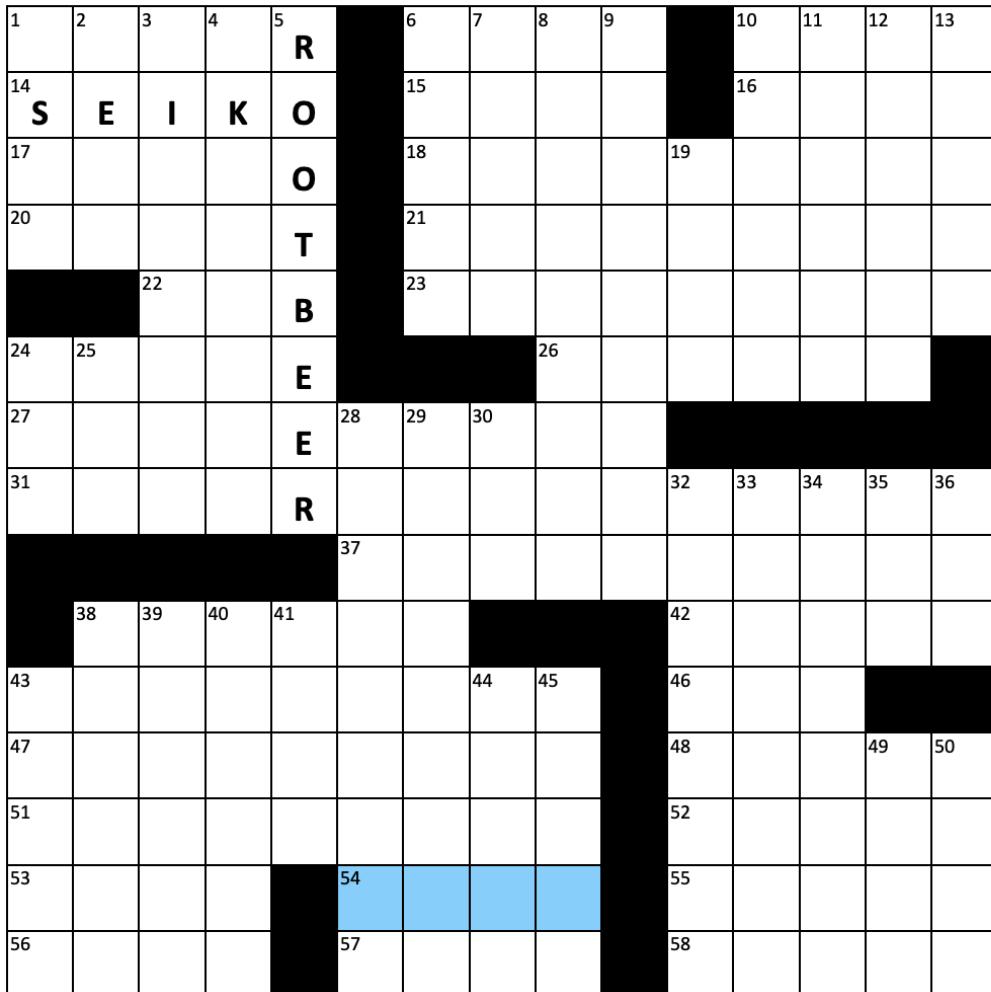
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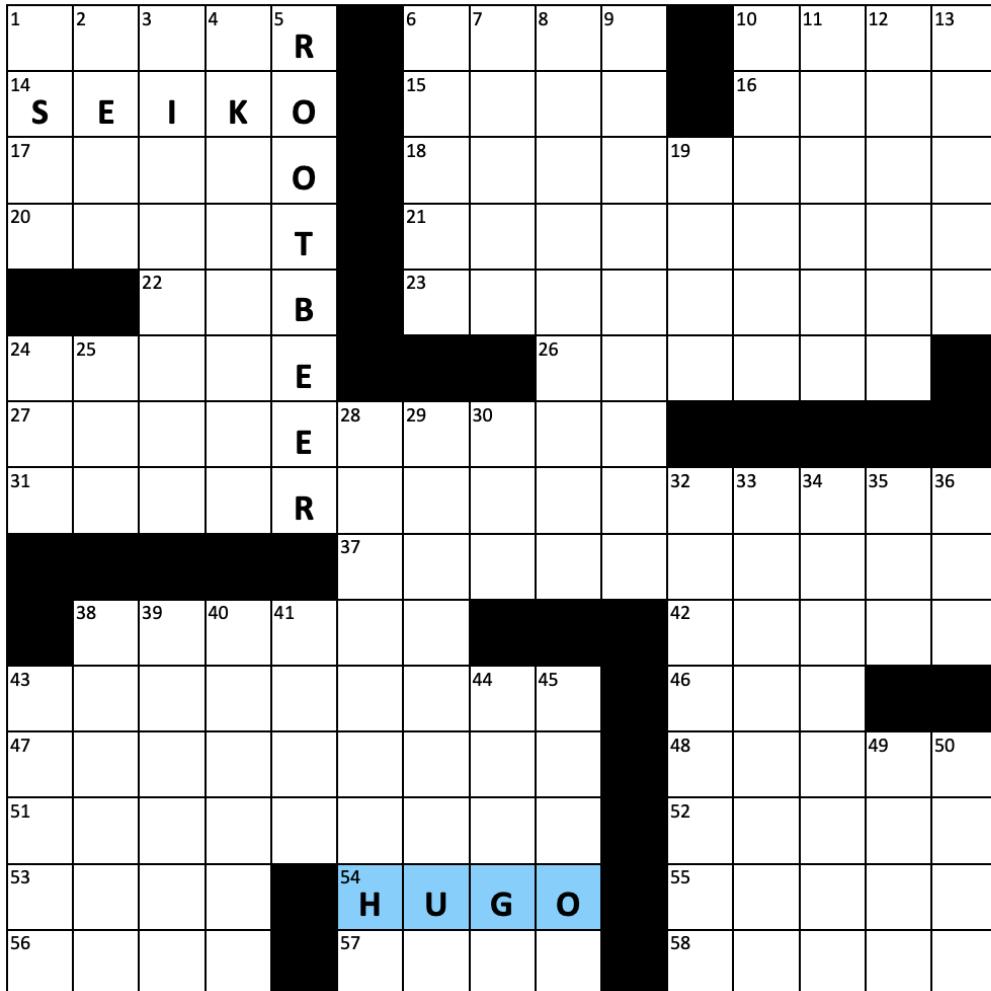
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The New York Times Crossword from Saturday, May 22, 2021. Constructed by Sid Sivakumar and Matthew Stock and edited by Will Shortz.



# Example Crossword



## Across

- 14 **R** 14 Across: **S E I K O**
- 17 **O** 17 Across: **T**
- 20 **B** 20 Across: **E**
- 24 **E** 24 Across: **E**
- 27 **E** 27 Across: **R**
- 31 **R** 31 Across: **37**
- 38 **39** 38 Across: **40**
- 40 **41** 40 Across: **41**
- 43 **44** 43 Across: **45**
- 47 **48** 47 Across: **49**
- 51 **52** 51 Across: **55**
- 53 **54** 53 Across: **H U G O**
- 56 **57** 56 Across: **58**
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# Example Crossword

A crossword puzzle grid with the following visible labels:

- Row 1: 1, 2, 3, 4, 5, R
- Row 14: 14, S, E, I, K, O
- Row 17: 17, O
- Row 20: 20, T
- Row 22: 22, B
- Row 24: 24, 25, E, 26
- Row 27: 27, E, 28, 29, 30
- Row 31: 31, R
- Row 37: 37
- Row 38: 38, 39, 40, 41
- Row 43: 43, 44, 45
- Row 47: 47
- Row 51: 51
- Row 53: 53, 54, H, U, G, O
- Row 56: 56, 57
- Row 61: 61, 62, 63, 64, 65, 66, 67, 68, 69, 60
- Row 71: 71, 72, 73, 74, 75, 76, 77, 78, 79, 70
- Row 81: 81, 82, 83, 84, 85, 86, 87, 88, 89, 80
- Row 91: 91, 92, 93, 94, 95, 96, 97, 98, 99, 90

Blacked-out sections include:

- A vertical column from R down to 22.
- A horizontal row from 27 to 30.
- A large rectangular area from 31 to 37.
- A horizontal row from 38 to 41.
- A vertical column from 43 down to 47.
- A horizontal row from 53 to 56.
- A vertical column from 56 down to 59.
- A large rectangular area from 61 to 68.
- A horizontal row from 71 to 78.
- A vertical column from 81 down to 88.
- A large rectangular area from 91 to 98.

Blue-highlighted sections include:

- A horizontal row from 33 to 36.
- A vertical column from 46 down to 50.
- A horizontal row from 52 to 55.
- A vertical column from 58 down to 60.

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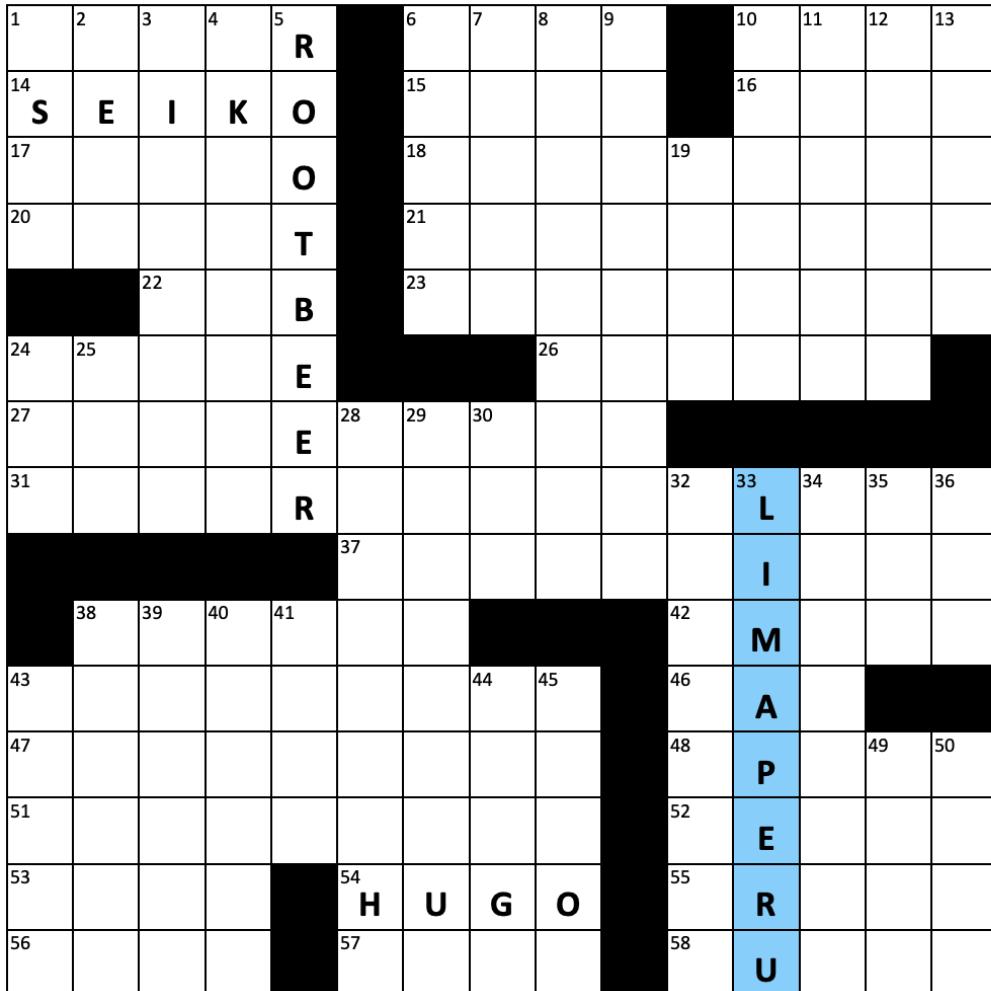
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  - 31 R
  - 37
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  - 43
  - 47
  - 51
  - 53 H U G O
  - 56
  - 57
  - 58
  - 6 7 8 9
  - 15
  - 18
  - 21
  - 23
  - 25
  - 26
  - 28 29 30
  - 32
  - 33 L
  - 34
  - 35
  - 36
  - 42 M
  - 46 A
  - 48 P
  - 52 E
  - 55 R
  - 57
  - 44 45
  - 46
  - 48
  - 52
  - 55
  - 49 50
  - 58
  - U
- 1 Across: 5 letters  
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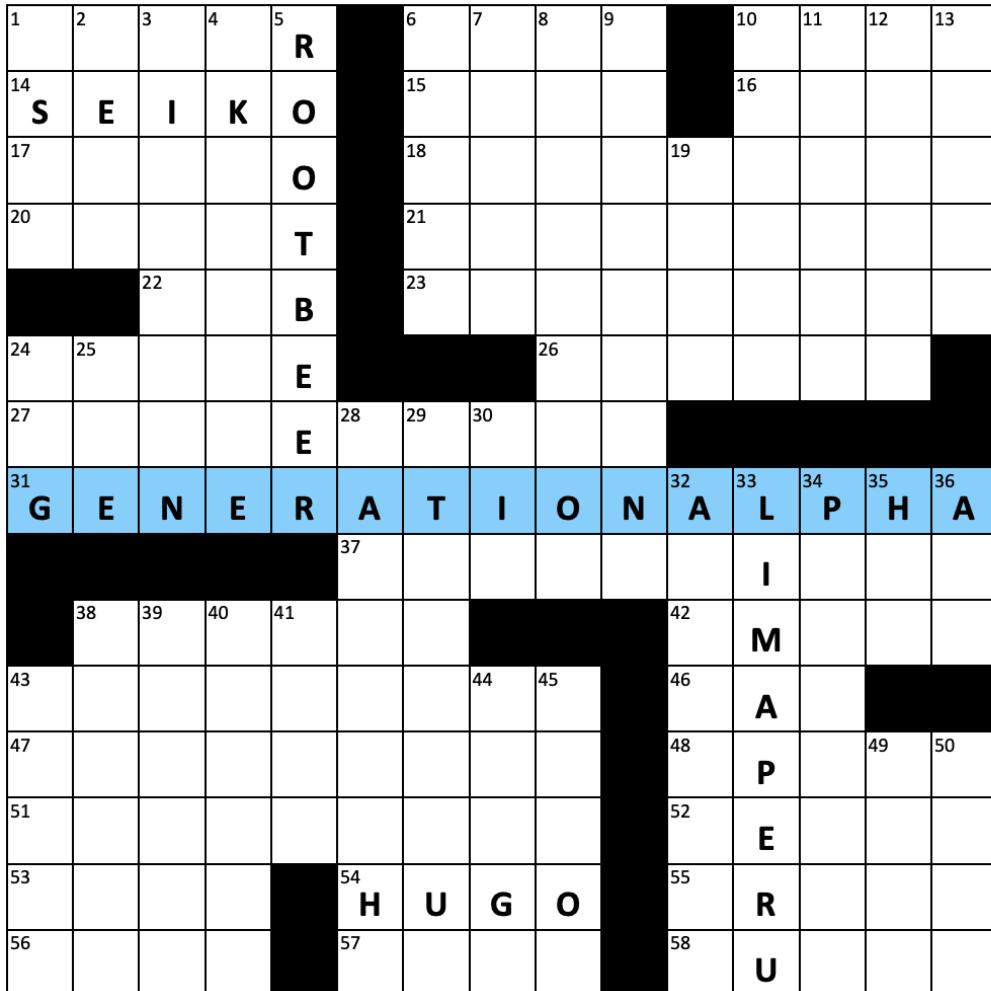
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- 651 G
- 652 O
- 653 E
- 654 R
- 655 U
- 656 G
- 657 O
- 658 E
- 659 R
- 660 U
- 661 G
- 662 O
- 663 E
- 664 R
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- 666 G
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- 669 R
- 670 U
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- 673 E
- 674 R
- 675 U
- 676 G
- 677 O
- 678 E
- 679 R
- 680 U
- 681 G
- 682 O
- 683 E
- 684 R
- 685 U
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- 689 R
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- 691 G
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- 693 E
- 694 R
- 695 U
- 696 G
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- 698 E
- 699 R
- 700 U
- 701 G
- 702 O
- 703 E
- 704 R
- 705 U
- 706 G
- 707 O
- 708 E
- 709 R
- 710 U
- 711 G
- 712 O
- 713 E
- 714 R
- 715 U
- 716 G
- 717 O
- 718 E
- 719 R
- 720 U
- 721 G
- 722 O
- 723 E
- 724 R
- 725 U
- 726 G
- 727 O
- 728 E
- 729 R
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- 731 G
- 732 O
- 733 E
- 734 R
- 735 U
- 736 G
- 737 O
- 738 E
- 739 R
- 740 U
- 741 G
- 742 O
- 743 E
- 744 R
- 745 U
- 746 G
- 747 O
- 748 E
- 749 R
- 750 U
- 751 G
- 752 O
- 753 E
- 754 R
- 755 U
- 756 G
- 757 O
- 758 E
- 759 R
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- 762 O
- 763 E
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- 766 G
- 767 O
- 768 E
- 769 R
- 770 U
- 771 G
- 772 O
- 773 E
- 774 R
- 775 U
- 776 G
- 777 O
- 778 E
- 779 R
- 780 U
- 781 G
- 782 O
- 783 E
- 784 R
- 785 U
- 786 G
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- 788 E
- 789 R
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- 791 G
- 792 O
- 793 E
- 794 R
- 795 U
- 796 G
- 797 O
- 798 E
- 799 R
- 800 U
- 801 G
- 802 O
- 803 E
- 804 R
- 805 U
- 806 G
- 807 O
- 808 E
- 809 R
- 810 U
- 811 G
- 812 O
- 813 E
- 814 R
- 815 U
- 816 G
- 817 O
- 818 E
- 819 R
- 820 U
- 821 G
- 822 O
- 823 E
- 824 R
- 825 U
- 826 G
- 827 O
- 828 E
- 829 R
- 830 U
- 831 G
- 832 O
- 833 E
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- 835 U
- 836 G
- 837 O
- 838 E
- 839 R
- 840 U
- 841 G
- 842 O
- 843 E
- 844 R
- 845 U
- 846 G
- 847 O
- 848 E
- 849 R
- 850 U
- 851 G
- 852 O
- 853 E
- 854 R
- 855 U
- 856 G
- 857 O
- 858 E
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- 866 G
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- 870 U
- 871 G
- 872 O
- 873 E
- 874 R
- 875 U
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- 899 R
- 900 U
- 901 G
- 902 O
- 903 E
- 904 R
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- 906 G
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- 908 E
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- 920 U
- 921 G
- 922 O
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- 924 R
- 925 U
- 926 G
- 927 O
- 928 E
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- 930 U
- 931 G
- 932 O
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- 970 U
- 971 G
- 972 O
- 973 E
- 974 R
- 975 U
- 976 G
- 977 O
- 978 E
- 979 R
- 980 U
- 981 G
- 982 O
- 983 E
- 984 R
- 985 U
- 986 G
- 987 O
- 988 E
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- 994 R
- 995 U
- 996 G
- 997 O
- 998 E
- 999 R
- 1000 U

## Down

- 1 Drink similar to sarsaparilla
- 2 Co-star of 1984's "Ghostbusters"
- 3 Right on
- 4 Aces with aces?
- 5 Like some households
- 6 Designer with an eponymous hotel in the Burj Khalifa
- 7 Currency units in West Africa
- 8 Grievous
- 9 "Golden Boy" playwright
- 10 Actress Shawkat of "Arrested Development"
- 11 Assignment for an anchor
- 12 "\_\_\_\_ noticed ..."
- 13 Great Hindu sage
- 14 Late-Triassic flier
- 15 It can be found right on a clock
- 16 "100 Years ... 100 Stars" and others, in brief
- 17 The world's largest desert capital, after Cairo, Egypt



# Example Crossword



## Across

- — — — —
- 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
- 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

- — — — —
- 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
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# Crosswords as a Weighted CSP

- Variables: entries in the grid
  - Domains: all possible words (??)
  - Constraints:
    - Hard constraints: intersecting words match
    - Scoring function: match the clues
  - Questions:
    - Where does the scoring function come from?
    - What's the search algorithm?





# Scoring Function

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## 14. Omega competitor





# Scoring Function

---

## 14. Omega competitor



Domain

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



# Scoring Function

## 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

Domain



# Scoring Function

## 14. Omega competitor



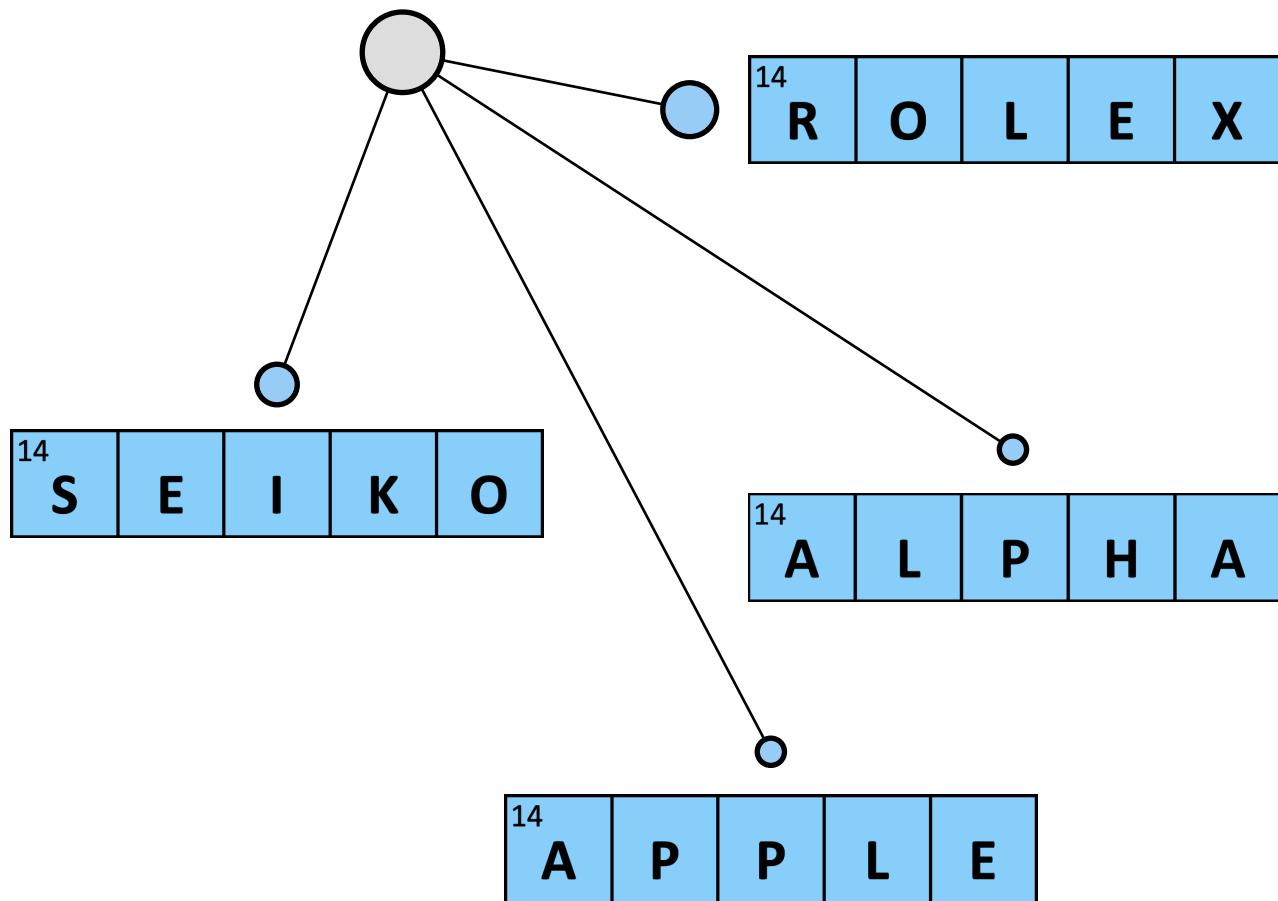
Domain

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



# Scoring Function

## 14. Omega competitor



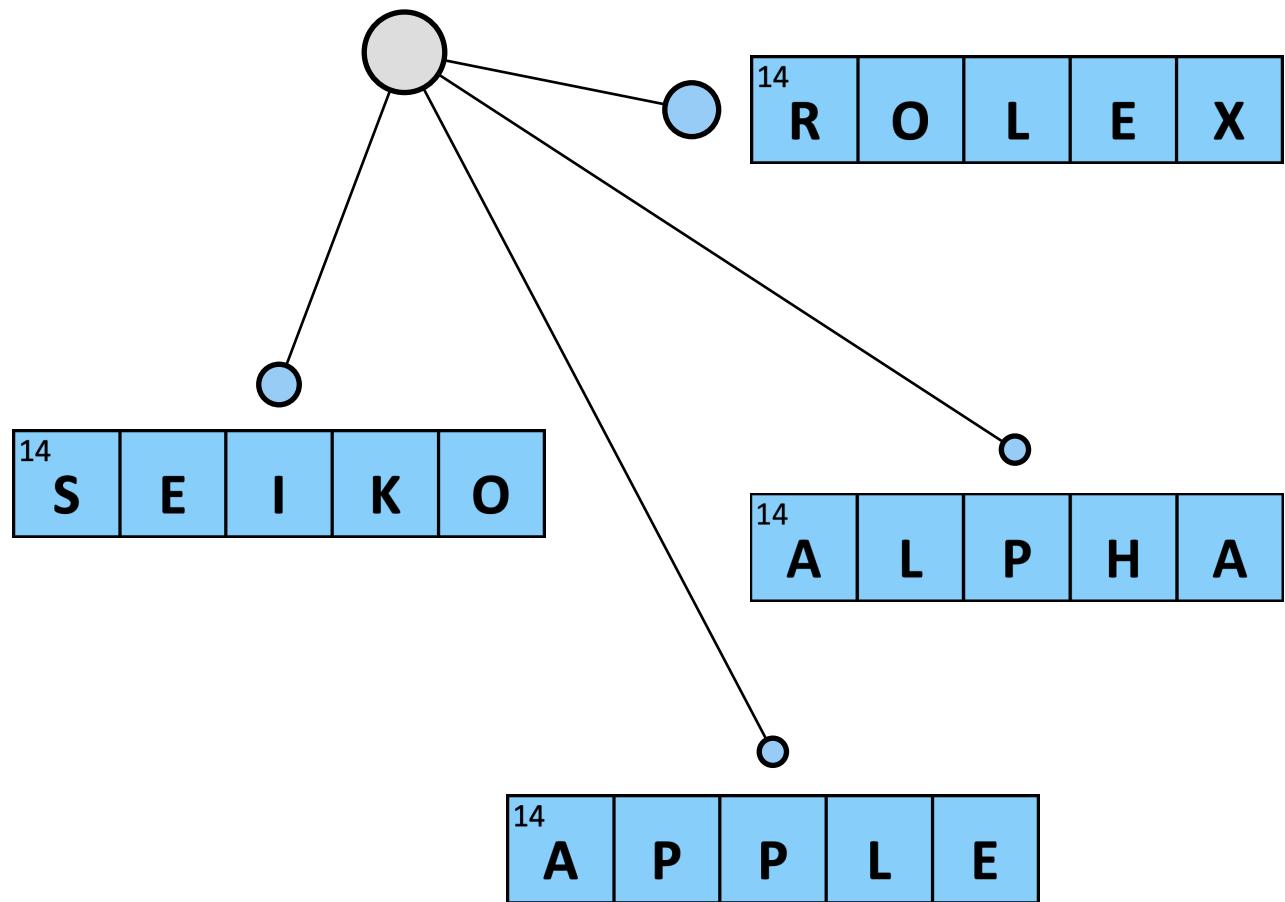
Domain

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



# Scoring Function

## 14. Omega competitor



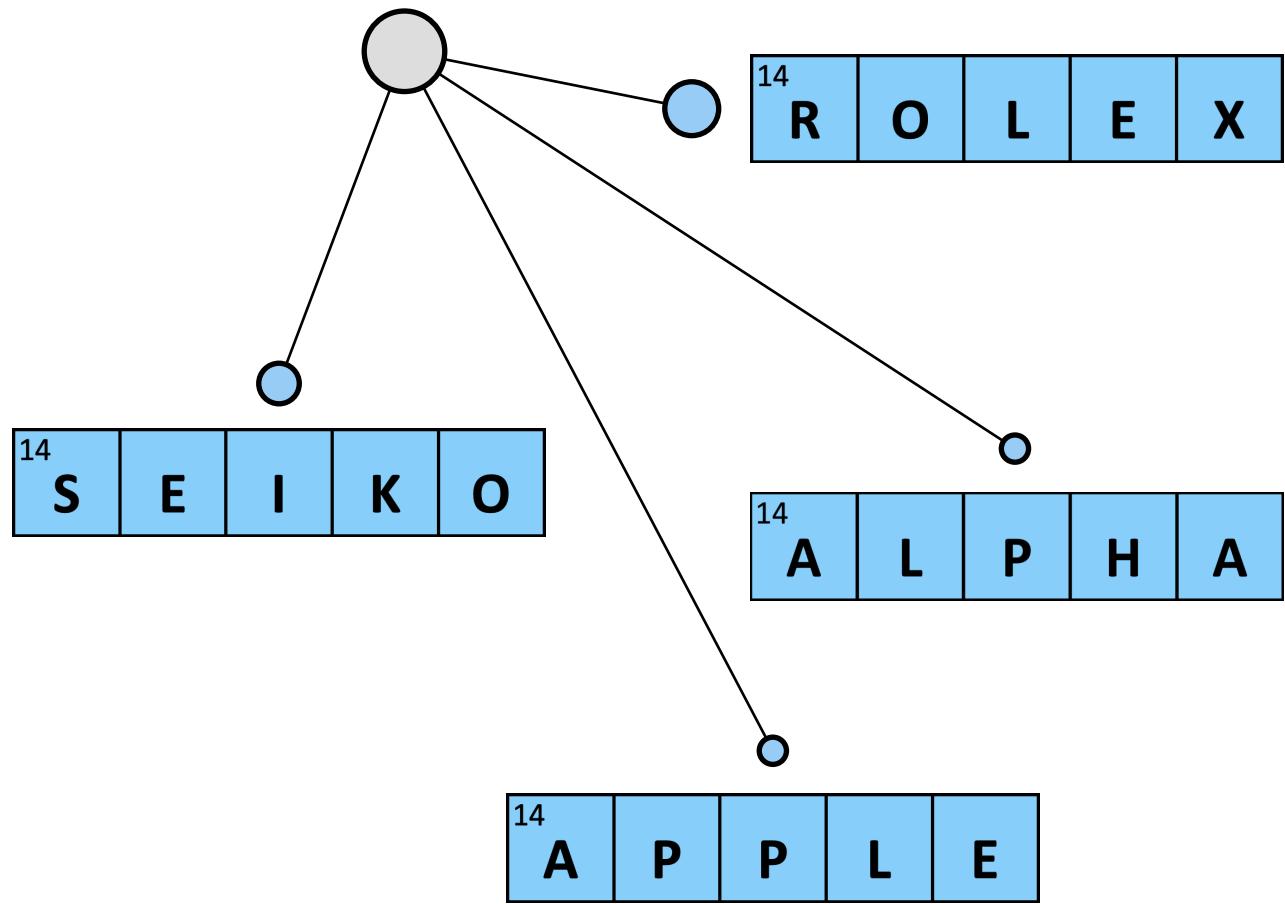
Domain

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



# Scoring Function

## 14. Omega competitor



Domain

$^{14}$ 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

# Search Algorithm for Crosswords

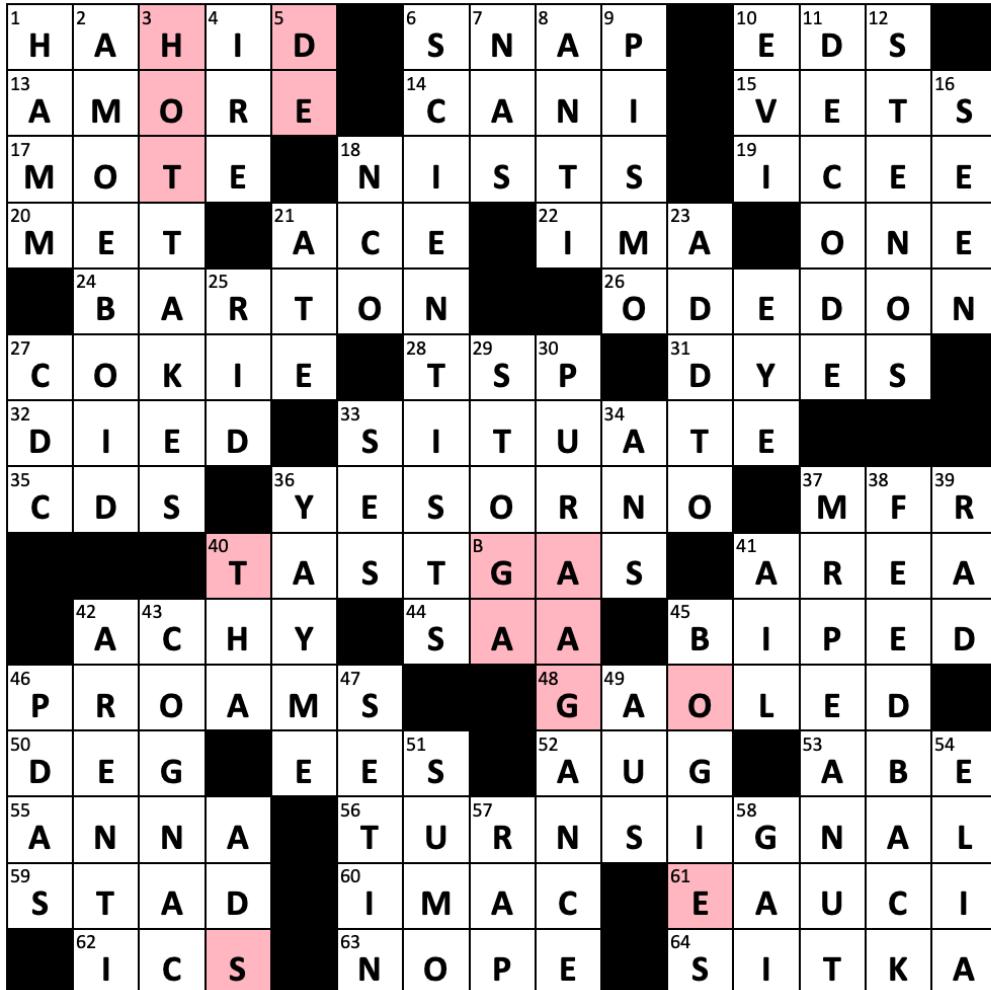
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- Our approach:
  - Use QA model to get probability distribution over answers
  - Belief propagation (we'll talk more about this later in the class)
  - Initialize solution with greedy search
  - Iterative improvement on individual letters





# Iterative Improvement



## 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



# Iterative Improvement



## Across

- 1** Beloved, in Arabic
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  - 10** Masthead listings, for short
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# Iterative Improvement



## Across

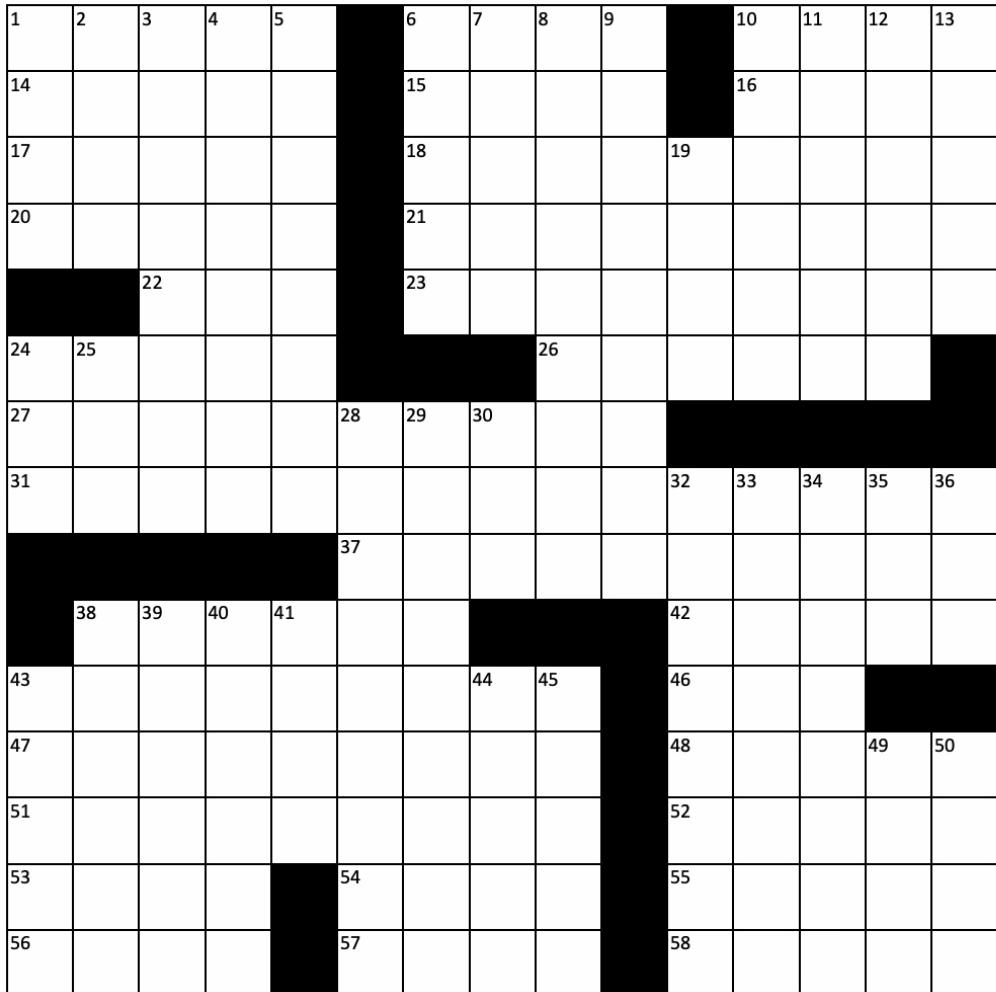
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  - 10** Masthead listings, for short
  - 13** Italian herbal liqueur
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**Down**

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  - 25** Purge (of)
  - 27** Atlanta-based health org.
  - 29** Long fur scarfs



# Demo



## 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
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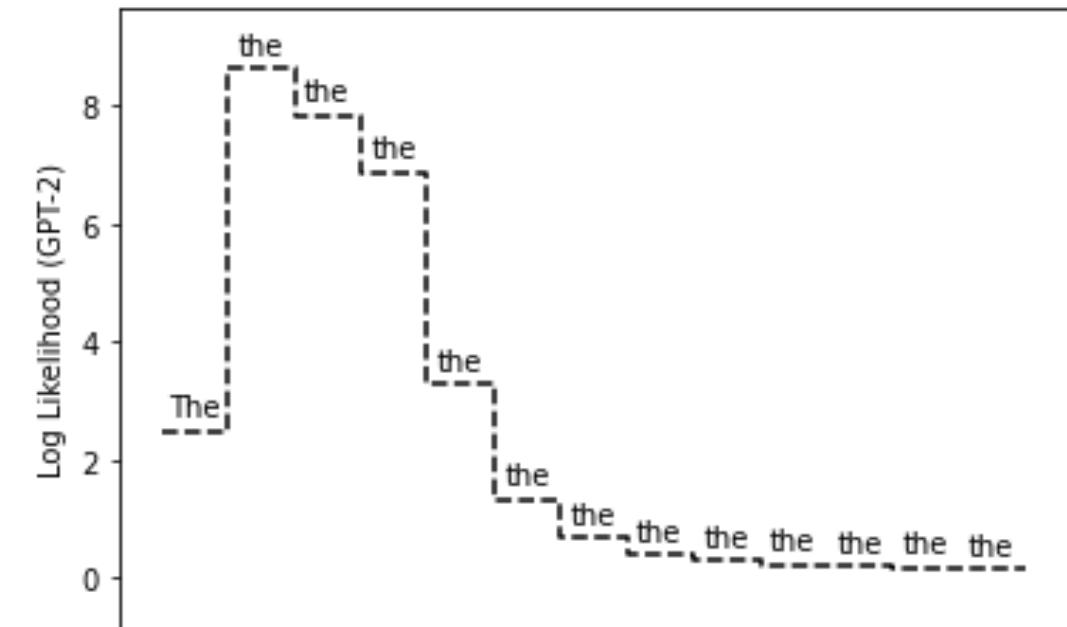
## Down

- 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
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# Bonus: Fortuitous Search Errors

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- Scoring function can be *incorrectly calibrated*
- Example: decoding from language models
  - Language models assign probabilities to strings of words
  - Decoding uses greedy or beam search
  - But what if you searched over all possible strings (exponentially many) and chose the highest scoring one?
  - Answer: you often end up generating the empty string, or “The the the the the...”



# Summary: CSPs

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- CSPs are a special kind of search problem:
  - States are partial assignments
  - Goal test defined by constraints
- Basic solution: backtracking search
- Speed-ups:
  - Ordering
  - Filtering
  - Structure – trees are easy!
- Local search often effective in practice

