Announcements

happy groundhog day!

Assignments:

- HW3 (online)
  - Due Tue 2/7, 10 pm

  up to 1 late day
- P1: Search and Games
  - Due Mon 2/6, 10 pm

    up to 2 late days
  - Submit to Gradescope early and as often as you like

Recitation:

- Last week to "shop around"
- Stay tuned to Piazza for informal recitation switch form

  online

Outlook: HW4 due 2/14, Exam 1 2/16

Plan

Last Time

- Constraint Satisfaction Problems

Today

- CSPs continued (MRV, LCV)
- Local Search

Back to CSPs Lecture

AI: Representation and Problem Solving

Local Search

Instructor: Stephanie Rosenthal

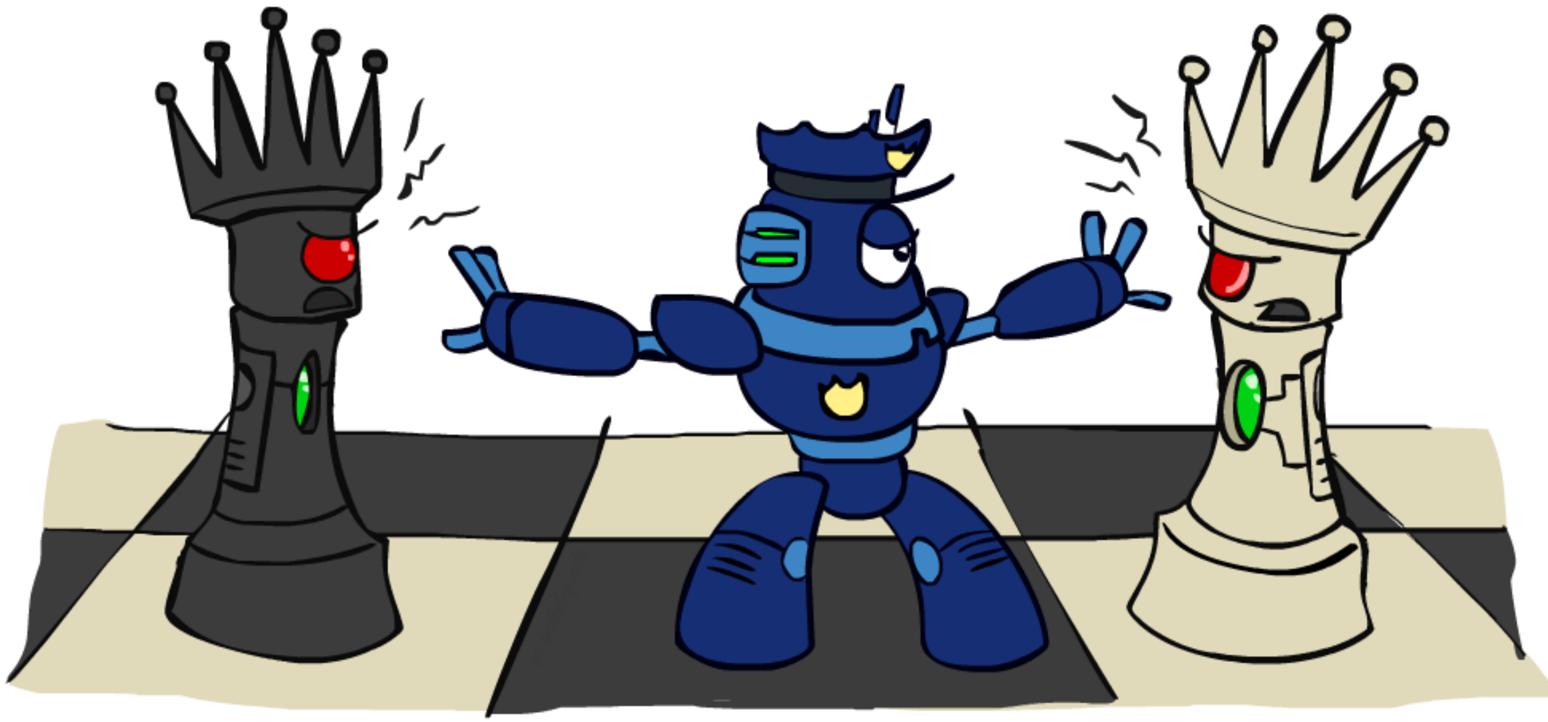
Slide credits: CMU AI, http://ai.berkeley.edu

Local Search

- Can be applied to identification problems (e.g., CSPs), as well as some planning and optimization problems

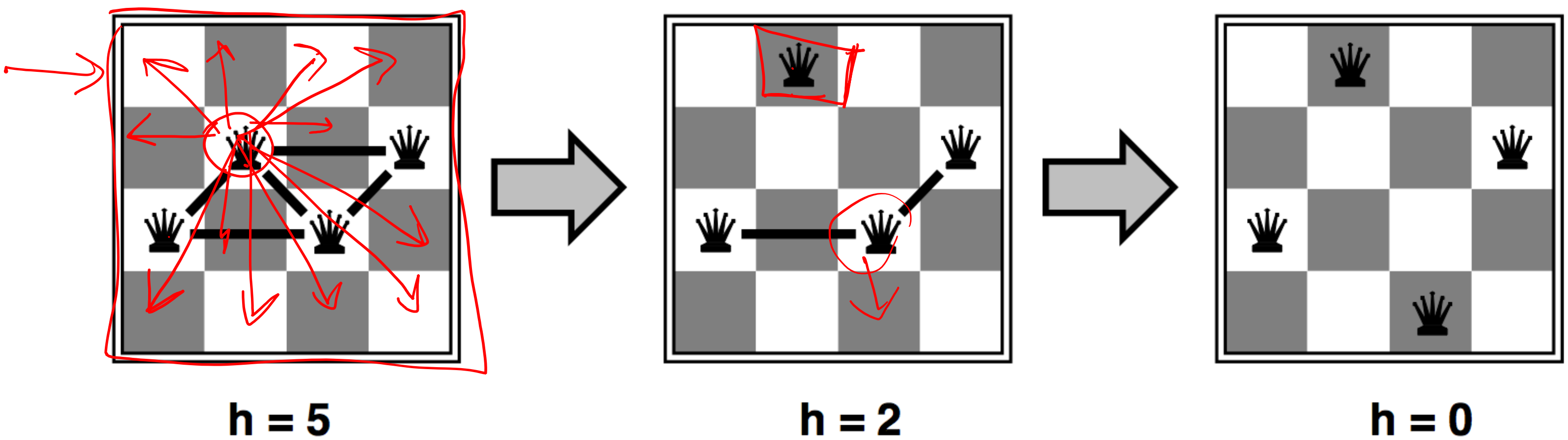
- For identification problems, we use a complete-state formulation, e.g., all variables assigned in a CSP (may not satisfy all the constraints)
- For planning problems, typically we make local decisions. e.g., not a plan all the way to the goal or not a deep search

Iterative Improvement for CSPs



Iterative Improvement for CSPs

- Start with an arbitrary assignment, iteratively *reassign* variable values
- While not solved,
  - Variable selection: randomly select a conflicted variable
  - Value selection with min-conflicts heuristic h: Choose a value that violates the fewest constraints (break tie randomly)
- For n-Queens: Variables $x_i \in \{1..n\}$; Constraints $x_i \neq x_j$, $|x_i - x_j| \neq |i - j|, \forall i \neq j$

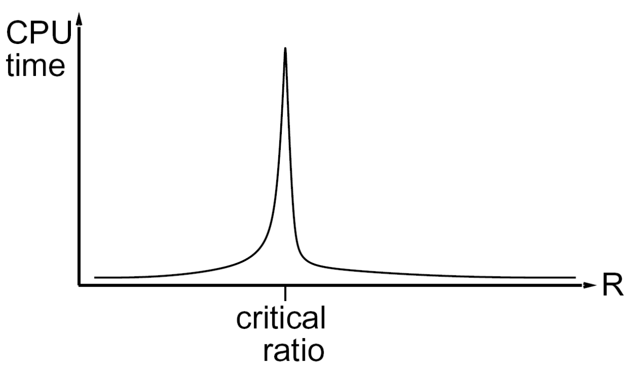


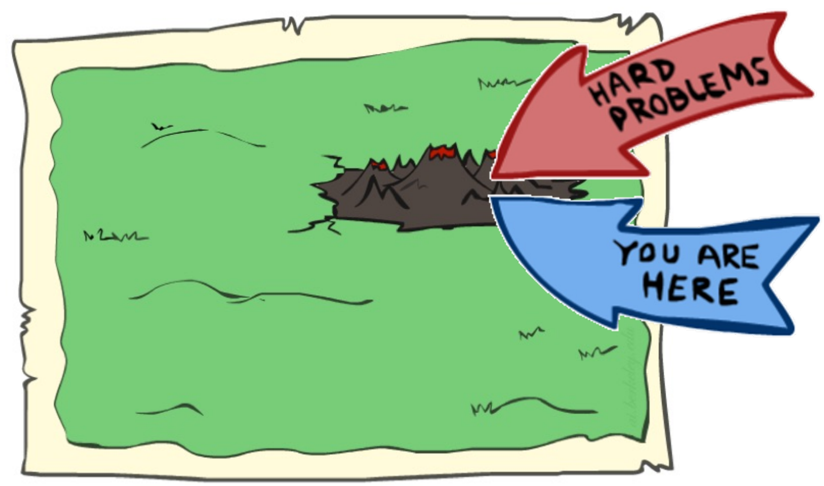
Iterative Improvement for CSPs

- Given random initial state, can solve n-queens in almost constant time for arbitrary n with high probability (e.g., n = 10,000,000)!

- Same for any randomly-generated CSP *except* in a narrow range of the ratio

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

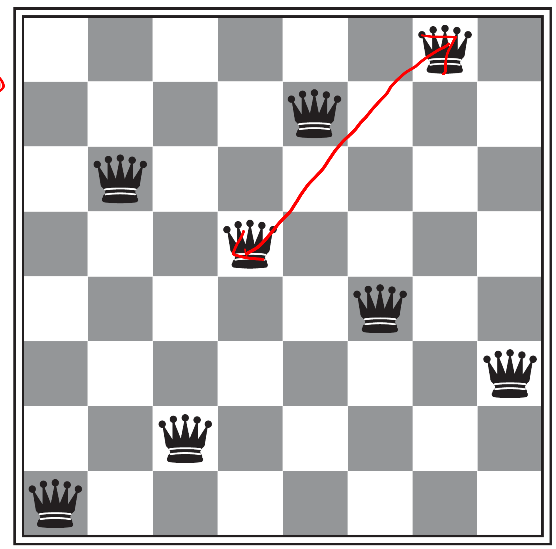




Local Search

- A local search algorithm is…
  - Optimal if it always finds a global minimum/maximum heuristic value

$h = 1$

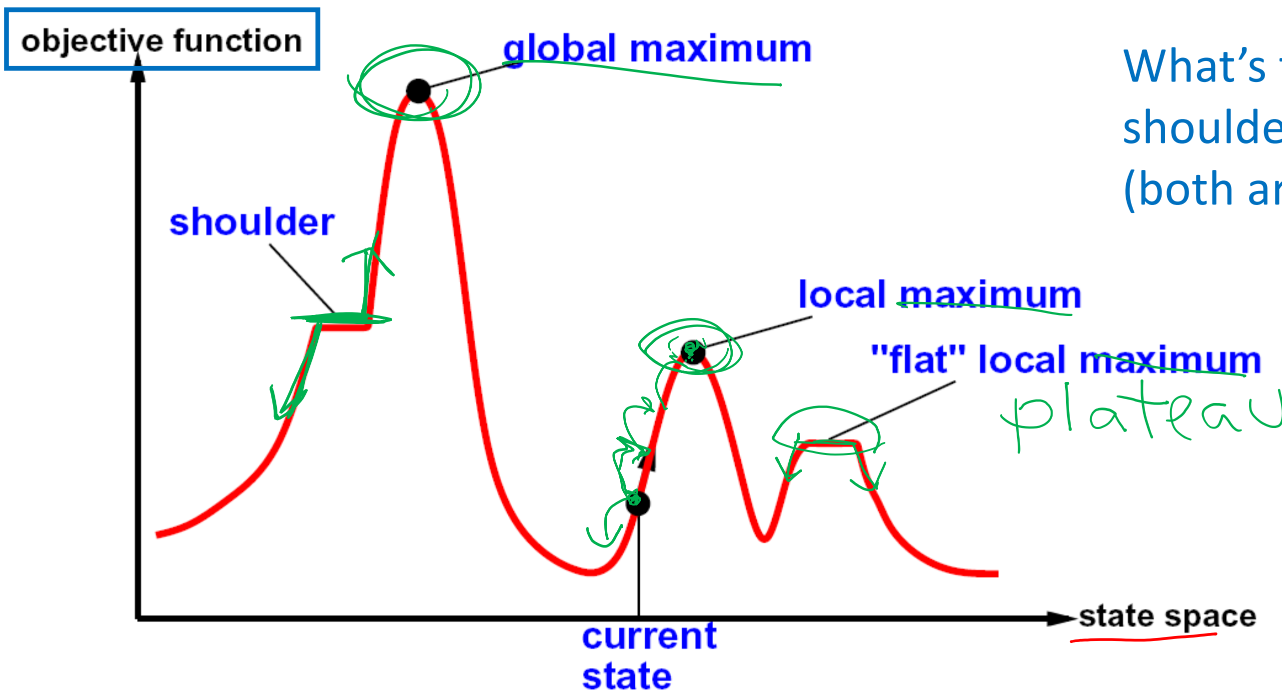


Will an iterative improvement algorithm for CSPs always find a solution?

No! May get stuck in a local optima

State-Space Landscape

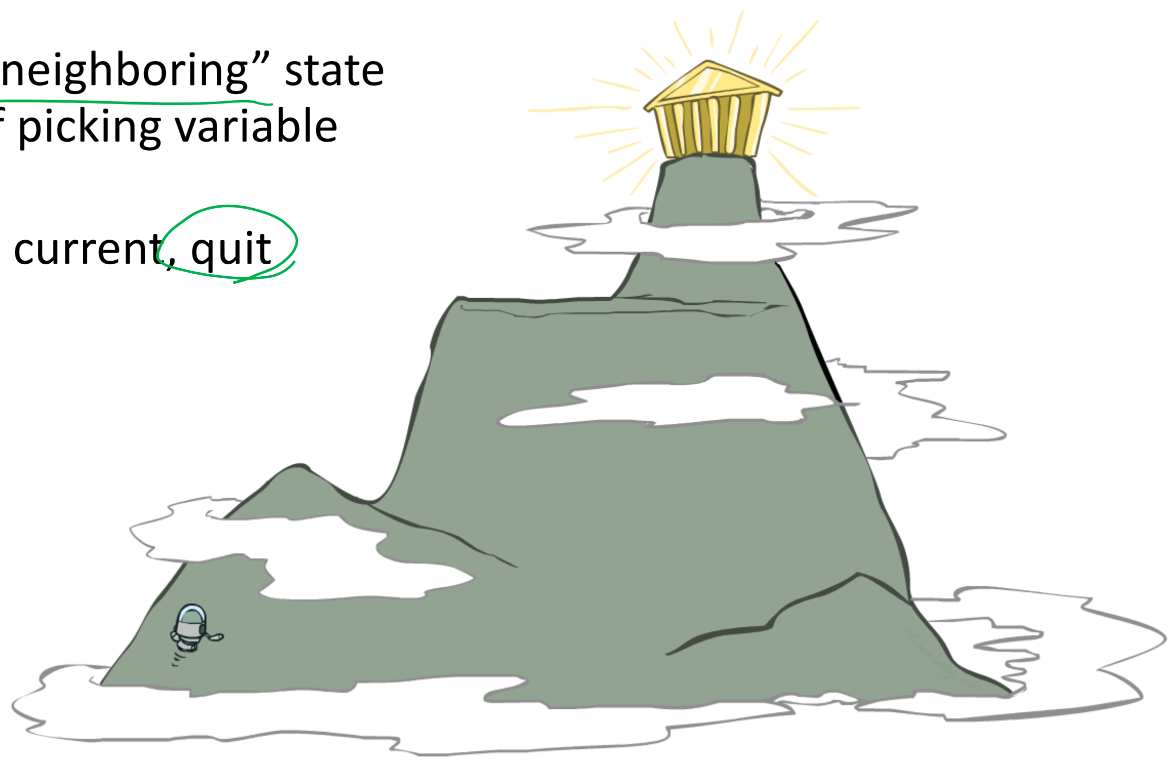
In identification problems, could be a function measuring how close you are to a valid solution, e.g., $-1\times$ #conflicts in n-Queens/CSP



What’s the difference between shoulder and flat local maximum (both are plateaux)?

Hill Climbing (Greedy Local Search)

- Simple, general idea:
  - Start wherever
  - Repeat: move to the best "neighboring" state (successor state) instead of picking variable randomly
  - If no neighbors better than current, quit



Hill Climbing (Greedy Local Search)

function HILL-CLIMBING(*problem*) **returns** a state that is a local maximum

  current ← MAKE-NODE(*problem*.INITIAL-STATE)
  loop do
    neighbor ← a highest-valued successor of *current*
    if neighbor.VALUE ≤ current.VALUE **then** **return** *current*.STATE
    current ← *neighbor*

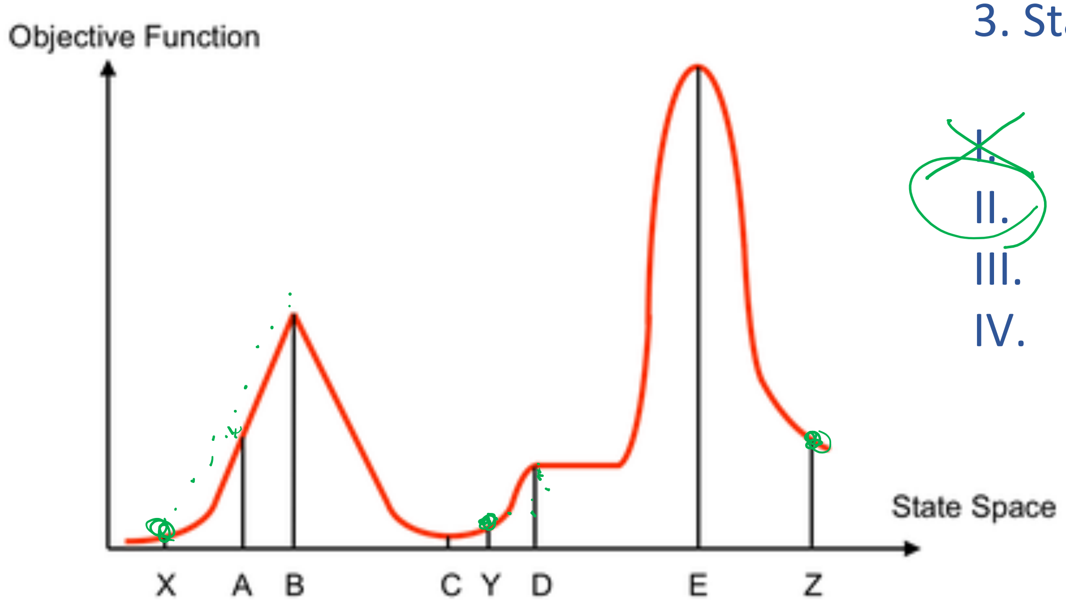
What if there is a tie?

Typically break ties randomly

What if we do not stop here? Make a sideway move if “=”

- In 8-Queens, steepest-ascent hill climbing solves 14% of problem instances
  - Takes 4 steps on average when it succeeds, and 3 steps when it fails
- When allow for ≤100 consecutive sideway moves, solves 94% of problem instances
  - Takes 21 steps on average when it succeeds, and 64 steps when it fails

Poll 1: Hill Climbing



1. Starting from X, where do you end up?
2. Starting from Y, where do you end up?
3. Starting from Z, where do you end up?

I. $X \rightarrow A, Y \rightarrow D, Z \rightarrow E$

II. $X \rightarrow B, Y \rightarrow D, Z \rightarrow E$

III. $X \rightarrow B, Y \rightarrow E, Z \rightarrow E$

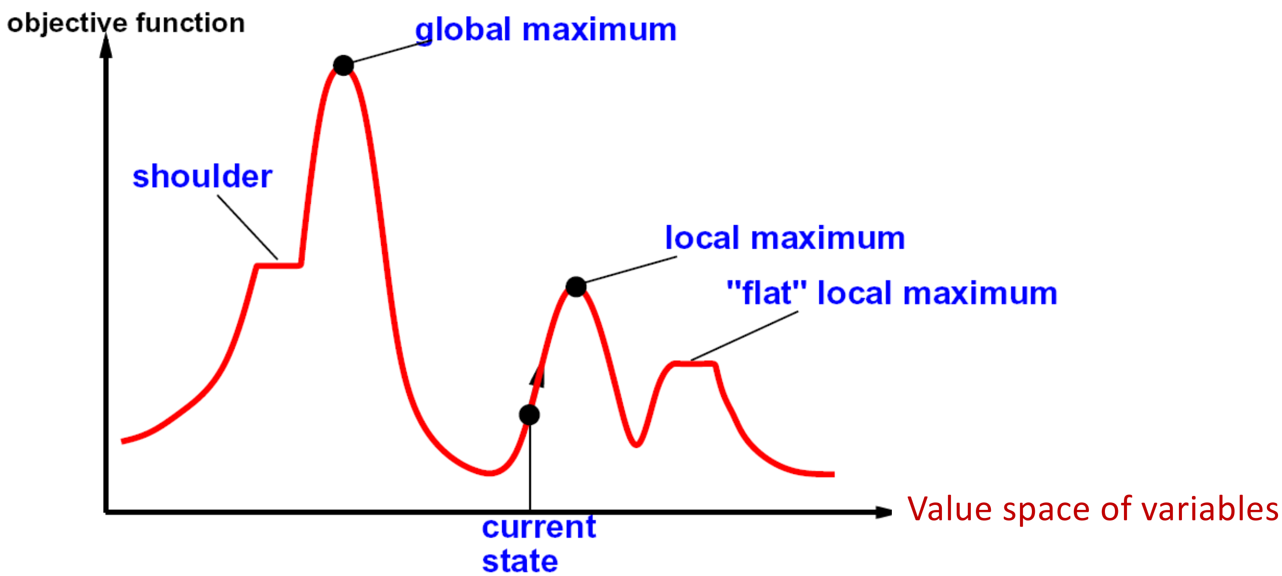
IV. I don't know

Variants of Hill Climbing

- Random-restart hill climbing
  - “If at first you don’t succeed, try, try again.”
  - What kind of landscape will random-restarts hill climbing work the best?
- Stochastic hill climbing
  - Choose randomly from the uphill moves, with probability dependent on the “steepness” (i.e., amount of improvement)
  - Converge slower than steepest ascent, but may find better solutions
- First-choice hill climbing
  - Generate successors randomly (one by one) until a better one is found
  - Suitable when there are too many successors to enumerate

Variants of Hill Climbing

- What if variables are continuous, e.g. find $x \in [0,1]$ that maximizes $f(x)$?
  - Gradient ascent
    - Use gradient to find best direction
    - Use the magnitude of the gradient to determine how big a step you move



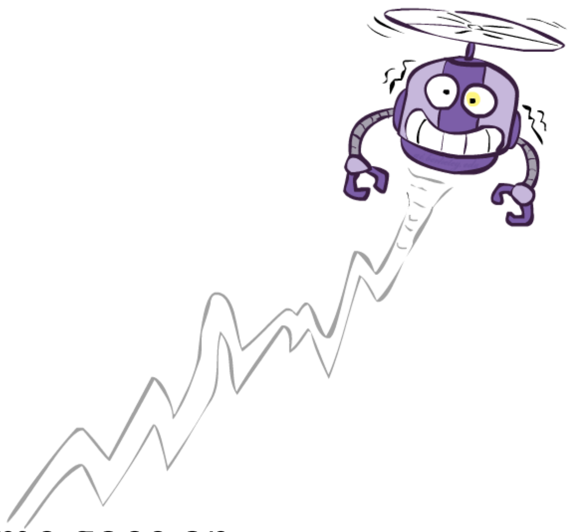
Random Walk

- Uniformly randomly choose a neighbor to move to
- Save the best you’ve seen so far
- Stop after K moves

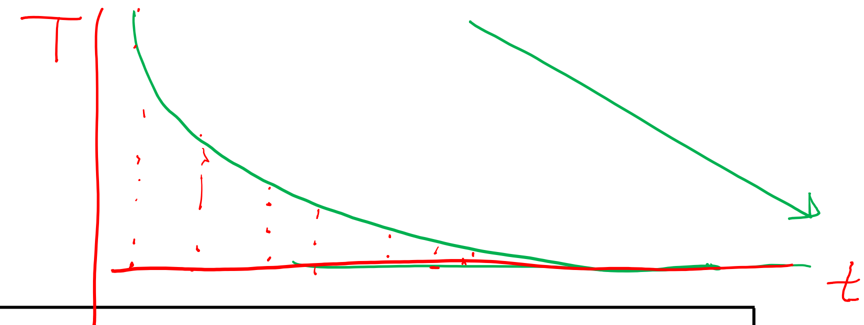
- What happens to the solution as K increases?

Simulated Annealing

- Combines random walk and hill climbing
- Inspired by statistical physics
- Annealing – Metallurgy
  - Heating metal to high temperature then cooling
  - Reaching low energy state
- Simulated Annealing – Local Search
  - Allow for downhill moves and make them rarer as time goes on
  - Escape local maxima and reach global maxima



Simulated Annealing



function SIMULATED-ANNEALING(*problem*, *schedule*) **returns** a solution state
  inputs: *problem*, a problem
    schedule, a mapping from time to "temperature"

current ← MAKE-NODE(*problem*.INITIAL-STATE)
for t = 1 **to** ∞ **do** time
  $T \leftarrow schedule(t)$ ← temperature
  if T = 0 **then return** *current*
  next ← a randomly selected successor of *current*
  $\Delta E \leftarrow$ *next*.VALUE – *current*.VALUE
  if $\Delta E > 0$ **then** *current* ← *next*
  else *current* ← *next* only with probability $e^{\Delta E/T}$

next better

Control the change of temperature T (↓ over time)

random neighbor

Almost the same as hill climbing except for a *random* successor

Unlike hill climbing, move downhill with some prob.

Poll 2:

Which of the following will make it more likely that we'll take a downward step?

~~A.~~ Decrease T, decrease ΔE

B. Decrease T, increase ΔE

~~C.~~ Increase T, decrease ΔE

$\boxed{\text{D.}}$ Increase T, increase ΔE

function SIMULATED-ANNEALING(*problem*, *schedule*) **returns** a solution state
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  current ← MAKE-NODE(*problem*.INITIAL-STATE)
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$\Delta E < 0$

$T > 0$

dec ΔE

$e^{-1/1} = .36$

$e^{-2/1} = .14$

$e^{-1/2} = .61$

$\uparrow T$

Poll 2:

Which of the following will make it more likely that we'll take a downward step?

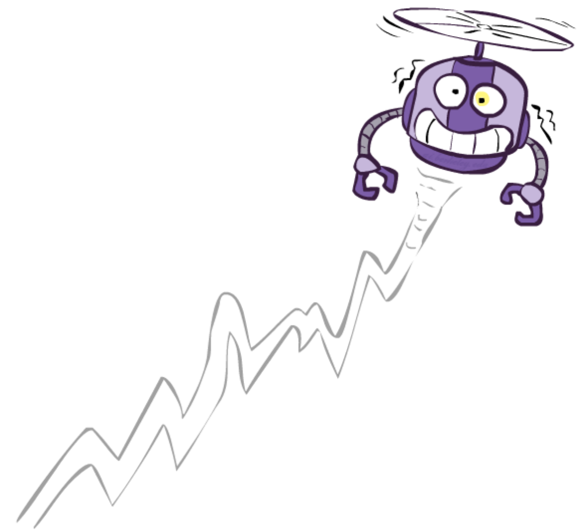
A. Decrease T, decrease ΔE
B. Decrease T, increase ΔE
C. Increase T, decrease ΔE
D. $\boxed{\text{Increase } T\text{, increase } \Delta E}$

ΔE is negative but should be close to 0,
T should be big because of E's negative

```
function SIMULATED-ANNEALING(problem, schedule) returns a solution state
  inputs: problem, a problem
          schedule, a mapping from time to "temperature"

  current ← MAKE-NODE(problem.INITIAL-STATE)
  for t = 1 to ∞ do
     T ← schedule(t)
     if T = 0 then return current
     next ← a randomly selected successor of current
     ΔE ← next.VALUE – current.VALUE
     if ΔE > 0 then current ← next
     else current ← next only with probability e^(ΔE/T)
```

Simulated Annealing



- $P[\text{move downhill}] = e^{\Delta E/T}$
  - Bad moves are more likely to be allowed when T is high (at the beginning of the algorithm)
  - Worse moves are less likely to be allowed

- Guarantee: If T decreased slowly enough, will converge to optimal state!

- But! In 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

Summary: Local Search

- Maintain a constant number of current nodes or states, and move to "neighbors" or generate "offspring" in each iteration
  - Do not maintain a search tree or multiple paths
  - Typically, do not retain the path to the node

- Advantages
  - Use little memory
  - Can potentially solve large-scale problems or get a reasonable (suboptimal or almost feasible) solution