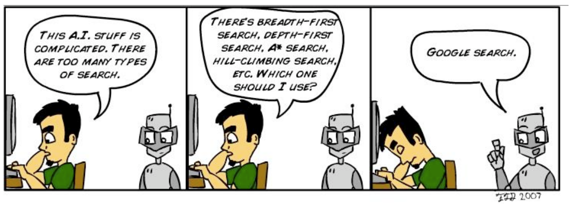


http://blog.lib.umn.edu/torre107/si/pics/superficialintelligence2.jpg

Uninformed Search

CS151
David Kauchak
Fall 2010

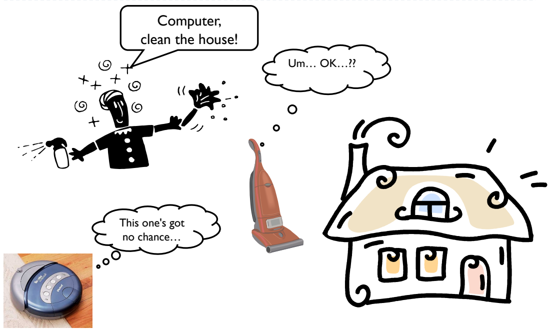
Adapted from notes from:
Sara Owsley Sood, Eric Eaton

Happy labor day!

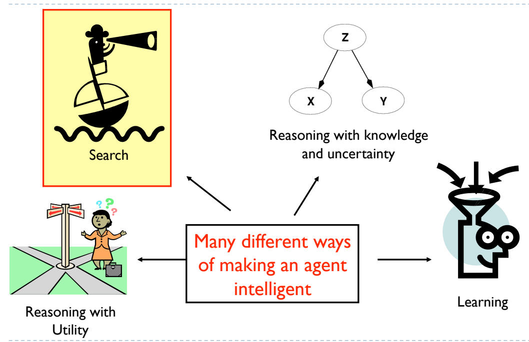
Administrative

- Send me fun stuff!
- Written problems will be posted today
- Programming assignment 1 due before class on Wed.
- TA office hours posted:
  - Mon 7-9pm
  - Tue 7-9pm

How do we make a computer "smart?"



Fundamental problem of AI



Today: search

- Brute force approach
- Very unlikely how humans do it

Think like a human Cognitive Modeling	**Think rationally** Logic-based Systems
Act like a human Turing Test	**Act rationally** Rational Agents

- Enumerate out possibilities in a reasonable order

What is an "agent"?

"anything that can be viewed as perceiving its environment through sensors and acting upon that environment through actuators"

- Human agent
  - sensors = eyes, ears, etc
  - actuators = hands, legs, mouth, etc
- Software agent
  - sensors = any input devices - keyboard gives it keystrokes, commands over the network, files give it text or data
  - actuators = any output devices - using the screen to display things, pass things over the network, write things to files, etc

search agents

- Search agent is an agent that approaches *problem solving* via *search*
- To accomplish a task:
  1. Formulate problem and goal
  2. Search for a sequence of actions that will lead to the goal (the policy)
  3. Execute the actions one at a time

done offline!

Formulating the problem:

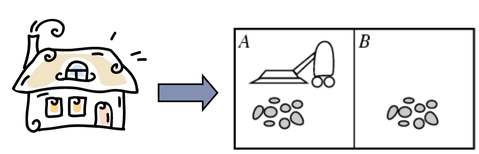
What information does a search agent need to know to plan out a solution?

Formulating the problem:

- **Initial state**: where are we starting from
  - **what are the states?**
- **Actions**: what are the possible actions
- **Transition model**: aka state-space, mapping from action x state to state
- **Goal/goal test**: what is the end result we're trying to achieve?
- **Cost**: what are the costs of the different actions

Let's start with our vacuum cleaner example

- State space
  - Just two possible spaces in the house (though this generalizes easily to more)
  - each space can either be dirty or clean
  - vaccum is in one space at a time

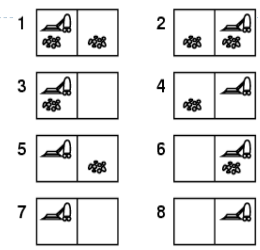


Let's start with our vacuum cleaner example

- State space
  - Just two possible spaces in the house (though this generalizes easily to more)
  - each space can either be dirty or clean
  - vaccum is in one space at a time

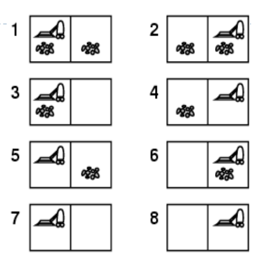
How many states?

Vacuum world



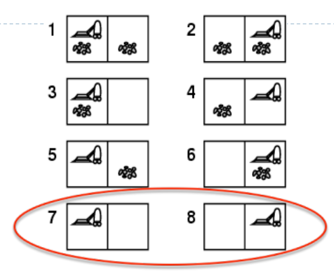
Only 8 states (spaces^3)

Vacuum world



goal state(s)?

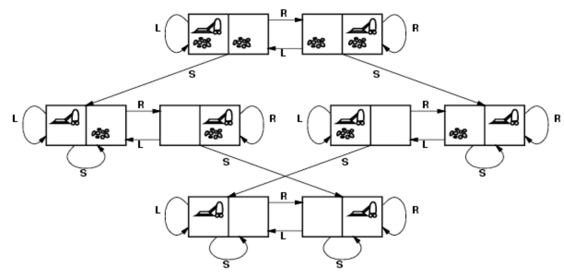
Vacuum world



Vacuum world

- Actions?
  - move left
  - move right
  - suck
  - no-op

Vacuum world: state space/transition model



Problem characteristics

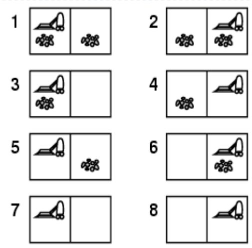
- Fully observable vs. partially observable
  - do we have access to all of the *relevant* information
  - noisy information, inaccurate sensors, missing information
- Deterministic vs. non-deterministic (stochastic)
  - outcome of an action are not always certain
  - probabilistic sometimes
- Known/unknown environment
  - Do we know a priori what the problem space is like (e.g. do we have a map)

Search problem types

- Deterministic, fully observable
  - Agent knows exactly which state it will be in
  - solution is a sequence of actions
- Non-observable → sensorless problem
  - Agent may have no idea where it is
  - solution is still a sequence
- Non-deterministic and/or partially observable → contingency problem
  - percepts provide new information about current state
  - often interleave search, execution
- Unknown state space → exploration problem
  - this is how roomba works

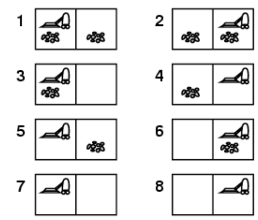
Example: vacuum world

- Deterministic, fully observable
- start in #5. Solution?



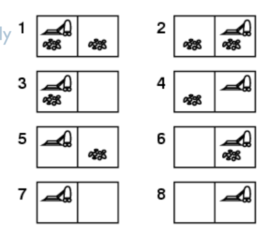
Example: vacuum world

- Sensorless
- start in {1,2,3,4,5,6,7,8} Solution?



Example: Vacuum world

- Non-deterministic and/or partially
  - Nondeterministic: *Suck* may dirty a clean carpet
  - Partially observable: location, dirt at current location.
  - Percept: *[L, Clean]*, i.e., start in #5 or #7 Solution?



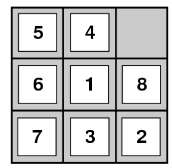
Vacuum world

- Cost?

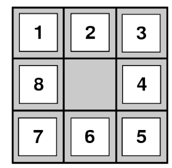
Some example problems

- Toy problems and micro-worlds
  - 8-Puzzle
  - Missionaries and Cannibals
  - Cryptarithmetic
  - Remove 5 Sticks
  - Water Jug Problem
- Real-world problems

Another problem: 8-Puzzle



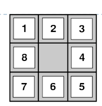
Start State



Goal State

8-puzzle

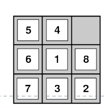
- goal
- states?
- actions?
- path cost?



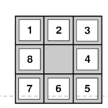
Goal State

8-Puzzle

- **state:**
  - all 3 x 3 configurations of the tiles on the board
- **actions:**
  - Move Blank Square Left, Right, Up or Down.
  - This is a more efficient encoding than moving each of the 8 distinct tiles
- **path cost:**
  - +1 for each action



Start State



Goal State

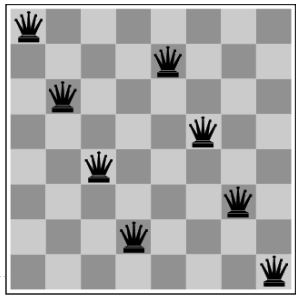
The 8-Queens Problem

State transition: ?

Initial State: ?

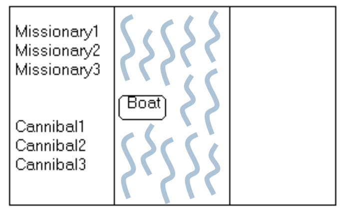
Actions: ?

Goal: Place eight queens on a chessboard such that no queen attacks any other!



Missionaries and Cannibals

Three missionaries and three cannibals wish to cross the river. They have a small boat that will carry up to two people. Everyone can navigate the boat. If at any time the Cannibals outnumber the Missionaries on either bank of the river, they will eat the Missionaries. Find the smallest number of crossings that will allow everyone to cross the river safely.



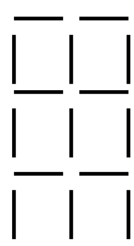
Cryptarithmetic

- Find an assignment of digits (0, ..., 9) to letters so that a given arithmetic expression is true. examples: SEND + MORE = MONEY and

```
   FORTY      Solution:  29786
 +  TEN                    850
 +  TEN                    850
   -----                 -----
   SIXTY                 31486
 F=2, O=9, R=7, etc.
```

Remove 5 Sticks

Given the following configuration of sticks, remove exactly 5 sticks in such a way that the remaining configuration forms exactly 3 squares.



Water Jug Problem

Given a full 5-gallon jug and a full 2-gallon jug, fill the 2-gallon jug with exactly one gallon of water.

Some real-world problems

- Route finding
  - directions, maps
  - computer networks
  - airline travel
- VLSI layout
- Touring (traveling salesman)
- Agent planning

Search algorithms

- We've defined the problem
- Now we want to find the solution!
- Use search techniques
  - offline, simulated exploration of state space by generating successors of already-explored states (a.k.a. expanding states)
  - Start at the initial state and search for a goal state
- What are candidate search techniques?
  - BFS
  - DFS
  - Uniform-cost search
  - Depth limited DFS
  - Depth-first iterative deepening

Finding the path: Tree search algorithms

- Basic idea:
  - keep a set of nodes to visit next (frontier)
  - pick a node from this set
  - check if it's the goal state
  - if not, expand out adjacent nodes and repeat

```
def treeSearch(start):
  add start to the frontier
  while frontier isn't empty:
    get the next node from the frontier
    if node contains goal state:
      return solution
    else:
      expand node and add resulting nodes to frontier
```

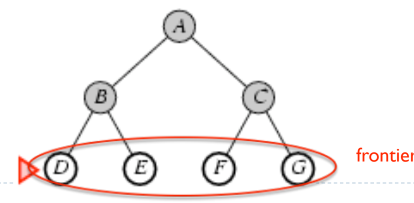
BFS and DFS

How do we get BFS and DFS from this?

```
def treeSearch(start):
  add start to the frontier
  while frontier isn't empty:
    get the next node from the frontier
    if node contains goal state:
      return solution
    else:
      expand node and add resulting nodes to frontier
```

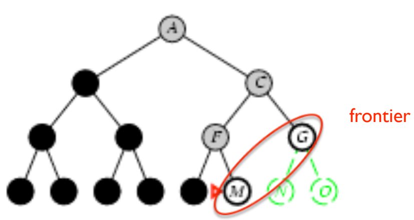
Breadth-first search

- Expand shallowest unexpanded node
- Nodes are expanded a level at a time (i.e. all nodes at a given depth)
- Implementation:
  - *frontier* is a FIFO queue, i.e., new successors go at end



Depth-first search

- Expand deepest unexpanded node
- Implementation:
  - *frontier* = LIFO queue, i.e., put successors at front



Search algorithm properties

- Time (using Big-O)
- Space (using Big-O)
- Complete
  - If a solution exists, will we find it?
- Optimal
  - If we return a solution, will it be the best/optimal solution
- A divergence from data structures
  - we generally won't use V and E to define time and space. Why?
    - Often V and E are infinite!
    - Instead, we often use the branching factor (*b*) and depth (*d*)

Activity

- Analyze DFS and BFS according to the criteria time, space, completeness and optimality
  (for time and space, analyze in terms of *b*, *d*, and *m* (max depth); for complete and optimal - simply YES or NO)
  - Which strategy would you use and why?
- Brainstorm improvements to DFS and BFS

BFS

- Time: $O(b^d)$
- Space: $O(b^d)$
- Complete = YES
- Optimal = YES if action costs are fixed, NO otherwise

Time and Memory requirements for BFS

Depth	Nodes	Time	Memory
2	1100	.11 sec	1 MB
4	111,100	11 sec	106 MB
6	10^7	19 min	10 GB
8	10^9	31 hours	1 terabyte
10	10^{11}	129 days	101 terabytes
12	10^{13}	35 years	10 petabytes
14	10^{15}	3,523 years	1 exabyte

BFS with b=10, 10,000 nodes/sec; 10 bytes/node

DFS

- Time: $O(b^m)$
- Space: $O(bm)$
- Complete = YES, if space is finite (and no circular paths), NO otherwise
- Optimal = NO

Problems with BFS and DFS

- BFS
  - doesn't take into account costs
  - memory! ☹
- DFS
  - doesn't take into account costs
  - not optimal
  - can't handle infinite spaces
  - loops

Uniform-cost search

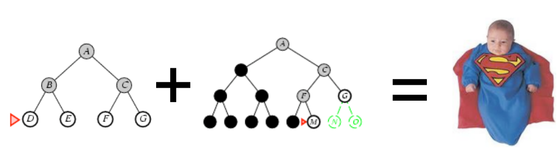
- Expand unexpanded node with the smallest *path* cost, g(x)
- Implementation:
  - *frontier* = priority queue ordered by **path** cost
  - similar to Dijkstra's algorithm
- Equivalent to breadth-first if step costs all equal

Uniform-cost search

- Time? and Space?
  - dependent on the costs and optimal path cost, so cannot be represented in terms of *b* and *d*
  - Space will still be expensive (e.g. take uniform costs)
- Complete?
  - YES, assuming costs > 0
- Optimal?
  - Yes, assuming costs > 0
- This helped us tackle the issue of costs, but still going to be expensive from a memory standpoint!

Ideas?

Can we combined the optimality and completeness of BFS with the memory of DFS?



Depth limited DFS

- DFS, but with a depth limit **L** specified
  - nodes at depth **L** are treated as if they have no successors
  - we only search down to depth **L**
- Time?
  - O(b^L)
- Space?
  - O(bL)
- Complete?
  - No, if solution is longer than L
- Optimal
  - No, for same reasons DFS isn't

Ideas?

Iterative deepening search

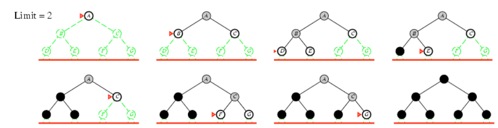
For depth 0, 1, …., ∞
    run depth limited DFS
    if solution found, return result

- Blends the benefits of BFS and DFS
  - searches in a similar order to BFS
  - but has the memory requirements of DFS
- Will find the solution when **L** is the depth of the shallowest goal

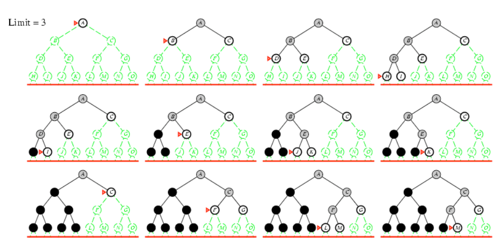
Iterative deepening search L =0

Iterative deepening search $L = 1$

Iterative deepening search $L = 2$



Iterative deepening search $L = 3$



Time?

- L = 0: 1
- L = 1: 1 + b
- L = 2: 1 + b + b^2
- L = 3: 1 + b + b^2 + b^3
- …
- L = d: 1 + b + b^2 + b^3 + … + b^d
- Overall:
  - $d(1) + (d-1)b + (d-2)b^2 + (d-3)b^3 + \ldots + b^d$
  - $O(b^d)$
  - the cost of the repeat of the lower levels is subsumed by the cost at the highest level

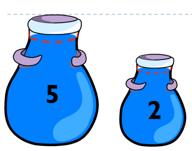
Properties of iterative deepening search

- Space?
  - *O(bd)*
- Complete?
  - Yes
- Optimal?
  - Yes, if step cost = 1

Missionaries and Cannibals Solution

	Step	Near side			Far side
0	Initial setup:	MMMCCC	B		-
1	Two cannibals cross over:	MMMC		B	CC
2	One comes back:	MMMCC	B		C
3	Two cannibals go over again:	MMM		B	CCC
4	One comes back:	MMMC	B		CC
5	Two missionaries cross:	MC		B	MMCC
6	A missionary & cannibal return:	MMCC	B		MC
7	Two missionaries cross again:	CC		B	MMMC
8	A cannibal returns:	CCC	B		MMM
9	Two cannibals cross:	C		B	MMMCC
10	One returns:	CC	B		MMMC
11	And brings over the third:	-		B	MMMCCC

Water Jug Problem



- State = (x,y), where x is the number of gallons of water in the 5-gallon jug and y is # of gallons in the 2-gallon jug
- Initial State = (5,2)
- Goal State = (*,1), where * means any amount

Operator table

Name	Cond.	Transition	Effect
Empty5	–	(x,y)→(0,y)	Empty 5-gal. jug
Empty2	–	(x,y)→(x,0)	Empty 2-gal. jug
2to5	x ≤ 3	(x,2)→(x+2,0)	Pour 2-gal. into 5-gal.
5to2	x ≥ 2	(x,0)→(x-2,2)	Pour 5-gal. into 2-gal.
5to2part	y < 2	(1,y)→(0,y+1)	Pour partial 5-gal. into 2-gal.