Search

CPSC 383: Explorations in Artificial Intelligence and Machine Learning
Fall 2025

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Outline

- Knowledge processing
- Search vs Computation
- Search
- Search Component Definitions
- Examples
- Graphs and Trees
- Uniformed Search

Knowledge Processing

Knowledge Processing in general

- Task: use knowledge represented in system plus new knowledge and produce a result:
  - Add knowledge to knowledge base
  - Find inconsistencies in knowledge base
  - Answer user question

☞ make implicit knowledge explicit

- Approaches:
  - Search (produce a certain result or new consistent knowledge base)
  - Apply procedural knowledge (computation)

General Problems

- What parts of the knowledge base are needed?
- What parts of the knowledge base must be changed (frame problem)?
- What pieces of knowledge are applicable?
- What concrete piece of knowledge to choose next?

Search versus Computation

Search versus Computation

- Deep down in our computers everything is a computation

- On higher levels, there are different computation processes:

  1. Processes where each step is always necessary to achieve their goals
     ☞ computation

  2. **Processes where after they finished you can identify steps that did not contribute to achieving the goals**
     ☞ search

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What does computation offer?

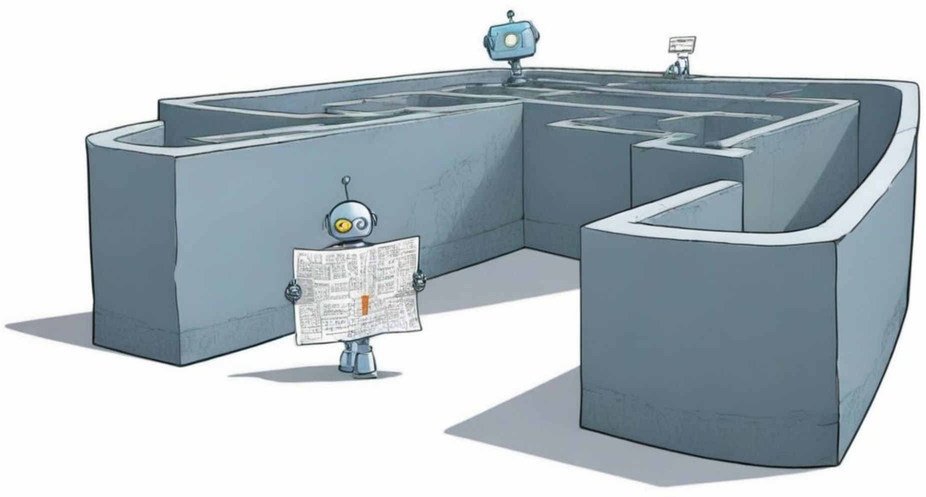
- Usually run time is predictable
- No dealing with choices
- No unnecessary steps
- Implicit knowledge representation
  - ☞ difficult to know what is going on
- Not always possible to achieve
  - ☞Nice to have, but in AI systems often not possible

Search

Search: Basic Definitions

Search is at the core of many systems that seem to be intelligent

- Learning: search for a structure that explains/ predicts/justifies some experiences
- Planning: search for a series of decisions that best achieves a goal while fulfilling certain conditions
- Deduction: search for a justification for a certain fact
- Natural language understanding: search for the best interpretation of a text
- …



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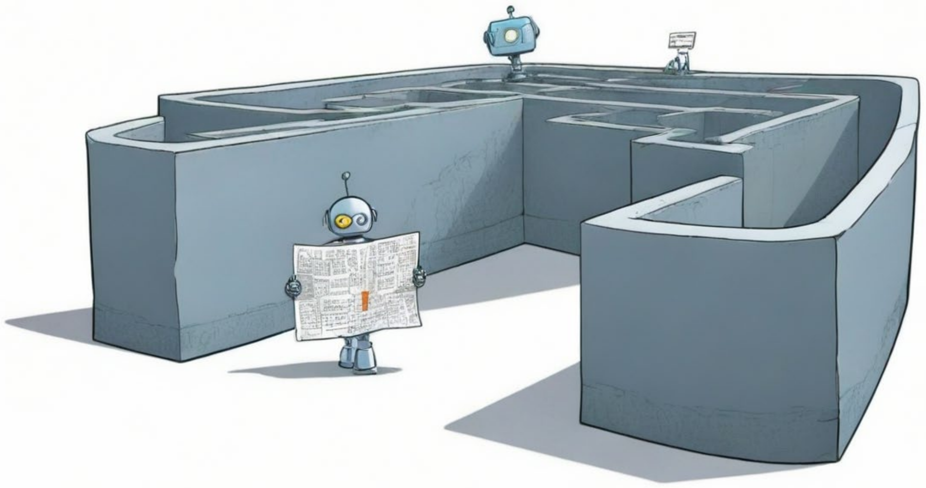


How is "intelligence" achieved?

- By defining a good search model
- By finding good controls for search processes

But: do not expect your system to be good for every problem instance it can theoretically solve!

No free lunch theorem:

For every search system there is a search instance that shows the worst case behavior

Definitions

Basic Definitions (I)

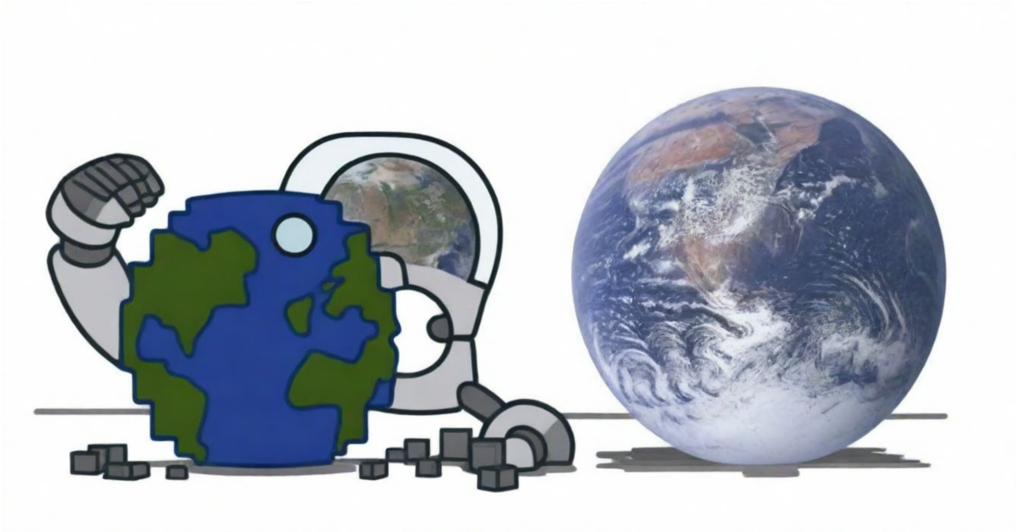
Search Model $A = (S, T)$

S	set of possible states
T	transitions between states

☞

- Defines main data structure and possibilities (space)
- Tells us what the control can work with
- Limits the choices of the control

Search Problems Are Models



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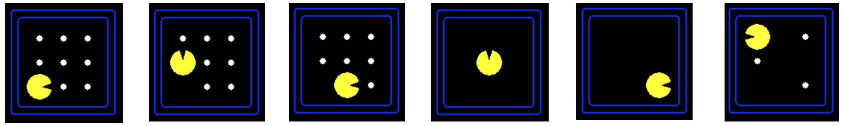

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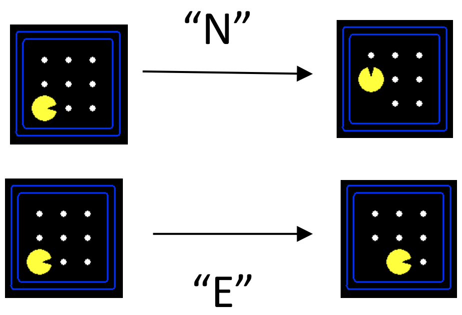
Two transitions from state 1



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Basic Definitions (II)

Search Process $P = (A, Env, K)$

A	search model
Env	environment of process *(sometimes your configuration of algorithm)*
K	search c(K)ontrol is a function transitioning from current state to next state

☞

- Defines how to deal with indeterminism of search model.
- Has to deal with all possible states and all searches you want to perform

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Basic Definitions (III)

Search Instance $Ins = (s_0, G)$:

s_0 start state for the instance

$G(state) \rightarrow \{yes, no\}$ goal condition (function on current state that halts)

☞

- Defines concrete input for a search run
- Defines when search ends (positively)
- Normally is generated out of user input

Basic Definitions (IV)

Search Derivation:

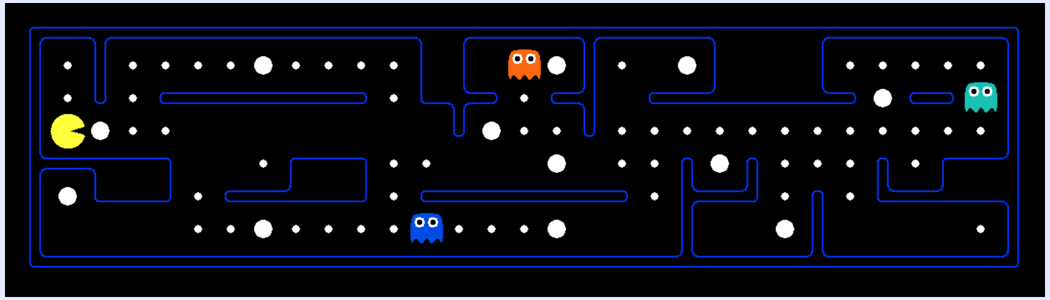
P applied on Ins leads to a sequence of states

- Needed to analyze quality of search control
  - distinguish between necessary and unnecessary steps
  - compare with shortest possible sequence of states that leads to a solution
- Might be looked at to determine solution

Examples

What's in a State Space?

The world state includes every last detail of the environment



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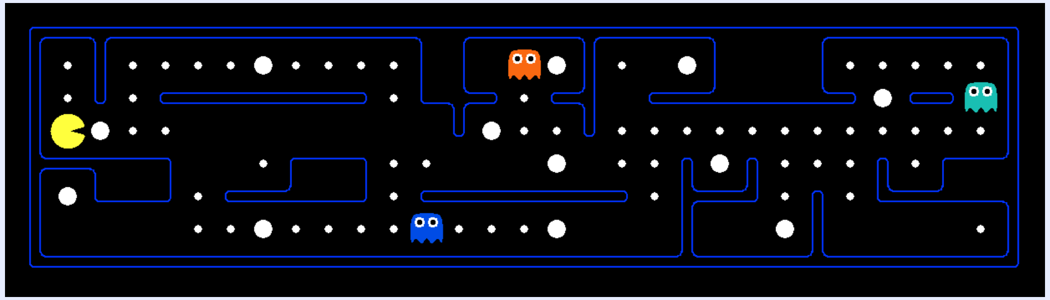

A search state keeps only the details needed for planning (abstraction)

- Problem: Pathing
  - States: (x,y) location (make up S)
  - Actions: NSEW (help us decide T)
  - Successor: update location only (make T)
  - Goal test: is (x,y)= END (make G)

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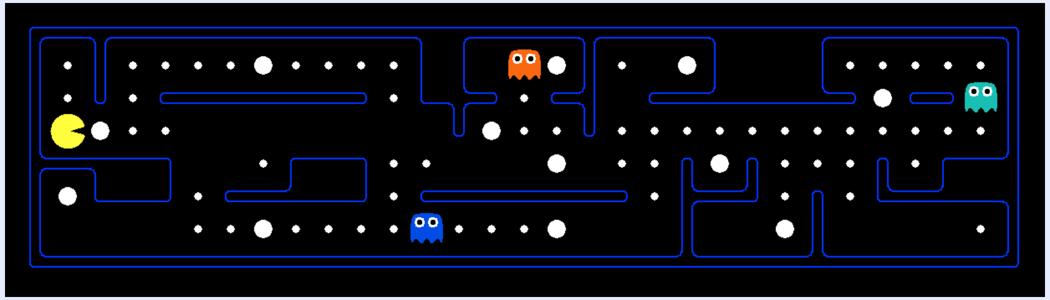

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  - Successor: update location only (make T)
  - Goal test: is (x,y)= END (make G)
- Problem: Eat-All-Dots
  - States: {(x,y), dot booleans}
  - Actions: NSEW
  - Successor: update location and possibly a dot boolean
  - Goal test: dots all false

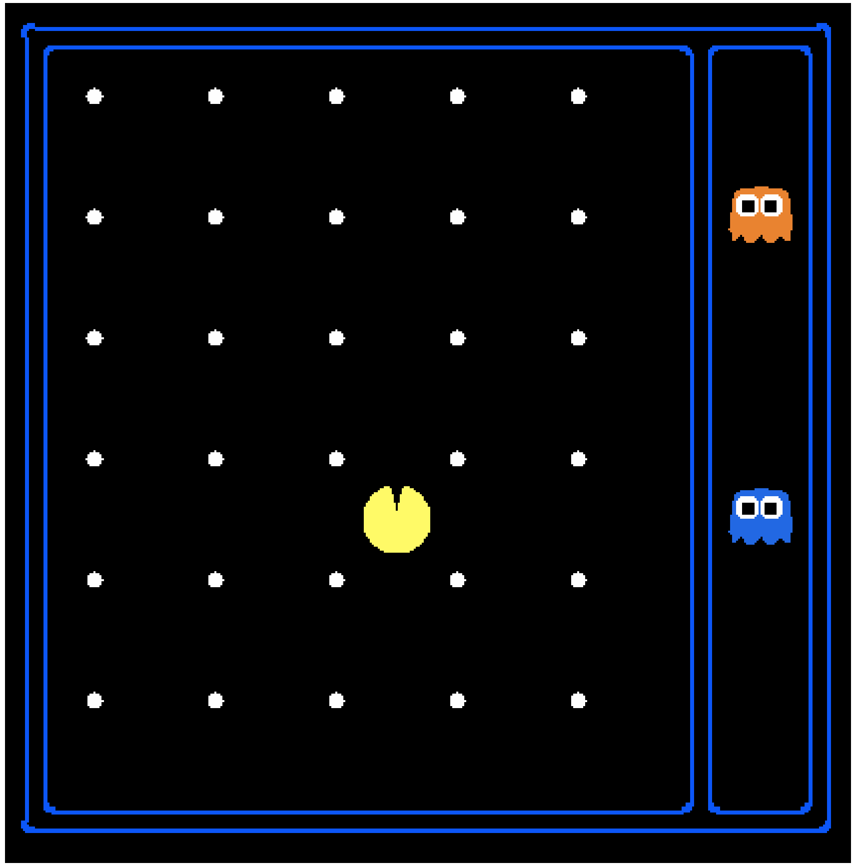
State Space Sizes?

- World state:
  - Agent positions: 120
  - Food count: 30
  - Ghost positions: 12
  - Agent facing: NSEW

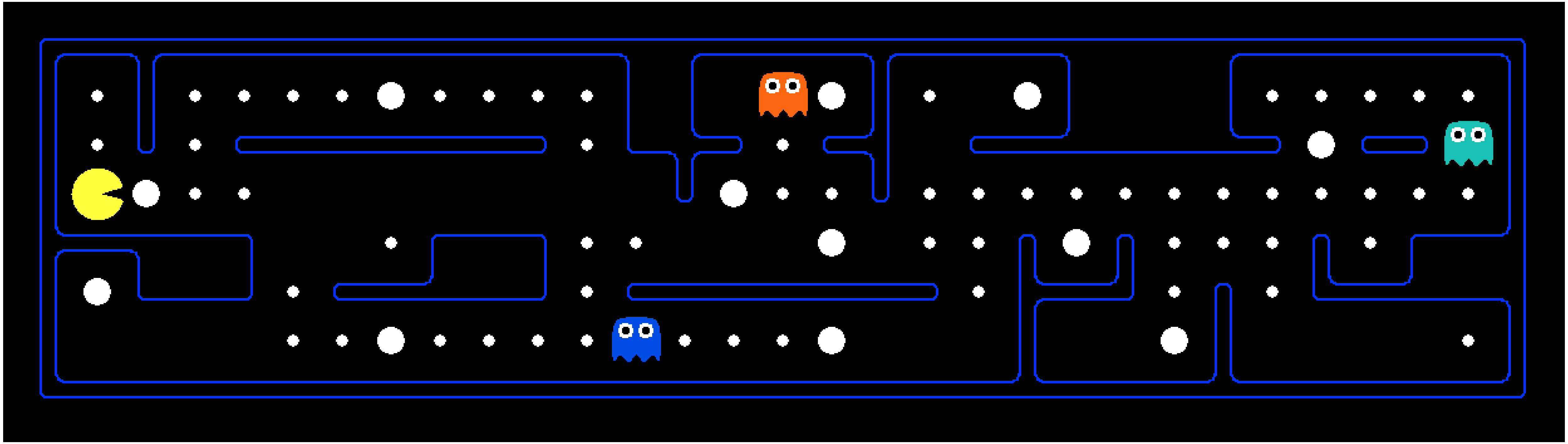
- How many
  - World states?
    $120x(2^{30})x(12^2)x4$
  - States for pathing?
    120
  - States for eat-all-dots?
    $120x(2^{30})$

12 x 10 grid (dot and spaces)

._._._._._ is one row (10 spots)



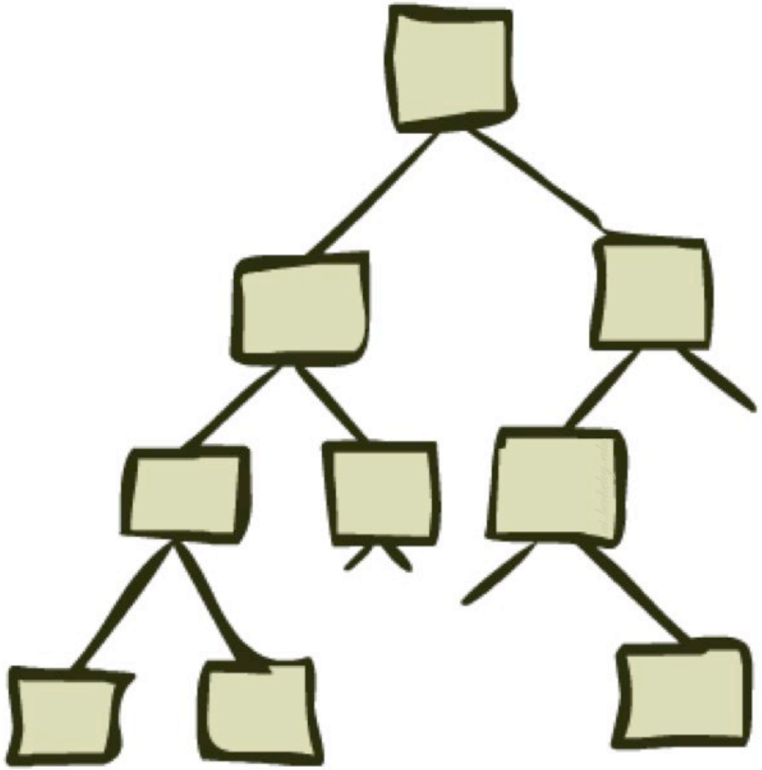
Safe Passage



- Problem: eat all dots while keeping the ghosts perma-scared
- What does the state space have to specify?
  - (agent position, dot booleans, power pellet booleans, remaining scared time)

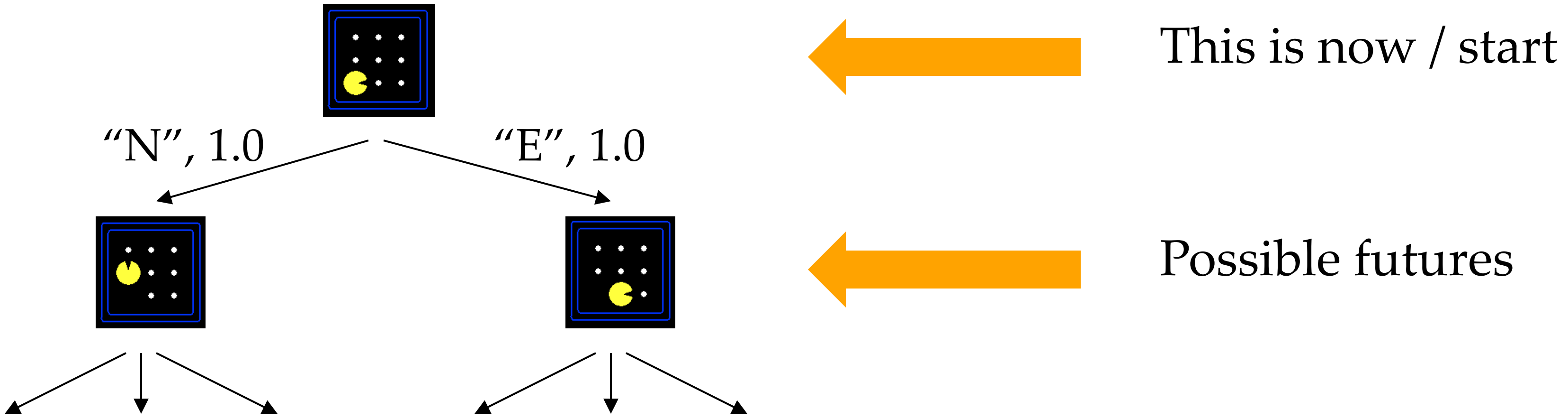
Graphs? Trees?

Search Trees



- A search tree:
  - A "what if" tree of plans and their outcomes
  - The start state is the root node
  - Children correspond to successors
  - Nodes show states, but correspond to PLANS that achieve those states
  - For most problems, we can never actually build the whole tree

Search Trees



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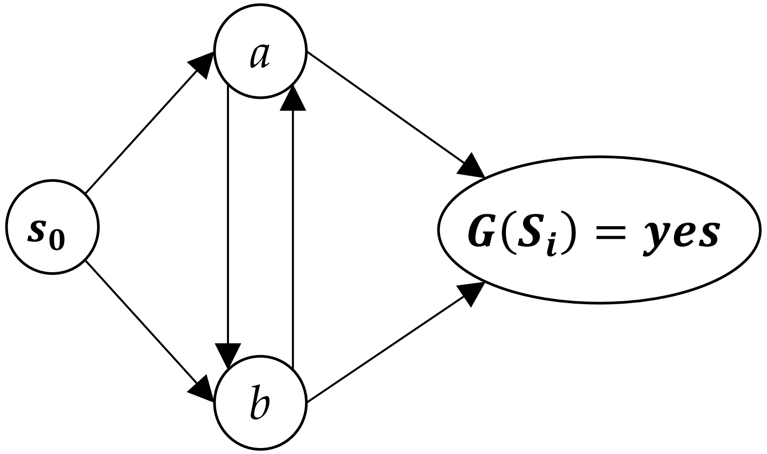
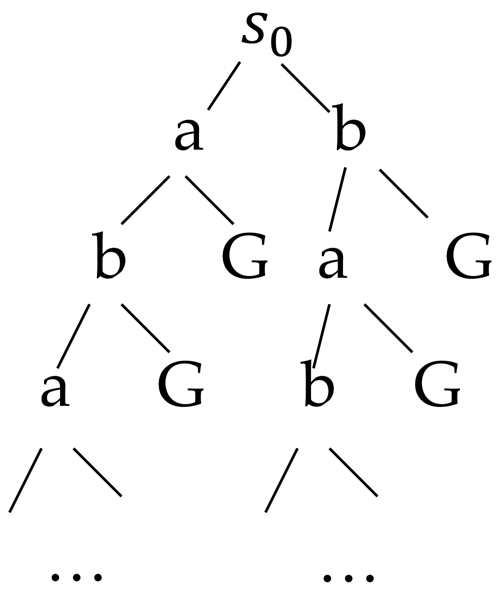
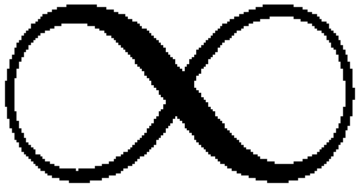
State Space Graphs vs. Search Trees

Consider this 4-state graph:



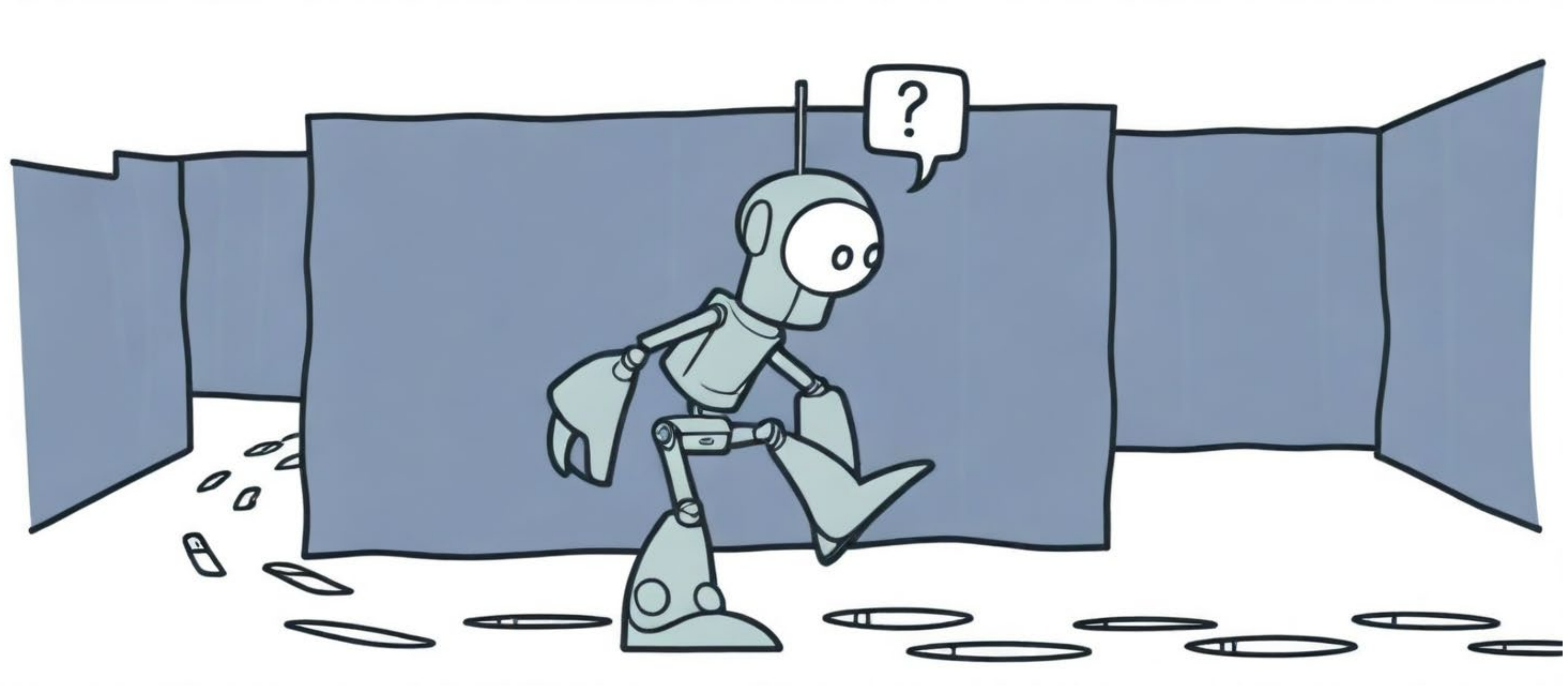
How big is its search tree (from S)?





Important: Lots of repeated structure in the search tree!

Graph Search



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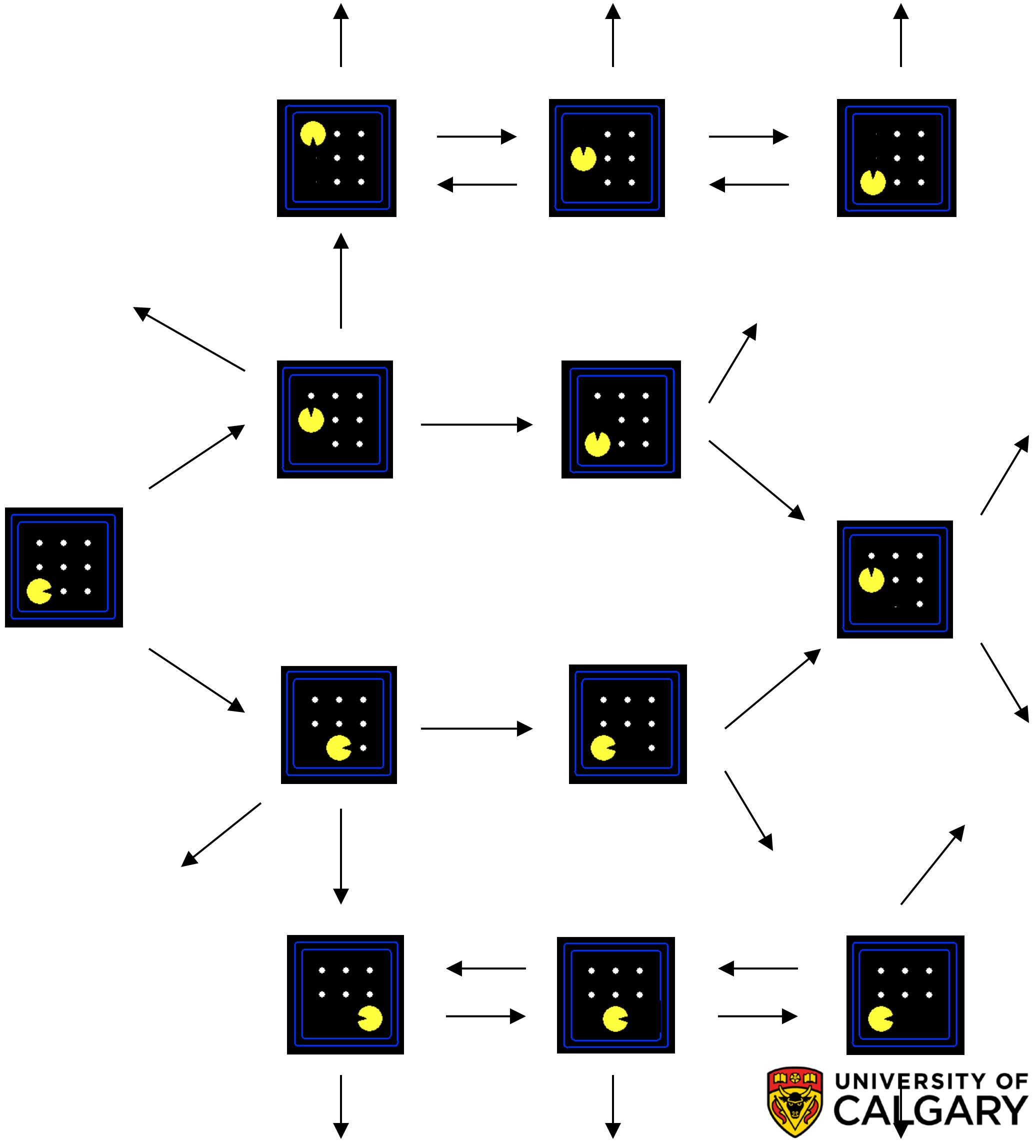
State Space Graphs

- In a state space graph, each state occurs only once!
- We can rarely build this full graph in memory (it's too big), but it's a useful idea



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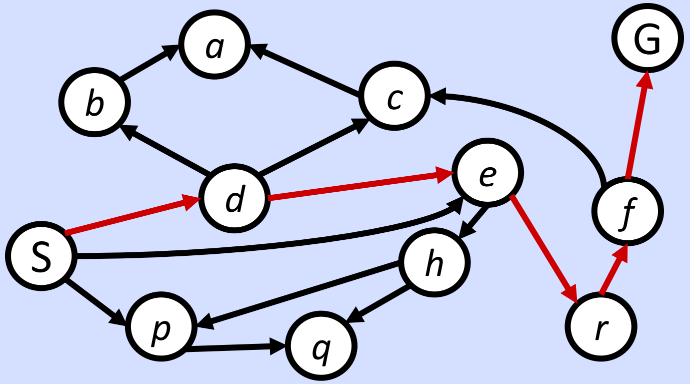
State Space Graphs vs. Search Trees

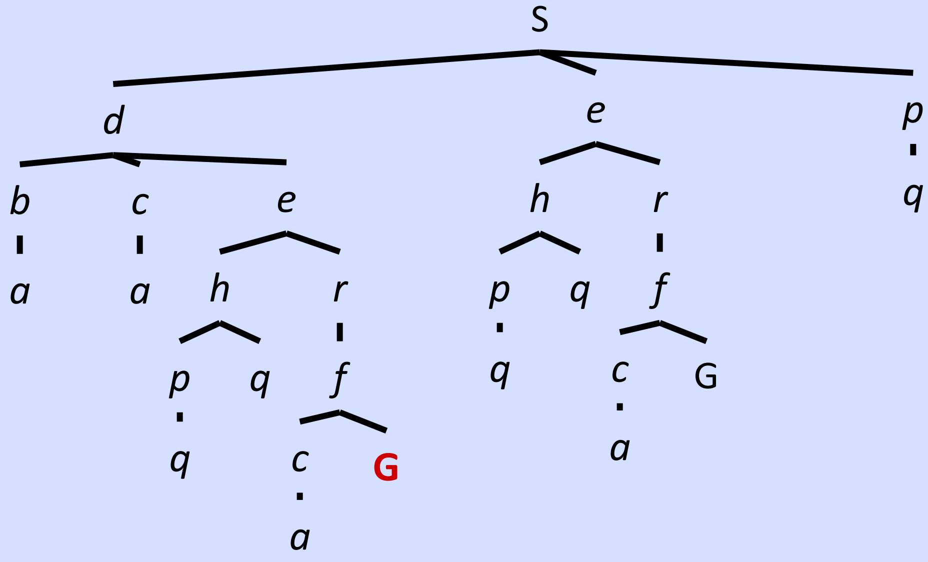
State Space Graph



Each NODE in in the search tree is an entire PATH in the state space graph.

We construct both on demand – and we construct as little as possible.

Search Tree



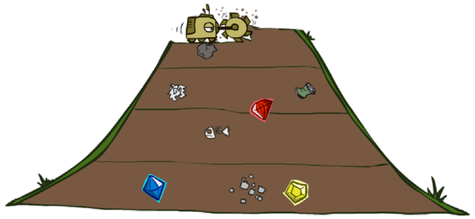
Uniformed Search

Search strategies

- A K(control) is defined by picking the order of node expansion for the derivation
- Strategies are evaluated along the following dimensions:
  - completeness—does it always find a solution if one exists? (can we trust it!)
  - optimality—does it always find a least-cost solution? (is it the best!)
  - time complexity (how long!)
  - space complexity (how taxing on my storage!)
- Time and space complexity are measured (for trees which are most common)
  - b—maximum branching factor of the search tree
  - d—depth of the least-cost solution
  - m—maximum depth of the state space (may be ∞)

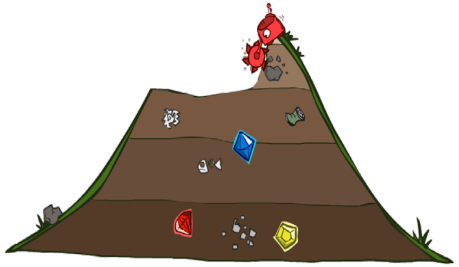
Uniformed Search strategies

Uninformed strategies use only the information available in the problem definition



- Breadth-first search
  - Explore level closest to root first

- Depth-first search
  - Explore farthest from root first



- Uniform-cost search
  - Explore lowest cost region next

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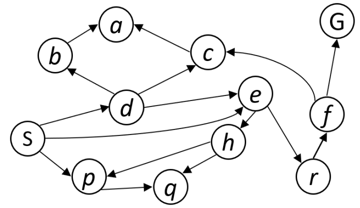
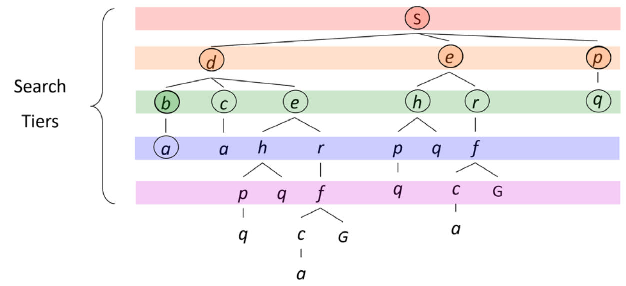
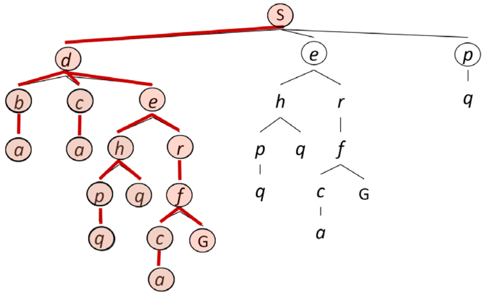
Uniformed Search strategies

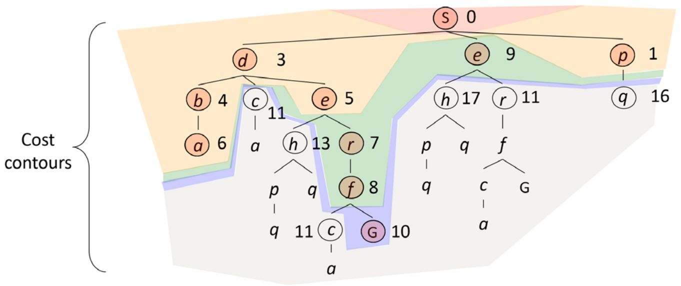
Uninformed strategies use only the information available in the problem definition

- Breadth-first search
  - Explore level closest to root first
  - **stores a lot of state, waste time on early**
  - **but complete**
- Depth-first search
  - Explore farthest from root first
  - **less state, may get lost in infinite trees**
- Uniform-cost search
  - Explore lowest cost region next
  - **medium state, could get lost in infinite trees depending on cost measure**

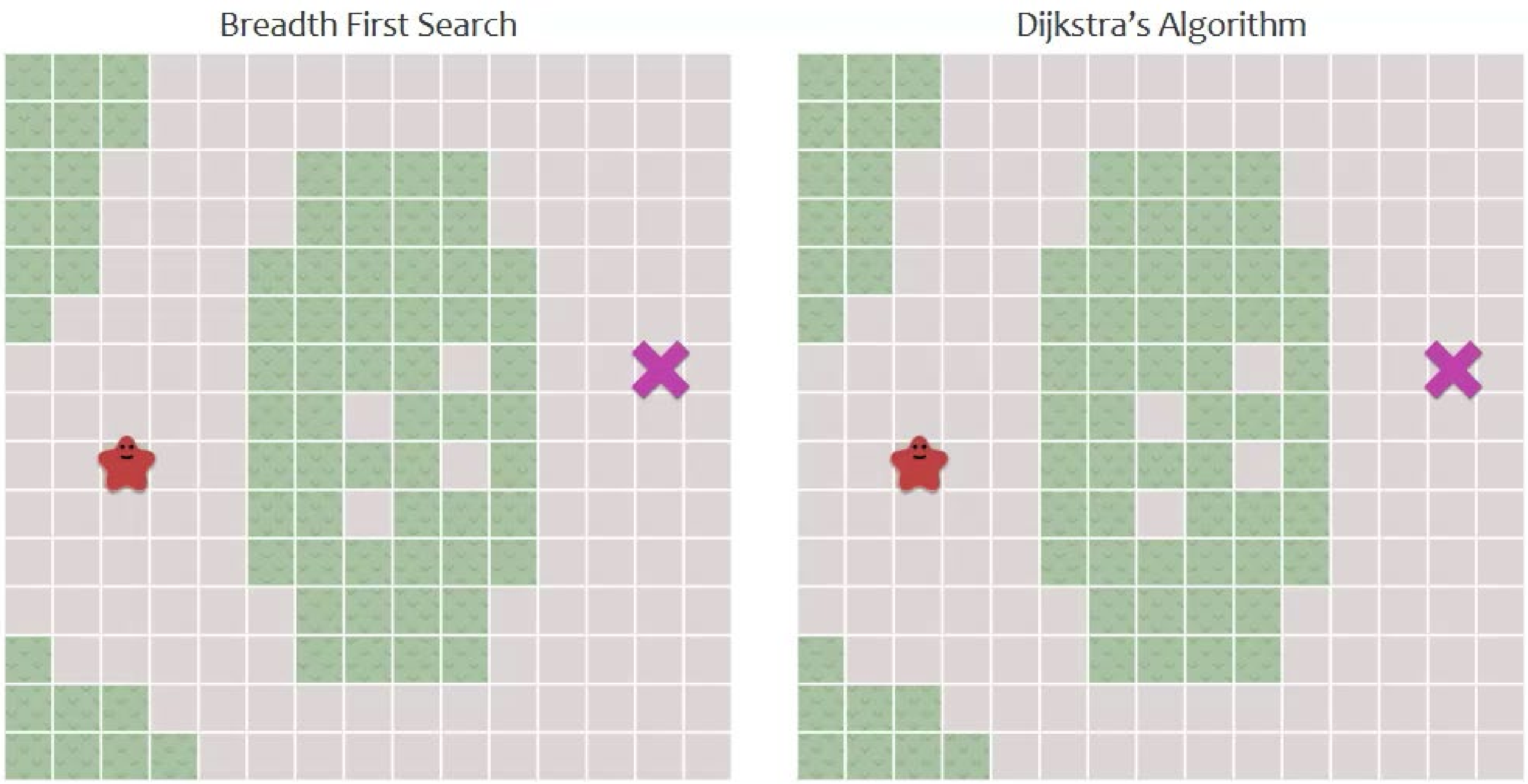








Uniformed Search strategies



Uniformed Search strategies

- Depth-limited search
  - depth to level L
  - **least state, won't get lost in infinite trees**
  - **might not go deep enough to find answer**

- Iterative deepening search
  - Do depth limited to increasing depth level L
  - **less state, more time, 1 to infinity**

Summary

Summary

- Search is a process where after they finished you can identify steps that did not contribute to achieving the goals
- Intelligence Achieved by
  - defining a good search model
  - finding good controls for search processes
- There is always a worst case
- You need to define a Model and Process, you start these on an Instance which creates a Derivation (history of you search)
- Search spaces are often really really large (This is fundamental problem)
- Can use graphs and trees to manage search space exploration
- Uniformed search (structure of problem only) includes breadth, depth, and simple variants of these two

Next…path-finding

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