Search

CPSC 433: Artificial Intelligence
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Outline

- Knowledge processing
- Search vs Computation
- Search
- Search Component Definitions
- Examples
- Graphs and Trees
- Problems that need solving when designing Search solution

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

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

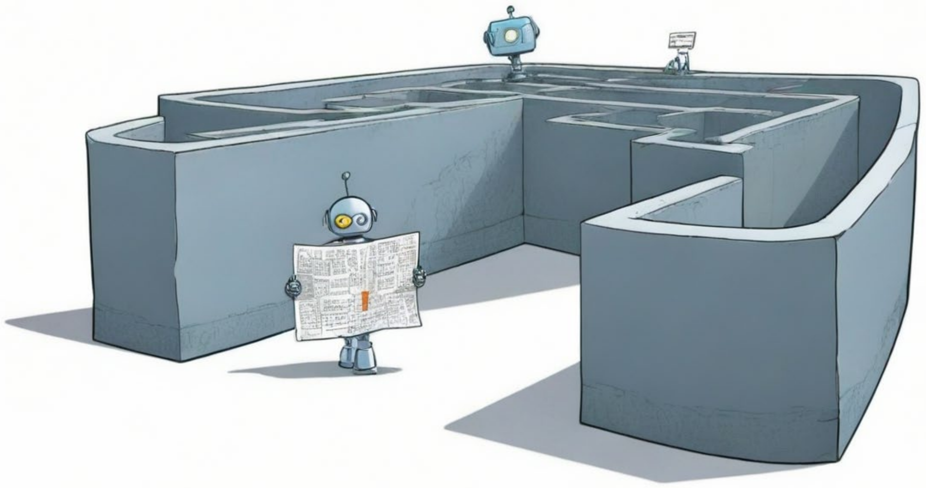
Search

Search Problems

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 (or that comes very near to it)
- 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

General search knowledge

In this course we are going to first define a **general search paradigm**

- A bunch of formalization of the fundamental pieces we need for a search
- We'll discuss which pieces we need for this in the remainder of this slide deck

Then we will introduce **3 sub-variants** of this general search paradigm

- **Set-based search, And-tree-based search, Or-tree-based search**
- Each of these come with a **basic core** design that fulfills the **general search knowledge** requirement
- They also each come with some simpler components into which you fit **application knowledge** to make that search work for your specific problem

3 sub-variants

Set-based Search

- Good for local search (low impact on space needs)
- Good for greedy solutions like hill-climbing solutions (simple algorithms that don't need history)
- Often lose guarantee of optimization but often can find good solutions fast

And-tree-based Search

- Good for optimization problems
  - Structure an exhaustive search for all options and then return the optimal option
  - Tree can be bounded (pruned) (branch-and-bound algorithms – CPSC 413)
- Good for problems where you need to solve all sub-problems and combine them
- Take a lot of space and computation (but that's how we get optimal results)

Or-tree-based Search

- Good for finding one valid solution (like hard constraint satisfaction), but unlike set based search designed so we can keep a history so that we don't repeat steps when one path of search fails, less space than and-tree generally

Model

Basic Definitions (I)

Search Model

$A = (S, T)$

S set of possible states

$T \subseteq S \times S$ 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

Basic Definitions (I)

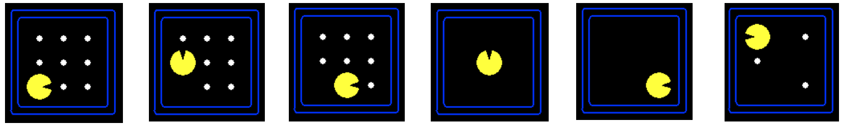
Search Model

$A = (S, T)$

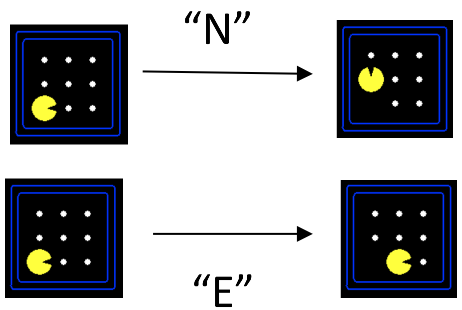
S set of possible states

$T \subseteq S \times S$ transitions between states

$S = \{s_1, s_2, s_3, s_4, s_5, s_6\}$



Two transitions from state 1



$(s_1, s_2) \in T$

$(s_1, s_3) \in T$

Process

Basic Definitions (II)

Search Process

$P = (A, Env, K)$

A search model

Env environment of process

(sometimes your configuration of algorithm)

$K\colon S \times Env \rightarrow S$ search control is a function K transitioning from current state to next state (based on possible additional environment input)

$K(s, e) = s'$ where $(s, s') \in T, e \in Env$

☞

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

Instance

Basic Definitions (III)

Search Instance

$Ins = (s_0, G)$

$s_0 \in S$ start state for the instance

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

$G(s_i) = result$ where $s_i \in S$, and result is **yes** if search is done, **no** otherwise

☞

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

Derivation

Basic Definitions (IV)

Search Derivation:

$\boldsymbol{P}$ applied on $\boldsymbol{Ins}$ leads to a sequence of states

$s_0, \ldots, s_i, \ldots$

with $\boldsymbol{K}(s_i, e_i) = s_{i+1}, \quad s_i, s_{i+1} \in \boldsymbol{S}, \; e_i \in \boldsymbol{Env}$

☞

1. Protocols a search run
2. 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
3. Might be looked at to determine solution

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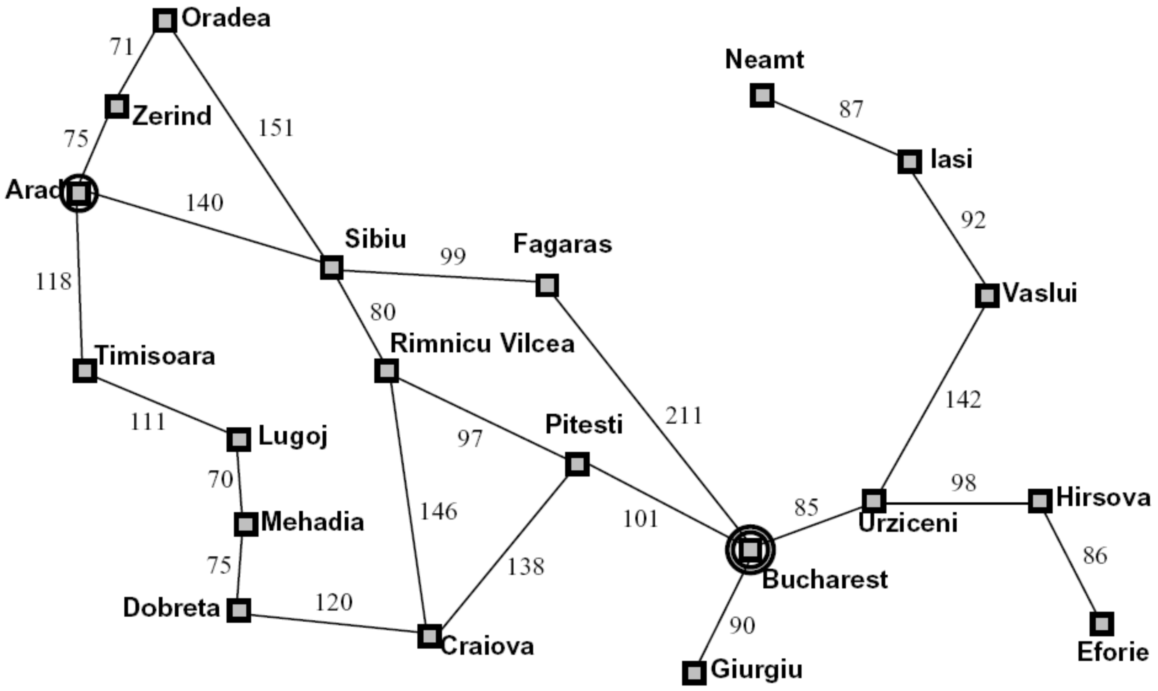
Examples

Example: Traveling in Romania



Travel from Arad to Bucharest

- State space model:
  - Cities = S
- Transitions:
  - Roads = T
    - Go to adjacent city
    - cost = distance
- Start state :
  - $s_0 = 'Arad'$
- Goal test:
  - $\boldsymbol{G}('Bucharest') \rightarrow \boldsymbol{yes}$
  - $\boldsymbol{G}(state) \rightarrow \boldsymbol{no}$
    - if state $!= 'Bucharest'$

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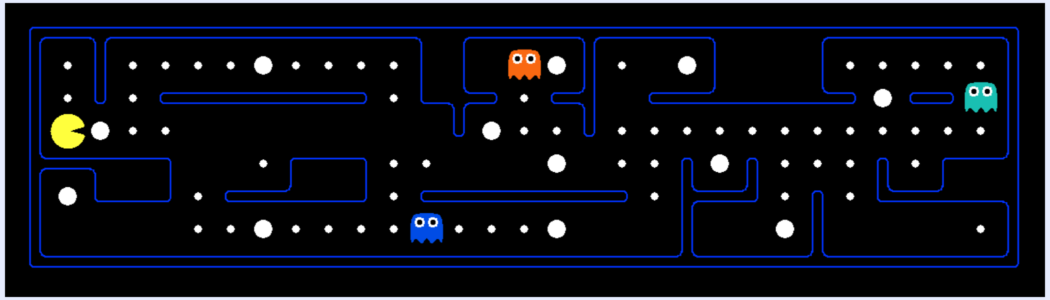
What's in a State Space?

The world state includes every last detail of the environment



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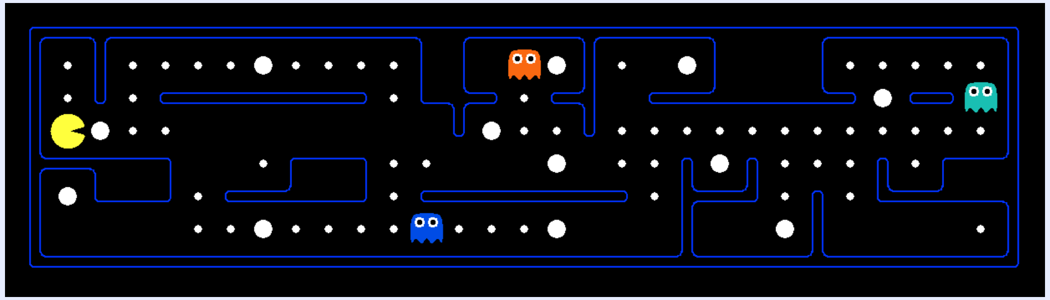

A search state keeps only the details needed for planning (abstraction)

- 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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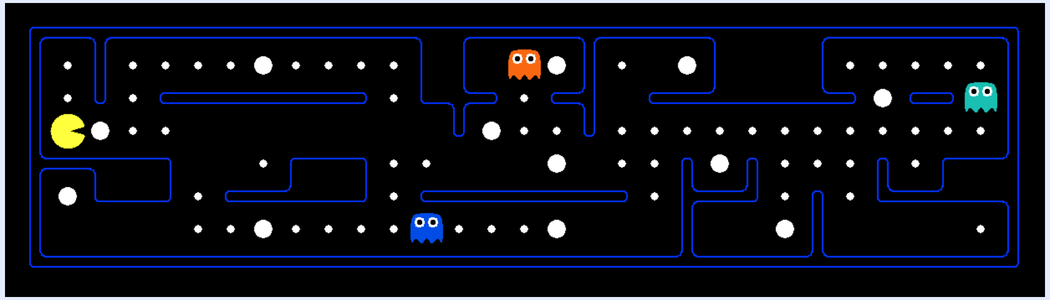

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- Problem: Pathing
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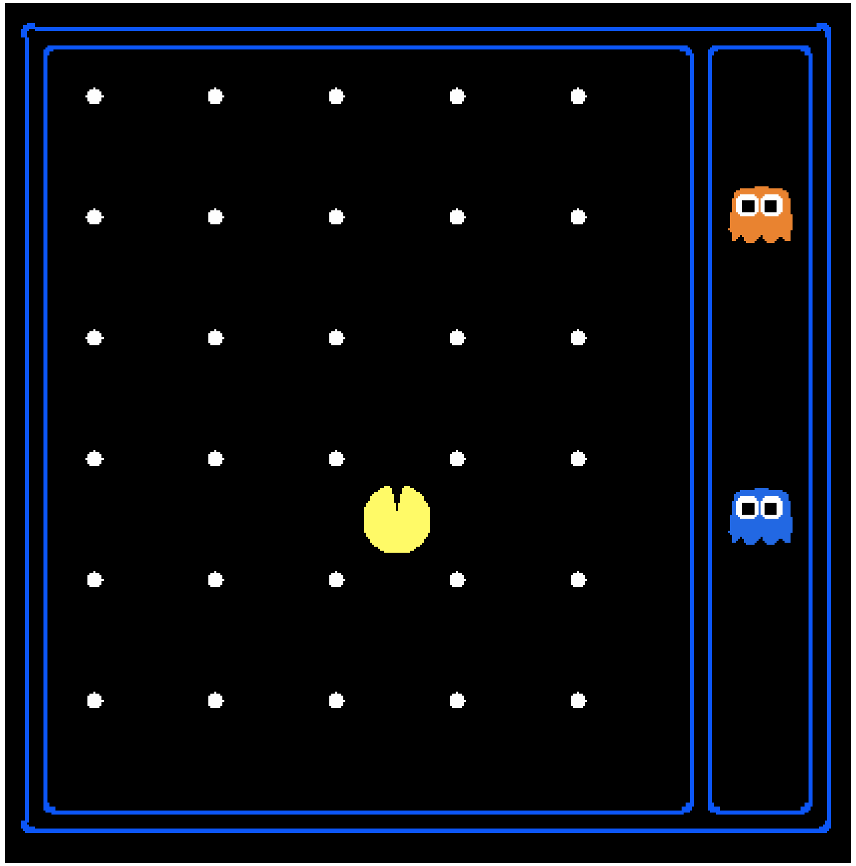
  - Actions: NSEW (help us decide T)
  - Successor: update location only (make T)
  - Goal test: is (x,y)= END (make G)
- Problem: Eat-All-Dots
  - States: {(x,y), **dot booleans**}
  - Actions: NSEW
  - Successor: update location and **possibly a dot boolean**
  - Goal test: **dots all false**

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)



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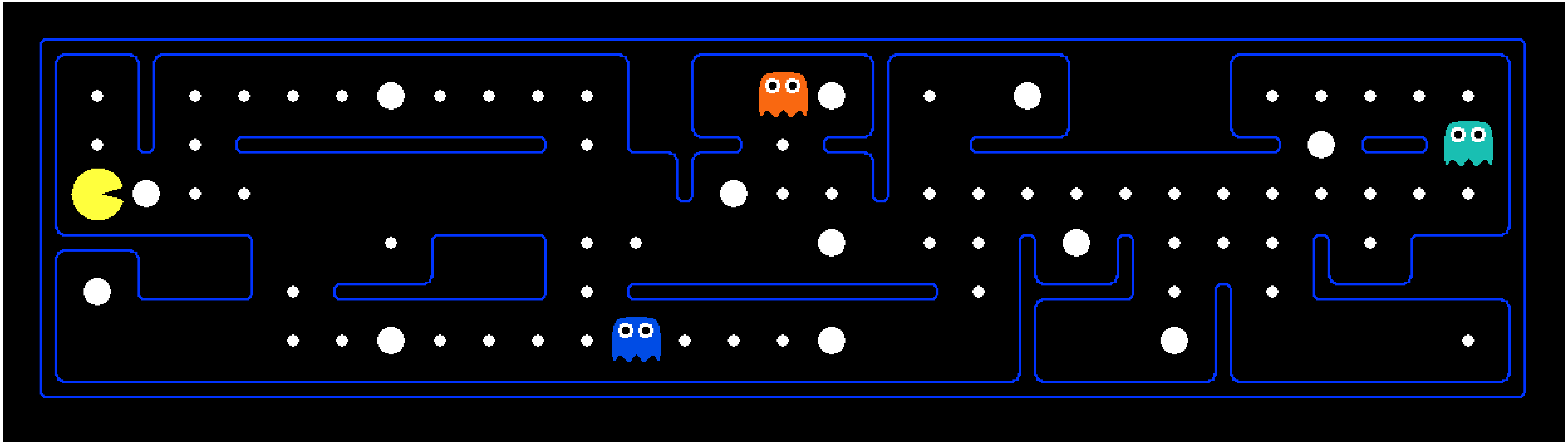
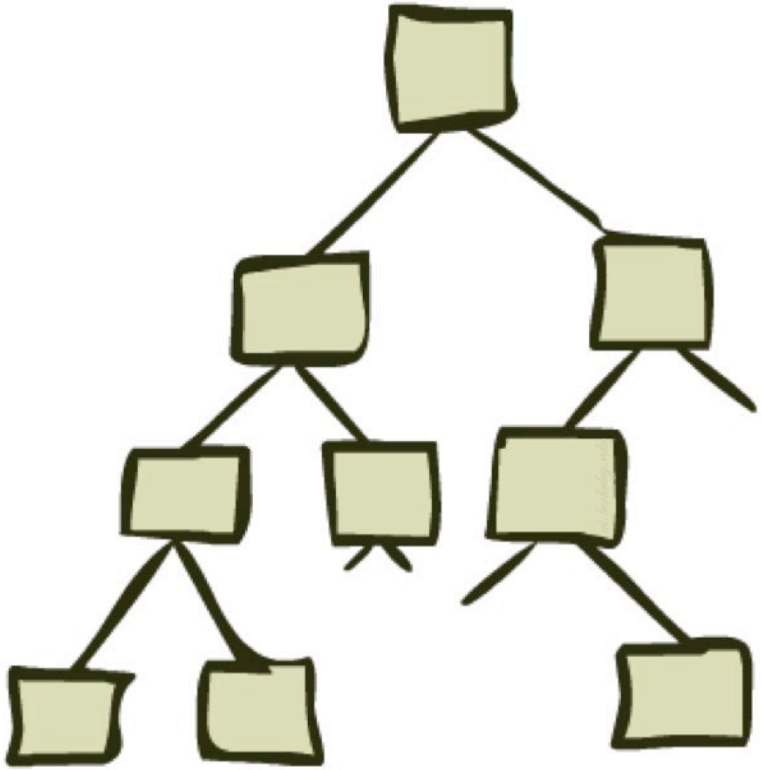
Safe Passage



- 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**)

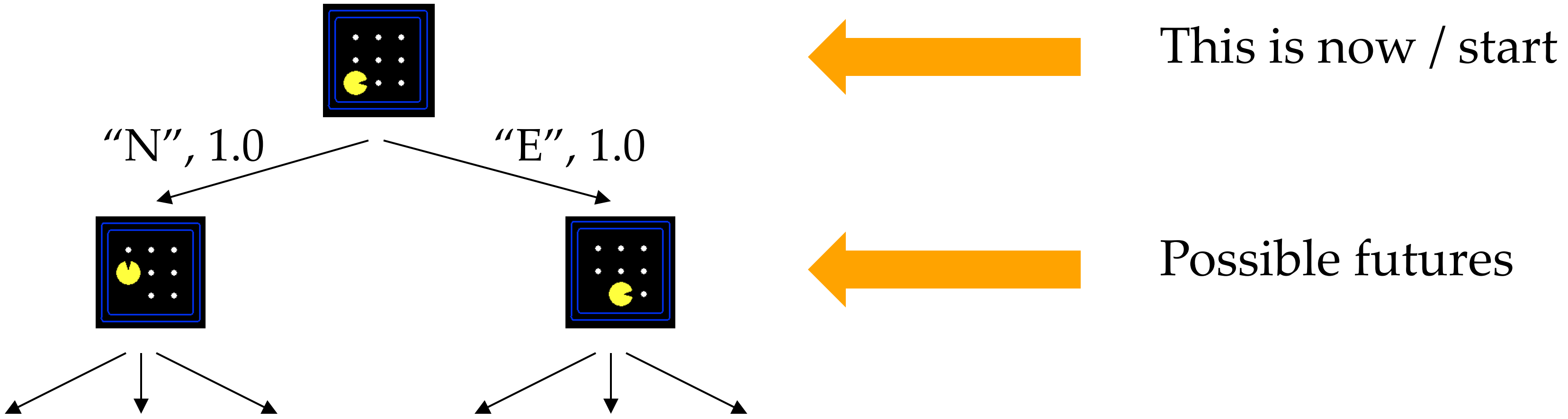
Graphs? Trees?

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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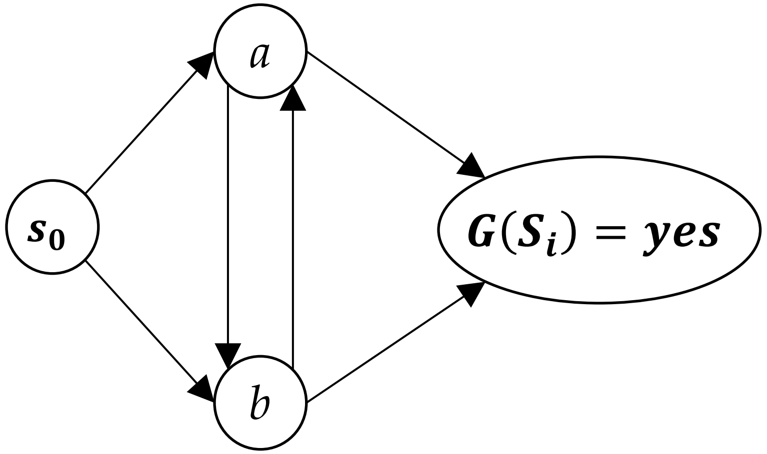
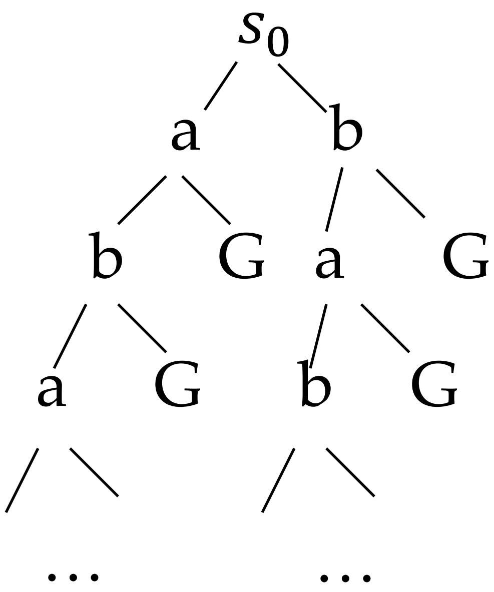
State Space Graphs vs. Search Trees

Consider this 4-state graph:



How big is its search tree (from S)?



∞

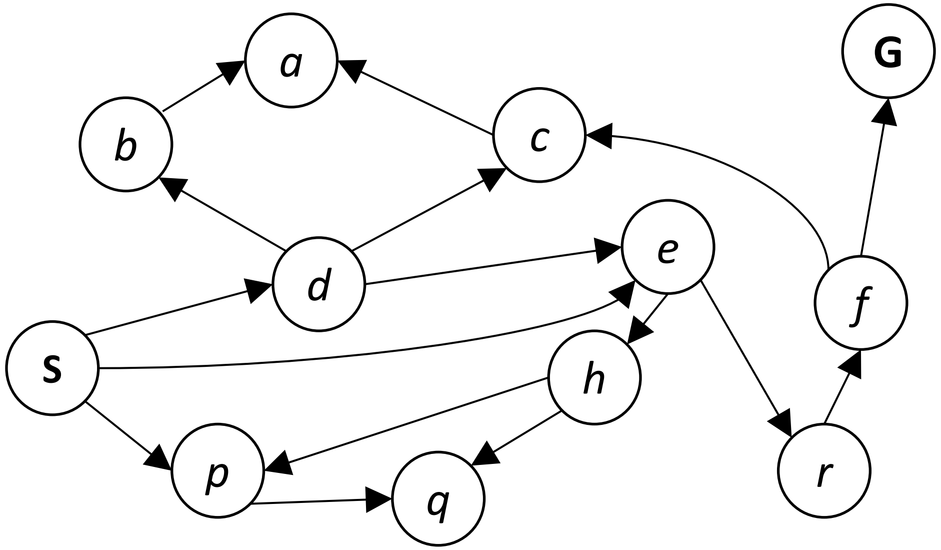
Important: Lots of repeated structure in the search tree!

State Space Graphs

- State space graph: A mathematical representation of a search problem
  - Nodes are (abstracted) world configurations
  - Arcs represent successors (action results)
  - The goal test is a set of goal nodes (maybe only one)

- 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



Tiny search graph for a tiny search problem

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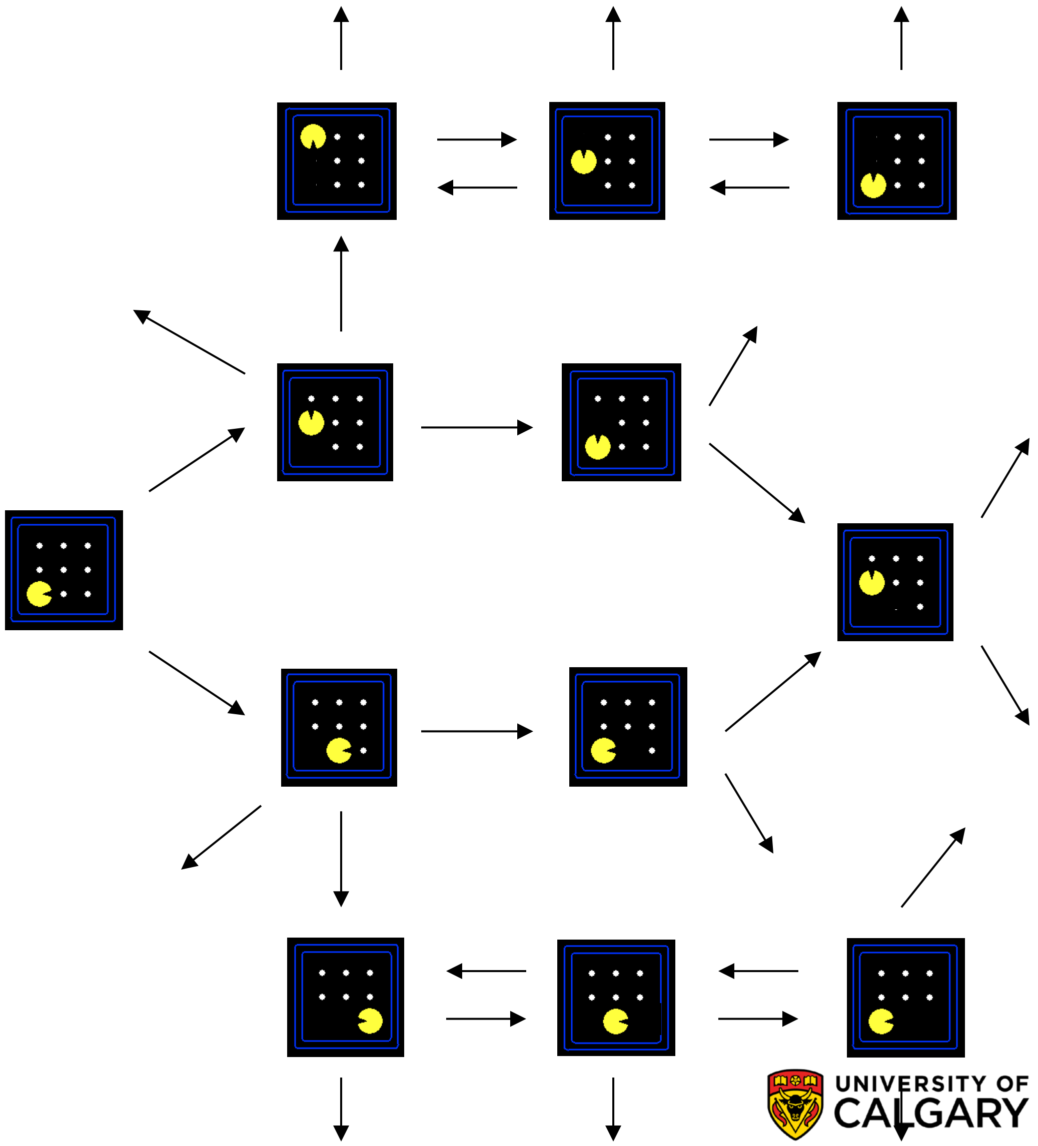

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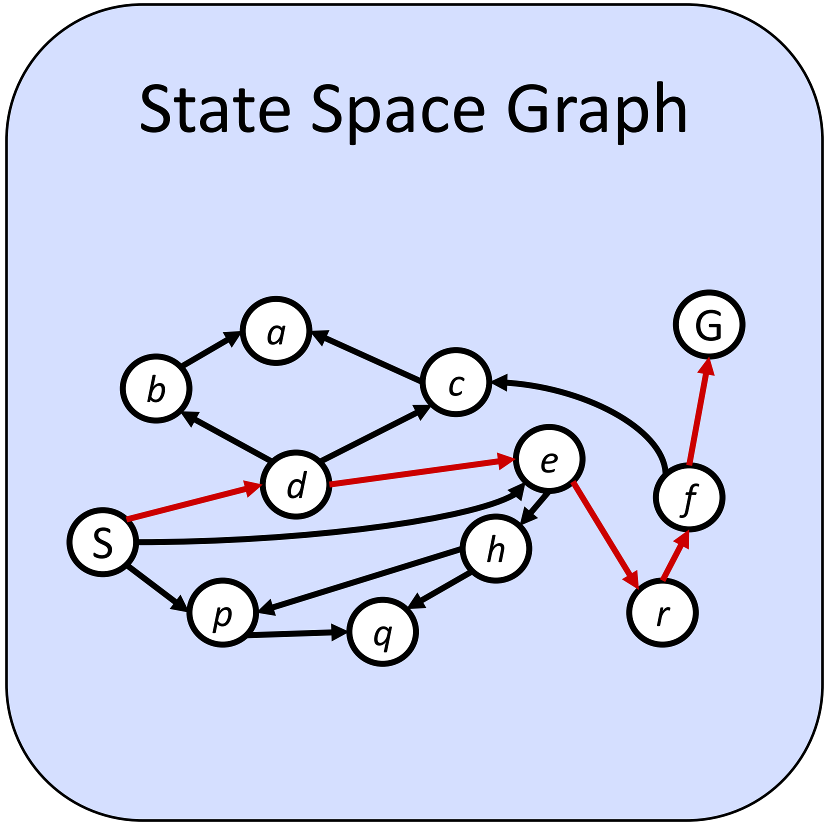
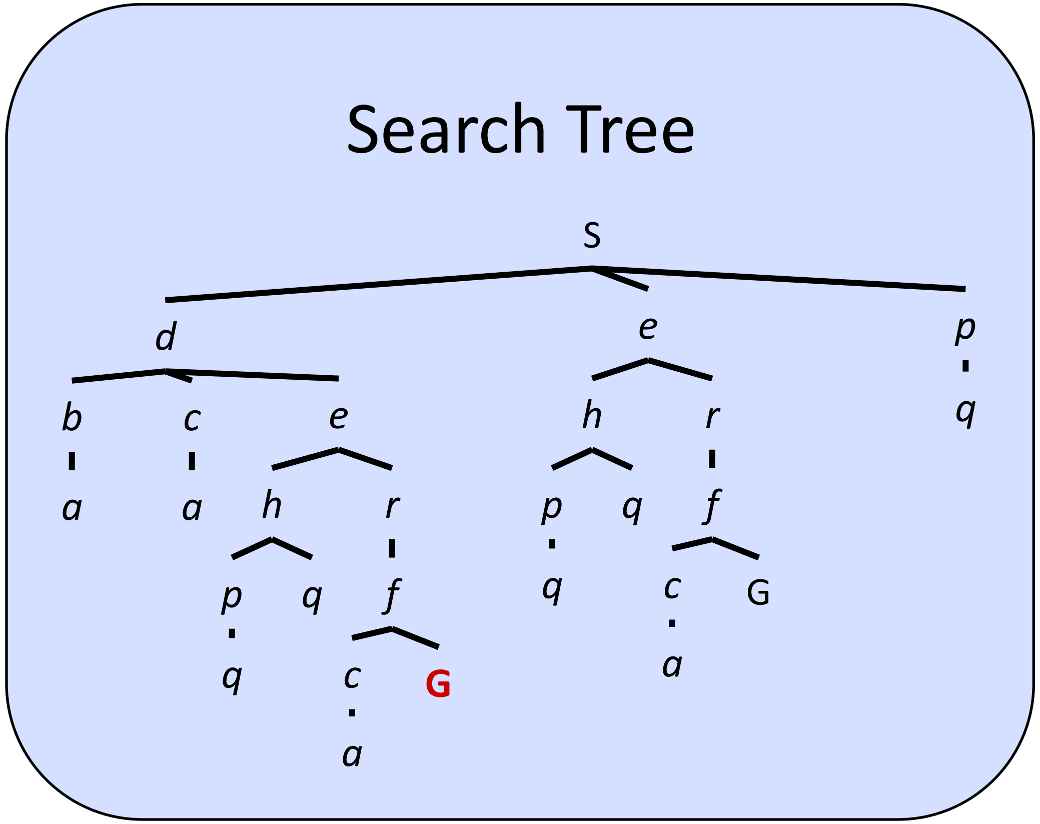
State Space Graphs vs. Search Trees



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.



Problems that need solving

Problems to solve when designing search model and process

- Combine
  1. **application knowledge** and
  2. **general search knowledge** (from search paradigms [ex. set, and, or, …])

- Define what input knowledge is necessary
- Define outside influences

- Select search paradigm
- Define search control knowledge
  ☞ part from application, part from paradigm

- Look for limitations in knowledge

Search States

Search States: General Comments

In general, they contain information about

- application
- past search
- future possibilities
- particular user interest (i.e. input; instance).

State vs Environment

- Data from outside of knowledge base and given instance
  ☞ **environment**
  - Example: new sensor data, changes in the world the system acts in, new tasks to be scheduled

- Data that never changes during search
  ☞ **environment**
  - Example: cost-profit vectors

- Data describing internal beliefs, (partial) solutions, results of reasoning and everything not mentioned above
  ☞ **state**

Transitions

Transitions: General Comments (I)

In general, they connect two states:

- Directed relation: (s_1,s_2) means you can go from s_1 to s_2 (not vice versa)

- Based on rules from
  - Application area
  - Semantics of states

Transitions: General Comments (II)

Big problem:

relation, i.e. there might be many states you can go to from a particular state

☞ the less the better

Use of more application knowledge in both states and rules for transitions can reduce number of potential successor states.

But: you can lose short search derivations and even correctness and completeness of algorithm

☞ less transitions **vs** better search control

Processes

Search Processes: General Comments

- Main tasks
  - Selection of the next search state
  - Integration of environment information

- Usually, many processes possible to a given search model
  - ☞ selection of search control essential for efficiency of search system

☞(will return to search controls but first talk about types of search)

Summary

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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
- What problems do we have to solve when designing search solutions

Next…set-based search

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