CSCE 590-1: From Data to Decisions with Open Data: A Practical Introduction to AI

Lecture 15: Reasoning

PROF. BIPLAV SRIVASTAVA, AI INSTITUTE

4TH MAR, 2021

Carolinian Creed: "I will practice personal and academic integrity."

Organization of Lecture 15

- Introduction Segment
  - Recap/ Discussion of Lecture 14
  - Mid-sem review of Project (Mar 2)

- Main Segment
  - Reasoning: drawing insights from knowledge (known or learnt)
  - Propositional Logic
  - Problem-solving agent
    - Deterministic
    - Search

- Concluding Segment
  - About Next Lecture – Lecture 16
  - Ask me anything

Introduction Segment

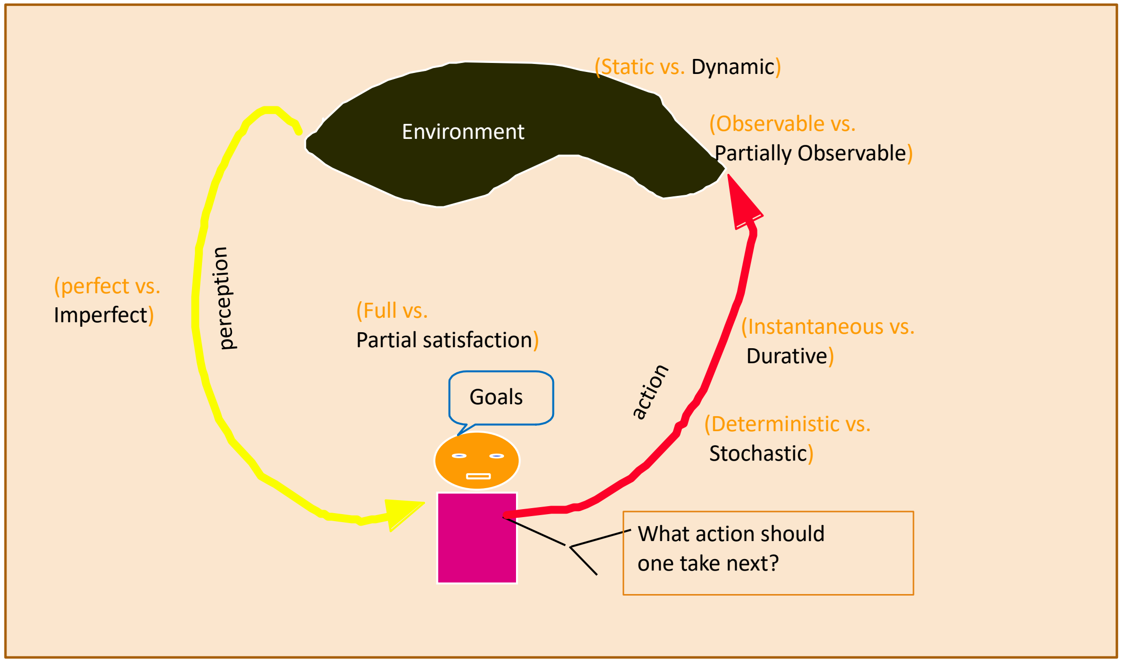
Recap of Lecture 14

- Guest talk on timing errors by Sandeep Sandha, UCLA
- We heard about timing errors and their impact on devices
- Implications for their usage in detecting human activities and applications built using them
- Touched on other Computer Science areas
  - Distributed systems, software engineering, networking – specifically
  - AI on edge devices

Mid-sem review of Project (Mar 2)

- Instructor met students to review projects
  - Project outline should be clear and actionable, relevant to the problem
  - Should increase probability of doing well in course project
- Student responsibilities
  - Work as per plan
  - Flag issues early and discuss alternative
  - Track progress
- Next milestone
  - In-class update: March 25, 2021

Main Segment



Recap: AI as Intelligent Agent

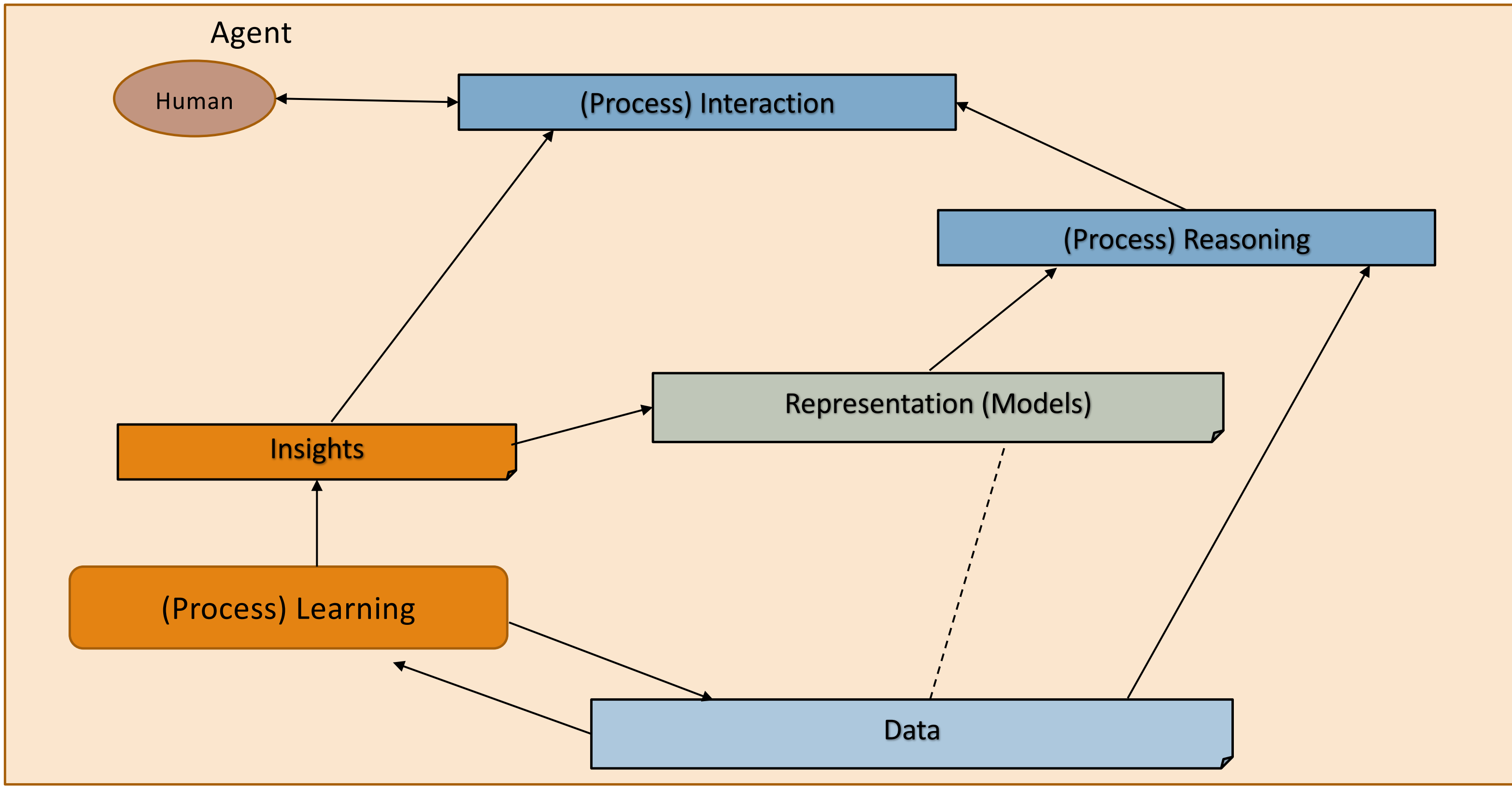
From Subbarao Kambhampati's AI Planning Course

Examples of Agents

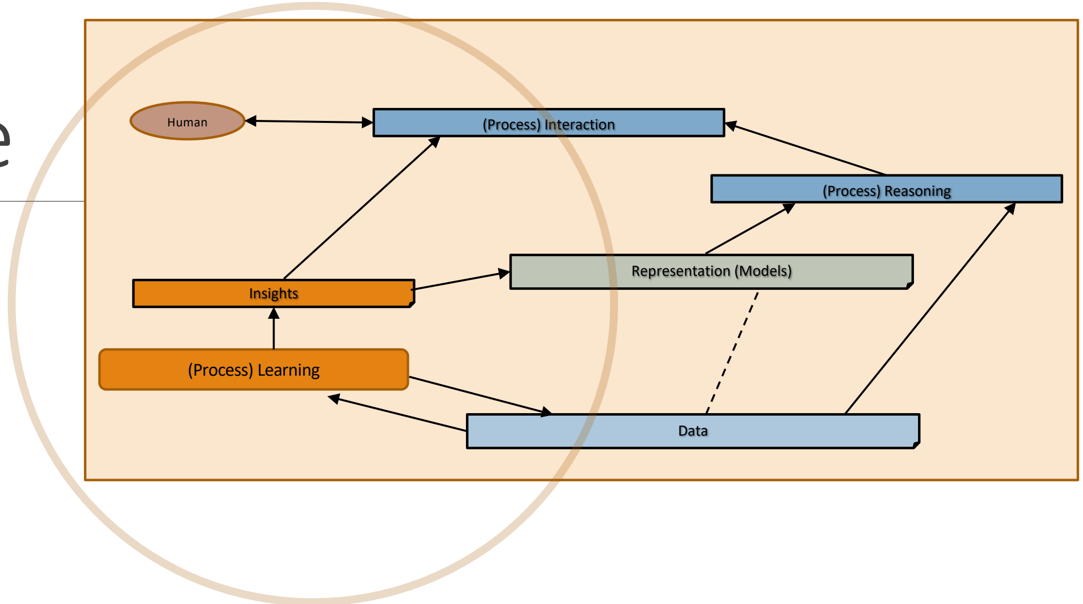
Agent Type	**Percepts**	**Actions**	**Goals**	**Environment**
Medical diagnosis system	Symptoms, findings, patient's answers	Questions, tests, treatments	Healthy patient, minimize costs	Patient, hospital
Satellite image analysis system	Pixels of varying intensity, color	Print a categorization of scene	Correct categorization	Images from orbiting satellite
Part-picking robot	Pixels of varying intensity	Pick up parts and sort into bins	Place parts in correct bins	Conveyor belt with parts
Refinery controller	Temperature, pressure readings	Open, close valves; adjust temperature	Maximize purity, yield, safety	Refinery
Interactive English tutor	Typed words	Print exercises, suggestions, corrections	Maximize student's score on test	Set of students

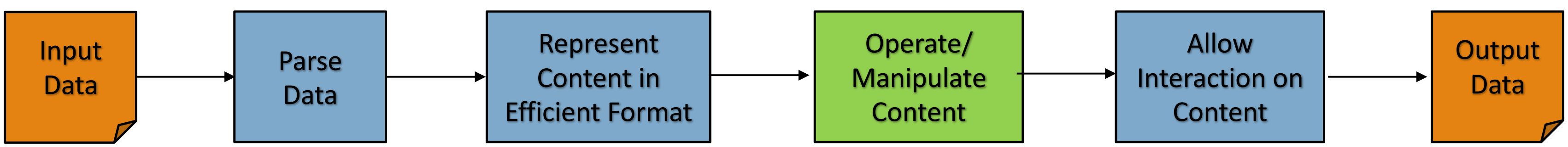
Source: Russell & Norvig, AI: A Modern Approach

Relationship Between AI Processes



Data Analysis Pipeline





Reasoning and Its Role in AI

- Reasoning: drawing insights from knowledge (known or learnt)
- Help various settings for an Intelligent Agent
  - Deterministic
  - Uncertain knowledge
  - Optimal decisions

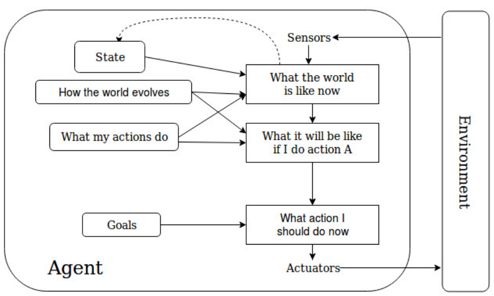


Figure Source: Russell & Norvig, AI: A Modern Approach

Example Situation – Course Selection

- A person wants to pass an academic program in two majors: A and B
- There are three subjects: A, B and C, each with three levels (*1, *2, *3). There are thus 9 courses: A1, A2, A3, B1, B2, B3, C1, C2, C3
- To graduate, at least one course at beginner (*1) level is needed in major(s) of choice(s), and two courses at intermediate levels (*2) are needed
- Answer questions
  - Q1: How many minimum courses does the person have to take ?
  - Q2: Can a person graduate in 2 majors studying 3 courses only?
  - …

How to Tackle Such Situations ?

- Represent and reason with the world
  - Perform Q/A

- Solve problems about courses selection scenarios

Representation - Example

- Domain Description: “There are three subjects: A, B and C, each with three levels (*1, *2, *3).”
- Representation
  - has_studied_courseA1: yes – student has taken course; no – student has not taken
  - has_studied_courseA2
  - has_studied_courseA3
  - has_studied_courseB1
  - has_studied_courseB2
  - has_studied_courseB3
  - has_studied_courseC1
  - has_studied_courseC2
  - has_studied_courseC3

Inference Procedure

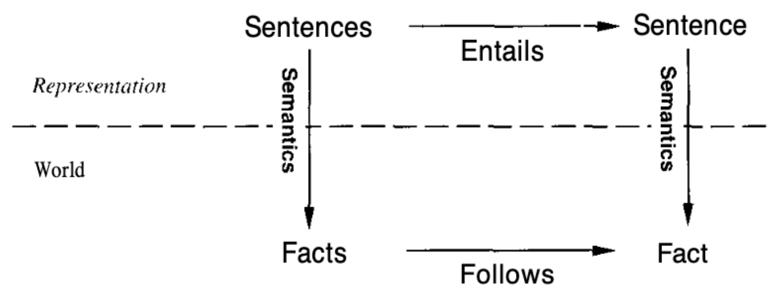
- Given a knowledge base (KB), generate new sentences α that are entailed by KB
  - KB $\models \alpha$

- Given KB and α, report whether or not α is entailed by KB
  - KB $\vdash \alpha$

-

Formal Logic – 1/3

- An automaton for manipulating symbols and drawing conclusions
- Consists of a knowledge base with:
  - a set of true statements (sentences). Sentences have
    - Syntax
    - Semantics – compositional property
  - Proof theory: a set of rules for deducing the entailments / interpretations of the sentences



- Properties of sentences
  - **Valid**: A sentence is **valid** or necessarily true if and only if it is true under all possible interpretations in all possible worlds. Also called a **tautology**
  - **Satisfiable:** A sentence is satisfiable if and only if there is some interpretations in some possible worlds where it is true.

Credits:

- Russell & Norvig, AI - A Modern Approach
- Deepak Khemani - A First Course in AI

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  - has_studied_courseB1
  - has_studied_courseB2
  - has_studied_courseB3
  - has_studied_courseC1
  - has_studied_courseC2
  - has_studied_courseC3

LowerThan_Course_A1_CourseA2
LowerThan_Course_A2_CourseA3
LowerThan_Course_B1_CourseB2
LowerThan_Course_B2_CourseB3
LowerThan_Course_C1_CourseC2
LowerThan_Course_AC_CourseC3

- Previous statements set did not capture hierarchy between levels; new sentences would not have followed the reality in the world. Need more statements – LowerThan as shown.

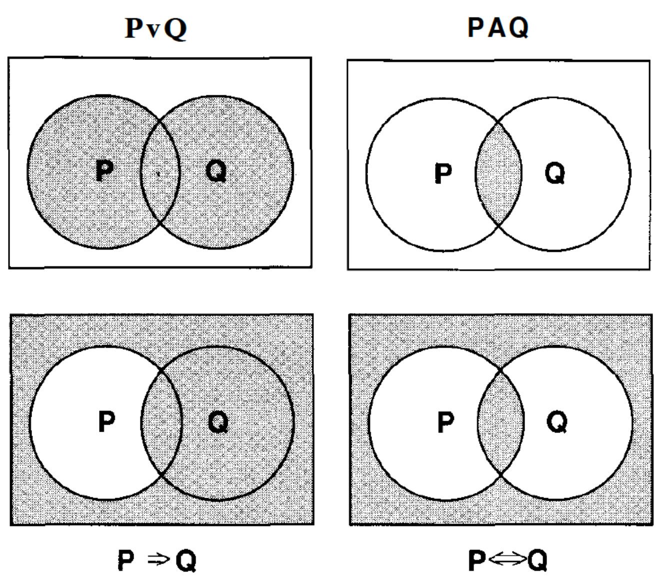
Propositional Logic - Syntax

$$
\begin{array}{rcl}
\mathit{Sentence} & \rightarrow & \mathit{AtomicSentence} \mid \mathit{ComplexSentence} \\
\\
\mathit{AtomicSentence} & \rightarrow & \mathbf{\mathit{True}} \mid \mathbf{\mathit{False}} \\
 & \mid & P \mid Q \mid R \mid \ldots \\
\mathit{ComplexSentence} & \rightarrow & (\ \mathit{Sentence}\ ) \\
 & \mid & \mathit{Sentence}\ \mathit{Connective}\ \mathit{Sentence} \\
 & \mid & \neg \mathit{Sentence} \\
\\
\mathit{Connective} & \rightarrow & \wedge \mid \vee \mid \Leftrightarrow \mid \Rightarrow
\end{array}
$$

BNF (Backus-Naur Form) grammar of sentences in propositional logic

Source: Russell & Norvig, AI: A Modern Approach

Propositional Logic - Semantics



Model of sentence: Any world in which a sentence is true (under a particular interpretation)

α	β	γ	$\alpha \vee \beta$	$\neg\beta \vee \gamma$	$\alpha \vee \gamma$
False	*False*	*False*	*False*	*True*	*False*
False	*False*	*True*	*False*	*True*	*True*
False	*True*	*False*	*True*	*False*	*False*
False	*True*	*True*	*True*	*True*	*True*
True	*False*	*False*	*True*	*True*	*True*
True	*False*	*True*	*True*	*True*	*True*
True	*True*	*False*	*True*	*False*	*True*
True	*True*	*True*	*True*	*True*	*True*

Truth table to prove soundness of inference

Source: Russell & Norvig, AI: A Modern Approach

Propositional Logic

Inference Procedures

◇ **Modus Ponens or Implication-Elimination:** (From an implication and the premise of the implication, you can infer the conclusion.)

$$\frac{a \Rightarrow \beta, \qquad a}{\beta}$$

◇ **And-Elimination**: (From a conjunction, you can infer any of the conjuncts.)

$$\frac{\alpha_1 \mathrm{A}\, \alpha_2 \mathrm{A} \ldots \mathrm{A}\, \alpha_n}{\alpha_i}$$

◇ **And-Introduction**: (From a list of sentences, you can infer their conjunction.)

$$\frac{\alpha_1, \alpha_2, \;\bullet\bullet\bullet\;, \;\; \alpha_n}{\alpha_1 \mathrm{A}\, \alpha_2 \mathrm{A} \ldots \mathrm{A}\, \alpha_n}$$

0 **Or-Introduction**: (From a sentence, you can infer its disjunction with anything else at all.)

$$\frac{\alpha_i}{\alpha_1 \mathrm{V}\, \alpha_2 \mathrm{V} \ldots \mathrm{V}\, \alpha_n}$$

◇ **Double-Negation Elimination:** (From a doubly negated sentence, you can infer a positive sentence.)

$$\frac{\neg\neg \mathrm{a}}{\alpha}$$

◇ **Unit Resolution:** (From a disjunction, if one of the disjuncts is false, then you can infer the other one is true.)

$$\frac{a \mathrm{V}\, \beta, \qquad \neg\beta}{a}$$

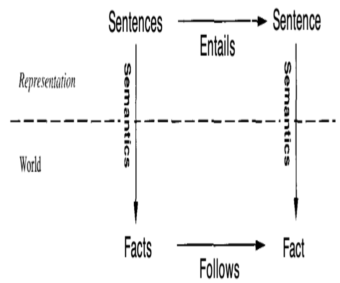
◇ **Resolution:** (This is the most difficult. Because *0* cannot be both true and false, one of the other disjuncts must be true in one of the premises. Or equivalently, implication is transitive.)

$$\frac{a \vee \beta, \qquad \neg\beta \mathrm{V}\, 7}{a \vee \gamma} \quad \text{or equivalently} \quad \frac{\neg\alpha \Rightarrow \beta, \qquad \beta \Rightarrow \gamma}{\neg\alpha \Rightarrow \gamma}$$

Source: Russell & Norvig, AI: A Modern Approach

Formal Logic – 2/3

- Levels at which sentences are encoded
  - Epistemic (also called knowledge): what agents knows or believes
  - Logical: how sentences are encoded to allow inferencing. E.g., symbols
  - Executional: how sentences are encoded during execution. E.g., vectors, symbols



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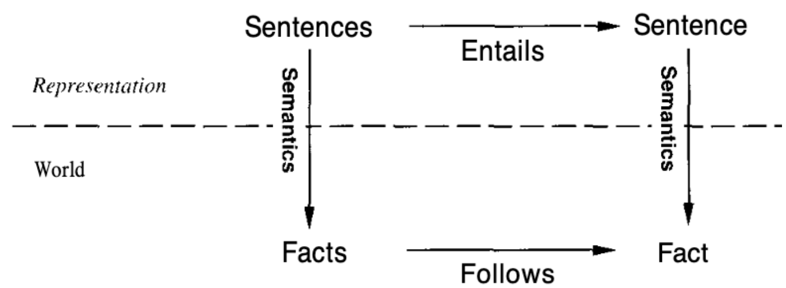
Formal Logic – 3/3

- Properties of Logic System
  - **Soundness**: if it produces only true statements
  - **Completeness**: if it produces all true statements
  - **Consistency**: if it does not produce a sentence and its negation



Language	Ontological Commitment (What exists in the world)	Epistemological Commitment (What an agent believes about facts)
Propositional logic	facts	true/false/unknown
First-order logic	facts, objects, relations	true/false/unknown
Temporal logic	facts, objects, relations, times	true/false/unknown
Probability theory	facts	degree of belief 0…1
Fuzzy logic	degree of truth	degree of belief 0…1

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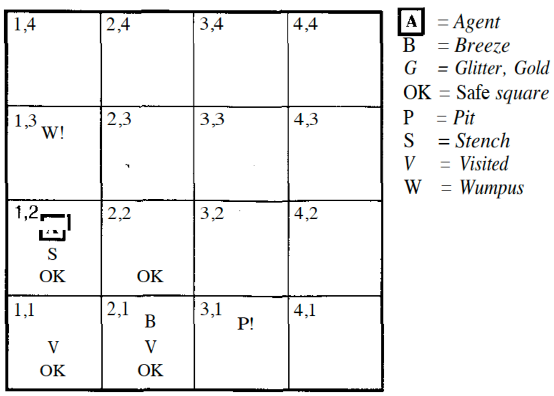
Major Types of Reasoning

- Inference: From premises to conclusions
  - Major types
    - **Deduction**: deriving logical conclusions from premises known or assumed to be true
    - **Induction**: deriving from particular premises to a universal conclusion.
    - **Abduction**: from an observation, find the most likely conclusion from the observations

- Usage
  - Deduction is useful to build knowledge bases from parts
  - Induction: to generalize
  - Abduction is a good source for hypothesis / priors in Bayesian learning

Exercise and Code

- Logical Reasoning
  - From Book: AI – A Modern Approach, https://github.com/aimacode/aima-python/blob/master/logic.ipynb



Source: Russell & Norvig, AI: A Modern Approach

Problem Solving Agents

Goal-directed agents

1. **Goal Formulation: Set of one or more (desirable) world states (e.g. majors in).**
2. **Problem formulation: What actions and states to consider given a goal and an initial state.**
3. **Search for solution: Given the problem, search for a solution --- *a sequence of actions to achieve the goal starting from the initial state.***
4. **Execution of the solution**

Source: Bart Selman's CS 4700 Course

Goal:
Reach Bucharest (Romania)

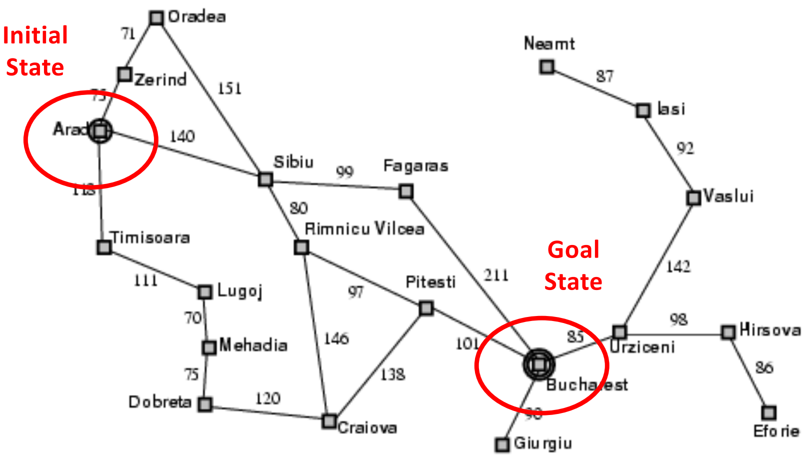
Problem:
action: drive between pair of connected cities (direct road)

state: be in a city
(20 world states)

Solution:
sequence of cities leading from start to goal state, e.g., Arad, Sibiu, Fagaras, Bucharest

Execution
drive from Arad to Bucharest according to the solution

Example: Path Finding Problem

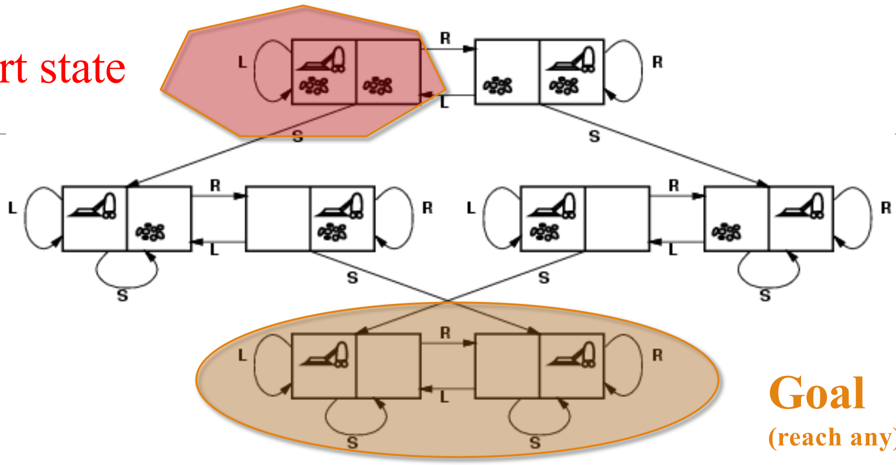


Environment: fully observable (map), deterministic, and the agent knows effects of each action.

Source: Bart Selman's CS 4700 Course

Example: Vacuum World State Space Graph

Start state



Goal
(reach any)

States: The agent is in one of 8 possible world states.

Actions: ***Left, Right, Suck [simplified: left out No-op]***

goal test: **No dirt at all locations**

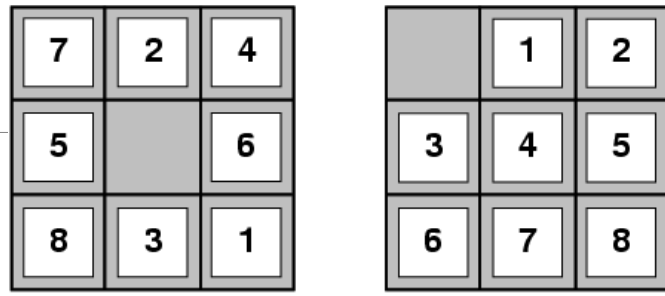
path cost: **1 per action**

Minimum path from Start to Goal state: **3 actions**

Alternative, longer plan: **4 actions**

Source: Bart Selman's CS 4700 Course

Example: The 8-puzzle“sliding tile puzzle”



Start State Goal State

States: the boards, i.e., locations of tiles

Actions: move blank left, right, up, down

goal test: goal state (given; tiles in order)

Path cost: 1 per move

Note: finding optimal solution of *n*-puzzle family is NP-hard! Also, from certain states you can’t reach the goal. Total number of states 9! = 362,880

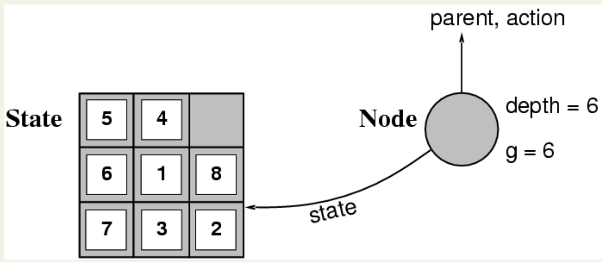
Source: Bart Selman’s CS 4700 Course

Search Techniques

Search Concepts: States and Nodes

A state is a representation of a physical configuration.

A node is a data structure constituting part of a search tree includes state, tree parent node, action (applied to parent), path cost (initial state to node) *g(x)*, depth



The `Expand` function creates new nodes, filling in the various fields and using the `SuccessorFn` of the problem to create the corresponding states.

Fringe is the collection of nodes that have been generated but not (yet) expanded. Each node of the fringe is a leaf node.

Source: Bart Selman's CS 4700 Course

Tree-search Algorithms

Basic idea: simulated exploration of state space by generating successors of already-explored states (a.k.a. ~ expanding states)

function TREE-SEARCH(*problem*, *strategy*) **returns** a solution, or failure
  initialize the search tree using the initial state of *problem*
  loop do
    if there are no candidates for expansion **then return** failure
    choose a leaf node for expansion according to *strategy*
    if the node contains a goal state **then return** the corresponding solution
    else expand the node and add the resulting nodes to the search tree

Source: Bart Selman's CS 4700 Course

Implementation: General Tree Search

```
function TREE-SEARCH( problem, fringe) returns a solution, or failure
   fringe ← INSERT(MAKE-NODE(INITIAL-STATE[problem]), fringe)
   loop do
        if fringe is empty then return failure
        node ← REMOVE-FRONT(fringe)
        if GOAL-TEST[problem](STATE[node]) then return SOLUTION(node)
        fringe ← INSERTALL(EXPAND(node, problem), fringe)
```

```
function EXPAND( node, problem) returns a set of nodes
   successors ← the empty set
   for each action, result in SUCCESSOR-FN[problem](STATE[node]) do
        s ← a new NODE
        PARENT-NODE[s] ← node;   ACTION[s] ← action;   STATE[s] ← result
        PATH-COST[s] ← PATH-COST[node] + STEP-COST(node, action, s)
        DEPTH[s] ← DEPTH[node] + 1
        add s to successors
   return successors
```

A search strategy is defined by picking the order of node expansion.

Uninformed Search Strategies

Uninformed (blind) search strategies use only the information available in the problem definition:

- Breadth-first search
- Uniform-cost search
- Depth-first search
- Depth-limited search
- Iterative deepening search
- Bidirectional search

Key issue: type of queue used for the fringe of the search tree (collection of tree nodes that have been generated but not yet expanded)

Source: Bart Selman's CS 4700 Course

Search Strategies

- A search strategy is defined by picking the **order of node expansion.**

- Strategies are evaluated along the following dimensions:
  - **completeness**: does it always find a solution if one exists?
  - **time complexity**: number of nodes generated
  - **space complexity**: maximum number of nodes in memory
  - **optimality**: does it always find a least-cost solution?

- Time and space complexity are measured in terms of
  - *b:* maximum branching factor of the search tree
  - *d:* depth of the least-cost solution
  - *m*: maximum depth of the state space (may be ∞)

Source: Bart Selman's CS 4700 Course

Exercise and Code

- Search Methods
  - From Book: AI – A Modern Approach, https://github.com/aimacode/aima-python/blob/master/search.ipynb

Source: Russell & Norvig, AI: A Modern Approach

Goal-Based Agents
Generating Sequence of Actions

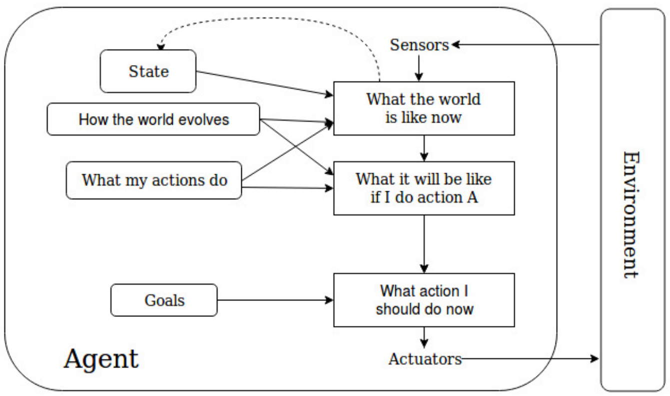
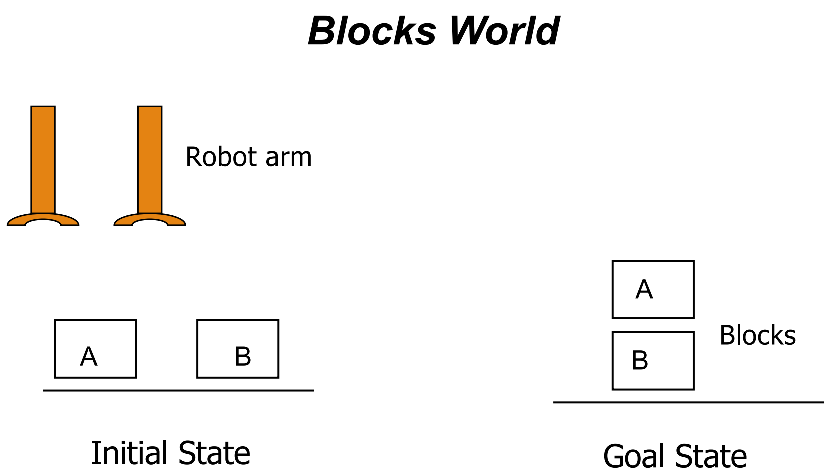


Figure Source: Russell & Norvig, AI: A Modern Approach

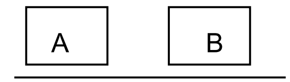
Reasoning Illustration - Planning Example



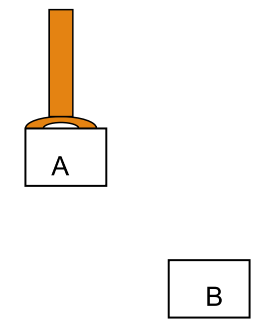
All robots are equivalent

Reasoning Illustration - Representation

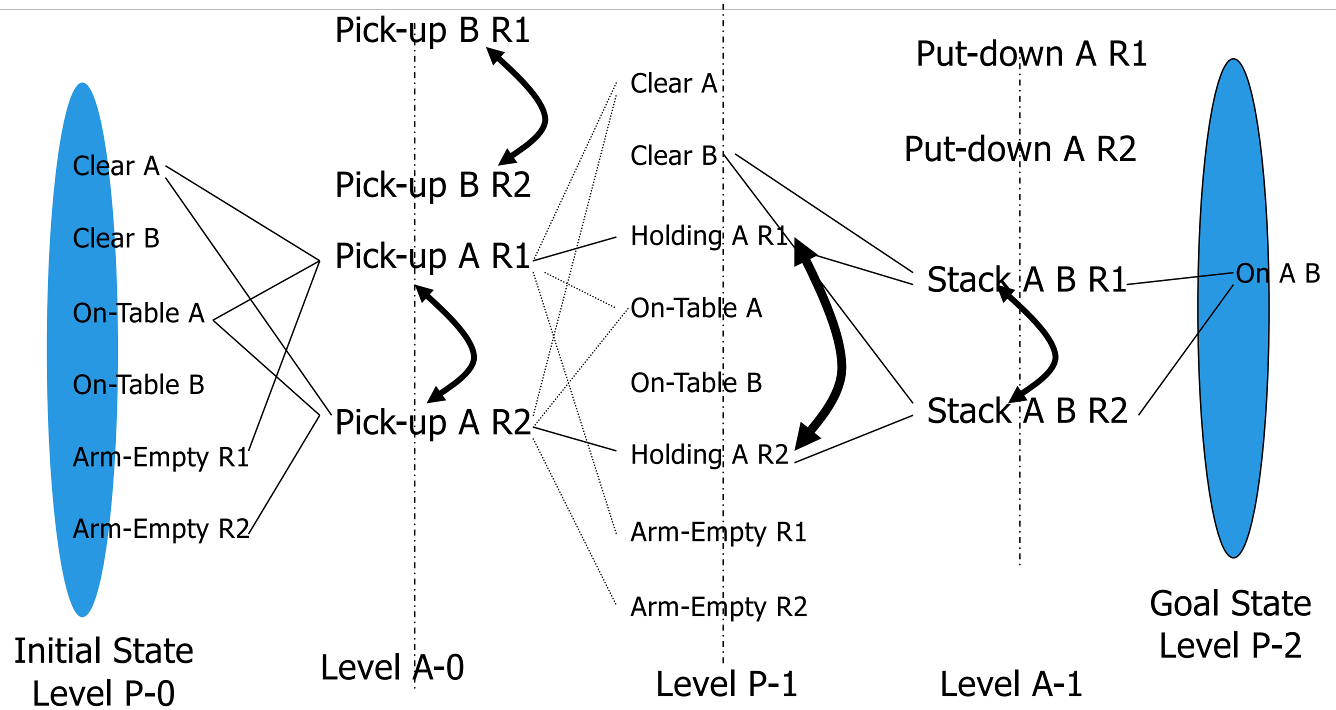
States: ((On-Table A) (On-Table B) …)



Actions: ((Name: (Pickup ?block ?robot)
Precondition: ((Clear ?block)
(Arm-Empty ?robot)
(On-Table ?block))
Add: ((Holding ?block ?robot))
Delete: ((Clear ?block)
(Arm-Empty ?robot)))…)



Reasoning Illustration - Planning Process



Active Area of Research

Considerations

- What to find:
  - Any workable plan
  - Optimal plan – but then what is the criteria
  - All plans
  - Diverse plans
- How to find
  - Plan at the end
  - Plan anytime
- How to represent problem
- How to explain solution

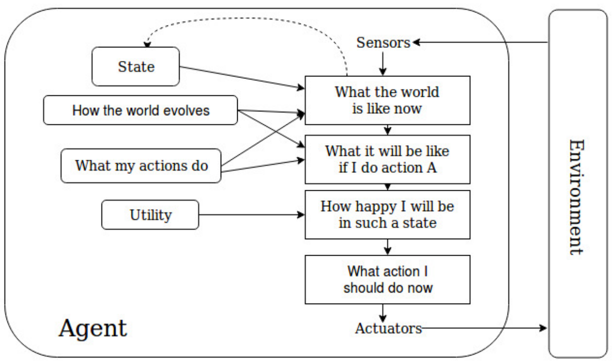
Lecture 15: Concluding Comments

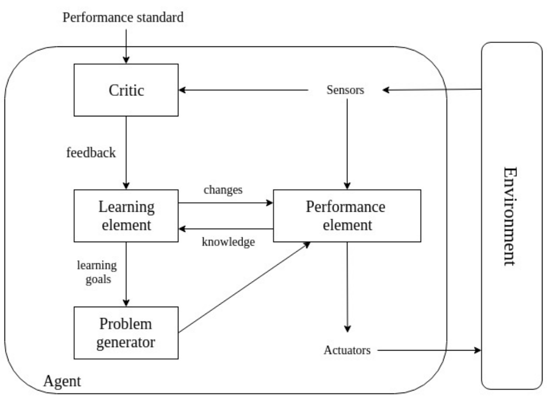
- We revisited what it means to have an AI system as Intelligent Agent
- Understood knowledge representation and relationship to facts in the world
- Discussed logic procedures to draw inferences
- Discussed search methods to solve problems
- Saw a planning problem – generating sequence of actions to meet a goal

Concluding Segment

Exercise – Intelligent Agent Types

- Search Methods
  - From Book: AI – A Modern Approach, https://github.com/aimacode/aima-python/blob/master/vacuum_world.ipynb





Source: Russell & Norvig, AI: A Modern Approach

Adjustment to Upcoming Schedule

15	**Mar 4 (Th)**	**Reasoning and Search**	**Semester - Midpoint**
16	Mar 9 (Tu)	Agent – Optimization	
17	Mar 11 (Th)	Agent – Handling Uncertain World	
18	Mar 16 (Tu)	Agent – Learning	
19	Mar 18 (Th)	Text: Data Prep (NLP)	Quiz 3
20	Mar 23 (Tu)	Text: Analysis - Supervised (NLP)_	
21	Mar 25 (Th)	Review, Paper presentations, Discussion	
22	Mar 30 (Tu)	Text: Advanced – Summarization, Sentiment	
23	Apr 1 (Th)	Text: Visualization, Explanation	
24	Apr 6 (Tu)	Multimodal Agents: Structured+Text: Examples	
25	Apr 8 (Th)	Case Study 1: Water	Quiz 4
26	Apr 13 (Tu)	Case Study 2: Finance	

Focus on Integrated Agent Behavior (Lectures 17, 18)

Reduce focus on Case-studies (1 per domain)

About Next Lecture – Lecture 16

Lecture 16: Reasoning, Agents Continued

- Reasoning – advanced settings
  - Agents Making Optimal Decisions
- What is an Optimal Decision ?
- Some methods