CSCE 580: Introduction to AI
CSCE 581: Trusted AI

Lecture 4: Formal Represention and Logic

PROF. BIPLAV SRIVASTAVA, AI INSTITUTE

5TH SEP 2023

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

Credits: **Copyrights of all material reused acknowledged**

Organization of Lecture 4

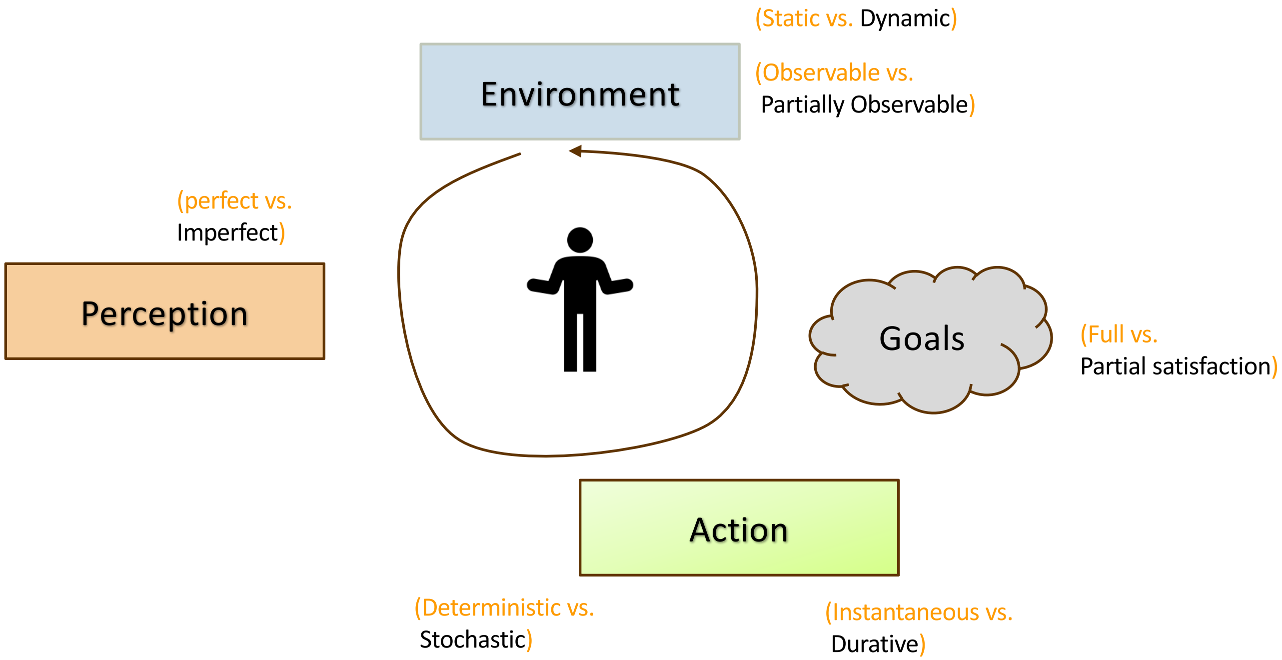
- Introduction Segment
  - Recap of Lecture 3
- Main Segment
  - Representing World Knowledge
  - Logic (Propositional)
  - Inferencing (Propositional)
  - Code setup for AIMA examples
- Concluding Segment
  - Course Project Discussion
  - About Next Lecture – Lecture 5
  - Ask me anything

Introduction Section

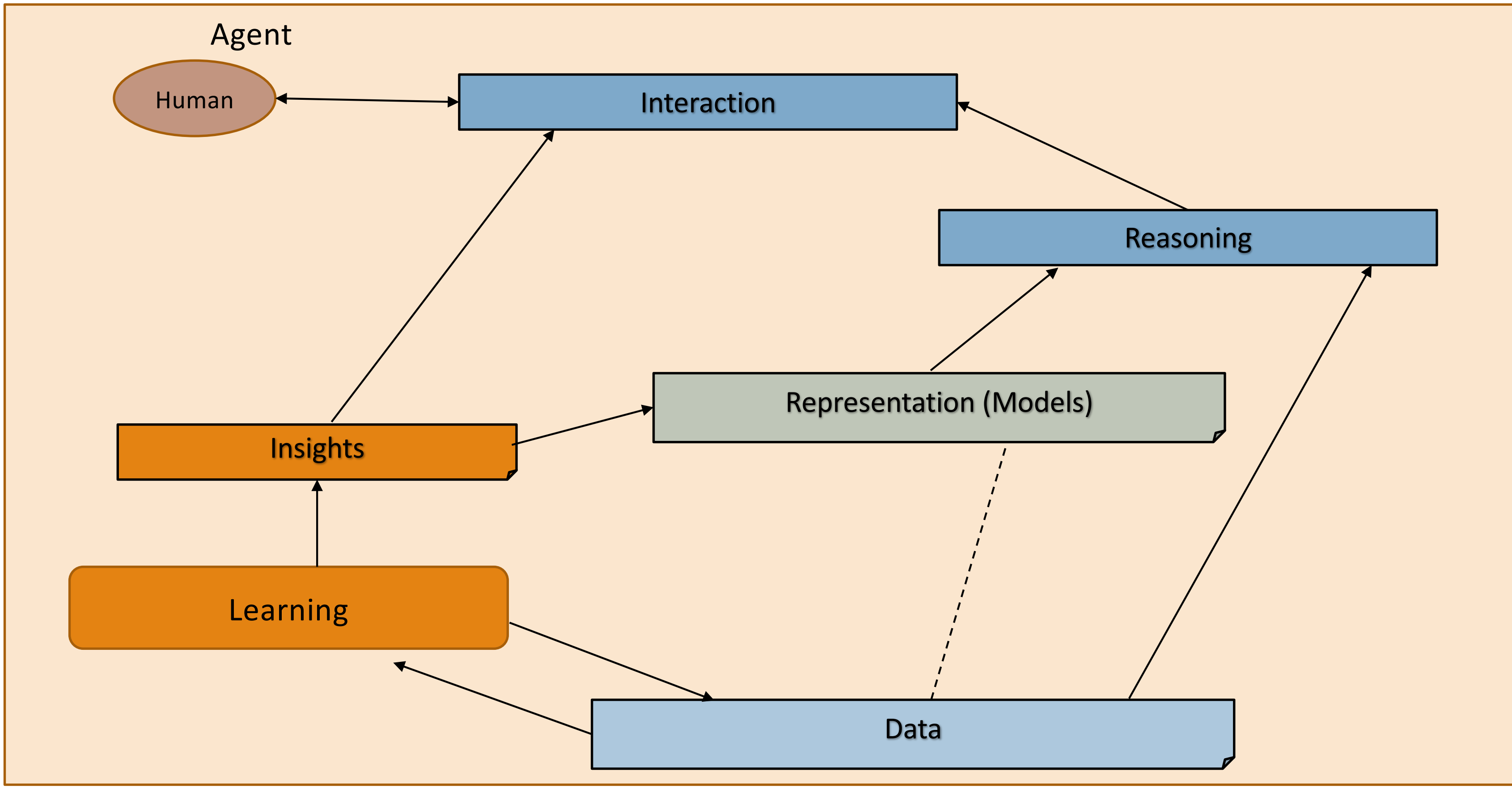
Recap of Lecture 3

- Data preparation
- Knowledge representation/ graph
- Ontology

Intelligent Agent Model



Relationship Between Main AI Topics



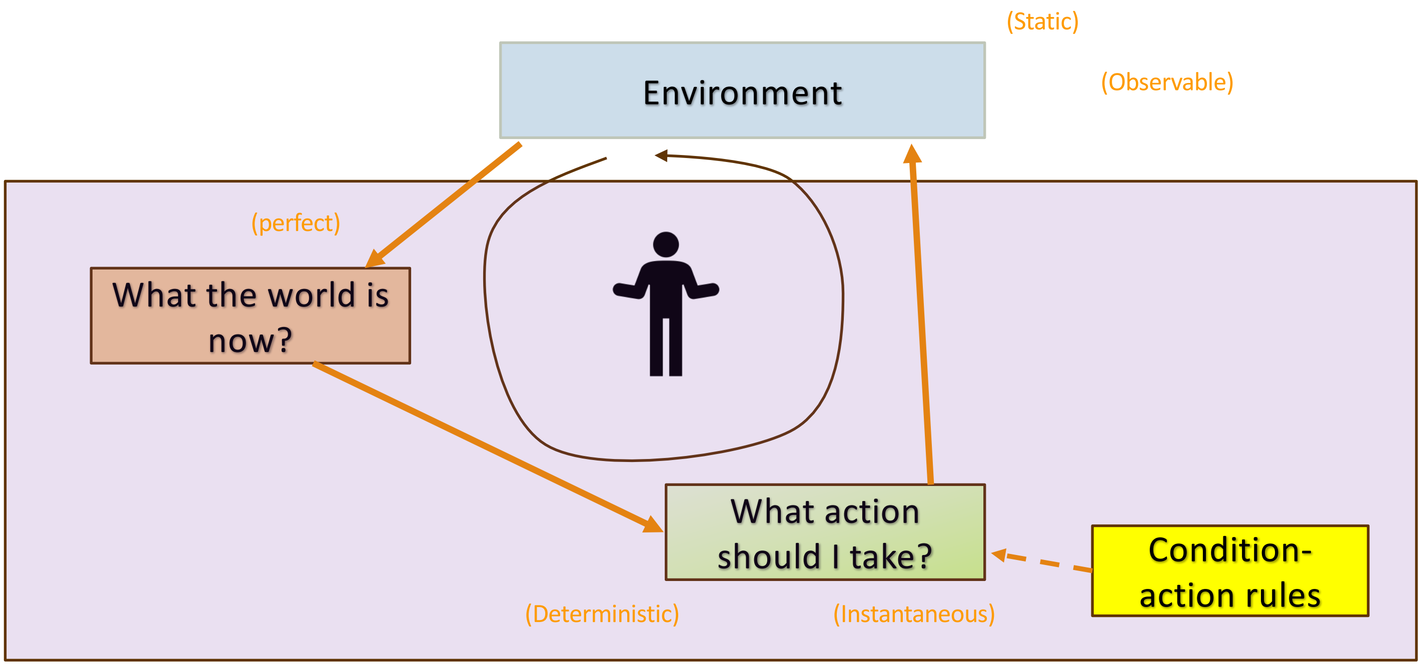
Where We Are in the Course

CSCE 580/ 581 – In This Course

- Week 1: Introduction, Aim: Chatbot / Intelligence Agent
- Weeks 2-3: Data: Formats, Representation and the Trust Problem
- Week 4-5: Search, Heuristics - Decision Making
- Week 6: Constraints, Optimization – Decision Making
- Week 7: Classical Machine Learning – Decision Making, Explanation
- Week 8: Machine Learning - Classification
- Week 9: Machine Learning - Classification – Trust Issues and Mitigation Methods
- Topic 10: Learning neural network, deep learning, Adversarial attacks
- Week 11: Large Language Models – Representation, Issues
- Topic 12: Markov Decision Processes, Hidden Markov models - Decision making
- Topic 13: Planning, Reinforcement Learning – Sequential decision making
- Week 14: AI for Real World: Tools, Emerging Standards and Laws; Safe AI/ Chatbots

Main Section

Intelligent Agent – Simple Knowledge Based

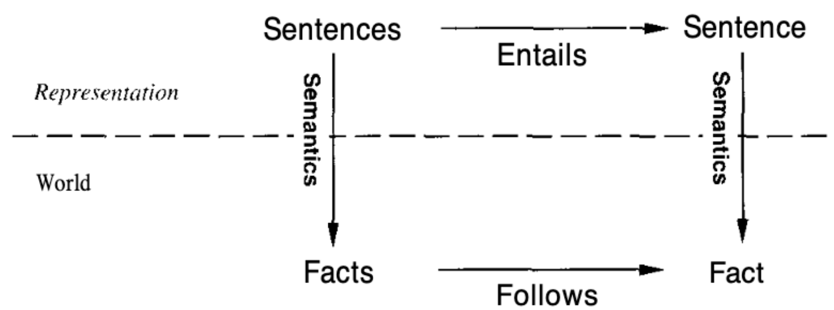


Logic – Basic Idea

- Starting with true assumptions, a knowledge-based system (automaton) to draw true conclusions
- Logic consists of three components
  - Syntax -- allowable sentences
  - Semantics -- determining truth of sentence given a model (assignment of values to sentences)
  - Inference Procedure -- rules to draw conclusion given a set of sentences

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

Propositional Logic

- Sentences: assertions about the world

  - Atomic sentence: propositional symbol
    - ClassToday – whether there is a class today: Yes, No
    - A -- any fact of interest: Yes, No
    - True -- always true
    - False -- always false

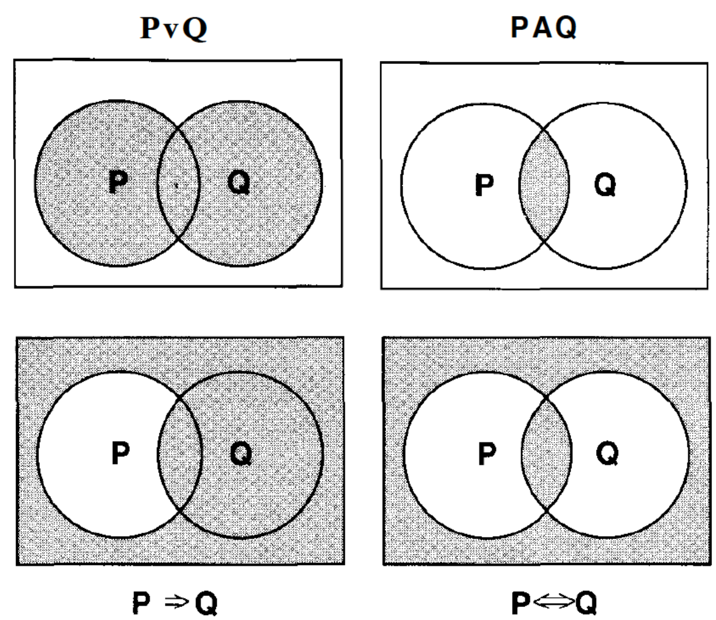
Propositional Logic - Syntax

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

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

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 $\vdash \alpha$

-

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.)

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

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

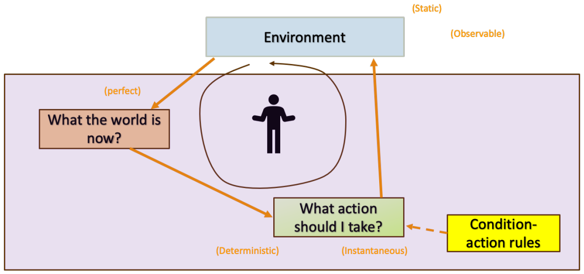
$$\frac{a \mathrm{V}\, \beta, \qquad \neg\beta}{a}$$

◇ **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.)

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

Source: Russell & Norvig, AI: A Modern Approach

KB Agent Procedure



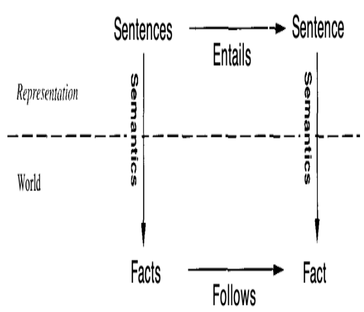
function KB-AGENT(*percept*) **returns** an *action*
 static: *KB*, a knowledge base
  t, a counter, initially 0, indicating time

 TELL(*KB*, MAKE-PERCEPT-SENTENCE(*percept*, *t*))
 action ← ASK(*KB*, MAKE-ACTION-QUERY(*t*))
 TELL(*KB*, MAKE-ACTION-SENTENCE(*action*, *t*))
 $t \leftarrow t + 1$
 return *action*

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

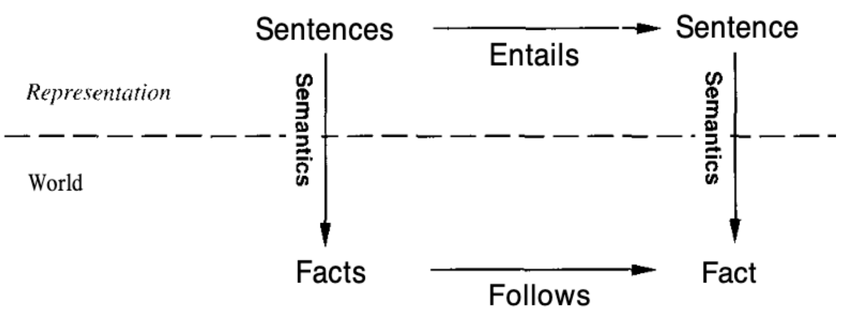


- Properties of sentences
  - **Valid**: A sentence is **valid** or necessarily true if and only if it is true under all possible interpretations in all possible worlds. Also called a **tautology**
  - **Satisfiable:** A sentence is satisfiable if and only if there is some interpretations in some possible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

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

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 $0 \ldots 1$
Fuzzy logic	degree of truth	degree of belief $0 \ldots 1$

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

Example: Course Selection

Example Situation – Course Selection

- A person wants to pass an academic program in two majors: A and B
- There are three subjects available: 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?
  - …

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

Issue: What about hierarchy among courses?

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

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.

How to Tackle Course Selection Problem ?

- Represent the world as sentences in KB
  - Update KB based on scenarios
- Solve problems about courses selection scenarios
  - Pose problems as queries to KB
  - Interpret answers // reason with the world

```
function KB-AGENT(percept) returns an action
   static: KB, a knowledge base
           t, a counter, initially 0, indicating time

   TELL(KB, MAKE-PERCEPT-SENTENCE(percept, t))
   action ← ASK(KB, MAKE-ACTION-QUERY(t))
   TELL(KB, MAKE-ACTION-SENTENCE(action, t))
   t ← t + 1
   return action
```

Source: Russell & Norvig, AI: A Modern Approach

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

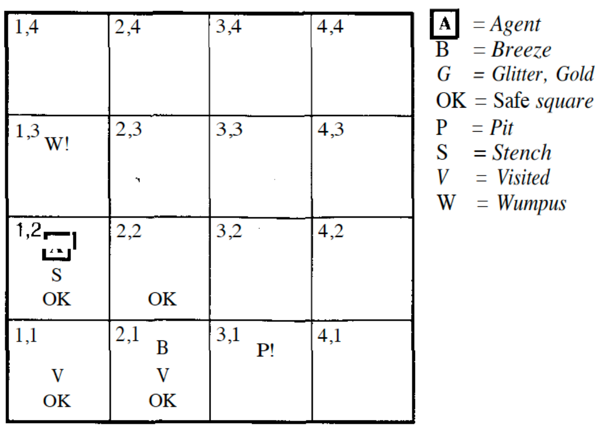
- Usage
  - Deduction is useful to build knowledge bases from parts
  - Induction: to generalize
  - Abduction is a good source for hypothesis / priors in Bayesian learning

Setting Up for AIMA Code

- AI resources
https://github.com/biplav-s/course-ai-tai-f23/blob/main/sample-code/AI-Resources.md
- Setting up for Python code from AIMA book
https://github.com/biplav-s/course-ai-tai-f23/tree/main/sample-code/ai-book-samples

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

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

Lecture 4: Summary

- We talked about
  - Knowledge-based agents
  - Logic (Propositional)
  - Inferencing (Propositional)

Concluding Section

Course Project

Project Discussion: What Problem Fascinates You ?

- Data
  - Water
  - Finance
- Analytics
- Application
  - Building chatbot
- Users
  - Diverse demographics
  - Diverse abilities
  - Multiple human languages

Project execution in sprints

- Sprint 1:
  - Solving: Choose a decision problem, identify data, work on solution methods
  - Human interaction: Develop a basic chatbot (no AI), no problem focus
- Sprint 2:
  - Solving: Evaluate your solution on problem
  - Human interaction: Integrated your choice of chatbot (rule-based or learning-based) and methods
- Sprint 3:
  - **Evaluation:** Comparison of your solver chatbot with an LLM-based alternative, like ChatGPT

Project Discussion

1. Create a private Github repository called "CSCE58x-Fall2023-<studentname>-Repo". Share with Instructor (biplav-s) and TA (kausik-l)
2. Create Google folder called "CSCE58x-Fall2023-<studentname>-SharedInfo". Share with Instructor (prof.biplav@gmail.com) and TA (lakkarajukausik90@gmail.com)
3. Create a Google doc in your Google repo called "Project Plan" and have the following by next class (Sep 5, 2023)

- 1. Instructor:
  - City snapshot for Columbia, SC (like for London - http://citydashboard.org/london/)
  - …
- 2. Students
  - Pedestrian detection using …
  - Health monitoring …

1. Title:
2. Key idea: (2-3 lines)
3. Who will care when done:
4. Data need:
5. Methods:
6. Evaluation:
7. Users:
8. Trust issue:

About Next Lecture – Lecture 5

Lecture 5: Representing Knowledge

- Logic – First Order
- Inferencing