CSCE 580: Introduction to AI
CSCE 581: Trusted AI

Lecture 5: Formal Represention and Logic

PROF. BIPLAV SRIVASTAVA, AI INSTITUTE

7TH SEP 2023

Carolinian Creed: “I will practice personal and academic integrity.”

Organization of Lecture 5

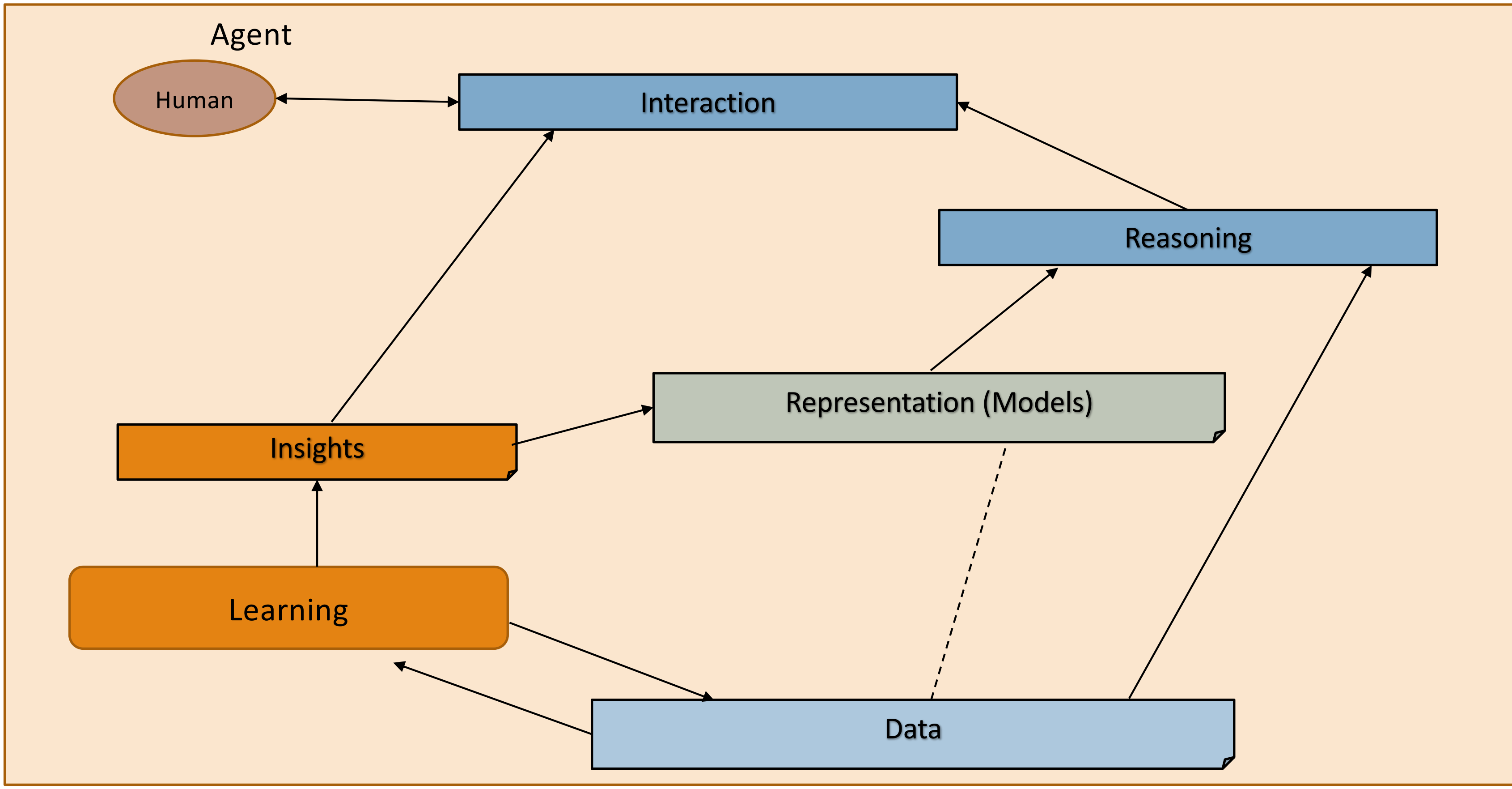
- Introduction Segment
  - Recap of Lecture 4
- Main Segment
  - Logic – First Order
  - Inferencing
  - Representation in the Large: ConceptNet, Cyc
  - Trust Issues with Knowledge Representation
- Concluding Segment
  - Course Project Discussion
  - About Next Lecture – Lecture 6
  - Ask me anything

Introduction Section

Recap of Lecture 4

- Representing World Knowledge
- Logic (Propositional)
- Inferencing (Propositional)
- Code setup for AIMA examples

Relationship Between Main AI Topics



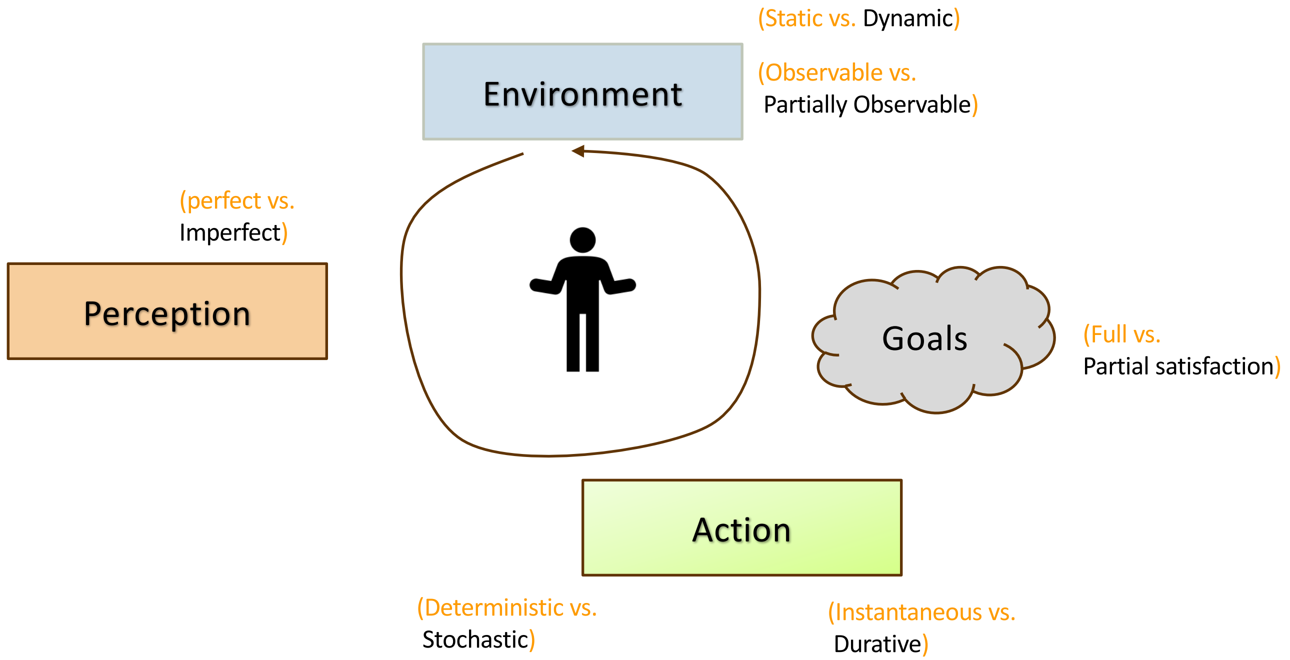
Where We Are in the Course

CSCE 580/ 581 – In This Course

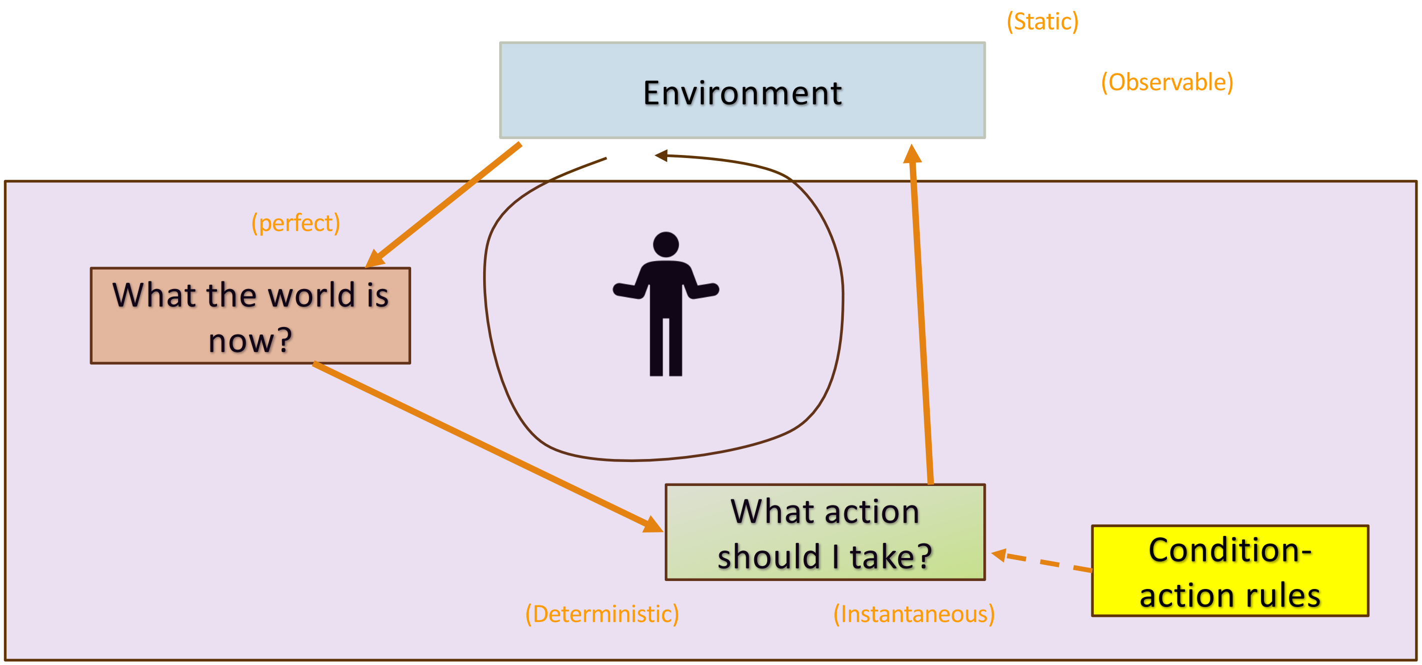
- Week 1: Introduction, Aim: Chatbot / Intelligence Agent
- Weeks 2-3: Data: Formats, Representation and the Trust Problem
- Week 4-5: Search, Heuristics - Decision Making
- Week 6: Constraints, Optimization – Decision Making
- Week 7: Classical Machine Learning – Decision Making, Explanation
- Week 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

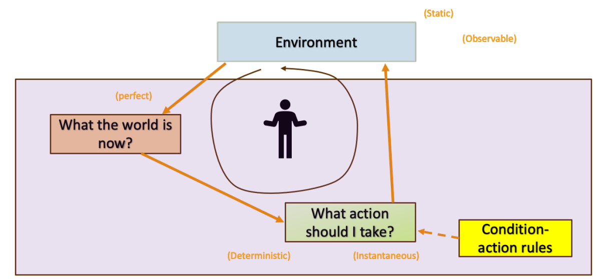
Intelligent Agent Model



Intelligent Agent – Simple Knowledge Based



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

First Order Predicate Logic (FOPL)

Concepts

Constants: a, b, student123, teacher94

- Name of a specific object.

Variables: X, Y.

- Refer to an object without naming it.

Predicates: Father, Before

- Relationships between objects. May be many and may not be unique. Objects are specified as arguments (arity of a predicate).

Functions: father-of

- Mapping from objects to objects. Mapping must be present and be unique. Objects are specified as arguments (arity of a predicate).

Terms: dad-of(organism33), leftLeg(John)

- A logical expression that refers to an object

Atomic Sentences: in(dad-of(dog33), food6)

- Can be true or false
- Correspond to propositional symbols P, Q

Objects
Relations
Functions

Adapted from:
a) Dan Weld's AI course (CSE 573, Univ. of Washington)
b) Russell & Norvig, AI: A Modern Approach

FOPL - Syntax

Sentence — *AtomicSentence*
| *Sentence Connective Sentence*
| *Quantifier Variable*,. . . *Sentence*
| ¬ *Sentence*
| (*Sentence*)

AtomicSentence — *Predicate*(*Term*, . . .) *Term* = *Term*

Term → *Function*(*Term*, . . .)
| *Constant*
\ *Variable*

Connective → ⇒ | A V | ⇔
Quantifier → V | 3
Constant → *A* \ *X*\ \ *John* | · · ·
Variable → a | *x* *s* • • •
Predicate → *Before* \ *HasColor* \ *Raining* \ · · ·
Function → *Mother* \ *LeftLegOf* \ · · ·

BNF (Backus-Naur Form) grammar of sentences in FOPL

Source: Russell & Norvig, AI: A Modern Approach

Connectives and Quantifiers

Logical connectives: and, or, not, =>

Quantifiers:
- $\forall$: Forall
- $\exists$: There exists

Examples:
1. All students: $\forall$ **students**
2. All students are university members:
   $\forall$x Student(x) => UniversityMember(x)
   (For all x, if x is a student, then x is a UniversityMember)
3. A phone: **$\exists$x Phone(x)**
4. John has a phone:
   $\exists$x Phone(x) $\wedge$ Owns(John,x)
   (There exists a phone such that John owns it.)

Connections / Equivalences

$$
\begin{array}{lcl@{\qquad\qquad}lcl}
\forall x\ \neg P & \equiv & \neg\exists x\ P & \neg P \land \neg Q & \equiv & \neg(P \lor Q) \\
\neg\forall x\ P & \equiv & 3x\ \neg P & \neg(P \land Q) & \equiv & \neg P \lor \neg Q \\
\forall x\ P & \equiv & \neg\exists x\ \neg P & P \land Q & \equiv & \neg(\neg P \lor \neg Q) \\
\exists x\ \mathrm{P} & \equiv & \neg\forall x\ \neg P & P \lor Q & \equiv & \neg(\neg P \land \neg Q)
\end{array}
$$

Derivable from De Morgan's law about sets:
$(A \cup B)' = A' \cap B'$ and $(A \cap B)' = A' \cup B'$

Source: Russell & Norvig, AI: A Modern Approach

Comparing Syntax - FOPL and Propositional Logic

Sentence — *AtomicSentence* | *ComplexSentence*

AtomicSentence — ***True*** | ***False***
| *P* | *Q* | *R* | ...

ComplexSentence — (*Sentence*)
| *Sentence Connective Sentence*
| ¬*Sentence*

Connective — A | V | ⇔ | ⇒

Sentence — *AtomicSentence*
| *Sentence Connective Sentence*
| *Quantifier Variable*, . . . *Sentence*
| ¬ *Sentence*
| (*Sentence*)

AtomicSentence — *Predicate*(*Term*, . . .) | *Term* = *Term*

Term → *Function*(*Term*, . . .)
| *Constant*
| *Variable*

Connective → ⇒ | A | V | ⇔
Quantifier → V | 3
Constant → *A* | *X*1 | *John* | · · ·
Variable → a | *x* | *s* | • • •
Predicate → *Before* | *HasColor* | *Raining* | · · ·
Function → *Mother* | *LeftLegOf* | · · ·

Source: Russell & Norvig, AI: A Modern Approach

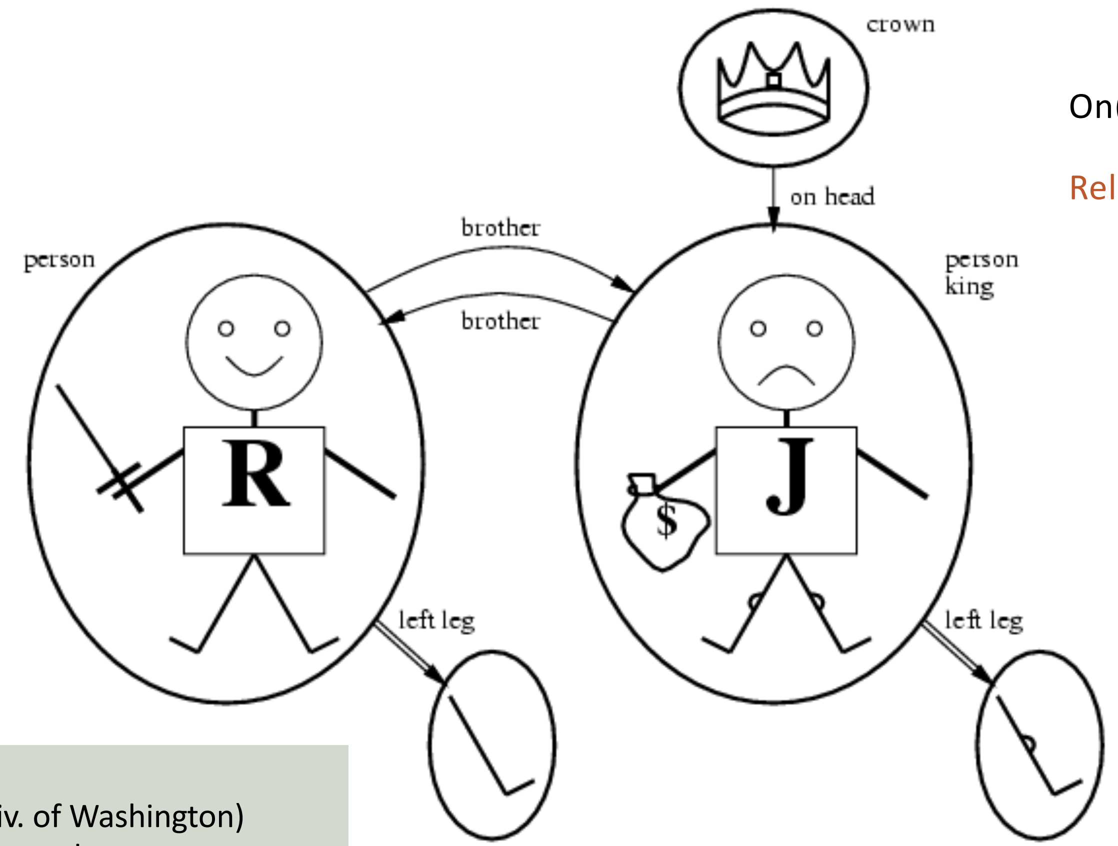
FOPL Semantics – Models and Interpretations

On(x,y) King(p)

Relations

Richard John

Constants



Leg(p,l)

Functions

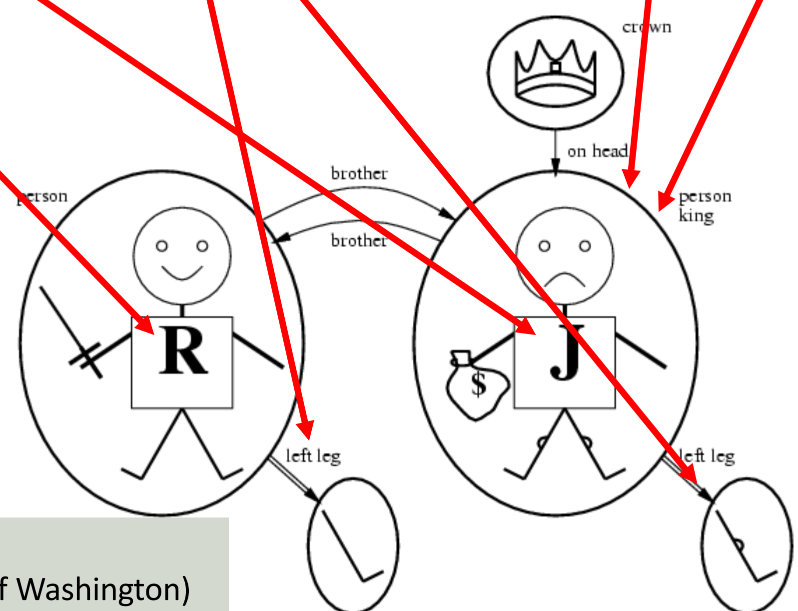
Adapted from:
a) Dan Weld's AI course (CSE 573, Univ. of Washington)
b) Russell & Norvig, AI: A Modern Approach

Interpretations - Mappings from Syntactic tokens → Model elements

Richard John
Constants

Leg(p,l)
Functions

On(x,y) King(p)
Relations



Depiction of one possible interpretation

Adapted from:
a) Dan Weld's AI course (CSE 573, Univ. of Washington)
b) Russell & Norvig, AI: A Modern Approach

Satisfiability, Validity, & Entailment

- S is **valid** if it is true in all interpretations
- S is **satisfiable** if it is true in some interpretations
- S is **unsatisfiable** if it is false for all interpretations
- S1 **entails** S2 if forall interpretations where S1 is true, S2 is also true

Source: Dan Weld's AI course (CSE 573, Univ. of Washington

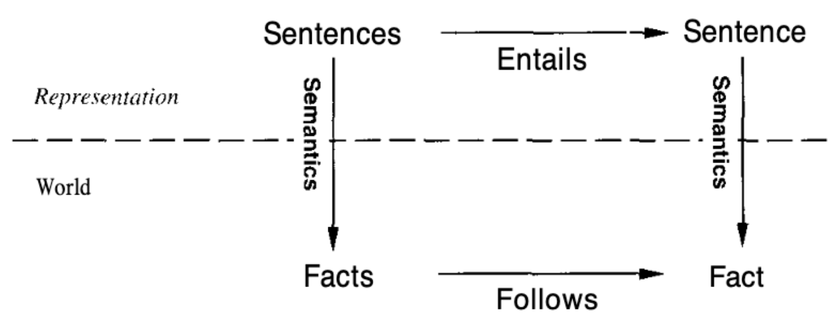
Comparing - FOPL and Propositional Logic

Ontology	Facts (P, Q)	Objects, Properties, Relations
Syntax	Atomic sentences Connectives	Variables & quantification Sentences have structure: terms father-of(mother-of(X)))
Semantics	Truth Tables	Interpretations *(Much more complicated)*
Inference Algorithm	DPLL, GSAT Fast in practice	Unification Forward, Backward chaining Prolog, theorem proving
Complexity	NP-Complete	Semi-decidable

Source: Dan Weld's AI course (CSE 573, Univ. of Washington

Formal Logic

- 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

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 – Propositional 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.

Representation – FOPL Example

- Domain Description: "There are three subjects: A, B and C, each with three levels (*1, *2, *3)."
- Representation
  - has_studied (?x , ?y)
    - ?x: course name // A, B, C
    - ?y: course level // 1, 2, 3
  - lower_than _level(?x, ?y)
    - ? x: 1, 2
    - ?y: 2, 3

Revisiting Formal Representations: Ontologies

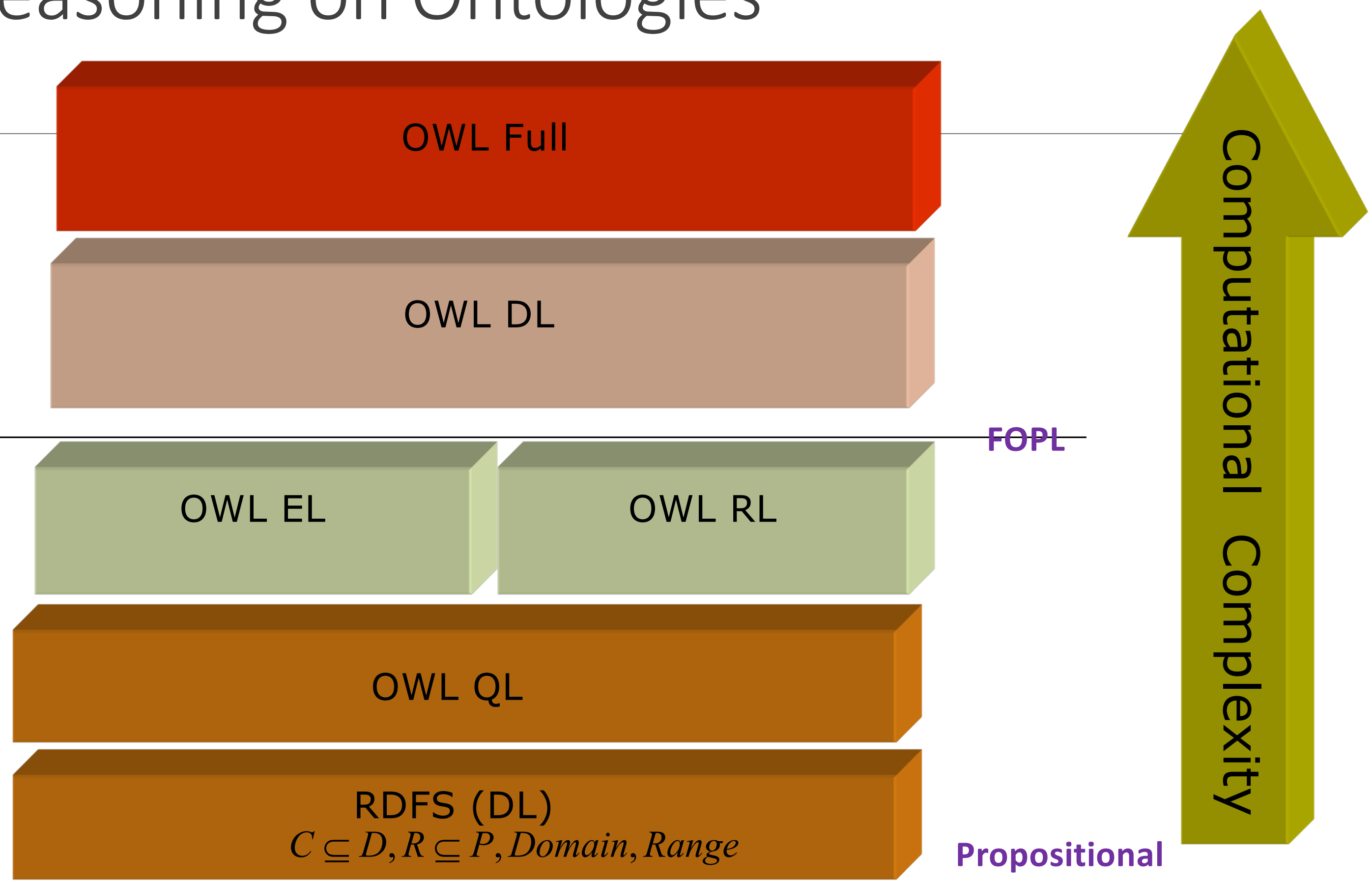
Challenge of Reasoning on Ontologies

•Undecidable

•Data Complexity open (NP-hard)
• Optimized tableau-based reasoners

• PTime-complete Data Complexity
• Efficient implementation on top of rule engine

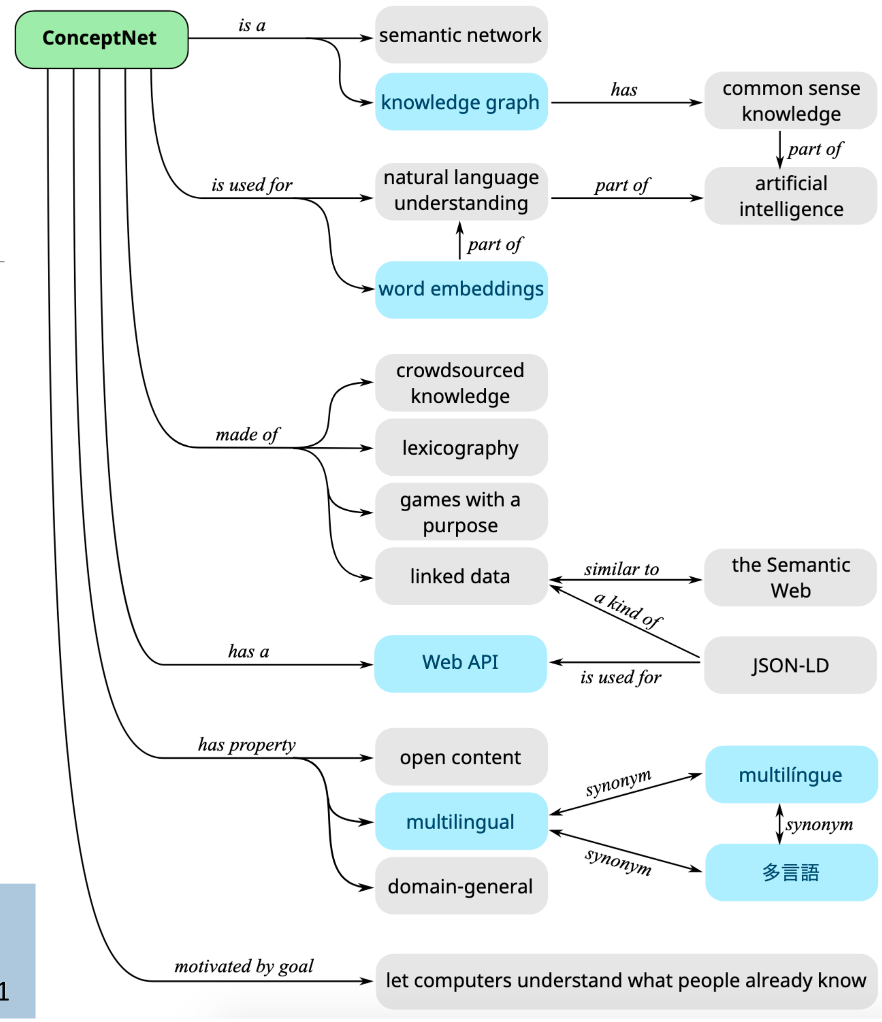
• LogSpace Data Complexity
• Efficient evaluation on top of RDBMS



Formal Representation in the Large

ConceptNet

- NLP focused graph knowledge graph that connects words and phrases of natural language with labeled edges.
- Concepts collected from experts, crowd-sourcing, and games with a purpose
- Supports multiple languages



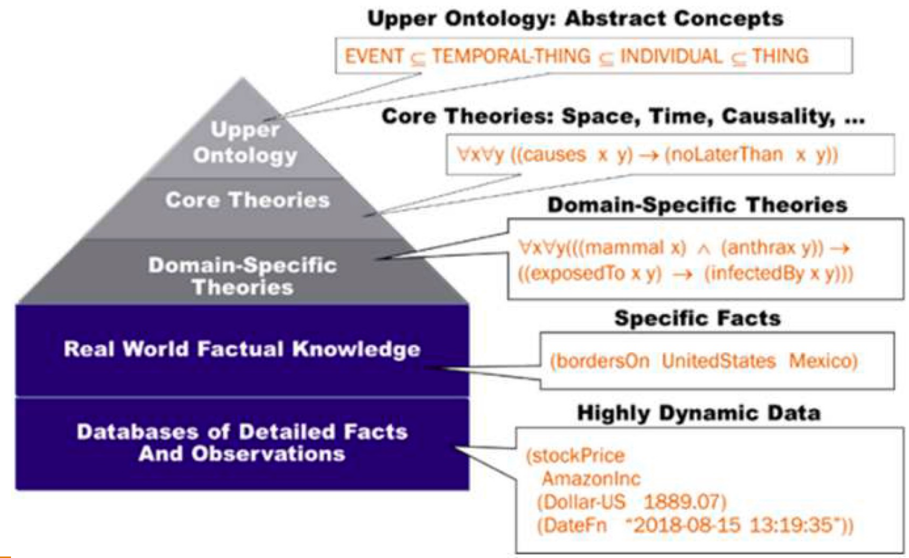
Details: http://conceptnet.io/, https://github.com/commonsense/conceptnet5/wiki,
Paper: https://www.aaai.org/ocs/index.php/AAAI/AAAI17/paper/viewFile/14972/14051

Demonstration - ConceptNet

Examples:
- Concepts:
  - Word: http://conceptnet.io/c/en/word ,
  - duck: http://conceptnet.io/c/en/duck
- Relationships:
  - http://conceptnet.io/s/resource/wordnet/rdf/3.1

Project CYC

- A large ontology to capture the world and human common sense
  - Doug Lenat lead team of computer scientists, computational linguists, philosophers, and logicians
  - Identify and formally axiomatize the tens of millions of rules about world
  - ~40 years effort by Cycorp
- Reasoners on the ontology to make decisions
  - 1000+ specialized reasoners



Details: https://www.cyc.com/

Source: Cyc White Paper

Cyc Details

- Ontology of about 1.5 million general concepts (e.g., taxonomically "placing" terms like eyes, sleep, night, person, unhappiness, hours, posture, being woken up, etc.);
- More than 25 million general rules and assertions involving those concepts
  - *"Most people sleep at night, for several hours at a time, lying down, with their eyes closed, they can be awakened by a loud noise but don't like that, "*
- Domain-specific extensions to the common sense ontology and knowledge base
  - healthcare, intelligence, defense, energy, transportation and financial services.
- Promoting synergistic use of ontology and learning based approaches (now)
  - Cyc and LLM - https://arxiv.org/ftp/arxiv/papers/2308/2308.04445.pdf.

Source: White Paper – Cyc Technology Overview

Trust Issues With Data and Representation

- Data
  - Respecting data privacy; using open data whenever available
  - Diversity
  - Handling missing/ unknown data; standard representations
- Representation
  - Using appropriate logic
  - Having expressive facts in the knowledge base; reusing standards

Exercise and Code

- FOPL Reasoning
  - https://github.com/biplav-s/course-ai-tai-f23/blob/main/sample-code/Class5-fo-logic/ExploreFOLogic.ipynb

Source: Russell & Norvig, AI: A Modern Approach

Lecture 5: Summary

- We talked about
  - Logic – First Order
  - Inferencing
  - Representation in the Large: ConceptNet, Cyc
  - Trust Issues with Knowledge Representation

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

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. 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 6

Lecture 6: Searching for Problem Solving

- Search
- Heuristics