AI INSTITUTE #AIISC
UNIVERSITY OF SOUTH CAROLINA

UNIVERSITY OF SOUTH CAROLINA

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."

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

Organization of Lecture 5

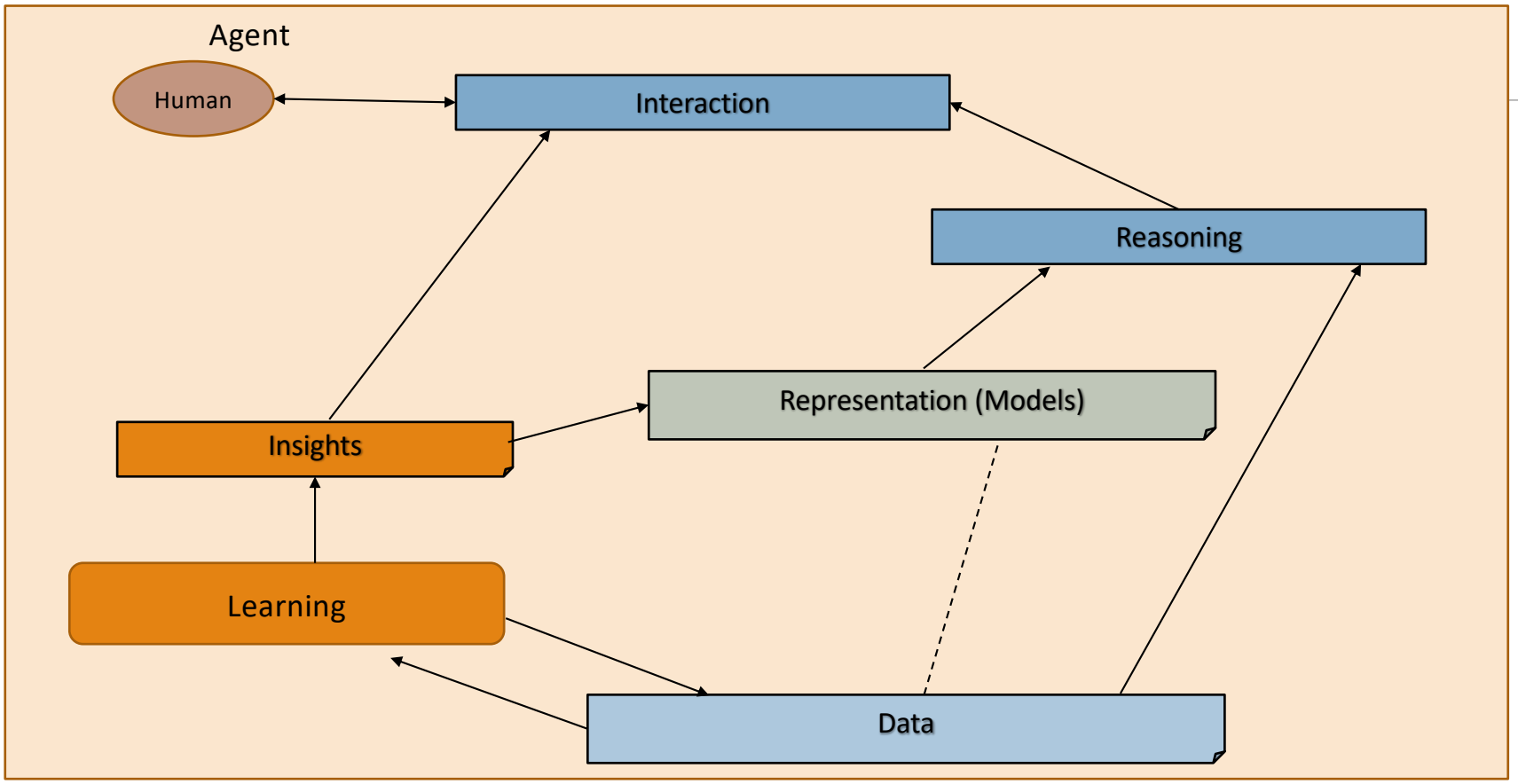
- Introduction Segment
  - Recap of Lecture 4
- Main Segment
  - Logic – First Order
  - Inferencing
  - Representation in the Large: ConceptNet, Cyc
  - Trust Issues with Knowledge Representation
- Concluding Segment
  - Course Project Discussion
  - About Next Lecture – Lecture 6
  - Ask me anything

Introduction Section

Recap of Lecture 4

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

Relationship Between Main AI Topics



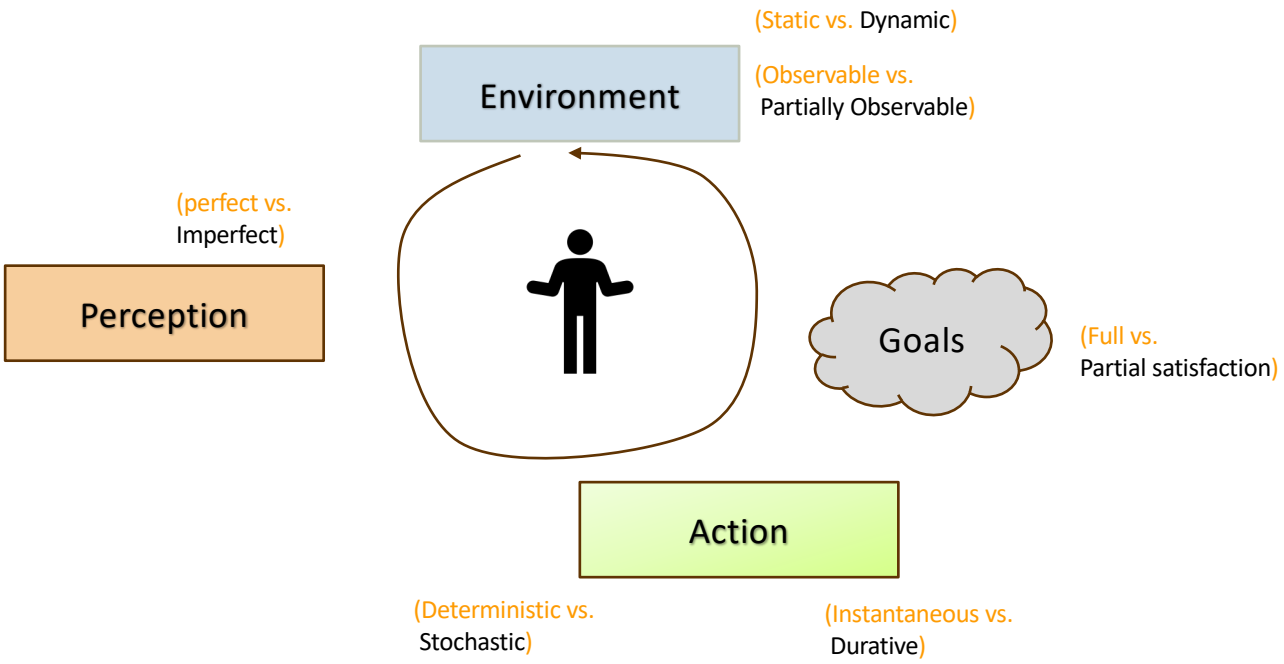
Where We Are in the Course

CSCE 580/ 581 – In This Course

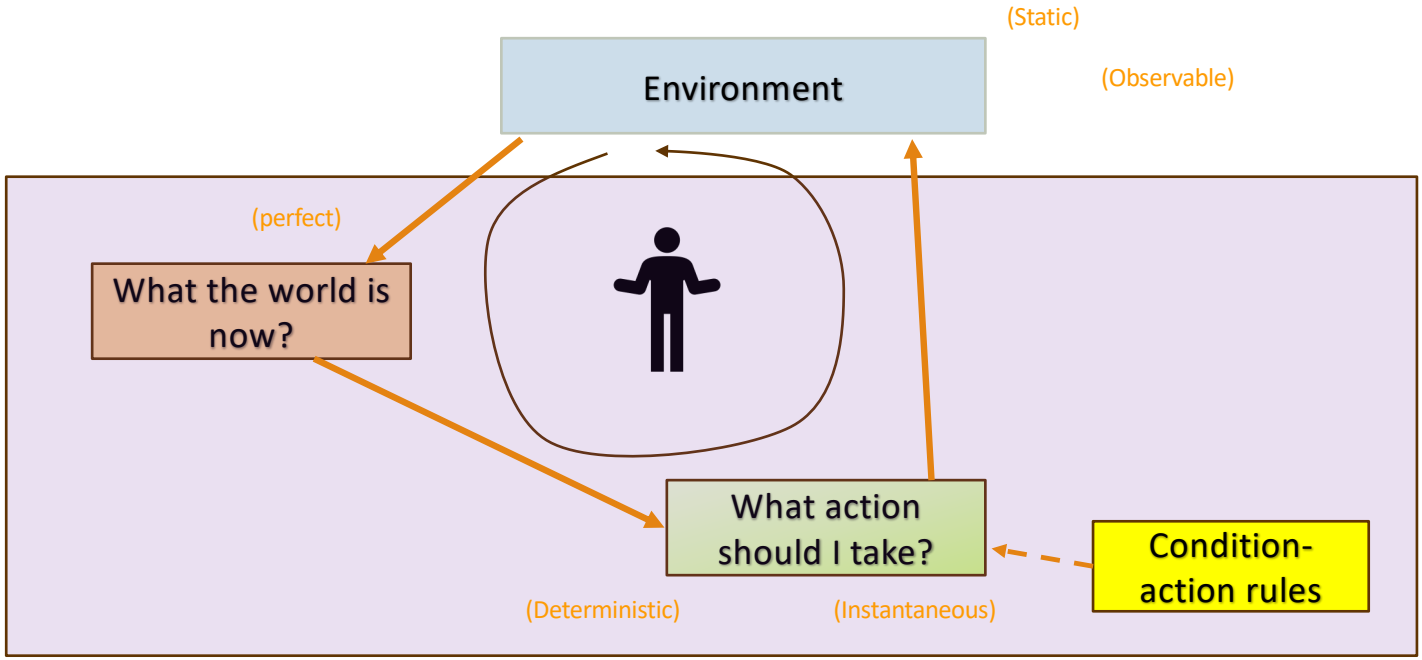
- Week 1: Introduction, Aim: Chatbot / Intelligence Agent
- Weeks 2-3: Data: Formats, Representation and the Trust Problem
- Week 4-5: Search, Heuristics - Decision Making
- Week 6: Constraints, Optimization – Decision Making
- Week 7: Classical Machine Learning – Decision Making, Explanation
- Week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

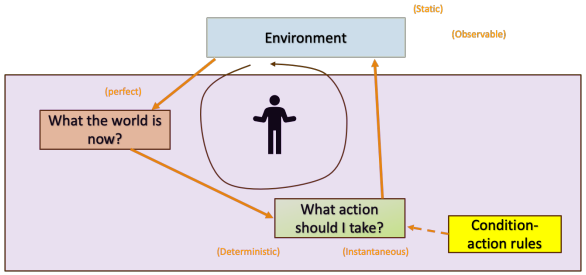
Intelligent Agent Model



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

$$
\begin{aligned}
\textit{Sentence} &\rightarrow \textit{AtomicSentence} \\
&\mid \textit{Sentence Connective Sentence} \\
&\mid \textit{Quantifier Variable},\ldots \textit{Sentence} \\
&\mid \neg \textit{Sentence} \\
&\mid (\textit{Sentence}) \\
\\
\textit{AtomicSentence} &\rightarrow \textit{Predicate}(\textit{Term},\ldots) \mid \textit{Term} = \textit{Term} \\
\\
\textit{Term} &\rightarrow \textit{Function}(\textit{Term},\ldots) \\
&\mid \textit{Constant} \\
&\mid \textit{Variable} \\
\\
\textit{Connective} &\rightarrow \Rightarrow \mid \wedge \mid \vee \mid \Leftrightarrow \\
\textit{Quantifier} &\rightarrow \forall \mid \exists \\
\textit{Constant} &\rightarrow A \mid X_1 \mid \textit{John} \mid \cdots \\
\textit{Variable} &\rightarrow a \mid x \mid s \mid \cdots \\
\textit{Predicate} &\rightarrow \textit{Before} \mid \textit{HasColor} \mid \textit{Raining} \mid \cdots \\
\textit{Function} &\rightarrow \textit{Mother} \mid \textit{LeftLegOf} \mid \cdots
\end{aligned}
$$

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
- ∃ : There exists

Examples:

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

Connections / Equivalences

$$\forall x\ \neg P = \neg\exists x\ P \qquad \neg P \wedge \neg Q = \neg(P \vee Q)$$
$$\neg\forall x\ P = 3x\ \neg P \qquad \neg(P \wedge Q) = \neg P \vee \neg Q$$
$$\forall x\ P = \neg\exists x\ \neg P \qquad P \wedge Q = \neg(\neg P \vee \neg Q)$$
$$\exists x\ \mathrm{P} = \neg\forall x\ \neg P \qquad P \vee Q = \neg(\neg P \wedge \neg Q)$$

Derivable from De Morgan's law about sets:
(A ∪ B)' = A' ∩ B' and (A ∩ B)' = A' ∪ B'

Source: Russell & Norvig, AI: A Modern Approach

Comparing Syntax - FOPL and Propositional Logic

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

$$
\begin{aligned}
\textit{Sentence} &\rightarrow \textit{AtomicSentence} \\
&\mid \textit{Sentence Connective Sentence} \\
&\mid \textit{Quantifier Variable}, \ldots \textit{Sentence} \\
&\mid \neg \textit{Sentence} \\
&\mid (\textit{Sentence}) \\
\textit{AtomicSentence} &\rightarrow \textit{Predicate}(\textit{Term}, \ldots) \mid \textit{Term} = \textit{Term} \\
\textit{Term} &\rightarrow \textit{Function}(\textit{Term}, \ldots) \\
&\mid \textit{Constant} \\
&\mid \textit{Variable} \\
\textit{Connective} &\rightarrow \Rightarrow \mid \wedge \mid \vee \mid \Leftrightarrow \\
\textit{Quantifier} &\rightarrow \forall \mid \exists \\
\textit{Constant} &\rightarrow A \mid X_1 \mid \textit{John} \mid \ldots \\
\textit{Variable} &\rightarrow a \mid x \mid s \mid \ldots \\
\textit{Predicate} &\rightarrow \textit{Before} \mid \textit{HasColor} \mid \textit{Raining} \mid \ldots \\
\textit{Function} &\rightarrow \textit{Mother} \mid \textit{LeftLegOf} \mid \ldots
\end{aligned}
$$

Source: Russell & Norvig, AI: A Modern Approach

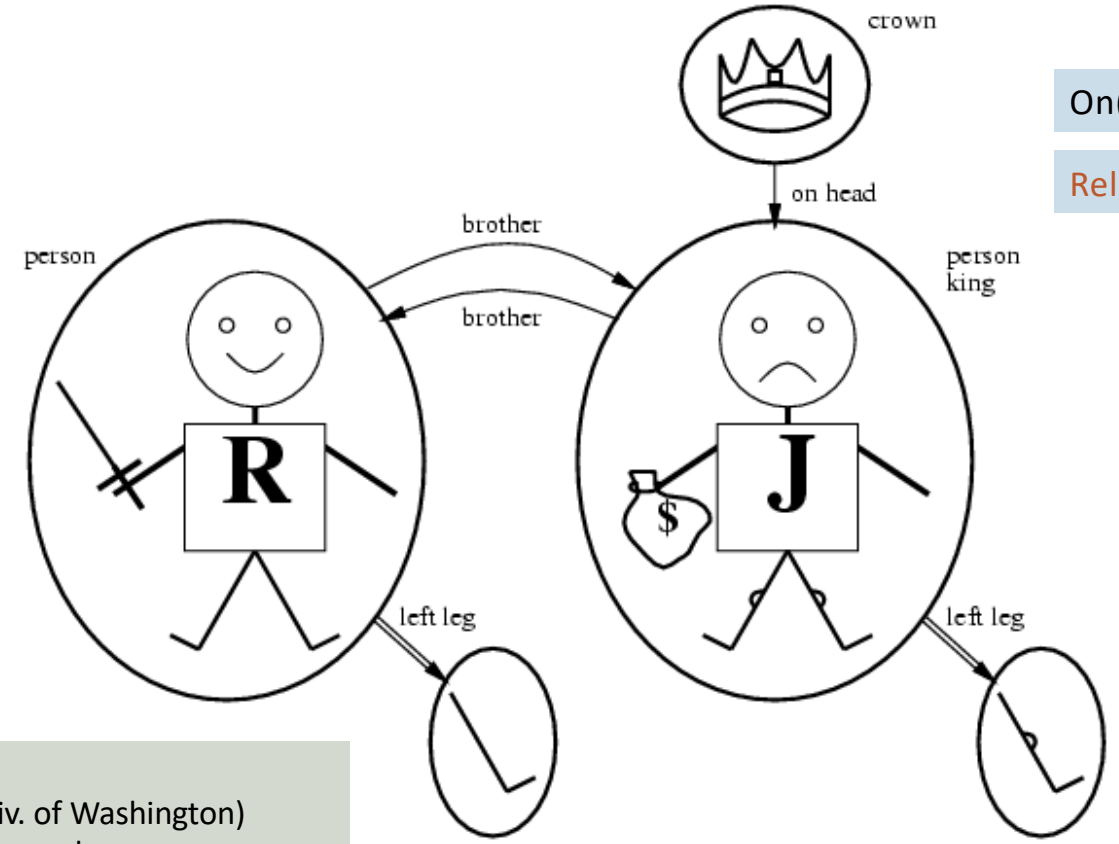
FOPL Semantics – Models and Interpretations

Richard, John
Constants

Leg(p,l)
Functions

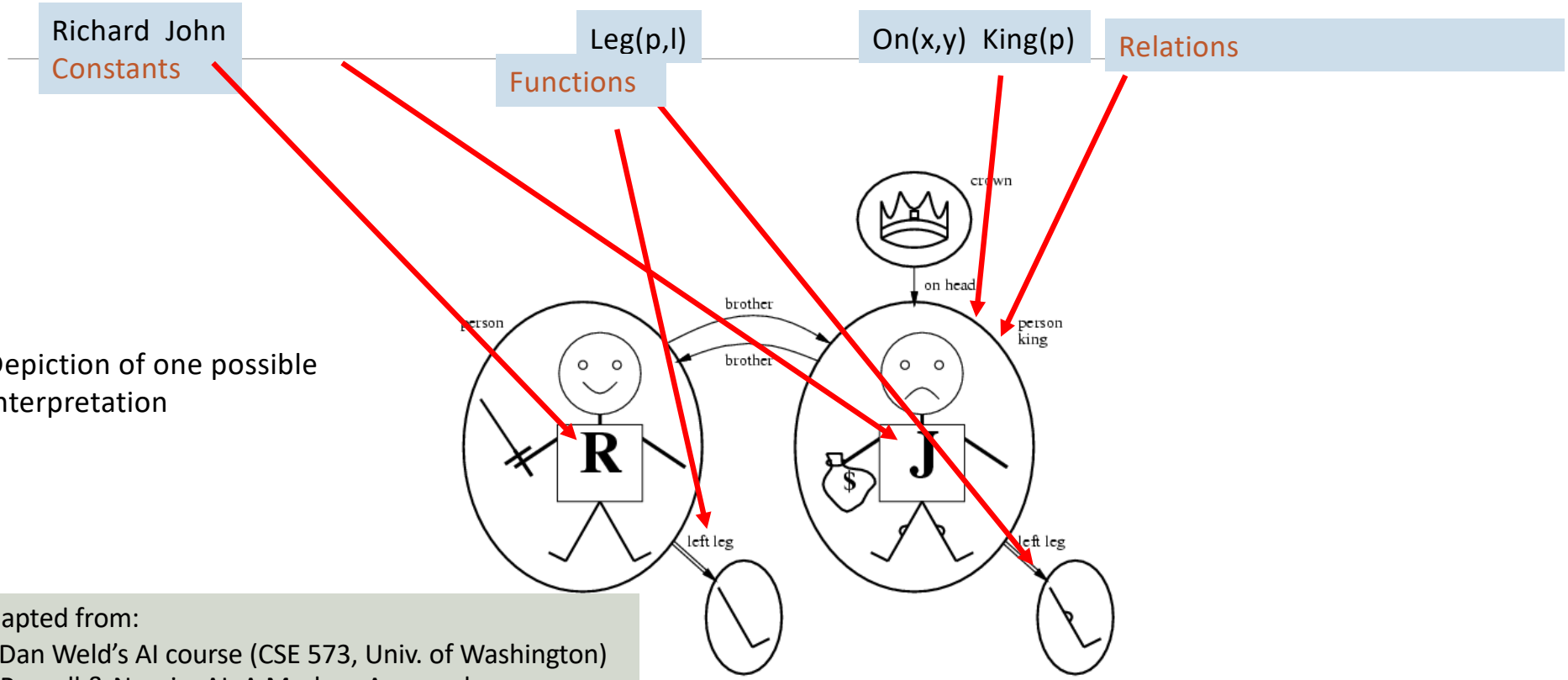
On(x,y) King(p)

Relations



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



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

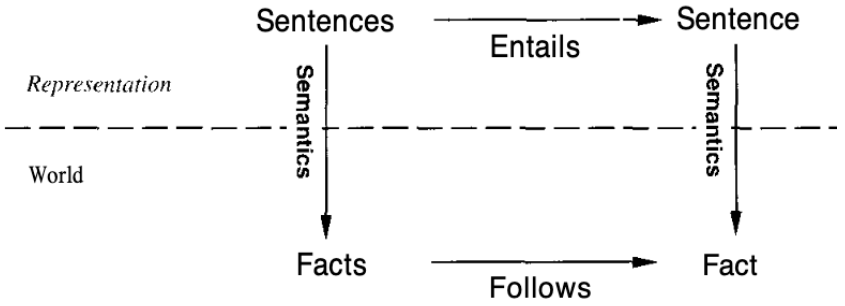
Comparing - Propositional Logic and FOPL

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

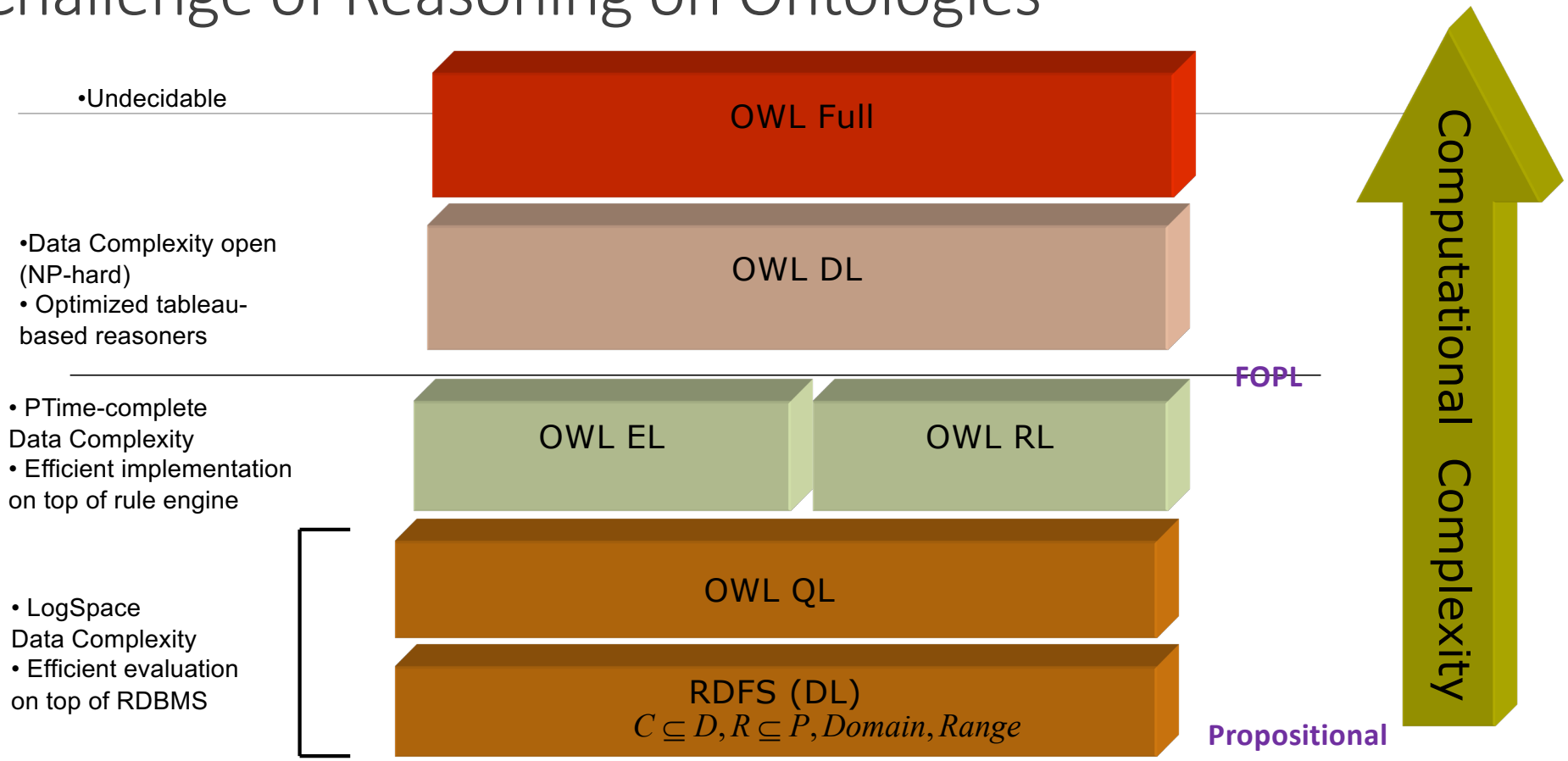
- Previous statements set did not capture hierarchy between levels; new sentences would not have followed the reality in the world. Need more statements – LowerThan as shown.

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

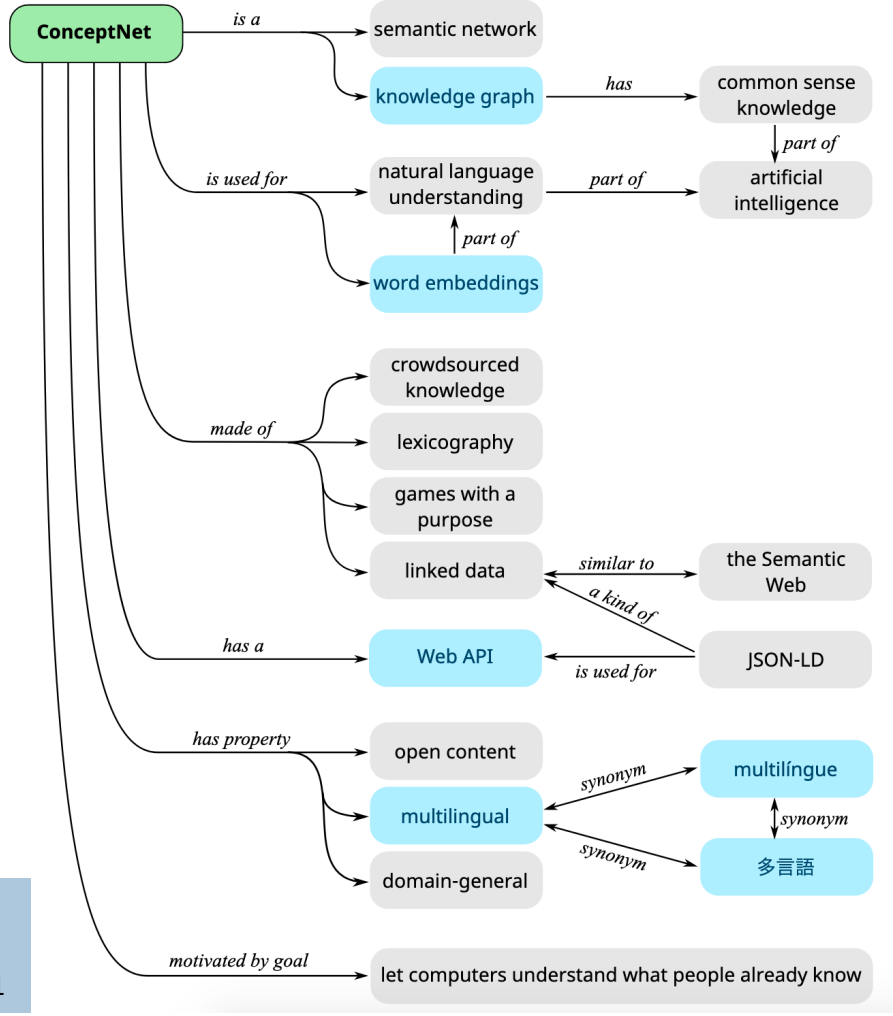
Challenge of Reasoning on Ontologies



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

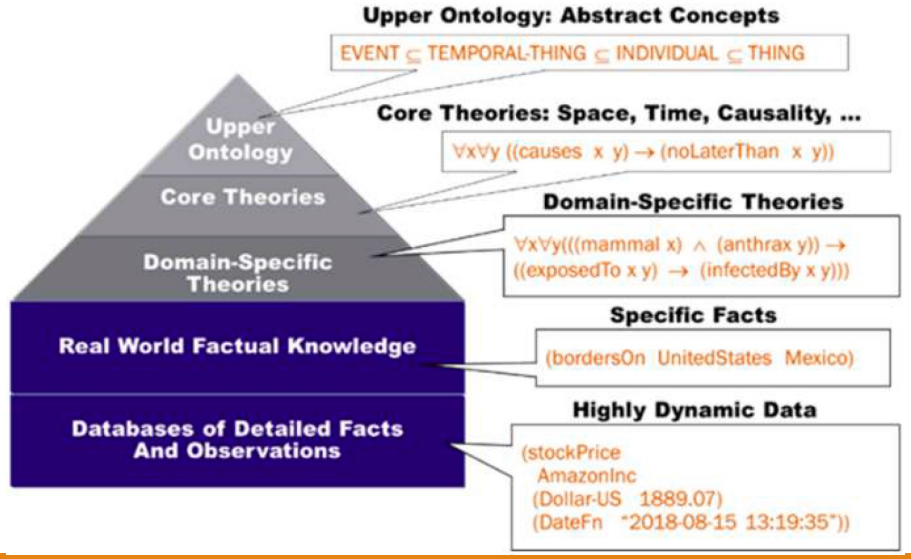
Demonstration - ConceptNet

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
  - Search, Optimization, Learning, Planning, …
- Application
  - Building chatbot
- Users
  - Diverse demographics
  - Diverse abilities
  - Multiple human languages

Project execution in sprints

- Sprint 1: (Sep 12 – Oct 5)
  - Solving: Choose a decision problem, identify data, work on solution methods
  - Human interaction: Develop a basic chatbot (no AI), no problem focus
- Sprint 2: (Oct 10 – Nov 9)
  - Solving: Evaluate your solution on problem
  - Human interaction: Integrated your choice of chatbot (rule-based or learning-based) and methods
- Sprint 3: (Nov 14 – 30)
  - **Evaluation:** Comparison of your solver chatbot with an LLM-based alternative, like ChatGPT

Project Discussion: Dates and Deliverables

Project execution in sprints

- Sprint 1: (Sep 12 – Oct 5)
  - Solving: Choose a decision problem, identify data, work on solution methods
  - Human interaction: Develop a basic chatbot (no AI), no problem focus
- Sprint 2: (Oct 10 – Nov 9)
  - Solving: Evaluate your solution on problem
  - Human interaction: Integrated your choice of chatbot (rule-based or learning-based) and methods
- Sprint 3: (Nov 14 – 30)
  - **Evaluation:** Comparison of your solver chatbot with an LLM-based alternative, like ChatGPT

- Oct 12, 2023
  - Project checkpoint
  - In-class presentation
- Nov 30, 2023
  - Project report due
- Dec 5 / 7, 2023
  - In-class presentation

Project Discussion: Illustration

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**: Solve and explain solving of n-queens puzzle
2. **Key idea**: Show students how a course project will look like
3. **Who will care when done**: students of the course, prospective AI students and teachers
4. **Data need**: n: the size of game; interaction
5. **Methods**: search
6. **Evaluation**: correctness of solution, quality of explanation, appropriateness of chat
7. **Users**: with and without AI background; with and without chess background
8. **Trust issue**: user may not believe in the solution, may find interaction offensive (why queens, not kings? …)

Reference: Project Rubric

- **Project results** – 60%
  - Working system ? – 30%
  - Evaluation with results superior to baseline? – 20%
  - Considered related work? – 10%
- **Project effort**s – 40%
  - Project report – 20%
  - Project presentation (updates, final) – 20%
- **Bonus**
  - Challenge level of problem – 10%
  - Instructor discretion – 10%
- **Penalty**
  - Lack of timeliness as per announced policy (right) - up to 30%

Milestones and **Penalties**

- Oct 12, 2023
  - Project checkpoint
  - In-class presentation
  - **Penalty: presentation not ready by Oct 10, 2023 [-10%]**
- Nov 30, 2023
  - Project report due
  - **Project report not ready by date [-10%]**
- Dec 5 / 7, 2023
  - In-class presentation
  - **Project presentations not ready by Dec 4, 2023 [-10%]**

Project Discussion: Rubric

About Next Lecture – Lecture 6

Lecture 6: Searching for Problem Solving

- Search
- Heuristics