Lecture 3 - Artificial Intelligence Topics & Field Maps

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An Interdisciplinary Approach

- Artificial Intelligence is an interdisciplinary approach.
- It contains multiple research and development disciplines.
- It involves a variety of technologies in many different fields.
- So, what are major problems of the AI? and,
- what are cutting-edge techniques applied to AI problems successfully?

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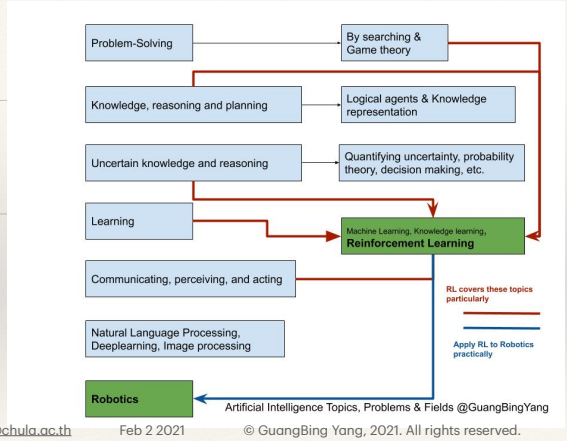
Topics, Problems & Fields

- The majorities of topics discussed in AI field are list in the diagram.
- To learn all of topics listed here needs 3 to 4 semesters study.
- Fortunately, Reinforcement Learning can be viewed as a **microcosm** for the **entire AI problems**.
- It covers almost every topics in AI except NLP.
- RL widely apply to modern robotics.
- Before focusing on RL, let's discuss each topic and problem in AI briefly.



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Problem-solving

- Reflex agents
  - simple.
  - having the simplest environments.
- Goal-based agents
  - problem-solving
  - planning agents.
- To solve the problems defined:
  - Uninformed search algorithms for pre-defined problems. (e.g., vacuum robots.)
  - Informed search algorithms for better solutions under guidance. (e.g., Tic Tac Toe games, chess games, etc.)
  - Advanced search algorithms used to find the solutions. E.g.,
    - Breadth-first,
    - depth-first,
    - best-first,
    - A* search, and
    - Local search, hill-climbing, local beam search, genetic algorithm, and so on.

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Problem-solving

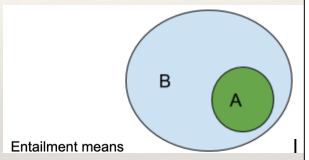
- Real-world search problems:
  - Optimal airline flights,
  - The traveling-salesperson problem,
  - VLSI layout methods
  - Robotic navigation
  - Mazes problem with dynamic programming
  - The two-point shortest-path algorithm of Dijkstra
- Non-classical search problems
  - Adversarial search problem, or games.
- Games are interesting because they are too hard to solve.

Knowledge & Reasoning

- Knowledge is essential to intelligent agents to reach good decisions.
- Knowledge is stored in the knowledge base as knowledge representation language.
- A representation language is defined by
  - Syntax, which specifies the structure of sentences,
  - Semantics, which defines the truth of each sentence in each possible world or model.
  - For example, two sentences,
    - "An aunt eats an apple", and
    - "An apple eats an aunt"
    - These two sentences have the same syntax structures. DT NN VBS DT NN, but
    - Their semantics are totally different. One is true, one if false.
- Thus, knowledge representation consists of syntax and semantics.

Knowledge & Reasoning

- To understand the reasoning, entailment (cause, necessary, inheritance) between sentences is crucial.
- A sentence A entails another sentence B if B is true in all worlds where A is true. B A, B is True, A is True.
- First-order logic is a representation language that represents knowledge.
- Logical inference in first-order logic determines the causal relations between sentences (objects & relations).



Knowledge Representation

- **First-order-logic** is a type of expressive language rather than the propositional logic.
- The propositional logic "*is a declarative, compositional semantics that is context-independent and unambiguous*." [1]
- However, its drawback is a lack of expressive power to describe an environment with many objects concisely.
- Natural language has expressive power but suffers from ambiguity.
- Hence, we need something that is more expressive logic with respect to the propositional logic, and borrowing representational ideas from natural language but avoiding its ambiguity.
- In other words, this kind of "language" shall cover both syntax and semantics of natural language.
  - Nouns and noun phrases refer to "object" from syntax. E.g., squares, balls, ships, vehicles, etc.
  - Verbs and verb phrases refer to "relations", e.g., is breezy, is nearby, is adjacent to, etc. and
  - functions for some of relations.

Knowledge Representation

- Given some examples:
  - Objects: people, houses, cars, theories, McDonald, countries, basketball games, rivers, etc.
  - Relations: unary relations or properties such as red, round, or n-ary relations such as brother of, bigger than, part of, occurred after, etc.
  - Functions: father of, best friend, third inning of, one more than, beginning of,…, etc.
- First-order logic is built around objects and relations. It is an expressive language that represents knowledge.
- Logical inference in first-order logic determines the causal relations between sentences (objects & relations).
- The main difference between first-order-logic and the propositional logic is that the first-order-logic is built upon the **ontological commitment**—what it assumes about the nature of *reality*.
- For example, the Probability theory is a kind of language for uncertainty (degree of belief), its ontological commitment is **facts**. The first-order-logic is a kind of language for knowledge representation, its ontological commitment is **facts, objects, relations.**

Knowledge Representation

- To construct the first-order-logic language:
  - need to define a **domain** of a model—the set of objects—also called **domain elements**.
  - need to define the relation—just a set of tuples of objects that are. {(John, Richard), (Richard, John)}. (Remember, Python tuple and set data structures)
  - need to define Functions: *<objects> -> a unary/n-ary function*. For example, <John> -> brother of.
- In addition, to model First-order logic, we also need define 'Symbols and interpretations'.
  - **constant symbols** for objects,
  - **predicate symbols** for relations,
  - **function symbols** for functions.
- The **interpretation** specifies exactly which objects, relations and functions are referred to by the constant, dedicate, and function symbols..
- Backus-Naur forms (BN) is used for the syntax of first-order-logic with equality. See book *"Artificial Intelligence—A Modern Approach" Figure 8.3.*
- List some of symbols for expression of quantifications:
  - Universal quantification: ∀, e.g., $\forall x \;\; John(x) \Rightarrow Person(x)$, $\forall x \;\; John(x) \Rightarrow Person(x) \wedge Brother(x)$
  - Existential quantification: ∃, e.g., $\exists x \;\; Crown(x) \wedge \; OnHead(x, John)$
  - Equality: =
  - Connections between ∀ and ∃: ¬, e.g., $\forall x \;\; \neg P \equiv \neg \exists x \;\; P$, means "all x dislike P" == "not exists any x likes P"
    - $\forall x \;\; Likes(x, IceCream) \equiv \neg \exists x \;\; \neg Likes(x, IceCream)$, means "everyone likes ice cream" == "no one does not like ice cream"

Knowledge Representation

- Where do all these come from? Human experts — Ontologists, ontological and knowledge engineers, and experts form Linguistics "manually" build them—the Knowledge Base or Ontological frameworks.
- Very expensive and time consuming tasks in NLP and AI.

Planning

- A **task** of a **sequence** of **actions** that will achieve a **goal**.
- **Actions** and **states** are two elements in the planning representations..
- States, actions, and goals consist of the logical structure of the planning problem.
- The representations of states, goals, and actions make the language of planning problem.
- More details of planning problem in RL

Uncertain Knowledge & Reasoning

- Exists because of lack of information.
- Inescapable in complex, dynamic, or inaccessible worlds.
- Probability theory is the expression or measure of the uncertainty--quantify the uncertainty.
- Bayes' rule evaluates the causal relationships, it allows unknown probabilities to be computed from known conditional probabilities, usually in the causal direction.
- Stochastic processes or Markov chain for dynamic and discrete random variables, usually not for the causal direction.
- How to deal with uncertainty with probability theory will be discussed more in following lectures.

Uncertain Knowledge & Reasoning

- Bayesian network is a directed acyclic graph (DAG).
- Inference in Bayesian networks means computing the probability distribution of a set of query variables, given a set of evident variables.
- Prior, likelihood, posterior, and evidence are important concepts in the Bayesian networks.
- Probability theory, Utility theory, and Decision theory tell
  - what an agent should believe on,
  - what an agent wants, and
  - what an agent should do.

Learning

- Learning takes many forms.
- A supervised learning takes the available feedback, either from the environments or supervision. It learns a function from examples of its inputs and outputs.
  - Learning a discrete-valued function is called classification;
  - Learning a continuous function is called regression.
- An unsupervised learning takes no available feedback, but discover the patterns or interests from inputs directly.
- Reinforcement learning takes actions in an environment to maximize the goal of cumulative rewards.

Learning

- Reinforcement learning continues to be one of the most active areas of machine learning research.
- Applications in robotics promise to be particularly valuable.

Robotics

- Intelligent agents that manipulate the physical world.
- Sensors and Effectors are main hardware of robots:
  - sensors for perceiving their environment;
  - effectors for physical forces on their environment.
  - Most robots are either manipulators anchored at fixed locations; or
  - mobile robots that can move..

Robotics

- Robotic perception is the software part of robotics, including:
  - estimating decision-relevant quantities from sensor data
  - localization and mapping,
  - probabilistic filtering algorithms to maintain belief state,
  - planning of robot motion,
  - configuration spaces search algorithms
- More detailed discussion about the robotics in industry in later lecture.

Recap

- Artificial Intelligence is an interdisciplinary approach.
- The majorities of topics discussed in AI field include:
  - problem-solving,
  - knowledge, reasoning, and planning
  - uncertain knowledge and reasoning
  - learning, communications, acting, and natural language processing.
  - robotics, etc.
- Reinforcement Learning can be viewed as a **microcosm** for the **entire AI problems**.
- RL widely apply to modern robotics.

- Reading task: Chapter 2 of the book: Artificial Intelligence—A Modern Approach

Questions

- Any questions?
- Lab demos & practices