Recap

- Types of Knowledge: declarative, procedural, meta, heuristic, structural.
- Knowledge Representation Techniques
  - Facts
    - Types of facts: single/multi values, uncertain, fuzzy
  - Object-attribute Value Triplets
  - Rules
    - Types of rules: relationship, recommendation, directive
    - Variable rules, fuzzy rules, meta rules, fuzzy rules
  - Object-attribute Value Triplets
  - Semantic Networks
  - Frames
  - Logic
    - Propositional Calculus
    - Predicate Calculus

Reasoning

- Deriving logical conclusions from given facts.
- 'The process of working with knowledge, facts and problem solving strategies to draw conclusions' Durkin

Deductive Reasoning

- **Deduce new information from logically related known information**
- **A deductive argument offers assertions that lead automatically to a conclusion**.
  - If there is dry wood, oxygen and a spark, there will be a fire

    Given: There is dry wood, oxygen and a spark

    We can deduce: There will be a fire.
  - All men are mortal. Socrates is a man.

    We can deduce: Socrates is mortal
- Modus Ponens is the basic form of deductive reasoning
  - Modus Ponens: If A is true and if A implies B is true, then B is true.

Inductive Reasoning

From a limited set of observations, we form a ‘generalization’.

- e.g.
  - –**Observation**: All the crows that I have seen in my life are black.
  - –**Conclusion**: All crows are black

Comparison

- Comparing deductive and inductive reasoning:
  - **Inductive**: By experience, every time I have let a ball go, it falls downwards. Therefore I conclude that the next time I let a ball go, it will also come down.
  - **Deductive**: I know Newton's Laws. So I conclude, if I let a ball go, it will certainly fall downwards.

Abductive Reasoning

- Deduction is exact in that the deductions follow in a logically provable way from the axioms.
- Abduction is a form of deduction that allows for plausible inference, i.e. the conclusion might be wrong, e.g.

  Implication: She carries an umbrella if it is raining

  Axiom: she is carrying an umbrella

  Conclusion: It is raining
- This conclusion might be false, because there could be other reasons that she is carrying an umbrella, e.g. she might be carrying it to protect herself from the sun.

Analogical Reasoning

- Draw analogy between two situations, looking for similarities and differences.
- e.g. when you say driving a truck is just like driving a car
  - By analogy you know that there are some similarities, same basic concepts
  - But you also know that there are certain other distinguishing characteristics of each

Common-sense Reasoning

- Gained through experience, rule-of-thumb
- Operates on heuristic knowledge and heuristic rules.

Non-Monotonic Reasoning

- Used when the facts of the case are not static, e.g.
  - Rule:
    - IF the wind blows
      THEN the curtains sway
    - When the wind stops blowing, the curtains should sway no longer.
    - However, if we use monotonic reasoning, this would not happen. The fact that the curtains are swaying would be retained even after the wind stopped blowing
  - In non-monotonic reasoning, we have a ‘truth maintenance system’. It keeps track of what caused a fact to become true. If the cause is removed, that fact is removed (retracted) also.

Inference

- **Inference is the process of deriving new information from known information**
- In the domain of AI, the component of the system that performs inference is called an ***inference engine***.
- We will look at inference within the framework of ‘logic’, which we introduced earlier

Logic

- Logic is a formal language
  - **Syntax**:
    - A description of valid statements, the expressions that are legal in that language. We have already looked at the syntax of two type of logic system called propositional logic and predicate logic.
      - Propositions: p, q, r
      - Associated truth value
      - Logical connectives
  - **Semantics**: what expressions mean.
    - e.g. the expression ‘the cat drove the car’ is syntactically correct, but semantically non-sensible.
  - Proof systems:
    - A logic comes with a proof system, which is a way of manipulating given statements to arrive at new statements. The idea is to derive ‘new’ information from the given information

Proof

- Recall proofs in math class. You write down all you know about the situation and then try to apply all the rules you know repeatedly until you come up with the statement you were supposed to prove.
- **A proof is a sequence of statements aiming at inferring some information.**
- Steps:
  - Initial statements are called premises of the proof (or knowledge base)
  - Use rules
  - Add new statements
  - Till you arrive at the statement you wished to prove.

Rules of Inference

- **“Modus Ponens", which means "affirming method“**
- **From now onwards, anything that is *written down* in a proof, is a statement that is true.**
- **If you know that alpha implies beta, and you know alpha to be true, you can automatically say that beta is true**

$$\frac{\begin{array}{l}\alpha \rightarrow \beta \\ \alpha\end{array}}{\beta}$$

Modus

Ponens

Rules of Inference

- **Modus Tolens: "alpha implies beta" and "not beta" you can conclude "not alpha".**
- **If Alpha implies beta is true and beta is known to be not true, then alpha could not have been true. Had alpha been true, beta would automatically have been true due to the implication.**

$$\frac{\begin{array}{l}\alpha \rightarrow \beta \\ \neg\beta\end{array}}{\neg\alpha}$$

Modus
Tolens

Rules of Inference

- **And-introduction say that from "Alpha" and from "Beta" you can conclude "Alpha and Beta". That seems pretty obvious.**
- **Conversely, and-elimination says that from "Alpha and Beta" you can conclude "Alpha".**

$$\frac{\begin{array}{l}\alpha \\ \beta\end{array}}{\alpha \wedge \beta} \qquad \frac{\alpha \wedge \beta}{\alpha}$$

And-Introduction   And-elimination

Rules of Inference

$$\frac{\begin{array}{l}\alpha \to \beta \\ \alpha\end{array}}{\beta}$$

Modus Ponens

$$\frac{\begin{array}{l}\alpha \to \beta \\ \neg\beta\end{array}}{\neg\alpha}$$

Modus Tolens

$$\frac{\begin{array}{l}\alpha \\ \beta\end{array}}{\alpha \wedge \beta}$$

And-Introduction

$$\frac{\alpha \wedge \beta}{\alpha}$$

And-elimination

Inference Example

Prove S

Step	Formula	Derivation
1	$P \wedge Q$	Given
2	$P \rightarrow R$	Given
3	$(Q \wedge R) \rightarrow S$	Given

Inference Example

Prove S

Step	Formula	Derivation
1	$P \wedge Q$	Given
2	$P \rightarrow R$	Given
3	$(Q \wedge R) \rightarrow S$	Given
4	P	1 And-elimination

Inference Example

Prove S

Step	Formula	Derivation
1	$P \wedge Q$	Given
2	$P \rightarrow R$	Given
3	$(Q \wedge R) \rightarrow S$	Given
4	P	1 And-elimination
5	R	4, 2 Modus Ponens

Inference Example

Prove S

Step	Formula	Derivation
1	$P \wedge Q$	Given
2	$P \rightarrow R$	Given
3	$(Q \wedge R) \rightarrow S$	Given
4	P	1 And-elimination
5	R	4, 2 Modus Ponens
6	Q	1 And-elimination

Inference Example

Prove S

Step	Formula	Derivation
1	$P \wedge Q$	Given
2	$P \rightarrow R$	Given
3	$(Q \wedge R) \rightarrow S$	Given
4	P	1 And-elimination
5	R	4, 2 Modus Ponens
6	Q	1 And-elimination
7	$Q \wedge R$	5, 6 And-introduction

Inference Example

Prove S

Step	Formula	Derivation
1	$P \wedge Q$	Given
2	$P \rightarrow R$	Given
3	$(Q \wedge R) \rightarrow S$	Given
4	P	1 And-elimination
5	R	4, 2 Modus Ponens
6	Q	1 And-elimination
7	$Q \wedge R$	5, 6 And-introduction
8	S	7, 3 Modus Ponens

Lecture Summary

- Reasoning
- Types of reasoning:
  - Deductive
  - Inductive
  - Adbuctive
  - Analogical
  - common-sense
  - non-monotonic reasoning
- Logic: syntax, semantics, Proof systems
- Rules of inference: Modus Ponens, Modus Tolens, And-introduction, And-elimination
- Inference example