Knowledge Representation

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- Outline
- Predicate logic
- Proofs
- Artificial intelligence

Predicate logic

- Propositional logic: "and, or, not" and variables.
- Propositional logic does not have quantifiers:
- "All poodles are dogs."
- "There is at least one black swan.
- "Only supervisors are allowed to fill in the form."
- "No person can solve this problem."

  These sentences cannot be expressed in propositional logic.

Predicate logic

- Quantifiers: all, at least one
- First order logic: quantifiers for individuals.
  "All squirrels eat nuts."
- Second order logic: quantifiers for predicates.
  S = "squirrels eat nuts"
  "All S involves chewing."
- Third order logic: ...

Syntax and semantics

- Predicate logic is a formal language (like a programming language) with rules for
- **syntax** (i.e. how to write expressions) and
- **semantics** (i.e. how to formalise the meaning of expressions).

Syntax: well-formed formulas

- **Logical symbols:** and, or, not, all, at least one, brackets, variables, equality (=), true, false
- **predicate and function symbols** (for example, Cat(x) for "x is a Cat")
- **term:** variables and functions (for example, Cat(x))
- **formula:** any combination of terms and logical symbols (for example, "Cat(x) and Sleeps(x)")
- **sentence:** formulas without free variables (for example, "All x: Cat(x) and Sleeps(x)")

Semantics: meaning

- The meaning of a term or formula is a set of elements. The meaning of a sentence is a truth value.
- The function that maps a formula into a set of elements is called an **interpretation**.
- An interpretation maps

  an **intensional description** (formula/sentence) into
- an **extensional description** (set or truth value).

Validity

A sentence is ...

- satisfiable if it is true under at least one interpretation.
- valid if it is true under all interpretations.
- invalid if it is false under some interpretation.
- contradictory if it is false under all interpretations.

  Example: “All x: Cat(x) and Sleeps(x)”

- If this is interpreted on an island which only has one cat that always sleeps, this is satisfiable.
- Since not all cats in all interpretations always sleep, the sentence is not valid.

Exercises

- Are these sentences satisfiable, valid, invalid or contradictory? If a sentence is satisfiable or invalid, provide an interpretation which makes it true (or false).

- $1+1=1$
- $A \cap B = \neg(\neg A \cup \neg B)$
- All x: ToBe(x) or not ToBe(x)

Axioms

- Mathematical theories distinguish between **axioms** and **theorems**.
- Axioms cannot be proved, but are accepted as facts.
- Theorems can be proved from axioms by using logical inference.

An example of using axioms

A Boolean logic is a set with operators: and ($\wedge$), or ($\vee$), not (A), the elements "true" and "false" and the axioms:

- associativity: $A \wedge (B \wedge C) = (A \wedge B) \wedge C$, $A \vee (B \vee C) = (A \vee B) \vee C$
- commutativity: $A \wedge B = B \wedge A$, $A \vee B = B \vee A$
- absorption: $A \vee (A \wedge B) = A$, $A \wedge (A \vee B) = A$
- distributivity: $A \vee (B \wedge C) = (A \vee B) \wedge (A \vee C)$, $A \wedge (B \vee C) = (A \wedge B) \vee (A \wedge C)$
- complements: $A \vee \bar{A} = 1$, $A \wedge \bar{A} = 0$

De Morgan's law is a theorem which can be proved from the axioms.

Modus ponens

The ancient Greek philosopher Aristotle introduced **Modus ponens**.

Premise 1: All humans are mortal.

Premise 2: Socrates is a human.

Conclusion: Therefore, Socrates is mortal.

Logical inference

- Law of excluded middle: either P is true or (not P) is true
- Principle of contradiction: P and (not P) cannot both be true

Examples:

- Either you are currently sitting in this class room or not.
- The gender of the baby is either male or female or unknown.
- Either you are wearing shoes or sandals.
- Are you wearing a shirt or a t-shirt? Could be both.

Exercise: which of these inferences are valid?

The days are becoming longer.
The nights are becoming shorter if the days are becoming longer.
Hence, the nights are becoming shorter.

The earth is spherical implies that the moon is spherical.
The earth is not spherical.
Hence, the moon is not spherical.

The new people in the neighborhood have a beautiful boat.
They also have a nice car.
Hence, they must be nice people.

All dogs are carnivorous.
Some animals are dogs.
Therefore, some animals are carnivorous.

Reasoning (Charles Sanders Peirce)

Induction: Every dog I know has ears. $\Rightarrow$ Dogs have ears.
(from specific examples to general)

Deduction: Dogs bark. Bobby is a dog. $\Rightarrow$ Bobby barks.
(from general to specific)

Abduction: Sherlock Holmes: the murderer was left-handed.
Smith is left-handed. $\Rightarrow$ Smith is the murderer.
(based on shared attributes)

Exercises: induction, deduction or abduction?

Birds fly. Penguins are birds.
Hence, penguins fly.

All swans on this lake are white.
Hence, all swans are white.

Some dogs are animals.
Some cats are animals.
Hence, some cats are dogs.

Exercises: induction, deduction or abduction?

Birds fly. Penguins are birds.
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Using deduction in unclear domains can lead to false results.
Induction and abduction always need to be treated with caution.

Artificial intelligence

- The term “artificial intelligence” was coined in 1956 by John McCarthy.
- An attempt to build computer software which has reasoning capabilities similar to humans.
- Processing of natural language.
- Understanding and modelling of spatial, temporal and social situations.
- Knowledge representation and problem solving.
- Many approaches: neural networks, evolutionary algorithms, robots, distributed devices, ...

Knowledge representation

- Uses formal languages to represent knowledge.

  Conceptual structures

  Ontologies

  Knowledge bases

  Expert systems

Tasks for knowledge representation systems

- Uses formal languages to represent knowledge.

- **Acquisition:** new information is integrated into the system
- **Retrieval:** existing information is retrieved, query answering
- **Reasoning:** logical inferences

Reasoning

- Uses formal languages to represent knowledge.

- Is this concept an element of this class?
- Are concepts, relations and assertions satisfiable/valid?
- Is the knowledge base consistent (i.e. free of contradictions)?

Complexity: the reasoning tasks must not take too much time or computing resources.

Natural language can be ambiguous

They drank two cups of tea because they were warm.

They drank two cups of tea because they were cold.

Time flies like an arrow.

Fruit flies like a banana. (Groucho Marx)

$\Rightarrow$ It is difficult to write software that extracts information from natural language or that translates between different languages.

Programming with logic

Prolog: declarative, logic programming language

Lisp: favourite language for artificial intelligence programming

Smalltalk: object-oriented, dynamically typed, reflective language

Description logics: knowledge representation languages

OWL: web ontology language