NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

CZ3005 Artificial Intelligence

Week 8b – Logical Agent

Yu Han

han.yu@ntu.edu.sg

Nanyang Assistant Professor
School of Computer Science and Engineering
Nanyang Technological University

Recap

- **Intelligent agents need …**
  - Knowledge about the world to make good decisions.
- **Knowledge can be …**
  - Defined using a knowledge representation language.
  - Stored in a knowledge base in the form of sentences.
  - Inferred, using an inference mechanism and rules.

Recap

```
function KB-Agent (percept) returns action
        static  KB,                      // a knowledge base
                t                        // a time counter, initially 0

        Tell (KB, Make-Percept-Sentence (percept, t))
        action ← Ask (KB, Make-Action-Query (percept, t))
        Tell (KB, Make-Action-Sentence (action, t))
        t ← t + 1
        return action
```

– > 3 steps: interpretation, inference, execution

– > KB: background knowledge (observed)
+ acquired information (deduced)

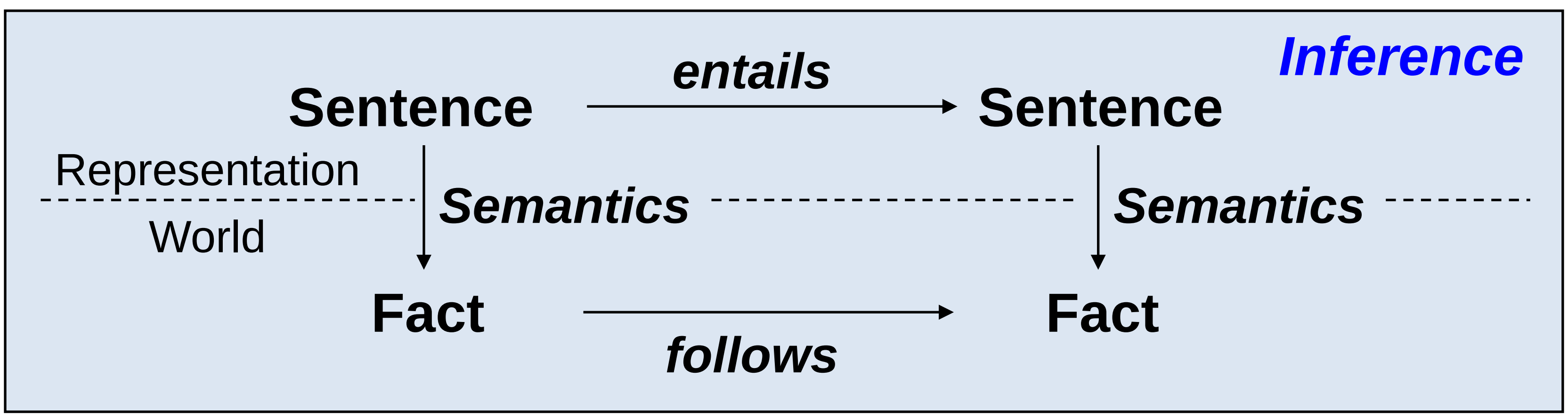
Knowledge Representations

- **Knowledge representation (KR)**
  - KB: set of sentences –> need to
  - Express knowledge in a (computer-) tractable form
- **Knowledge representation language**
  - Syntax – implementation level
    - Possible configurations that constitute sentences
  - Semantics – knowledge level
    - Facts of the world the sentences refer to
    - e.g. language of arithmetics: x, y numbers
      sentence: “$x \geq y$”, semantics: “greater or equal”

Logic

Reasoning and Logic

- **Logic**
  - Representation + Inference = Logic
    - Where representation = syntax + semantics
- **Reasoning**
  - Construction of new sentences from existing ones
- **Entailment** as logical inference
  - the relationship between sentences whereby one sentence will be true if all the others are also true



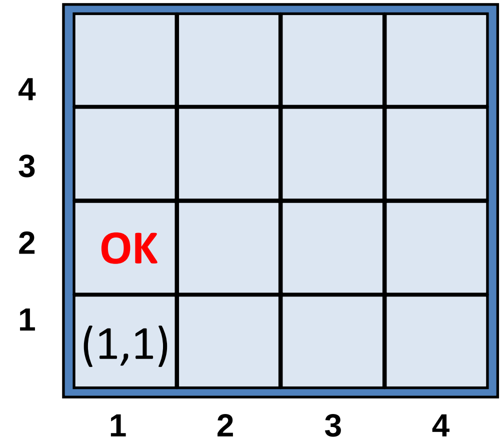
Deduction and Induction

- **Mechanical reasoning**
  - Example
    - If a chord sequence is tonal, then it can be generated by a context-sensitive grammar.
    - The twelve-bar blues has a chord sequence that is tonal. |-
    - The twelve-bar blues has a chord sequence that can be generated by a context-sensitive grammar.
- **Deductive inference**
  - KB: Monday $\Rightarrow$ Work, Monday |- Work *sound*
- **Inductive inference**
  - KB: Monday $\Rightarrow$ Work, Work |- Monday *unsound!*
  - Generalization e.g., *“all swans are white …”*

Deduction and Induction

Entailment and Inference

- **Entailment**
  - Generate sentences that are necessarily true, given that the existing sentences are true
  - Notation: KB $|= \alpha$
    - e.g. Wumpus world:
      { "¬S(1,1)", "¬B(1,1)" } |= "OK(2,1)"
      Arithmetics:
      { "$x \geq y$", "$y \geq z$" } |= "$x \geq z$"



- **Inference**
  - The act or process of deriving logical conclusions from premises known or assumed to be true.
  - **Tell**, given KB: (KB $|= \alpha$) !
  - **Ask**, given KB and α: (KB $|= \alpha$) ?

Properties of Inference

- *Can be described by the sentences it derives, KB |=* α_I

- **Soundness**
  - Generate only entailed sentences
  - Proof: sequence of operations of a sound inference
    - Record of operations that generate a specific entailed sentence

      e.g. "Smoke $\Rightarrow$ Fire" and "Smoke" |= "Fire"

      "Fire $\Rightarrow$ Call_911" and "Fire" |= "Call_911"

- **Completeness**
  - A proof can be found for any entailed sentence

An Example of Sound Inference

- Sentence: x
  - Semantics: an expression; can be a single symbol or number, the concatenation of 2 expressions, etc.
- Sentence: x y
  - Semantics: an expression which refers to a quantity that is the <u>product</u> of the quantities referred to by each of the expressions
- Sentence: x = y
  - Semantics: the 2 expressions on each side of "**=**" refer to the same quantity

- A sound inference: from $E = mc^2$

$$T_1 \geq T_2 \quad \models \quad E\ T_1 \geq mc^2\ T_2$$

Is this a Sound Inference?

- Sentence: x
  - Semantics: an expression; can be a single symbol or number, the concatenation of 2 expressions, etc.
- Sentence: x y
  - Semantics: an expression which refers to a quantity that is the <u>product</u> of the quantities referred to by each of the expressions
- Sentence: x = y
  - Semantics: the 2 expressions on each side of “**=**“ refer to the same quantity

- A sound inference? from $E = mc^2$

$$T_1 > T_2 \quad \models \quad E\,T_1 \geq mc^2\,T_2$$

Knowledge Representation Languages

- **Formal (programming) languages**
  - Good at describing algorithms and data structures
    - e.g. the Wumpus world as a 4x4 array, World[2,2] $\leftarrow$ Pit
  - Poor at representing incomplete / uncertain information
    - e.g. “there is a pit in [2,2] or [3,1]”, or “…a wumpus *somewhere*”
  - > *not <u>expressive</u> enough*
- **Natural languages**
  - Very expressive (too much, thus very complex)
  - More appropriate for communication than representation
  - Suffer from ambiguity
    - e.g. “It’s hot!”
    - e.g. “small cats and dogs” compared to “– x + y”.

Properties of Representations

  – *KR languages should combine the advantages of both programming and natural languages.*
- **Desired properties**
  – Expressive
    - Can represent everything we need to.
  – Concise
  – Unambiguous
    - Sentences have a unique interpretation.
  – Context independent
    - Interpretation of sentences depends on semantics only.
  – Effective
    - An inference procedure allows to create new sentences.

Properties of Semantics

- **Interpretation (meaning)**
  - *Correspondence between sentences and facts*
  - Arbitrary meaning, fixed by the writer of the sentence
    - e.g. Natural languages: meaning fixed by usage (cf. dictionary)
      exceptions: encrypted messages, codes (e.g. Morse)
      chat
  - Systematic relationship: compositional languages
    - *The meaning of a sentence is a function of the meaning of its parts*.
  - <u>Truth value</u>
    - A sentence make a claim about the world –> TRUE or FALSE
    - *Depends on the interpretation and the state of the world*
      - e.g. Wumpus world: S(1,2) true if means “Stench at [1,2]” and the world has a wumpus at either [1,3] or [2,2].

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Properties of Inference

- **Definition**
  - *Inference (reasoning) is the process by which conclusions are reached*
  - Logical inference (deduction) is the process that implements entailment between sentences
- **Useful properties**
  - Valid sentence (tautology)
    - iff TRUE under all possible interpretations in all possible worlds.
      - e.g. “S or ¬ S” is valid, “S(2,1) or ¬ S(2,1)”, etc.
  - Satisfiable sentence
    - iff there is some interpretation in some world for which it is TRUE
      - e.g. “S and ¬ S” is unsatisfiable

Inference and Agent Programs

- **Inference in computers**
  - Does not know the interpretation the agent is using for the sentences in the KB
  - Does not know about the world (actual facts)
  - Knows only what appears in the KB (sentences)
    - e.g. Wumpus world: doesn't know the meaning of "OK", what a
      wumpus or a pit is, etc. – can only see: KB |= "[2,2] is OK"
  - > *Cannot reason informally*
    - does not matter, however, if KB |= "[2,2] is OK" is a valid sentence
- **Formal inference**
  - Can handle arbitrarily complex sentences, KB |= P

Different Logics

- **Formal logic**
  - Syntax
    - A set of rules for writing sentences
  - Semantics
    - A set of rules (constraints) for relating sentences to facts
  - Proof theory / inference procedure
    - A set of rules for deducing entailments of sentences
- **Propositional logic**
  - Symbols, representing propositions (facts)
  - Boolean connectives, combining symbols
    - e.g. “Hot” or “Hot and Humid”

Different Logics

- **First-order logic**
  - Objects and predicates, representing properties of and relations between objects
  - Variables, Boolean connectives and quantifiers
    - e.g. “Hot(x)”, “Hot(Air)” or ”Hot(Air) and Humid(Air)”
- **Temporal logic**
  - World ordered by a set of time points (intervals)
- **Probabilistic and fuzzy logic**
  - Degrees of belief and truth in sentences
    - e.g. “Washington is a state” with belief degree 0.4, “a city” 0.6,
      ”Washington is a large city” with truth degree 0.6

Different Degrees of Truth

- *Q: Is there a tuna sandwich in the refrigerator?*
- *A: 0.5 !*

- **Probabilities**
  - There *is* or there *isn't* (50% chance either way).
- **Measures**
  - There is *half* a tuna sandwich there.
- **Fuzzy answer**
  - There is *something* there, but it *isn't really* a tuna sandwich. Perhaps it is some other kind of sandwich, or a tuna salad with no bread...

The Commitments of Logics

Formal (KR) Language	Ontological commitment (what exists in the world)	Epistemological commit-ment (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, rel., times	true / false / unknown
Probability logic	facts	degree of belief 0…1
Fuzzy logic	degrees of truth 0…1	degree of belief 0…1

Summary

- **A representation language is defined by …**
  - A syntax, which specify the structure of sentences, and
  - A semantics, which specifies how the sentences relate to facts in the world.
- **Inference is …**
  - The process of deducing new sentences from old ones.
  - Sound if it derives true conclusions from true premises.
  - Complete if it can derive all possible true conclusions.
- **Logics …**
  - Make different commitments about what the world is made of and what kind of beliefs we can have about facts.

Thank you!