NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

CZ3005 Artificial Intelligence

Knowledege Representation and Reasoning

Asst/P Mahardhika Pratama

Email: mpratama@ntu.edu.sg

Office: N4-02a-08

Knowledge Representation

- **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”

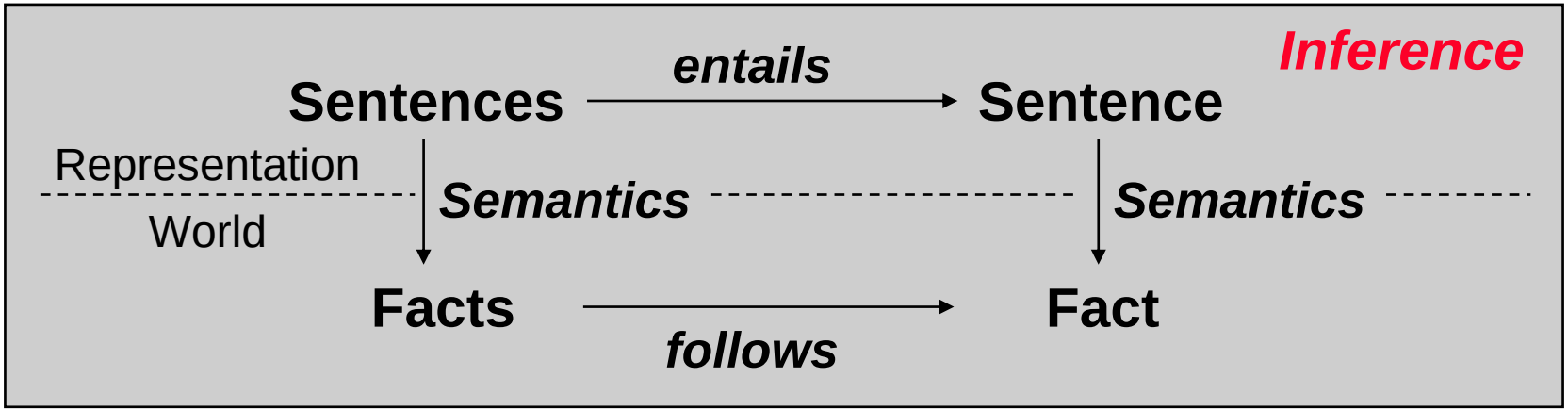
❑ Logic

- Representation + Inference = Logic
  - Where representation = syntax + semantics

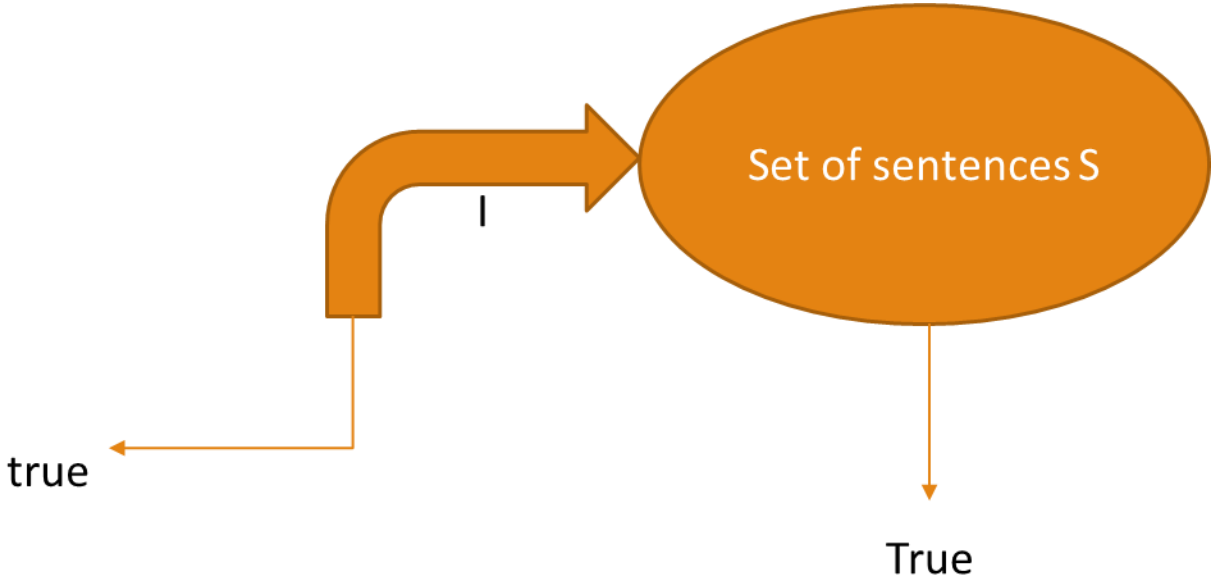
❑ Reasoning

- Construction of new sentences from existing ones

❑ Entailment as logical inference



Entailment



Entailment and Inference

- **Entailment**
  - Generate sentences that are necessarily true, given that the existing sentences are true
  - Notation: KB |= α
    - e.g. Wumpus world:
      { “¬S(1,1)”, “¬B(1,1)” } |= “OK(2,1)”
      Arithmetics:
      { “$x \geq y$”, “$y \geq z$” } |= “$x \geq z$”
- **Inference**
  - **Tell**, given KB: (KB |= α) !
  - **Ask**, given KB and α: (KB |= α) ?

- *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 ⇒ Fire” and “Smoke” |= “Fire”

    “Fire ⇒ Call_911” and “Fire” |= “Call_911”

❑ Completeness

- A proof can be found for any entailed sentence

❑ Proof theory

- Specify the reasoning operations that are sound

❑ 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

Quiz

Kahoot.it

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 product 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 $E = mc^2$

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

❑ 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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❑ 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”

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

Commitments of Logics

Formal (KR) 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, 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

Propositional Logic

- P is “It rains on Tuesday”
- Q is “John likes chocolate”

P and Q are either TRUE or FALSE.

First order Logic

- If x is a man, then x is a mortal
  - man(x) $\Rightarrow$ mortal(x)
  - $\neg$man(x) $\vee$ mortal(x)
- If n is a natural number, then *n* is either even or odd.
  - Natural(n) $\Rightarrow$ even(n) $\vee$ odd(n)

Fuzzy Logic

Sets with fuzzy boundaries

A = Set of tall people