Universidade do Minho
Escola de Engenharia
Departamento de Informática

Knowledge and Reasoning

LICENCIATURA EM ENGENHARIA INFORMÁTICA
MESTRADO integrado EM ENGENHARIA INFORMÁTICA
Inteligência Artificial
2025/26

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Synthetic Intelligence Lab

Knowledge representation

- Knowledge and Reasoning;
- Logic and Logic Programming;
- Production rules;
- Standards-Driven Programming;
- Hierarchical structures:
  - Semantic networks;
  - Frames;
- Scripts;
- Knowledge-Based Systems.

Knowledge and Reasoning

- What is knowledge?

  Knowledge can be defined as information about the environment (which can be expressed in the form of propositions).

- What is knowledge representation?

  Symbols used to represent information about the environment (propositions).

- What is knowledge representation and reasoning?

  The manipulation of symbols (which encode propositions to produce representations of new propositions).

The issue of representing knowledge is a fundamental question in Artificial Intelligence: How can human knowledge be represented by a computer language and in such a way that computers can use this knowledge to reason?

Source: Grosan C., Abraham A. (2011) Knowledge Representation and Reasoning. In: Intelligent Systems. Intelligent Systems Reference Library, vol 17. Springer, Berlin, Heidelberg

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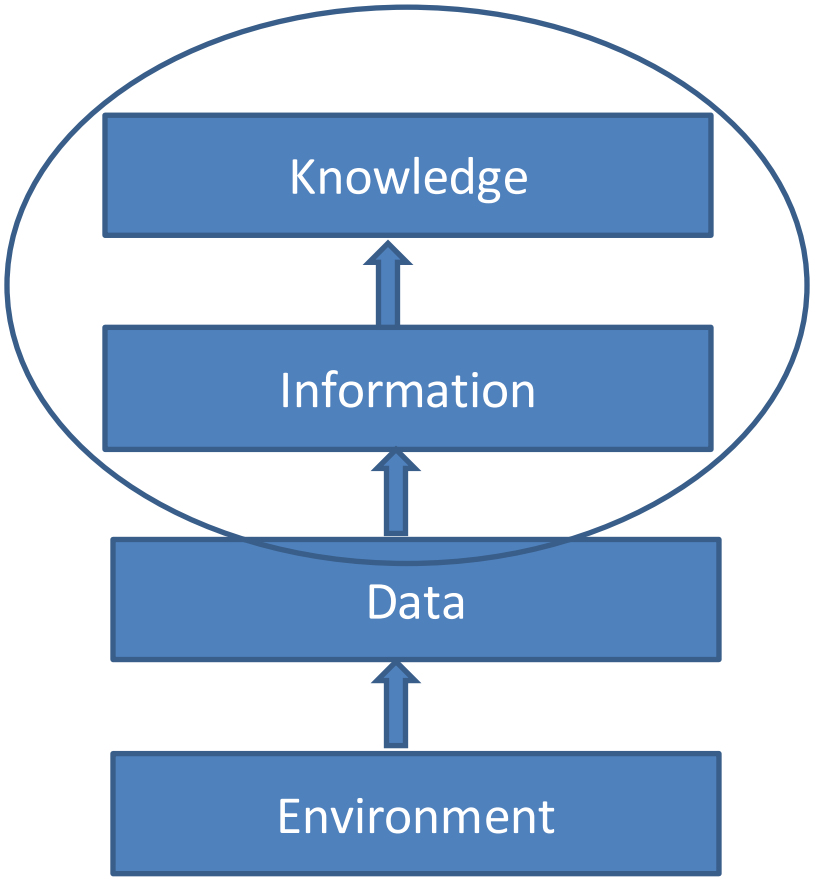
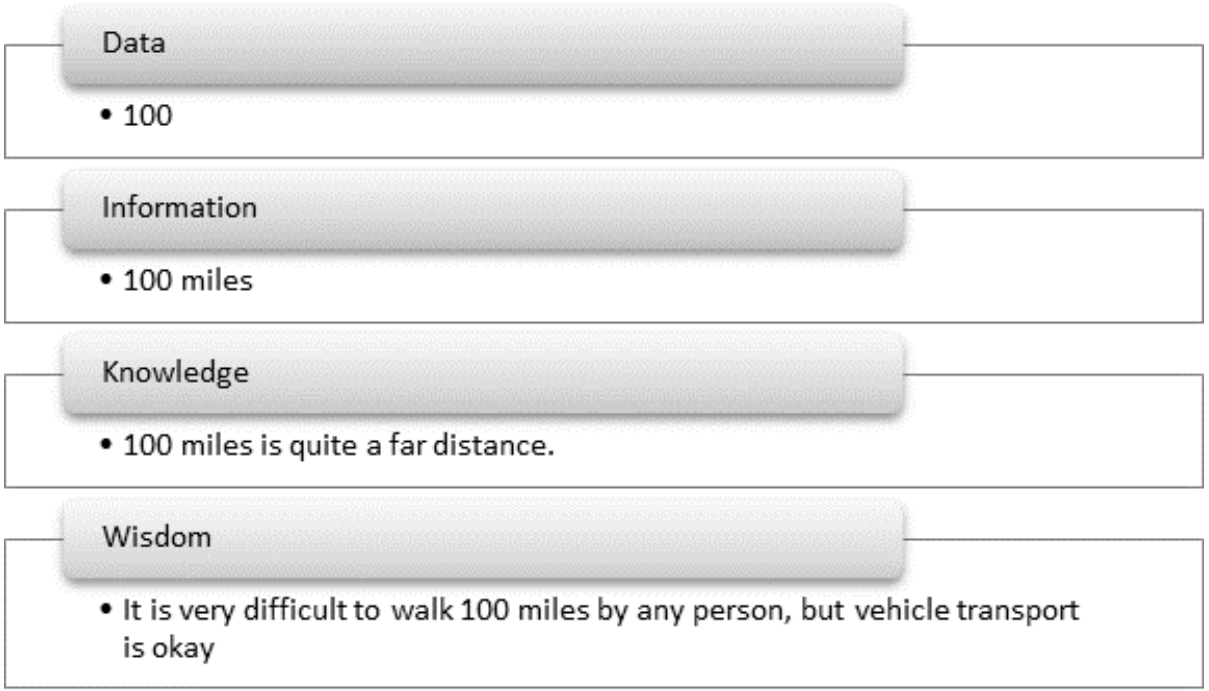
Knowledge?



Examples



Source: https://www.guru99.com/information-vs-knowledge-difference.html

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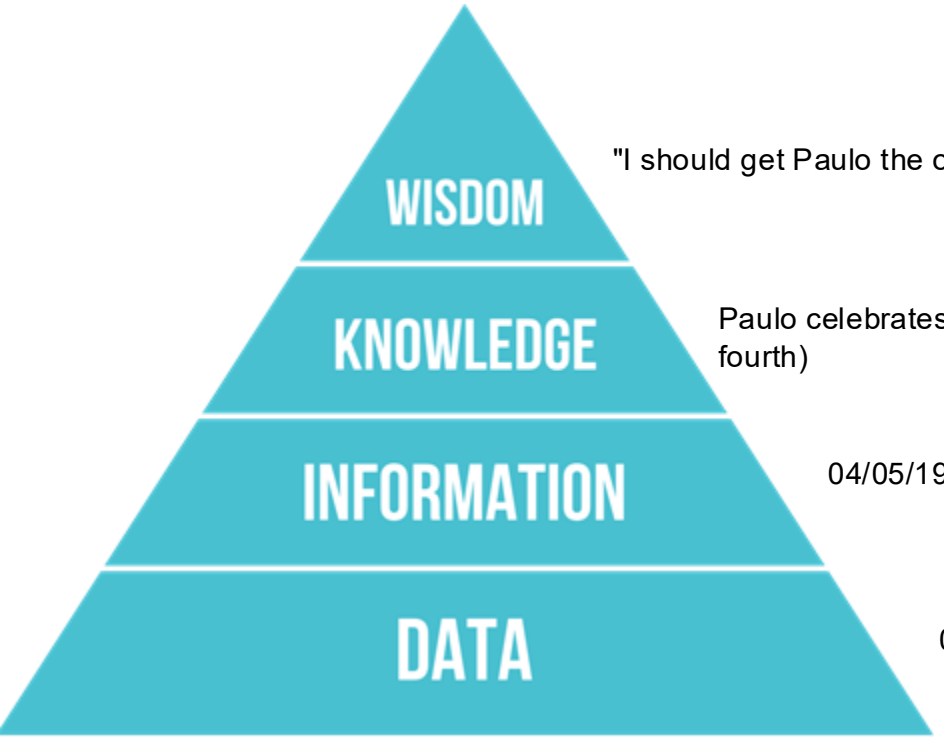
Examples



"I should get Paulo the official collector's edition of Star Wars!" — RATIONAL DECISIONS

Paulo celebrates this day as a Star Wars fan! (may the force/May the fourth) — INTERPRETATION

04/05/1986 (date of birth in the day/month/year format) — STRUCTURE

04051986 — SYMBOLS

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Types of problems

- Deterministic, fully observable environment → **single-state problem**
  - The agent "**knows**" exactly what state it will be in; the solution is a sequence.
- **Deterministic**, non-accessible environment → **multi-state problem**
  - The agent "**doesn't know**" where he is; the solution is a sequence
- **Non-deterministic** and/or partially accessible environment → **contingency problem**
  - Perceptions provide new information about the current state
  - They often intersperse search and execution
- Unknown state space → **exploration problem**

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Knowledge Engineering

- **Knowledge Engineering** develops and explains methods of "Knowledge Representation" and strategies for the computational processing of that same Knowledge;

- **Knowledge-Based Agents**
  - Knowledge Base (KB) made up of facts (from the domair
  - Inference Mechanism (domain-independent);
  - Declarative Approach to Building an Agent:
    - Tell him what he needs to know;
    - This way he can ask himself questions (answers come from the BC).
  - Agents can be seen at:
    - Knowledge level (what they know without worrying about how to implement it);
    - Implementation level (data structures in the BC and algorithms that manipulate them).

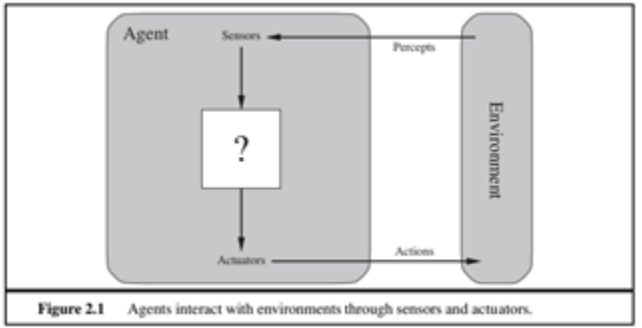


Figure 2.1 Agents interact with environments through sensors and actuators.

Source: Russell and Norvig, (2009) Artificial Intelligence - A Modern Approach.

Knowledge-based Agents
(Knowledge-based Agents)

- Humans know "things", which helps them do "things"!
  - Reasoning processes that operate on internal representations of knowledge
- Logic: a general class of representations to support knowledge-based agents
  - We combine and recombine information for a multitude of purposes
- Knowledge-based agents can accept new tasks in the form of explicitly described objectives;
  - "Hearing" or learning new knowledge about the environment
  - Adapting to changes in the environment, updating relevant knowledge

Knowledge-based agents
(Knowledge-based Agents)

```
function KB-AGENT(percept) returns an action
  persistent: KB, a knowledge base
              t, a counter, initially 0, indicating time

  TELL(KB, MAKE-PERCEPT-SENTENCE(percept, t))
  action ← ASK(KB, MAKE-ACTION-QUERY(t))
  TELL(KB, MAKE-ACTION-SENTENCE(action, t))
  t ← t + 1
  return action
```

- TELL the KB what it perceives
- ASK the KB what action to perform
  - Reasoning about the current state of the world, outcomes of possible actions, ...
- TELL the KB which action was performed in the world

Source: Russell and Norvig, (2009) Artificial Intelligence - A Modern Approach.

Knowledge vs. Implementation

- A knowledge-based agent can be described at the **knowledge level (KB)**
  - We just need to specify what the agent knows and what its objectives are

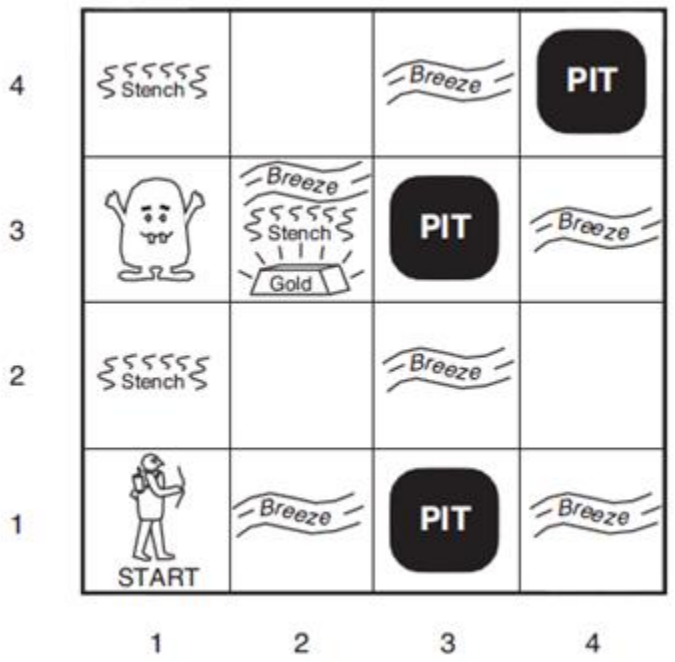
  Example:
  - An autonomous car aims to take a parcel from Guimarães to Braga and knows that it must use one of the roads that connect the two cities.
  - We can expect him to use one of the roads because he knows he'll reach his goal!
- **Declarative approach** to building the system: **TELL** the agent what it needs to know

- **Implementation**: data structures within the KB and algorithms
  - Procedural approach: coding behaviour directly as program code

Source: Russell and Norvig, (2009) Artificial Intelligence - A Modern Approach.

The World of Wumpus

The player must collect the Gold and return to the starting point without entering any cells with a well or the Wumpus.



Source: Russell and Norvig, (2009) Artificial Intelligence - A Modern Approach.

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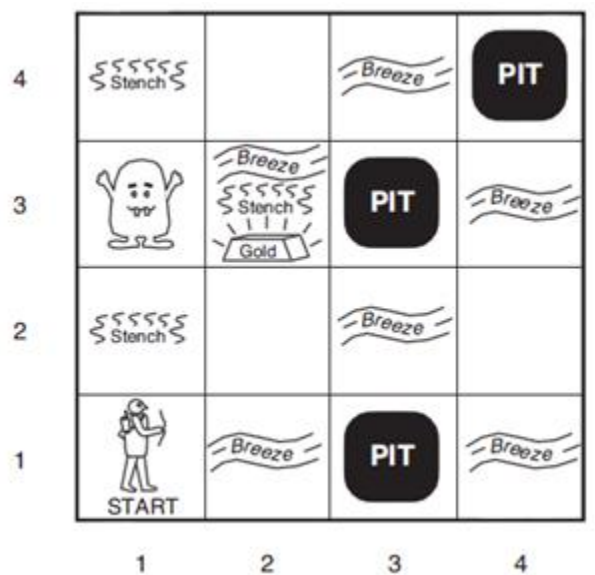
The World of Wumpus

- Perceptions (sensors): Smell, Breeze, Shine, Shock, Shout
- Actions: Turn Right, Turn Left, Forward, Grab, Drop, Shoot
- Objectives: Collect the Gold and return to the starting point without entering any cells with a well or Wumpus.
- Environment:
  - cells adjacent to the Wumpus have a **"bad" odour**
  - cells adjacent to the well have a **breeze** (wind)
  - cells with Gold **shine**
  - **Shooting** an arrow kills the Wumpus if we are facing him (i.e. in the same direction)
  - Only one arrow available
  - **Grab** takes Gold if it is in the same cell
  - **Drop** leaves Gold in the current cell



Source: Russell and Norvig, (2009) Artificial Intelligence - A Modern Approach.

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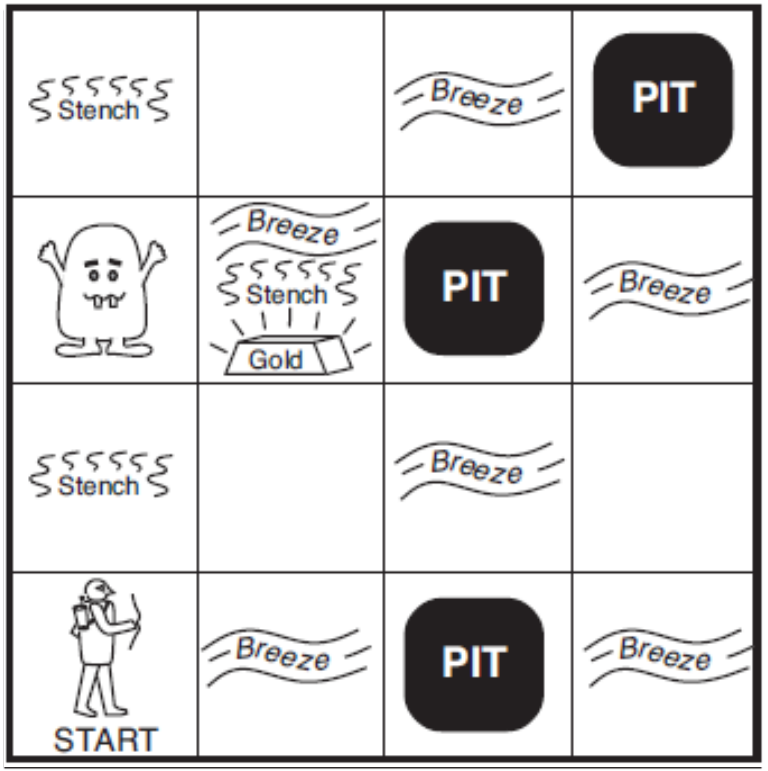
Characterisation of the World of Wumpus

- Deterministic?
  - Yes! Result is specified exactly!
- Accessible? Partially observable
  - No! There's only local perception!
- Static?
  - Yes! Wumpus, Wells and Gold don't move!
- Discreet?
  - Of course!

Reasoning and Action in Wumpus World

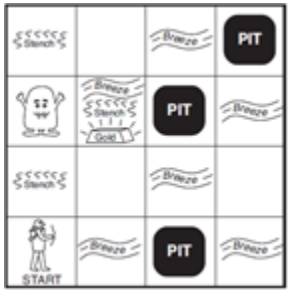


A = *Agent*
B = *Breeze*
G = *Glitter, Gold*
OK = *Safe square*
P = *Pit*
S = *Stench*
V = *Visited*
W = *Wumpus*

Source: Russell and Norvig, (2009) Artificial Intelligence - A Modern Approach.

Reasoning and Action in Wumpus World

1,4	2,4	3,4	4,4
1,3	2,3	3,3	4,3
1,2 OK	2,2	3,2	4,2
1,1 A OK	2,1 OK	3,1	4,1



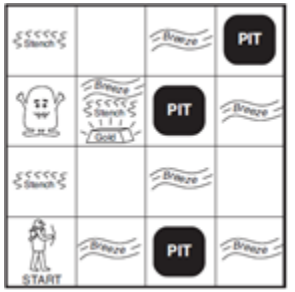
A = Agent
B = Breeze
G = Glitter, Gold
OK = Safe square
P = Pit
S = Stench
V = Visited
W = Wumpus

In (1,1) you don't feel anything, so (1,2) and (2,1) are safe

Source: Russell and Norvig, (2009) Artificial Intelligence - A Modern Approach.

Reasoning and Action in Wumpus World

1,4	2,4	3,4	4,4
1,3	2,3	3,3	4,3
1,2 OK	2,2 P?	3,2	4,2
1,1 V OK	2,1 A B OK	3,1 P?	4,1



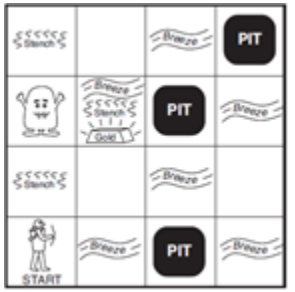
A = Agent
B = Breeze
G = Glitter, Gold
OK = Safe square
P = Pit
S = Stench
V = Visited
W = Wumpus

Move to (2,1) and feel the wind (B - Breeze)
Wind at (2,1) means well at (3,1) or (2,2)
He returns to the only safe point not yet explored (1,2) and smells it.

Source: Russell and Norvig, (2009) Artificial Intelligence - A Modern Approach.

Reasoning and Action in Wumpus World

1,4	2,4	3,4	4,4
1,3 W!	2,3	3,3	4,3
1,2 A S OK	2,2 OK	3,2	4,2
1,1 V OK	2,1 B V OK	3,1 P!	4,1



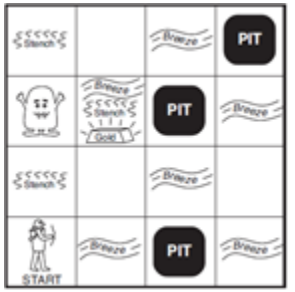
A = Agent
B = Breeze
G = Glitter, Gold
OK = Safe square
P = Pit
S = Stench
V = Visited
W = Wumpus

(1,1) was safe and (2,1) had no smell so Wumpus is in (1,3)
At (1,2) there is no wind, so the well is at (3,1) and there is no well at (2,2).

Source: Russell and Norvig, (2009) Artificial Intelligence - A Modern Approach.

Reasoning and Action in Wumpus World

1,4	2,4 P?	3,4	4,4
1,3 W!	2,3 A S G B	3,3 P?	4,3
1,2 S V OK	2,2 V OK	3,2	4,2
1,1 V OK	2,1 B V OK	3,1 P!	4,1

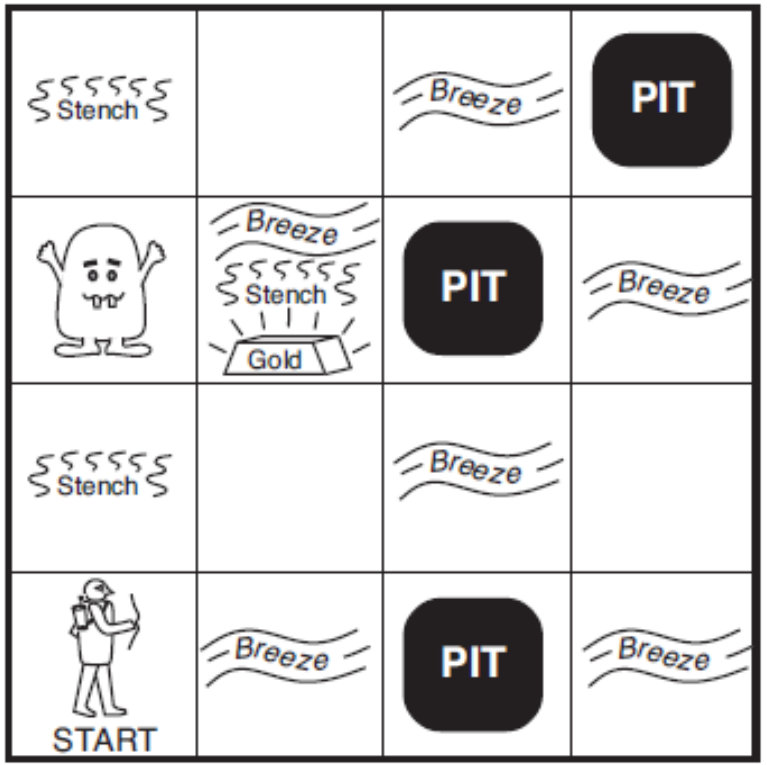


A = Agent
B = Breeze
G = Glitter, Gold
OK = Safe square
P = Pit
S = Stench
V = Visited
W = Wumpus

Move to the only safe point not explored (2,2)
As in (2,2) you don't feel anything (2,3) and (3,2) are safe
Move to (2,3) and feel the wind, smell and shine - you've discovered GOLD!

All actions were taken in full awareness of their consequences.

Reasoning and Action in Wumpus World



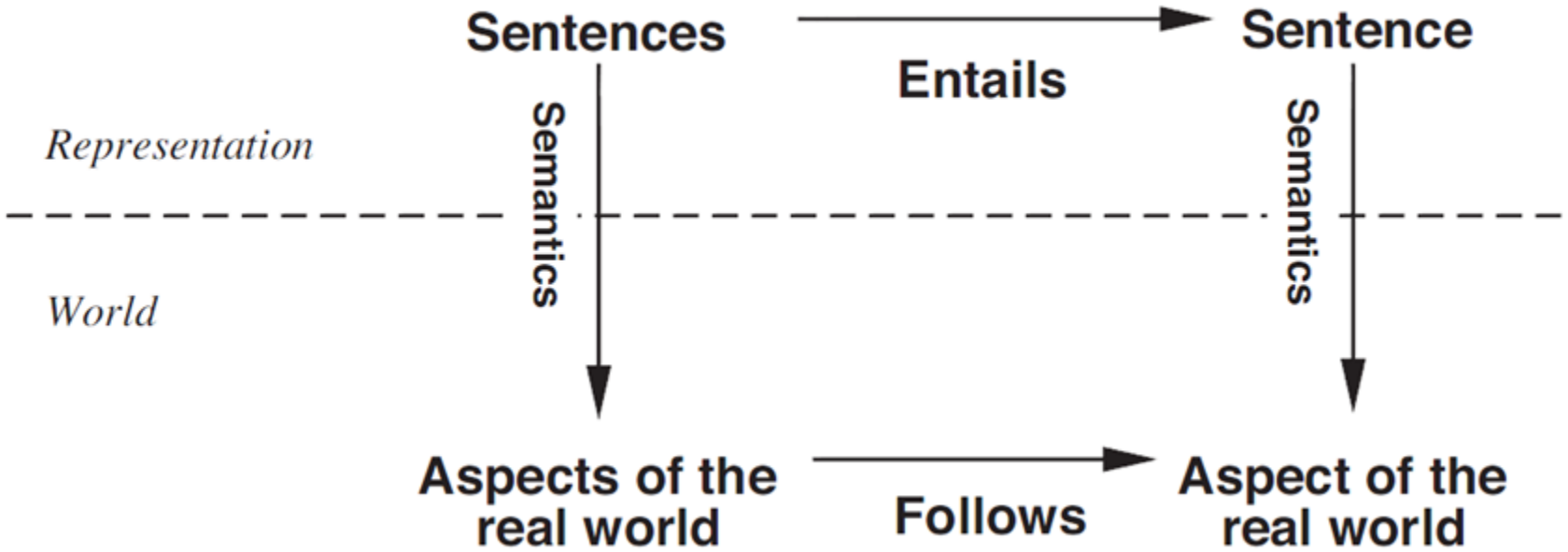
It should be noted that at each step the agent draws a conclusion from the information available, and this conclusion is guaranteed to be correct if the information available is correct.
This is a fundamental property of logical reasoning.

Source: Russell and Norvig, (2009) Artificial Intelligence - A Modern Approach.

Representation, Reasoning and Logic

- Knowledge representation seeks to represent knowledge in such a way that it can be manipulated by the computer
- Logics are formal languages for representing information in such a way that conclusions can be drawn
- Syntax defines the possible sentences of a language
- Semantics defines the facts of the world to which sentences refer (sentence meaning)
- For example, in arithmetic language:
  - x+2 >y is a sentence; x2+y> is not!
  - x+2>y is true if the number x+2 is greater than the number y
  - x+2>y is true in a world where x=5, y=3
  - x+2>y is false in a world where x=0, y=3

Representation



Source: Russell and Norvig, (2009) Artificial Intelligence - A Modern Approach.

Knowledge representation

Knowledge representation seeks to answer questions such as:

- How to represent knowledge?
- What is the nature of knowledge and how do we represent it?
- Do we all represent this knowledge in the same way?
- Should a representation scheme deal with a specific domain or should it be of general use?
- How expressive is a representation scheme?
- Should the scheme be declarative or procedural?
- How should so-called "intelligent" programmes represent and use this knowledge?
- Will we be able to represent all kinds of knowledge?

Desirable characteristics, among others:

- Explicitly define objects and their relationships;
- Display limitations and restrictions (express how an object or relationship affects them).
- Transparent;
- Fast;
- Computable.

Properties

- Adequate representation
  - ability to represent the necessary knowledge;
- Adequacy of inference
  - the ability to manipulate knowledge and "produce" new knowledge;
- Inference efficiency
  - ability to direct inference in productive directions;
  - ability to respond with limited resources;
- Efficiency in acquiring new knowledge
  - ability to "acquire" new knowledge;
  - Automatically (if possible).

Recommended Bibliography

- Stuart Russell and Peter Norvig, Artificial Intelligence - A Modern Approach, 4rd edition, ISBN: 978-0134610993, 2020, Chapter 7.

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