Agents that Reason Logically

Presentation Outline

1 A Knowledge-Based Agent

2 Representation, Reasoning, and Logic

3 Propositional Logic

4 Wumpus World Example

Knowledge-**B**ased Agents

- Hold information about the world in a Knowledge Base (**KB**)
- **KB** is built up of sentences.
- **KB** contains background knowledge

Knowledge-Based Agents (2)

Three levels we can describe them at:

- **Knowledge Level:** What the agent actually knows.
- **Logical Level:** A list of the sentences in the KB.
- **Implementation Level:** The actual way the information is held in a data structure.

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Representation, Reasoning and Logic

- Syntax: Describes the symbols in a language and how they can be used together.
- Semantics: Gives meaning to the syntax. Defines how the symbols in the syntax relate to in the real world.

Representation, Reasoning, and Logic

- Entailment:

  If x entails y, then if x is true y is true.
- Proof Theory: The way in which the entailments work for a set of sentences.

Inference

- Valid: A sentence that’s true in all situations.
- Satisfiability: A sentence that is true in at least one situation.
- Unsatisfiability: A sentence that isn’t satisfiable.

Inference in Computers

- Computer programs can use valid or unsatisfiable sentences to create new sentences.
- This is the basis of learning in **logically reasoning agents**.

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Propositional Logic (we covered)

- Syntax
- Sematics
- Validity & Inference
- Rules of Inference
- Complexity of propositional Inference

Semantics

- In BNF

A BNF Grammar of Sentences in Propositional Logic

```
S := <Sentence> ;
<Sentence> := <AtomicSentence> | <ComplexSentence> ;
<AtomicSentence> := "TRUE" | "FALSE" |
                    "P" | "Q" | "S" ;
<ComplexSentence> := "(" <Sentence> ")" |
          <Sentence> <Connective> <Sentence> |
          "NOT" <Sentence> ;
<Connective> := "NOT" | "AND" | "OR" | "IMPLIES" |
  "EQUIVALENT" ;
```

Validity

- A sentence is valid if it is true in all the cases.
- The validity of a sentence can be tested in a truth table.

Inference

- A sentence (Q) is inferred by a set of sentences {p1, p2, ... } if whenever Q is true, then {p1, p2, …} are all true.

Rules of Inference

- Modus Ponens

  if $\alpha \Rightarrow \beta$, α

  then β
- And-Elimination

  if $\alpha 1 \wedge \alpha 2 \wedge \ldots \wedge \alpha n$

  then αi

Rules of Inference

- And-Introduction

  if $\alpha 1, \alpha 2, \alpha 3, \ldots, \alpha n$

  then $\alpha 1 \wedge \alpha 2 \wedge \alpha 3 \wedge \ldots \wedge \alpha n$

- Or-Introduction

  if αi

  then $\alpha 1 \vee \alpha 2 \vee \alpha 3 \vee \ldots \vee \alpha n$

Rules of Inference

- Double Negation Elimination

  if $\neg \neg \alpha$

  then α

- Unit Resolution

  if $\alpha \vee \beta$, $\neg\beta$

  then α

Rules of Inference

- Resolution

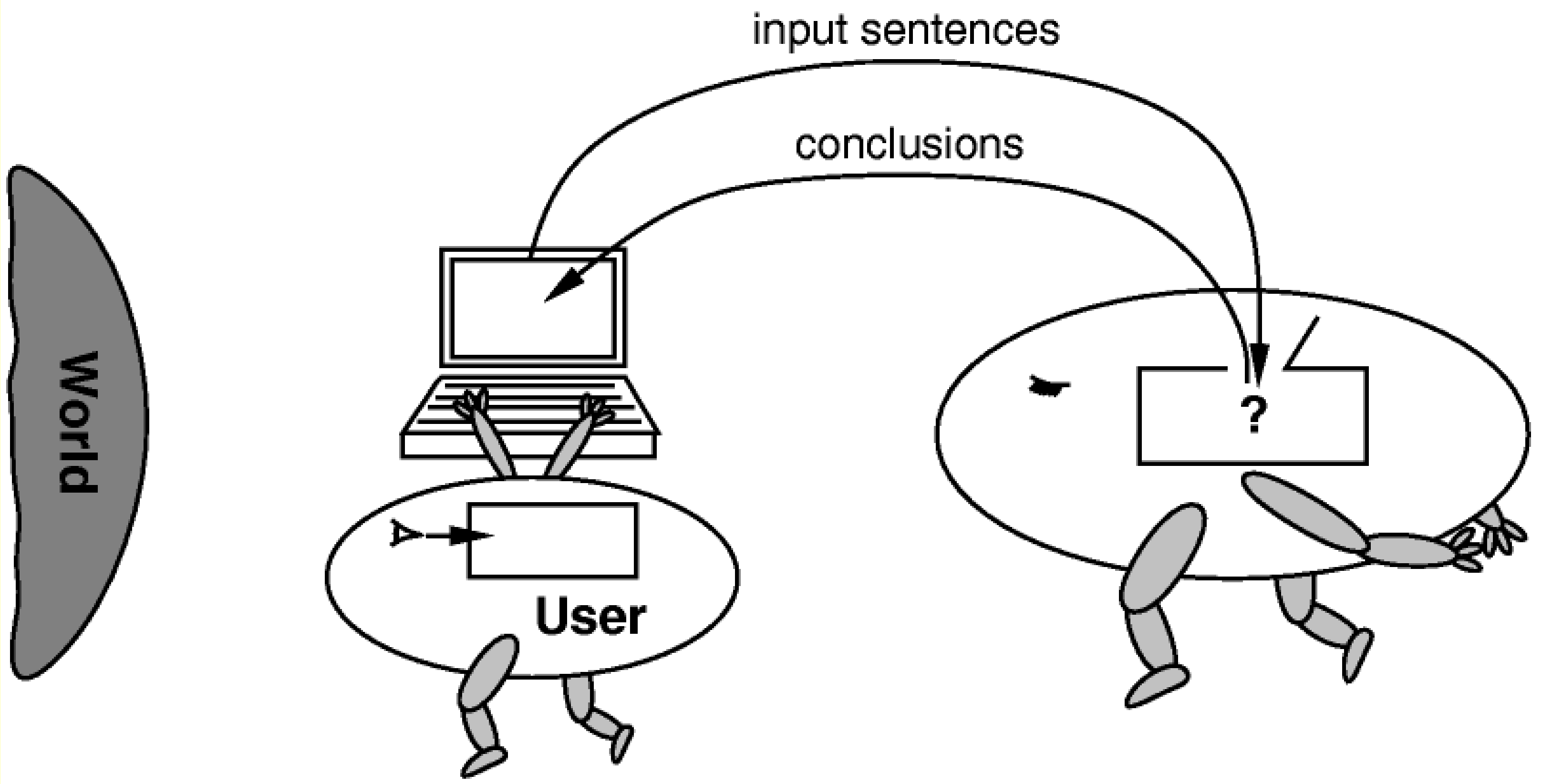
  if $\alpha \vee \beta$, $\neg\beta \vee \gamma$

  then $\alpha \vee \gamma$

Complexity of Propositional inference

- It was mentioned by Cook in 1971 that the complexity of propositional inference is **NP-complete.**
  - More precisely, it's 2^n.
- Basically, we have to try all the combinations of the truth values of symbols in a sentence.

Inference



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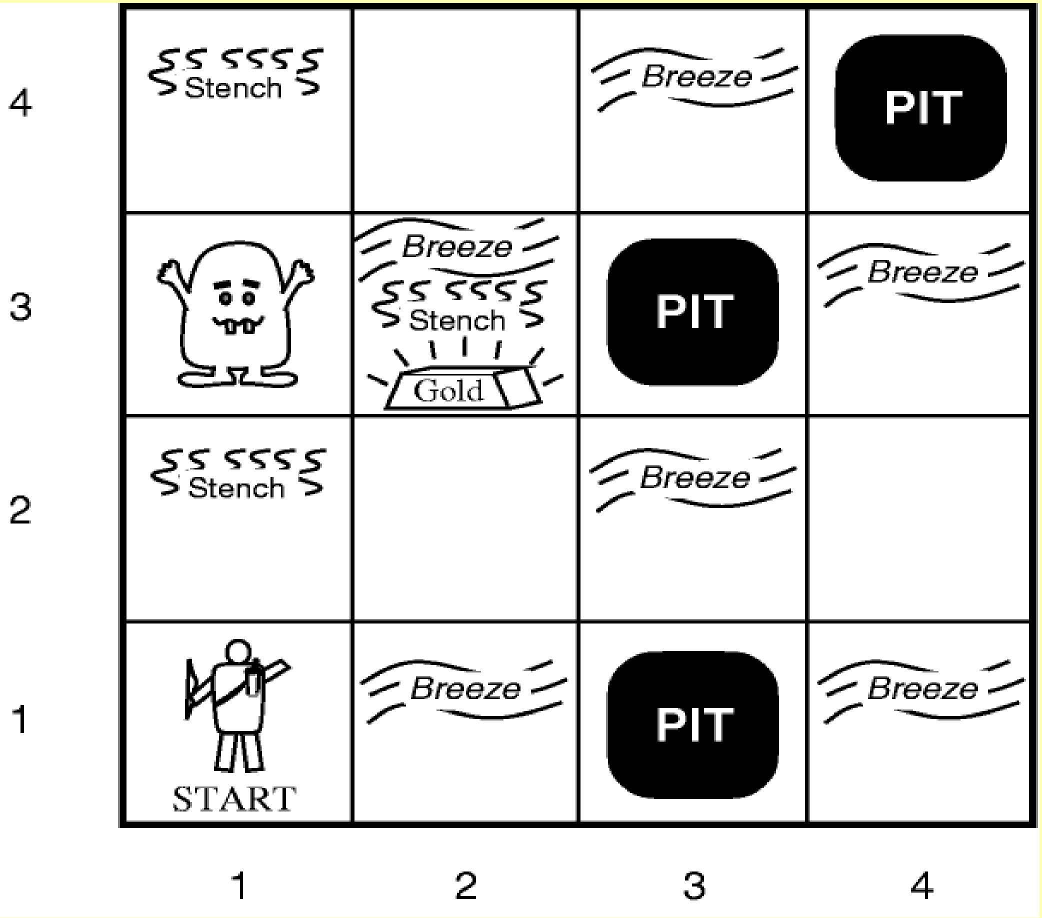
Wumpus World Example

- The Wumpus World Environment
- Simple Logic
- The agent acting in the wumpus world

Wumpus World



Wumpus World

- In the squares directly adjacent to the Wumpus, the agent will perceive a stench.
- In the square directly adjacent to a pit, the agent will perceive a breeze.
- In the square where the gold is, the agent will perceive a glitter.
- The agent dies a miserable death if it enters a square containing a pit or a live wumpus.
- The agent can kill the wumpus if it shoots the only arrow into the square it is facing when the Wumpus is in that square.

Wumpus World

- If the agent enters a square which has no pit or wumpus but has a wumpus next to it, a pit next to it and the gold in it, it will receive the percept[None, Stench, Breeze, Glitter].
- The agent's goal is to find the gold and bring it back.
- The agent uses logic, the percepts it receives and it's current KB to learn about the world around it.
- The agent adds to it's KB this new information it learns and can now use it.

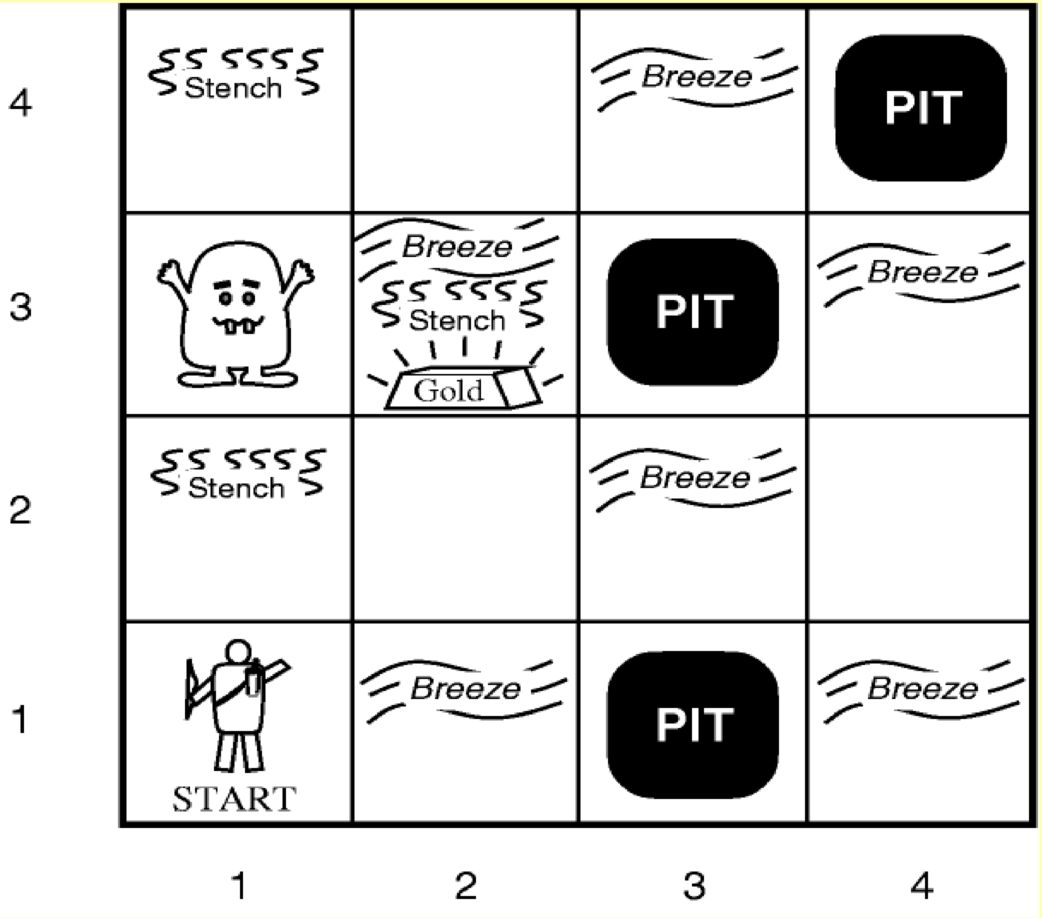
Simple logic

- If the agent senses a stench, then it knows the WUMPUS must be in the front or left or right square.
- If the agent feels a breeze, then it knows the PIT must be in the front or left or right square.
- If the agent perceives a glitter, then it is in the square with the gold.
- If the agent receives none, all directly adjacent squares are safe.

Logic in Wumpus World

- The agent has sentences in it's KB that correspond to the basic inferences it should be able to make.
- For example in the KB it will have a sentence that if an agent in 1,1 senses a stench then 1,2 or 2,1 has a wumpus in it.
- If in 1,1 the agent sense nothing then it will know that 1,2 2,1 and 1,1 all have neither a wumpus nor a pit in them.

Wumpus World



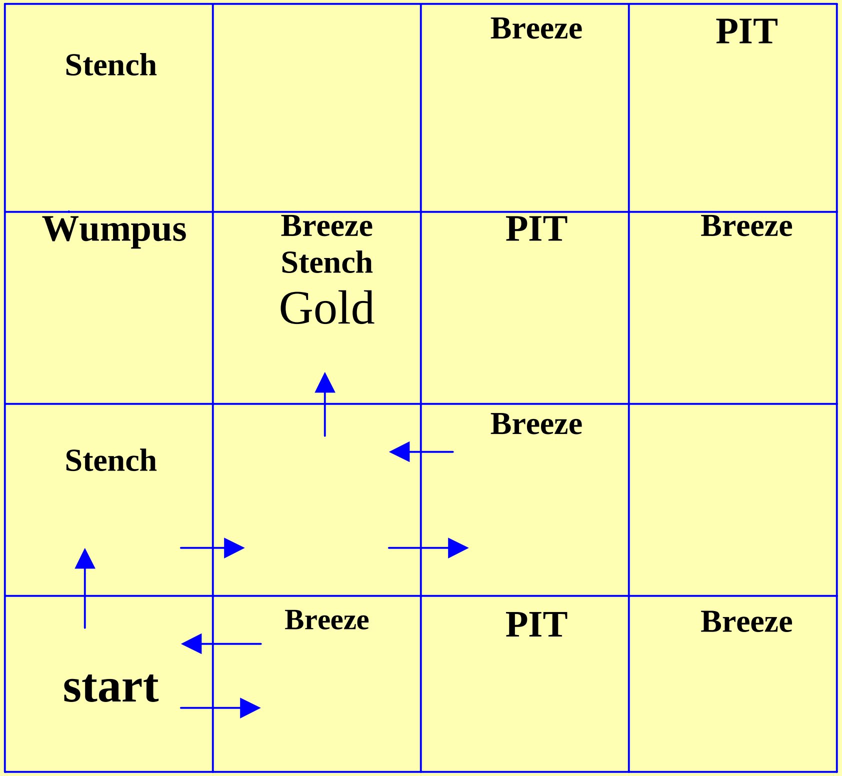
Logic Example in Wumpus World

- Our agent starts in 1,1 and feels no stench. By the rule Modus Ponens and the built in knowledge in it’s KB, it can conclude that 1,2 and 2,1 do not have a wumpus.
- Now by the rule And-Elimination we can see that 1,2 doesn’t contain a wumpus and neither does 2,1.
- If our agent now moves to 2,1 it receives a percept telling it there is a breeze but no percept of a stench. Using Modus Ponens and And-Elimination we can conclude that 2,2 does not contain a wumpus, 1,1 does not contain a wumpus and 3,1 does not contain a wumpus.
- If our agent now backtracks because it’s unsure of where a pit may be and moves to square 1,2. It senses a stench. By Modus Ponens this means that 1,1 1,3 or 2,2 contain a wumpus.

Logic Example in Wumpus World

- Now we can use the unit resolution with the last sentence telling us that a wumpus is in 1,1 1,3 or 2,2. We use the resolution with the sentence telling us that 2,2 does not contain a wumpus and we get 1,1 or 1,3 contain a wumpus
- We repeat the unit resolution rule with the new sentence 1,1 or 1,3 contain a wumpus and the sentence telling us that 1,1 does not contain a wumpus. What we get is that 1,3 contains a wumpus.
- The agent can now use the built in logic it would have that if it knows where the wumpus is to fire it's arrow at that square and kill it.

The Knowledge-Based Agent Acting in Wumpus world



Logic Example in Wumpus World

4	Stench		Breeze	PIT
3	Wumpus	Breeze Stench Gold	PIT	Breeze
2	Stench		Breeze	
1	Start	Breeze	PIT	Breeze
	1	2	3	4

S_{11} = None $\Rightarrow S_{12}$ = Safe $\wedge S_{21}$ = Safe

S_{12} = Breeze $\Rightarrow S_{13}$ = Pit $\vee S_{22}$ = Pit

S_{21} = Stench $\Rightarrow S_{31}$ = Wumpus $\vee S_{22}$ = Wumpus

S_{12} = Breeze $\wedge S_{21}$ = Stench $\Rightarrow S_{22}$ = Safe

S_{22} = None $\Rightarrow S_{23}$ = Safe $\wedge S_{32}$ = Safe

S_{23} = Breeze $\Rightarrow S_{13}$ = Pit $\vee S_{24}$ = Pit $\vee S_{33}$ = Pit

S_{32} = Glitter $\Rightarrow$ Find Gold.

S_{32} = Stench $\wedge S_{21}$ = Stench $\wedge S_{22}$ = $\neg$Wumpus

$\Rightarrow S_{31}$ = Wumpus (if only one Wumpus exists)

Summary

- Agents that reason logically have knowledge bases filled with information about the world around them in the form of sentences.
- Agents have both built in and acquired knowledge.
- Agents use the knowledge base to infer things.

Summary

- Logical languages have both syntax and semantics along with a proof theory.
- Propositional logic is very simple but not useful for real world applications.
- Can be implemented directly in hardware and thus very fast -
  - formal instinct

References and Sources

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