“Thinking Rationally”

- Computational models of human “thought” processes
- Computational models of human behavior
- Computational systems that “think” rationally
- Computational systems that behave rationally
Logical Agents

• “Reflex agents find their way from Arad to Bucharest by dumb luck”

• Chess program calculates legal moves of its king, but doesn’t know that no piece can be on 2 different squares at the same time

• Logic (Knowledge-Based) agents combine general knowledge with current percepts to infer hidden aspects of current state prior to selecting actions

    Crucial in partially observable environments

Outline

• Knowledge-based agents
• Wumpus world
• Logic in general
• Propositional logic
  Inference, validity, equivalence and satisfiability
  Reasoning
    • Resolution
    • Forward/backward chaining
Knowledge Base

Knowledge Base: set of sentences represented in a knowledge representation language; stores assertions about the world.

Inference rule: when one ASKs questions of the KB, the answer should follow from what has been TELLed to the KB previously.

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Generic KB-Based Agent

```plaintext
function KB-AGENT( percept) returns an action
static: 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
```
Abilities of a KB agent

- Agent must be able to:
  - Represent states and actions
  - Incorporate new percepts
  - Update internal representation of the world
  - Deduce hidden properties of the world
  - Deduce appropriate actions

Description level

- The KB agent is similar to agents with internal state
- Agents can be described at different levels
  - Knowledge level
    - What they know, regardless of the actual implementation (Declarative description)
  - Implementation level
    - Data structures in KB and algorithms that manipulate them, e.g., propositional logic and resolution
A Typical Wumpus World

Wumpus World PEAS Description

Performance measure
- gold +1000, death -1000
- -1 per step, -10 for using the arrow

Environment
- Squares adjacent to wumpus are smelly
- Squares adjacent to pit are breezy
- Glitter iff gold is in the same square
- Shooting kills wumpus if you are facing it
- Shooting uses up the only arrow
- Grabbing picks up gold if in same square
- Releasing drops the gold in same square

Sensors: Breeze, Glitter, Smell

Actuators: Left turn, Right turn,
            Forward, Grab, Release, Shoot
Wumpus World Characterization

- Observable? No, only local perception
- Deterministic?
- Episodic?
- Static?
- Discrete?
- Single-agent?
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Wumpus World Characterization

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- Static? Yes, Wumpus and pits do not move
- Discrete? Yes
- Single-agent? Yes, Wumpus is essentially a “natural” feature

Exploring the Wumpus World

1.4 2.4 3.4 4.4
1.3 2.3 3.3 4.3
1.2 2.2 3.2 4.2

(a) [1,1] KB initially contains the rules of the environment. First percept is [none, none, none, none, none], move to safe cell e.g. 2,1

[b] Breeze which indicates that there is a pit in [2,2] or [3,1], return to [1,1] to try next safe cell
Exploring the Wumpus World

[1,2] Stench in cell which means that wumpus is in [1,3] or [2,2] but not in [1,1]
YET ... not in [2,2] or stench would have been detected in [2,1]
THUS ... wumpus is in [1,3]
THUS [2,2] is safe because of lack of breeze in [1,2]
move to next safe cell [2,2]

[2,2] Move to [2,3]
[2,3] Detect glitter, smell, breeze
Pick up gold
THUS pit in [3,3] or [2,4]
What is a logic?

- **A formal language**
  - Syntax – what expressions are legal (well-formed)
  - Semantics – what legal expressions mean
    - In logic the truth of each sentence evaluated with respect to each possible world
- **E.g the language of arithmetic**
  - $x+2 \geq y$ is a sentence, $x^2+y$ is not a sentence
  - $x+2 \geq y$ is true in a world where $x=7$ and $y=1$
  - $x+2 \geq y$ is false in a world where $x=0$ and $y=6$

Entailment

- **One thing follows from another**
  - $KB \models \alpha$
- **KB entails sentence $\alpha$ if and only if $\alpha$ is true in all worlds where KB is true.**
  - E.g. $x+y=4$ entails $4=x+y$
- **Entailment is a relationship between sentences that is based on semantics.**
Models

- Logicians typically think in terms of models, which are formally structured worlds with respect to which truth can be evaluated.
- \( m \) is a model of a sentence \( \alpha \) if \( \alpha \) is true in \( m \).
- \( M(\alpha) \) is the set of all models of \( \alpha \).
- Then \( KB \models \alpha \iff M(KB) \subseteq M(\alpha) \).

E.g. \( KB = \) CSE 473 students are bored and CSE 473 students are sleepy;
\( \alpha = \) CSE 473 students are bored.

Wumpus world model

Situation after detecting nothing in [1,1], moving right, breeze in [2,1]

Consider possible models for ?s assuming only pits.

3 Boolean choices \( \Rightarrow \) 8 possible models.
Wumpus world model

$KB = \text{wumpus-world rules + observations}$
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\[ \alpha_1 = \text{"[1,2] is safe"}, \ KB \models \alpha_1, \text{proved by model checking} \]

\[ KB = \text{wumpus-world rules + observations} \]
Wumpus world model

$KB = \text{wumpus-world rules} \cup \text{observations}$

$\alpha_2 = \text{"[2,2] is safe"}, \ KB \not\models \alpha_2$

Next Time

• Propositional Logic
• Reasoning:
  Resolution
  Forward/backward Chaining