Knowledge-Based Agents

Chapter 7.1-7.3

Some material adopted from notes by Andreas Geyer-Schulz and Chuck Dyer
Big Idea

• Drawing reasonable conclusions from a set of data (observations, beliefs, etc.) seems key to intelligence

• Logic is a powerful and well developed approach and highly regarded by people

• Logic is also a strong formal system that computers can use (cf. John McCarthy)

• We can solve some AI problems by representing them in logic and applying standard proof techniques to generate solutions
Inference in People

• People can do logical inference, but are not always very good at it

• Reasoning with negation and disjunction seems particularly difficult

• But, people seem to employ many kinds of reasoning strategies, most of which are neither complete nor sound
Thinking Fast and Slow

- Popular 2011 book by Nobel prize winning cognitive psychologist
- His model is we have two types of reasoning facilities
  - **System 1** operates automatically and quickly, with little or no effort and no sense of voluntary control
  - **System 2** allocates attention to the effortful mental activities that demand it, including complex computations
Question #1

Here is a simple puzzle
Don’t try to solve it -- listen to your intuition
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Don’t try to solve it -- listen to your intuition

• A bat and ball cost $1.10
• The bat costs one dollar more than the ball
• How much does the ball cost?
Question #1

Here is a simple puzzle
Don’t try to solve it -- listen to your intuition

• A bat and ball cost $1.10
• The bat costs one dollar more than the ball
• How much does the ball cost?

The ball costs $0.05
Question #2

Determine, as quickly as you can, if the argument is logically valid, i.e. does the conclusion follow the premises?
Question #2

Try to determine, as quickly as you can, if the argument is logically valid. Does the conclusion follow the premises?

- All roses are flowers
- Some flowers fade quickly
  - Therefore some roses fade quickly
Question #2

Try to determine, as quickly as you can, if the argument is logically valid. Does the conclusion follow the premises?

• All roses are flowers
• Some flowers fade quickly
• Therefore some roses fade quickly

It is possible that there are no roses among the flowers that fade quickly
Question #3

It takes 5 machines 5 minutes to make 5 widgets.
How long would it take 100 machines to make 100 widgets?
Question #3

It takes 5 machines 5 minutes to make 5 widgets
How long would it take 100 machines to make 100 widgets?

• 100 minutes or 5 minutes?
Question #3

It takes 5 machines 5 minutes to make 5 widgets
How long would it take 100 machines to make 100 widgets?

• 100 minutes or 5 minutes?

5 minutes
Wason Selection Task

• I have a pack of cards; each has a letter on one side and a number on the other
• I claim the following rule is true:
  
  *If a card has a vowel on one side, then it has an even number on the other*

• Given these cards, which should you turn over to decide whether the rule is true or false?

    E  4  T  7
Wason Selection Task

• Wason (1966) showed people are bad at this task
• To disprove rule $P \Rightarrow Q$, find a situation in which $P$ is true but $Q$ is false, i.e., show $P \land \neg Q$
• To disprove vowel => even, find a card with a vowel and an odd number
• Thus, turn over the cards showing vowels and turn over cards showing odd numbers
Wason Selection Task

• This version is easier for people, as shown by Griggs & Cox, 1982

• You are the bouncer in a bar; which of these people do you card given the rule: You must be 21 or older to drink beer.

beer  coke  22  20

Perhaps easier because it’s more familiar or because people have special strategies to reason about certain situations, such as cheating in a social situation
Negation in Natural Language

• We often model the meaning of natural language sentences as a logic statements
• Logic maps these into equivalent statements
  – All elephants are gray
  – No elephant are not gray
• Double negation is common in informal language: *that won’t do you no good*
• But what does this mean: *we cannot underestimate the importance of logic*
Misnegation

we cannot underestimate the importance of logic

Does it mean:

• Logic is very important
• Logic is not very important

Language Log has many posts with examples of the phenomenon
Logic as a Methodology

Even if people don’t use formal logical reasoning for solving a problem, logic might be a good approach for AI for a number of reasons

– Airplanes don’t need to flap their wings
– Logic may be a good implementation strategy
– Solution by a formal system can offer other benefits, e.g., letting us prove properties of the approach (e.g., complexity)

• See neats vs. scruffies
Knowledge-based agents

• Knowledge-based agents have a knowledge base (KB) and an inference system
• KB: a set of representations of facts believed true
• Each individual representation is called a sentence
• Sentences are expressed in a knowledge representation language
• The agent operates as follows:
  1. It TELLS the KB facts it perceives
  2. It ASKS the KB what action it should perform
  3. It performs the chosen action
Wumpus World environment

• Cf. 1972 Hunt the Wumpus computer game
• Agent explores cave of rooms connected by passageways
• Lurking in a room is the Wumpus, a beast that eats any agent that enters its room
• Some rooms have bottomless pits that trap any agent that wanders into the room
• Somewhere is a heap of gold in a room
• Goal: collect gold & exit w/o being eaten
AIMA’s Wumpus World

The agent always starts in [1,1]

Agent’s task: find the gold, return to [1,1], and exit cave
Agent in a Wumpus world: Percepts

• The agent perceives
  – **stench** in square containing Wumpus and adjacent squares (not diagonally)
  – **breeze** in squares adjacent to a pit
  – **glitter** in the square where the gold is
  – **bump**, if it walks into a wall
  – Woeful **scream** everywhere if Wumpus killed

• Percepts given as five-tuple, e.g., if stench and breeze, but no glitter, bump or scream:
  
  \[(\text{Stench, Breeze, None, None, None})\]

• Agent cannot perceive its location, e.g., (2,2)
Wumpus World Actions

• go forward
• turn right 90 degrees
• turn left 90 degrees
• grab: Pick up object in same square as agent
• shoot: Fire arrow in direction agent faces. It continues until it hits & kills Wumpus or hits outer wall. Agent has one arrow, so only first shoot action has effect
• Climb: leave cave, only effective in start square
• die: automatically and irretrievably happens if agent enters square with pit or living Wumpus
Wumpus World Goal

Agent’s goal: find the gold and bring it back to the start square as quickly as possible, without getting killed

Reward function:

• +1,000 points for exiting cave with gold
• -1 point for every action taken
• -10,000 points for getting killed
Wumpus world characterization

Recall environment characteristics from ch. 2

- Fully Observable?
- Deterministic?
- Episodic?
- Static?
- Discrete?
- Single-agent?
Wumpus world characterization

- **Fully Observable** No, only *local* perception
- **Deterministic** Yes, outcomes exactly specified
- **Episodic** No, sequential at level of actions
- **Static** Yes, Wumpus and Pits do not move
- **Discrete** Yes
- **Single-agent?** Yes, Wumpus essentially a natural feature
AIMA’s Wumpus World

The agent always starts in [1,1]

Agent’s task: find gold, return [1,1], and climb out of the cave
The Hunter’s first step

<table>
<thead>
<tr>
<th></th>
<th>1,4</th>
<th>2,4</th>
<th>3,4</th>
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</tbody>
</table>

(a)

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

Since the agent is alive and perceives neither breeze nor stench at [1,1], it knows [1,1] and its neighbors are OK.

Moving to [2,1] is a **safe move** that reveals a breeze but no stench, implying that Wumpus isn’t adjacent but one or more pits are
Exploring a wumpus world

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
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<th>G</th>
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Legend:
- A: agent
- B: breeze
- G: glitter
- OK: safe cell
- P: pit
- S: stench
- W: wumpus
Exploring a wumpus world
Exploring a wumpus world
Exploring a wumpus world

A  agent
B  breeze
G  glitter
OK safe cell
P  pit
S  stench
W  wumpus
Exploring a wumpus world

A  agent
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G  glitter
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Exploring a wumpus world

A agent
B breeze
G glitter
OK safe cell
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Exploring a wumpus world

A  agent
B  breeze
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Exploring a wumpus world

A agent  
B breeze  
G glitter 
OK safe cell  
P pit  
S stench  
W wumpus
Logic in general

- **Logics** are formal languages for representing information so that conclusions can be drawn.
- **Syntax** defines the sentences in the language.
- **Semantics** define the "meaning" of sentences — i.e., define **truth** of a sentence in a 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 iff the number $x+2$ is no less than the number $y$.
- $x+2 \geq y$ is true in a world where $x = 7$, $y = 1$.
- $x+2 \geq y$ is false in a world where $x = 0$, $y = 6$.
- $x+1 > x$ is true for all numbers $x$. 
Entailment

• **Entailment:** one thing follows from another

• $\text{KB} \models \alpha$

• Knowledge base $KB$ entails sentence $\alpha$ iff $\alpha$ is true in *all possible worlds* where $KB$ is true
  – E.g., the KB containing “UMBC won” and “JHU won” entails “Either UMBC won or JHU won”
  – E.g., $x+y = 4$ entails $4 = x+y$
  – Entailment is a relationship between (sets of) sentences (i.e., *syntax*) that is based on *semantics*
Models

- Logicians talk of **models**: formally structured worlds w.r.t which truth can be evaluated.

- *m* is a model of sentence *α* if *α* is true in *m*.
  
  Lots of other things might or might not be true or might be unknown in *m*.

- *M(α)* is the set of all models of *α*.

- Then *KB ⊨ α* iff *M(KB) ⊆ M(α)*.
  
  - *KB* = UMBC and JHU won
  
  - *α* = UMBC won
  
  - Then *KB ⊨ α*.
Entailment in the Wumpus World

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

• Possible models for KB assuming only pits and restricting cells to {(1,3)(2,1)(2,2)}

• Two observations: ~B11, B12

• Three propositional variables: P13, P21, P22

⇒ 8 possible models
## Wumpus models

<table>
<thead>
<tr>
<th>P13</th>
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Each row is a possible world
Wumpus World Rules (1)

• If a cell has a pit, then a breeze is observable in every adjacent cell

• In propositional calculus we can not have rules with variables (e.g., forall X...)

\[ P_{11} \rightarrow B_{21} \]
\[ P_{11} \rightarrow B_{12} \]
\[ P_{21} \rightarrow B_{11} \]
\[ P_{21} \rightarrow B_{22} \ldots \]

If a pit in (1,1) then a breeze in (2,1), ...

These also follow:

\[ \sim B_{21} \rightarrow \sim P_{11} \]
\[ \sim B_{12} \rightarrow \sim P_{11} \]
\[ \sim B_{11} \rightarrow \sim P_{21} \]
\[ \sim B_{22} \rightarrow \sim P_{21} \]

...
Only three of the possible models are consistent with what we know.

\[ KB = \text{wumpus-world rules + observations} \]
Wumpus World Rules (2)

• Cell safe if it has neither a pit nor wumpus

  OK11 => ~P11 ∧ ~W11
  OK12 => ~P12 ∧ ~W12 ...

• From which we can derive

  P11 ∨ W11 => ~OK11
  P11 => ~OK11
  W11 => ~OK11 ...

OK11: (1,1) is safe
W11: Wumpus in (1,1)
Wumpus models

- $KB = \text{wumpus-world rules} + \text{observations}$
Wumpus models

- $KB = \text{wumpus-world rules + observations}$
- $\alpha_1 = \text{"[1,2] is safe"}$
- Since all models include $\alpha_1$
- $KB \models \alpha_1$, proved by model checking
Is (2,2) Safe?

- $KB = \text{wumpus-world rules} + \text{observations}$
- $\alpha_2 = "[2,2] \text{ is safe}"$
- Since some models don’t include $\alpha_2$, $KB \not\models \alpha_2$
- We cannot prove OK22; it might be true or false
Inference, Soundness, Completeness

- \( KB \models_i \alpha \) = sentence \( \alpha \) can be derived from \( KB \) by procedure \( i \)
- **Soundness**: \( i \) is sound if whenever \( KB \models_i \alpha \), it is also true that \( KB \models \alpha \)
- **Completeness**: \( i \) is complete if whenever \( KB \models \alpha \), it is also true that \( KB \models_i \alpha \)

- Preview: **first-order logic** is expressive enough to say almost anything of interest and has a **sound** and **complete** inference procedure
Soundness and completeness

• A *sound* inference method derives only entailed sentences
• Analogous to the property of *completeness* in search, a *complete* inference method can derive any sentence that is entailed
No independent access to the world

• Reasoning agents often get knowledge about facts of the world as a sequence of logical sentences and must draw conclusions only from them w/o independent access to world.

• Thus, it is very important that the agents’ reasoning is sound!
Summary

- Intelligent agents need knowledge about world for good decisions
- Agent’s knowledge stored in a knowledge base (KB) as sentences in a knowledge representation (KR) language
- Knowledge-based agents needs a KB & inference mechanism. They store sentences in KB, infer new sentences & use them to deduce which actions to take
- A representation language defined by its syntax & semantics, which specify structure of sentences & how they relate to facts of the world
- Interpretation of a sentence is fact to which it refers. If fact is part of the actual world, then the sentence is true