COMP219:
Artificial Intelligence

Lecture 14: Knowledge Representation

Overview

- Last time
  - Game playing
    - Minimax decisions
    - Alpha-beta pruning

- Today
  - Introduce the need for *explicit knowledge representation*
  - Describe means of knowledge representation
  - Consider *rules* as one particular means of knowledge representation

- Learning outcome covered today:

  Distinguish the characteristics, and advantages and disadvantages, of the major knowledge representation paradigms that have been used in AI, such as production rules, semantic networks, propositional logic and first-order logic;

Knowledge in AI

- Search is a “universal method” for problem solving
- ***But*** real problems require methods with more power, which comes from tailoring to the specific problem
  - Heuristic searches
  - Evaluation functions for game playing
  - Solution templates
- In order to solve the complex problems encountered in AI, one generally needs a large amount of knowledge, and suitable mechanisms for representing and manipulating all that knowledge

The Knowledge Principle

Ed Feigenbaum:

- "... power exhibited ... is primarily a consequence of the specialist knowledge employed by the agent and only very secondarily related to ... the power of the [computer]"

- "Our agents must be knowledge rich, even if they are methods poor"

The Role of Knowledge

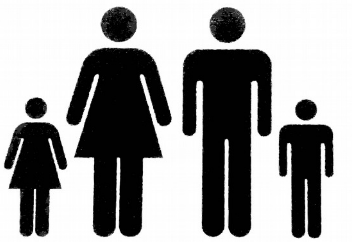
- Knowledge about a domain allows problem solving to be *focused* - it is not necessary to search exhaustively: useless branches need not be explored

- Explicit representations of knowledge allow a domain expert to understand the knowledge a system has, add to it, edit it, and so on
  - Knowledge engineering

- Comparatively *simple* algorithms can be used to *reason* with the knowledge and derive *new* knowledge

Wikipedia, Author: M93

What is Knowledge?



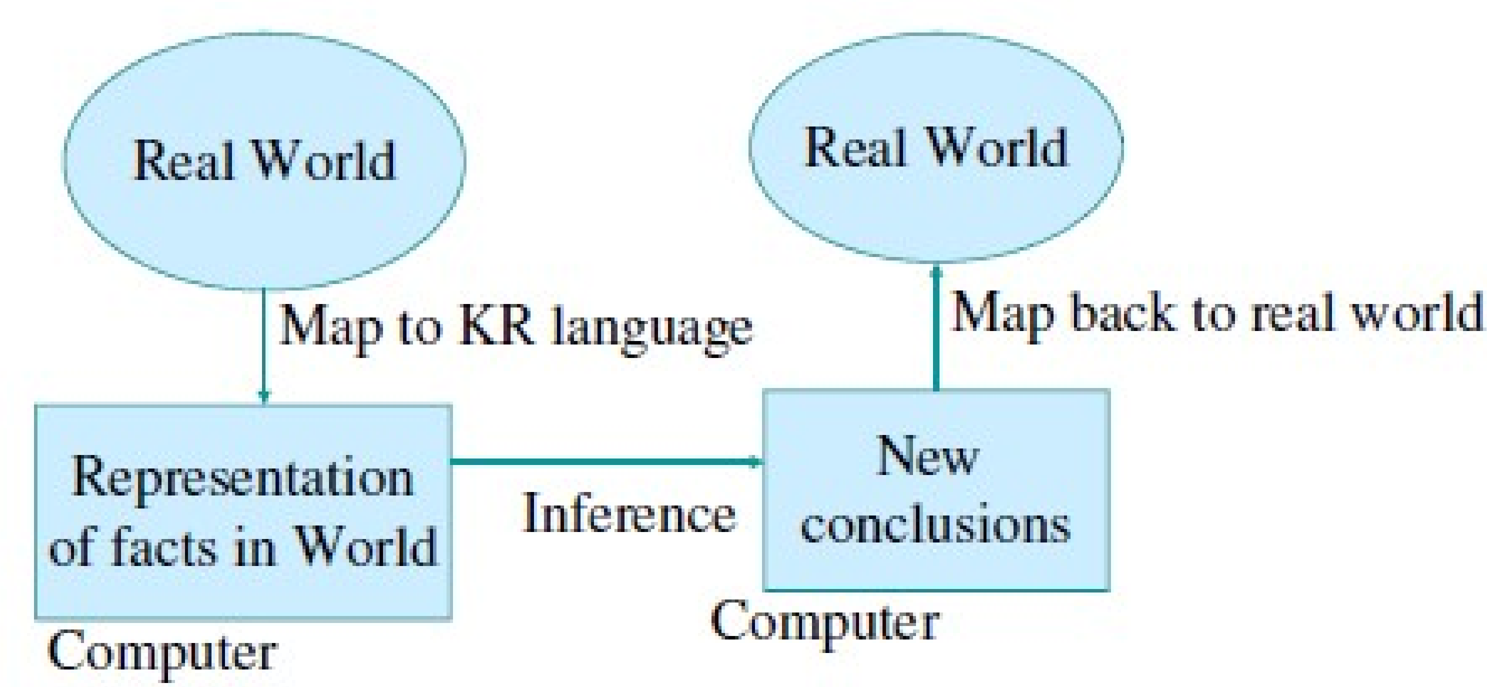
- Knowledge is information about some *domain* or subject area, or about *how to do* something

- Knowledge can take many forms. Some simple examples are:
  – Eve is a female, Adam is a male
  – Females with children are mothers
  – Mothers are females, fathers are males
  – *cf. Prolog facts and rules*

How to Represent Knowledge?

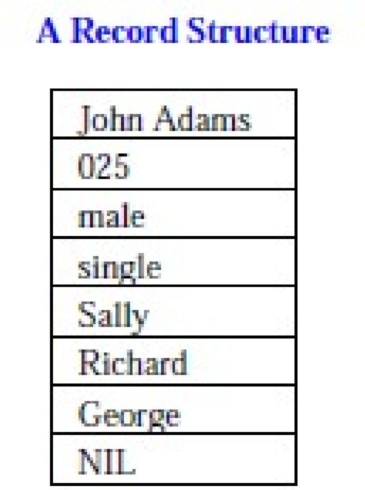
- Why don’t we use ***natural languages*** (e.g. English) to represent knowledge?
  - Natural language is certainly expressive enough!
  - But it is also too ambiguous for automated reasoning
  - No clear semantics
- Syntactic ambiguities
  - “Time flies like an arrow; Fruit flies like a banana”
- Semantic ambiguities
  - “bank” can be “river bank” or “financial bank”
- What about ‘computer’ languages?

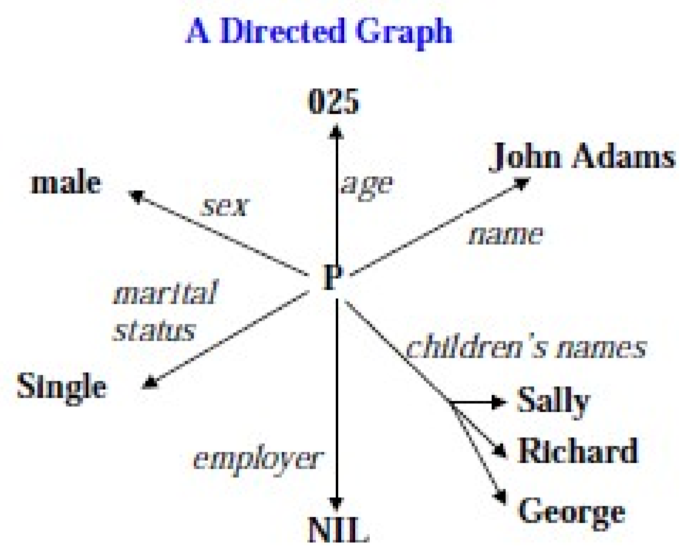
Computer Language



Databases

- Simple databases are commonly used to good effect in computer science
- They can be use to store and manipulate virtually any kind of information





- But storage and display are not enough - we also need to manipulate the knowledge

Databases as a KR

- ***Advantages***
  - Databases are well suited to efficiently representing and processing large amounts of data (and derivation from a database is virtually independent of its size)
  - We can build on traditional database systems to process more complex and more powerful representational devices (e.g. frames)

Databases as a KR

- ***Disadvantages***
  - Only simple aspects of the problem domain can be accommodated
  - We can represent entities, and relationships between entities, but not much more
    - Prolog *facts*
  - Reasoning is very simple. Basically, the only reasoning possible is simple lookup, and we usually need more sophisticated processing than that

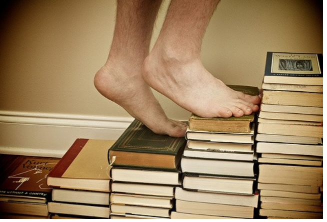
Knowledge Representation

- So, how can we represent knowledge in a form amenable to computer manipulation?

- Desirable features of a KR scheme
  - representational adequacy
  - inferential adequacy
  - inferential efficiency
  - well-defined syntax and semantics
  - naturalness

Representational Adequacy

- A KR scheme must be able to represent the knowledge appropriate to our problem
  - e.g. Chess: must represent type of piece, colour of piece, position
  - Cannot permit two pieces on same square
- Some KR schemes are better for particular sorts of knowledge than others
- *There is no one ideal KR scheme*



Inferential Adequacy

- A KR scheme must allow us to make new inferences from old knowledge
- It must make inferences that are
  - ***sound*** - the new knowledge really does follow from the old knowledge
  - ***complete*** - it should make all the right inferences
- Soundness is usually easy, completeness is often very hard

Exercise

- Is there a problem with the following inference?

Knowledge:

John is a man

All men are mortal

Inference:

Harry is mortal

Inferential Efficiency

- A KR scheme should be tractable - make inferences in reasonable (polynomial) time
- Unfortunately, any KR scheme with significant expressive power is not going to be efficient
- Often, the more general a KR scheme is, the *less efficient* it is
- Use KR schemes tailored to problem domain - less general, but more efficient
  - KR scheme with expressive power: first-order logic, is undecidable
  - Prolog uses Horn Clauses – a tractable subset of first order logic

Syntax and Semantics

- It should be possible to tell
  - whether any construction is "grammatically correct"
  - how to read any particular construction - no ***ambiguity***
- Thus a KR scheme should have a *well-defined syntax*

- It should be possible to precisely determine, for any given construction, exactly what its meaning is (the circumstances under which it is true)
- Thus a KR scheme should have *well-defined semantics*

- *Syntax is easy, semantics is hard!*

and	F	T
F	F	F
T	F	T

or	F	T
F	F	T
T	T	T

->	F	T
F	T	T
T	F	T

<->	F	T
F	T	F
T	F	T

not	
F	T
T	F

Example

- *Arithmetics*
- Syntax
  - The expression A + B > 3 is correct while A + B > is not
- Semantics
  - A + B > 3 evaluates to either “true” or “false” depending on the values of A and B
- *Java*

```
if(bePolite)
  System.out.println("Good morning");
else
  System.out.println("I am busy");
```

Naturalness

- Ideally, KR scheme should closely correspond to our way of thinking, reading, and writing
- Allow knowledge engineer to read and check knowledge base
- Again, the more general a KR scheme is, the less likely it is to be readable and understandable
  - People may have preferences: logic is natural to some; some people like diagrams or graphs while others do not

Basic Approaches

- Neither natural languages nor traditional computer formalisms are good enough for KR
- Some alternative basic approaches are
  - Rule-based systems (a.k.a. *production systems)*
    - Expert systems
  - Semantic networks
    - Graphical representation convenient for *knowledge engineers*
    - Later developed into ‘ontologies’
  - Logic
    - Formal semantics
  - …

Rule-Based Systems

- Knowledge is specified as a collection of *rules*
- Each rule has the form

  condition -> action

  which may be read *if* condition *then* action
- The condition (antecedent) is a ***pattern***
- The action (consequent) is an ***operation*** to be performed if the rule ***fires***
- Rules are applied to *facts* - unconditional statements that are assumed to be correct (at the time they are used)
  - A rule can fire if the condition matches the facts

Example Rule Base

Rules:

```
R1:  IF animal has feathers
    THEN animal is a bird
R2:  IF animal is a bird
    THEN animal can fly
R3:  IF animal can fly
    THEN animal is not scared of heights
```

Action is ADD this fact

Example Rule Base

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Suppose F1: kiwi has feathers

R1 fires so add F2: kiwi is a bird

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Suppose F1: kiwi has feathers

R1 fires so add F2: kiwi is a bird

R2 fires so add F3: kiwi can fly

Example Rule Base

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Action is ADD this fact

Suppose F1: kiwi has feathers

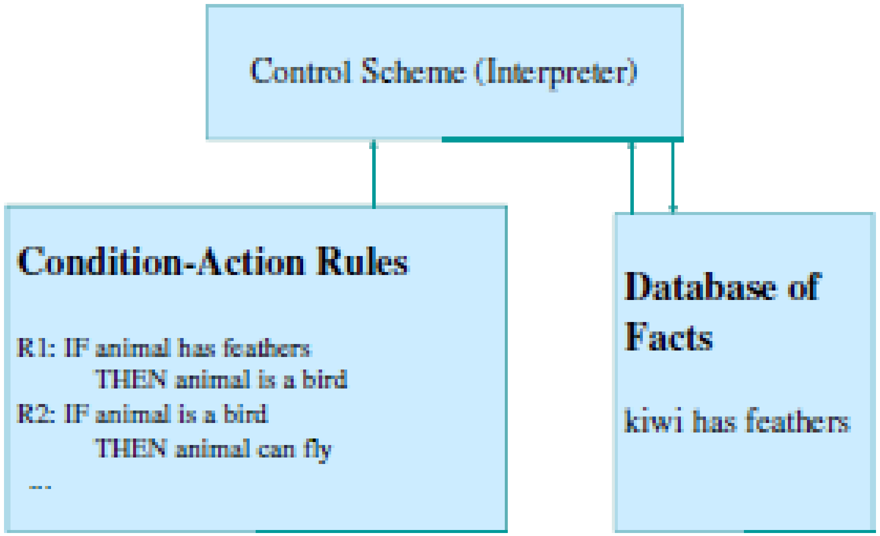
R1 fires so add F2: kiwi is a bird

R2 fires so add F3: kiwi can fly

R3 fires so add F4: kiwi is not scared of heights

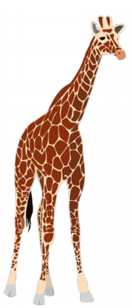
Rule-Based System Architecture

- A collection of rules
- A collection of facts
- A rule *fires* if a fact *matches* the *condition* of the rule
  - Mechanism that fires rules is *inference engine*



What can we do with rules?

- See what new facts can be derived, e.g.
  - F3: kiwi is not scared of heights
- Ask whether a fact is implied by the knowledge base and already known facts, e.g.
  - Can a giraffe fly?



Rule-Based Systems as KR

- ***Advantages***
  - These systems are very expressive
  - The rules lead to a degree of modularity
- ***Disadvantages***
  - There is a lack of precise semantics for the rules
  - The systems are not always efficient
  - What if several rules match the facts?

Relation to Search

- Using rules can be thought of as just another form of search
- The sets of facts are states
- Rules are the actions performed in states
- This suggests that there are schemes for applying rules that are similar to search techniques
- We will look at these in the next lecture

Summary

- Discussed the need for explicit knowledge representation
- Considered properties of KR schemes
- Looked at rules as one such scheme

- Next time
  - Algorithms for reasoning with rules