Knowledge Representation, Continued

- "When one encounters a new situation (or makes a substantial change in one's view of a problem one selects from a memory structure called a 'frame'. This is a remembered framework to be adapted to fit reality by changing details as necessary."
- (Minsky, 1975)

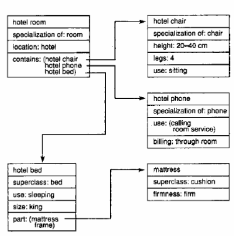
Minsky, 1970s)

From http://www.wiziq.com/educational-tutorials/presentation/485-Introduction-to-Artificial-Intelligence

Frame example

a frame is a structured collection of data

- has *slots* (properties) and *fillers* (values)
- fillers can be links to other frames



This work led to the ideas for object-oriented programming!

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Description logics (1990s, 2000s)

- Combination of semantic networks, frames, and first-order logic.
- Allows both structured conceptual representation and logical inference methods.
- Major current application: Language for "ontologies" for semantic web.

- E.g.,
  Bachelor = And(Unmarried, Adult, Male)

  First-order logic equivalent:
  Bachelor(x) = Unmarried(x) AND Adult(x) AND Male(x)

  DL allows direct logical operations on predicates, rather than having to first create sentences to be joined by connectives.

- DL: emphasis is on tractability of inference
- A problem instance is solved by describing it and then asking if it is subsumed by one of several possible solution categories. Need efficient algorithms for doing this.

An aside:
Can DL capture “fluid” concepts?

– Definition: A bachelor is an unmarried male.

But:

– Is the Pope a bachelor?

– Is an Arab man who is allowed to have 7 wives, but has only 6, a bachelor?

(Examples from D. Hofstadter)

Semantic Web:
Killer App for DL Reasoning?

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From:
http://www.cs.man.ac.uk/~horrocks/Slides/Sussex

History of the Semantic Web

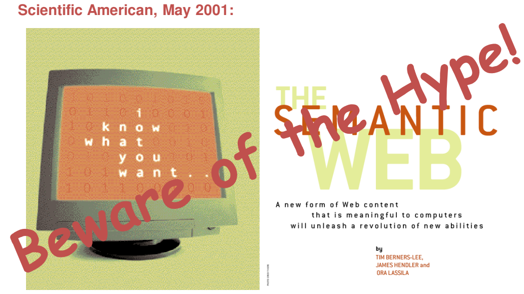
- Web was “invented” by Tim Berners-Lee (amongst others), a physicist working at CERN
- His vision of the Web was much more ambitious than the reality of the existing (syntactic) Web:

“… a plan for achieving a set of connected applications for data on the Web in such a way as to form a consistent logical web of data …”

“… an extension of the current web in which information is given well-defined meaning, better enabling computers and people to work in cooperation …”

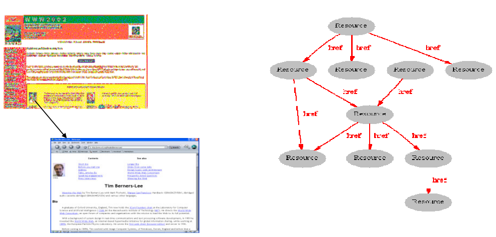
- This vision of the Web has become known as the Semantic Web

Scientific American, May 2001:



- Realising the complete “vision” is too hard for now (probably)
- Can make a start by adding semantic annotation to web resources
- Already seeing exciting applications of technology in e-Science

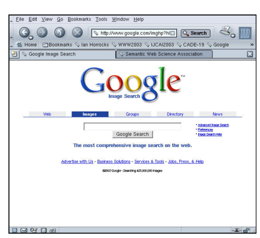
Where we are Today: the Syntactic Web



- A place where computers do the presentation (easy) and people do the linking and interpreting (hard)
- Why not get computers to do more of the hard work?

Hard Work using the Syntactic Web…

Find images of Peter Patel-Schneider, Frank van Harmelen and Alan Rector…



Rev. Alan M. Gates, Associate Rector of the Church of the Holy Spirit, Lake Forest, Illinois

Impossible (?) using the Syntactic Web…

- Complex queries involving background knowledge
  - Find information about “animals that use sonar but are neither bats nor dolphins”
- Locating information in data repositories
  - Travel enquiries
  - Prices of goods and services
  - Results of human genome experiments
- Finding and using “web services”
  - Visualise surface interactions between two proteins
- Delegating complex tasks to web “agents”
  - Book me a holiday next weekend somewhere warm, not too far away, and where they speak French or English

What is the Problem?

Consider a typical web page:

Markup consists of:
- **rendering information (e.g., font size and colour)**
- **Hyper-links to related content**

Semantic content is accessible to humans, but not (easily) to computers…

Requires (at least) NL understanding

Solution(?): Add “Semantic Markup”

- Annotations added to web pages (and other web accessible resources)
- “Semantics” given by ontologies
  - Ontologies provide a vocabulary of terms used in annotations
  - New terms can be formed by combining existing ones
  - Meaning (semantics) of such terms is formally specified
  - Need to agree on a standard web ontology language

Structure of an Ontology

Ontologies typically have two distinct components:

- Names for important concepts in the domain
  - Elephant is a concept whose members are a kind of animal
  - Herbivore is a concept whose members are exactly those animals who eat only plants or parts of plants
  - Adult_Elephant is a concept whose members are exactly those elephants whose age is greater than 20 years
- Background knowledge/constraints on the domain
  - Adult_Elephants weigh at least 2,000 kg
  - All Elephants are either African_Elephants or Indian_Elephants
  - No individual can be both a Herbivore and a Carnivore

A Semantic Web — First Steps

Make web resources more accessible to automated processes

- Extend existing rendering markup with semantic markup
  - Metadata annotations that describe content/funtion of web accessible resources
- Use Ontologies to provide vocabulary for annotations
  - “Formal specification” is accessible to machines
- A prerequisite is a standard web ontology language
  - Need to agree common syntax before we can share semantics
  - Syntactic web based on standards such as HTTP and HTML

```
<HTML>
<HEAD>
<META HTTP-EQUIV="SHOE" CONTENT="VERSION=1.0">
<TITLE>Prof. James A. Hendler</TITLE>
</HEAD>
<BODY>
<INSTANCE KEY="http://www.cs.umd.edu/users/hendler/">
<USE-ONTOLOGY ID="cs-dept-ontology" VERSION="1.0" PREFIX="cs" URL=
"http://www.cs.umd.edu/projects/plus/SHOE/cs.html" />
<CATEGORY NAME="cs.Professor" FOR="http://www.cs.umd.edu/users/hendler/"/>
<RELATION NAME="cs.member">
 <ARG POS=1 VALUE="http://www.cs.umd.edu/projects/plus/">
 <ARG POS=2 VALUE="http://www.cs.umd.edu/users/hendler/">
</RELATION>
<RELATION NAME="cs.name">
 <ARG POS=2 VALUE="Dr. James Hendler">
</RELATION>
<RELATION NAME="cs.doctoralDegreeFrom">
 <ARG POS=1 VALUE="http://www.cs.umd.edu/users/hendler/">
 <ARG POS=2 VALUE="http://www.brown.edu">
</RELATION>
<RELATION NAME="cs.emailAddress">
 <ARG POS=2 VALUE="hendler@cs.umd.edu">
</RELATION>
<RELATION NAME="cs.head">
 <ARG POS=1 VALUE="http://www.cs.umd.edu/projects/plus/">
 <ARG POS=2 VALUE="http://www.cs.umd.edu/users/hendler/">
</RELATION>
```

[Markup demo]

Ontologies

- "An ontology is a document or file that formally defines the relations among terms." (Berners-Lee et al., 2001)
- Consists of *taxonomy* and set of inference rules

Ontology examples

- http://www.schemaweb.info/default.aspx
- http://ebiquity.umbc.edu/ontology/event.owl

- What will the semantic web be good for?
- What kinds of knowledge and reasoning will be necessary?

A few other well-known knowledge representation methods

- Situation calculus
- Neural networks
- Decision trees
- Bayesian networks

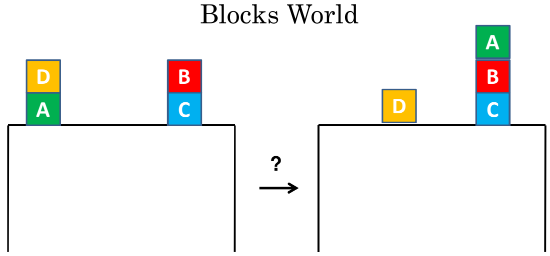
Logic, Knowledge Representation, and Planning

Planning: Given a space of states and actions, find sequence of actions that allow problem solver to get from start state to goal state. (E.g., robot navigation planning.)

Approaches to planning:

- Heuristic search:
- Reinforcement learning:
- Logic

Blocks World



Initial state: on(A,TABLE,0), on(D, A, 0), on(C, TABLE,0), on(B,C,0), clear(A,0), clear(B,0), clear(D,0)

Goal state: on(A,B,2), on(D, TABLE, 0), on(C, TABLE,2), on(B,C,2), clear(A,2), clear(D,0)

Predicates:

on (x,y,t)
clear (x,y,t)
move (x,y,z,i)

Axioms:

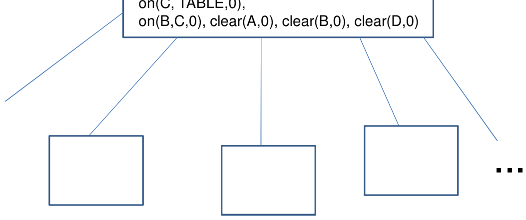
∀t: clear(TABLE,t)
∀x, y, z, t: on(x, y, i) ∧ clear (x,i) ∧ clear(z,i) ∧ move(x,y,z,i) ⊃ on(x,z, i+1) ∧ clear(y, i+1)
...

"Frame" Axioms:

Describe the propositions an action does *not* affect.

Planning as Search

Initial state: on(A,TABLE,0), on(D, A, 0), on(C, TABLE,0), on(B,C,0), clear(A,0), clear(B,0), clear(D,0)



Planning as Deduction

Initial state: on(A,TABLE,0), on(D, A, 0), on(C, TABLE,0), on(B,C,0), clear(A,0), clear(B,0), clear(D,0)

Goal state: on(A,B,2), on(D, TABLE, 0), on(C, TABLE,2), on(B,C,2), clear(A,2), clear(D,0)

Planning as Deduction

Initial state: on(A,TABLE,0), on(D, A, 0), on(C, TABLE,0), on(B,C,0), clear(A,0), clear(B,0), clear(D,0)

- **Add initial state to axioms.**
- **Use axioms to prove, via an automatic theorem proving method, that goal state can follow from initial state**
- **Plan is extracted from sequence of statements use in proof.**

Goal state: on(A,B,2), on(D, TABLE, 0), on(C, TABLE,2), on(B,C,2), clear(A,2), clear(D,0)

Planning as Satisfiability

(Kautz & Selman, 1992)

- Encode planning problem as a conjunction of axioms plus initial state plus goal state. Expand axioms with

  on(A,TABLE,0) ∧ on(D, A, 0) ∧ on(C, TABLE,0) ∧ on(B,C,0) ∧ clear(A,0) ∧ clear(B,0) ∧ clear(D,0) ∧ on(A,B,2) ∧ on(D, TABLE, 0) ∧ on(C, TABLE,2) ∧ on(B,C,2) ∧ clear(A,2) ∧ clear(D,0) ∧...

- Determine if this formula is satisfiable
- If so, extract plan from assignments to variables that satisfy formula
- If not, increment goal *t* and try again.

To convert actions to propositions:

move(d,a,b,1) => on(d, a, 1) $\wedge$ clear (d,1) $\wedge$ clear(b,1)
=> on(d,b, 2) $\wedge$ clear(a, 2)

To convert quantified formulas as propositions:

$\forall$t: clear(TABLE,t) →
clear(TABLE,0) $\wedge$ clear(TABLE,1) $\wedge$ clear(TABLE,2)

$\exists$: create disjunction of all possibilities

In short, formula has propositions for actions and states variables at each possible timestep