Knowledge Representation

What is knowledge representation?

- Structured knowledge base
- Search and inference algorithms
Examples of knowledge representation in AI

- **Logic** for general reasoning
- **Expert systems** for medical diagnosis
- **Semantic networks, frames** for reasoning about categories
- **Scripts** for story understanding
- **Description logics, ontologies** for web services, e-mail sorting, spam detection

Propositional logic: AND, OR, NOT, IMPLIES

First order logic: add functions (e.g., MotherOf(x)), predicates (e.g., Man(x)), and quantifiers (∃ and ∀)
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First order logic: add functions (e.g., MotherOf(x)), predicates (e.g., Man(x)), and quantifiers (∃ and ∀)

Example:
All men are mortal
Socrates is a man
Therefore, Socrates is mortal

Can’t do this in propositional logic
In first order logic, can do:
∀x, Man(x) → Mortal(x)
Man(Socrates)
Mortal(Socrates)

Planning via Logic
Example:
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:**
- $\forall t:\ clear(TABLE,t)$
- $\forall x, y, z, t:\ on(x, y, i) \land clear(x,i) \land clear(z,i) \land move(x,y,z,i) \supset on(x,z, i+1) \land clear(y, i+1)$
- ...

**“Frame” Axioms:**
Describe the propositions an action does not affect.

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**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)

- 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 used in proof.

**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 Satisfiability  
(Kautz & Selman, 1992)

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

\[
\text{on}(A, \text{TABLE}, 0) \land \text{on}(D, A, 0) \land \text{on}(C, \text{TABLE}, 0) \land \\
\text{on}(B, C, 0) \land \text{clear}(A, 0) \land \text{clear}(B, 0) \land \text{clear}(D, 0) \land \\
\text{on}(A, B, 2) \land \text{on}(D, \text{TABLE}, 0) \land \text{on}(C, \text{TABLE}, 2) \land \\
\text{on}(B, C, 2) \land \text{clear}(A, 2) \land \text{clear}(D, 0) \land...
\]

• 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:

\[
\text{move}(d,a,b,1) \Rightarrow \text{on}(d, a, 1) \land \text{clear}(d, 1) \land \text{clear}(b, 1) \\
\Rightarrow \text{on}(d, b, 2) \land \text{clear}(a, 2)
\]

To convert quantified formulas as propositions:

\[
\forall t: \text{clear}(\text{TABLE}, t) \Rightarrow \\
\text{clear}(\text{TABLE}, 0) \land \text{clear}(\text{TABLE}, 1) \land \text{clear}(\text{TABLE}, 2)
\]

\( \exists \): create disjunction of all possibilities

In short, formula has propositions for actions and
states variables at each possible timestep
Problems with First Order logic

- Hard to express many concepts
- Hard to express associations
- Hard to keep consistent
- Takes a long time to do inference
- ...

Semantic networks

- Retrieving knowledge = graph search problem
- E.g., “is Rusty an animal?”
- Inheritance: “does Rusty have a wing?”
Example: ConceptNet (Openmind Commonsense)

- Large-scale semantic net mined from OMCS corpus

  Teaching machines about everyday life

  1.6 million links interrelating
  300K concepts

Fig 2 A subset of ConceptNet.

Example: ConceptNet (Openmind Commonsense)

- Openmind Commons home page

- Demo
• **Reasoning in ConceptNet** = traversing links (or “spreading activation”)

• **Given an initial set of concepts, can infer:**
  – What events might come next
  – What might have happened earlier
  – What objects might be required to perform an action
  – What properties of objects are
  – Where object might be found
  – Goals of people with respect to events or objects

**Example:** A story-understanding program reads “He woke up and turned off his alarm clock”, then is asked “Why did he turn off his alarm clock?” “How did he turn off his alarm clock?”
Wordnet

- Wordnet (current projects)

Problems with semantic networks

- Can they scale?

- How to glom together entire “situations”? (e.g., alarm clock, morning, etc.) and to represent temporal order?

- How to learn the network automatically?
**Scripts and Conceptual Dependency**  
*(Schank, 1970s-1980s)*

- CD is a language that builds up meaning from primitives:
  - ACT  action
  - PP  objects (picture produces)
  - AA  modifiers of actions (action aided)
  - PA  modifiers of objects (picture aided)

- Primitive actions
  - ATRANS (transfer a relationship)
  - PTRANS (transfer a physical location)
  - MTRANS (transfer mental information)
  - Etc.

• **Scripts:** Stereotyped situations with temporal order, represented in CD.

• **Most famous example:** Restaurant script

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• **Scene 1: Entering**
  S PTRANS S into restaurant, S ATTEND eyes to tables, S MBUILD where to sit, S PTRANS S to table, S MOVE S to sitting position

• **Scene 2: Ordering**
  S PTRANS menu to S (menu already on table), S MBUILD choice of food, S MTRANS signal to waiter, waiter PTRANS to table, S MTRANS 'I want food' to waiter, waiter PTRANS to cook

• **Scene 3: Eating**
  Cook ATRANS food to waiter, waiter PTRANS food to S, S INGEST food

• **Scene 4: Exiting**
  waiter MOVE write check, waiter PTRANS to S, waiter ATRANS check to S, S ATRANS money to waiter, S PTRANS out of restaurant
**Story:**
- John went to a restaurant. John ordered a hamburger. When the hamburger came it was cooked perfectly. John was very happy and left a big tip for the waiter.

**Query:**
- Did John eat the hamburger?
Problems with scripts

• “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)

Frames
(Minsky, 1970s)

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• (Minsky, 1975)
This work led to the ideas for object-oriented programming!

**Frame example**

- A frame is a structured collection of data
  - has slots (properties) and fillers (values)
  - fillers can be links to other frames

**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.
Semantic web

- Extension of html, xml for marking up web resources with “semantics”, via “shared ontologies”

- Inference and reasoning algorithms for using this metadata.

- “Intelligent search” versus “intelligent data”
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://ebiquity.umbc.edu/ontology

- What will the semantic web be good for?

- What kinds of knowledge and reasoning will be necessary?

- Douglas Lenat – Cyc project, 1+ hour video
A few other well-known knowledge representation methods

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