Knowledge Representations

- How else can we represent knowledge in addition to formal logic?
Common Knowledge Representations

• Formal Logic
• Production Rules
• Semantic Nets
• Schemata and Frames
Production Rules

- Frequently used to formulate the knowledge in expert systems.
- BNF is commonly used in Computer Science.

For a subset of the German language:

<table>
<thead>
<tr>
<th>Syntax</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;sentence&gt;</td>
<td>&lt;subject phrase&gt; &lt;verb&gt; &lt;object phrase&gt;</td>
</tr>
<tr>
<td>&lt;subject phrase&gt;</td>
<td>&lt;determiner&gt; &lt;adjective&gt; &lt;noun&gt;</td>
</tr>
<tr>
<td>&lt;object phrase&gt;</td>
<td>&lt;determiner&gt; &lt;adjective&gt; &lt;noun&gt;</td>
</tr>
<tr>
<td>&lt;determiner&gt;</td>
<td>der</td>
</tr>
<tr>
<td>&lt;noun&gt;</td>
<td>Mann</td>
</tr>
<tr>
<td>&lt;verb&gt;</td>
<td>mag</td>
</tr>
<tr>
<td>&lt;adjective&gt;</td>
<td>schoene</td>
</tr>
</tbody>
</table>
for a subset of the German language

- `<sentence>`  
  - `<subject phrase>`  
    - `<determiner>` `<adjective>` `<noun>`
  - `<verb>`
  - `<object phrase>`  
    - `<determiner>` `<adjective>` `<noun>`

- `<determiner>`  
  - `der` | `die` | `das` | `den`

- `<noun>`  
  - `Mann` | `Frau` | `Kind` | `Hund` | `Katze`

- `<verb>`  
  - `mag` | `schimpft` | `vergisst` | `verehrt` | `verzehrt`

- `<adjective>`  
  - `schoene` | `starke` | `laute` | `duenne`
Prolog

- Prolog was developed for AI applications.
- It specifies rules as Horn clauses, a subset of predicate logic.

**Example**

```prolog
male(albert).
male(Edward).

female(alice).
female(Victoria).

parents(Edward, Victoria, Albert).
parents(Alice, Victoria, Albert).

sisterof(X, Y) :- female(X),
                parents(X, M, F),
                parents(Y, M, F).
```
% Automotive Diagnostic Expert System

defect_may_be(drained_battery) :-
    user_says(starter_was_ok, yes),
    user_says(starter_is_ok, no).

defect_may_be(wrong_gear) :-
    user_says(starter_was_ok, no).

defect_may_be(fuel_system) :-
    user_says(starter_was_ok, yes),
    user_says(fuel_is_ok, no).
Picture Pattern from my 1974 Thesis

\[
\text{PATTERN} = \text{CIRCLE} \, \$ \, \text{C1} \, \&\, \text{CIRCLE} \, \$ \, \text{C2} \, \&\, \\
\text{GT} (\text{VALU(C2,’RADIUS’)}, \text{VALU(C1,’RADIUS’)})) \, \&\, \\
\text{AT} (\text{POINT(C2,’TOP’)}, \text{POINT(C1,’BOT’)}) \, \&\, \\
\text{CIRCLE} \, \$ \, \text{C3} \, \&\, \\
\text{GT} (\text{VALU(C3,’RADIUS’)}, \text{VALU(C2,’RADIUS’)})) \, \&\, \\
\text{AT} (\text{POINT(C3,’TOP’)}, \text{POINT(C2,’BOT’)})
\]

What is it?
## Advantages of Production Rules

<table>
<thead>
<tr>
<th>Advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Simpler than full predicate logic</td>
</tr>
<tr>
<td>• Still pretty expressive</td>
</tr>
<tr>
<td>• Simple backtracking search algorithms</td>
</tr>
<tr>
<td>• Easy for programmers to construct the rules</td>
</tr>
<tr>
<td>• Humans tend to understand the rules</td>
</tr>
</tbody>
</table>

Disadvantages?
Semantic Nets

- Graphical representation for propositional information
- Originally developed by Quillian as a model for human memory
- Nodes represent objects, concepts, situations
- Edges represent relationships
Semantix Net Example

Abralracourcix is-boss-of Astérix
Cétaautomatix buys-from is-a Gaul
Panoramix sells-to is-a Human
Ordralfabetix is-a barks-at Idéfix
Dog takes-care of Obélix

[http://www.astérix.fm.fr]
Semantic Nets

• Relationships
  – Frequently used: IS-A, A-KIND-OF, PART-OF
  – Can be specified by the designer

• Attributes
  – Can be added to the nodes

• Advantages
  – Easy to encode and understand

• Disadvantages
  – May become large and lead to enormous searches
The Semantic Web: an effort to create a web that uses the concepts from semantic nets.

It would allow people (and programs) to better understand web content.

Two main representations at present:

- **RDF** (Resource Description Framework) low level, triples (node1, relationship, node2)
- **OWL** (web ontology language) adds semantics to RDF
Semantic Web Languages

- **RDF (Resource Description Framework)**
  - Triples: `<subject> <property> <object>`
  - RDF is a data model for objects ("resources") and relations between them. These data models can be represented in an **XML** syntax.

- **RDFS (RDF Schema)**
  - A vocabulary for describing properties (subclass, subproperty, domain, range) and classes of RDF resources, with a semantics for generalization-hierarchies of such properties and classes.
• **OWL (Web Ontology Language)**

- OWL adds more vocabulary for describing properties and classes: among others, *relations between classes* (e.g. disjointness), *cardinality* (e.g. "exactly one"), *equality*, richer typing of properties, *characteristics of properties* (e.g. symmetry), and *enumerated classes*.

- There are *constraints on classes* and the types of relationships permitted between them. These provide semantics by allowing systems (*reasoners*) to infer additional information and provide classification based on the data explicitly provided.
Three “flavors” of OWL:

**OWL Full**
- OWL Full includes all OWL language constructs without restrictions on how they can be used.
- Not decidable

**OWL DL (Description logic)**
- OWL DL includes all OWL language constructs, but they can be used only under certain restrictions.
- Decidable
- Most ontologies use OWL DL

**OWL Lite (even more restricted)**
Excerpt of an OWL Ontology:

```xml
<rdfs:Class rdf:ID="WINE">
  <rdfs:subClassOf rdf:resource="#POTABLE-LIQUID"/>
  <rdfs:subClassOf>
    <daml:Restriction>
      <daml:onProperty rdf:resource="#MAKER"/>
      <daml:minCardinality>1</daml:minCardinality>
    </daml:Restriction>
  </rdfs:subClassOf>
  <rdfs:subClassOf>
    <daml:Restriction>
      <daml:onProperty rdf:resource="#MAKER"/>
      <daml:toClass rdf:resource="#WINERY"/>
    </daml:Restriction>
  </rdfs:subClassOf>
  <rdfs:subClassOf>
    <daml:Restriction>
      <daml:onProperty rdf:resource="#GRAPE-SLOT"/>
    </daml:Restriction>
  </rdfs:subClassOf>
</rdfs:Class>
```
My Comments

• The international ontology community is sold on OWL, because it is powerful and portable.
• Part of the portability is that it is usually expressed in XML and then interpreted by XML readers.
• Thus, trying to read it as a human is rather difficult; it is for machines.
• But it allows people all over the world to share knowledge bases.
Frames

• A frame represents related knowledge about a subject
• Frames contain multiple named slots
• Slots contain values of many different kinds – rules, facts, images, links to other frames
• Slots can have related procedures that get executed when the value is added, modified or deleted
• Frames can be arranged in a hierarchy or graph
# Simple Frame Example

<table>
<thead>
<tr>
<th>Slot Name</th>
<th>Filler</th>
</tr>
</thead>
<tbody>
<tr>
<td>name</td>
<td>Astérix</td>
</tr>
<tr>
<td>height</td>
<td>small</td>
</tr>
<tr>
<td>weight</td>
<td>low</td>
</tr>
<tr>
<td>profession</td>
<td>warrior</td>
</tr>
<tr>
<td>armor</td>
<td>helmet</td>
</tr>
<tr>
<td>intelligence</td>
<td>very high</td>
</tr>
<tr>
<td>marital status</td>
<td>presumed single</td>
</tr>
</tbody>
</table>
Frames

• Advantages
  – Intuitive for many applications
  – Easier to understand than logic
  – Very flexible

• Problems
  – There are inheritance problems, particularly multiple inheritance in graphs
Ontologies

• An ontology is a **formal representation** of a set of **concepts** within a domain and the **relationships** among those concepts. **Does that sound familiar?**

• It allows deep understanding of and reasoning about a domain.

• UW Medical School has one enormous and now famous ontology: the **Foundational Model of Anatomy (FMA)**
Ontology Tools

- Ontology-development becomes more accessible with tools.
- **Protégé**
  - Developed at Stanford Medical Informatics
  - Is an extensible and customizable toolset for
    - constructing knowledge bases
    - developing applications that use these knowledge bases

[http://protege.stanford.edu](http://protege.stanford.edu)
What is Protégé?

- An ontology **editor**
- A **knowledge-acquisition** tool
- A **platform** for knowledge-based applications
An Ontology Editor

NCI Thesaurus
A Knowledge-Acquisition Tool

Gene Ontology
A Platform for Other Applications

- A **Java API** that enables developers to write plugins for
  - Visualization systems
  - Inferencing systems
  - Scripting facilities
  - Import and export formats
  - User-interface features
  - Means of accessing external data sources

- About **60 plugins** currently in the library (developed at Stanford and elsewhere)
Visualization: Jambalaya

Developed at University of Victoria
Graph Widget
Some Applications Supported by Protégé:

- Surveillance of data sources for evidence of potential bioterrorism
- Concept-based information retrieval
- Modeling of metabolic pathways
- Automation of guideline-based therapy
What Makes Protégé Different

• Easy-to-use graphical interface
• Scalability
  – currently can handle up to 5 million concepts
• Plugin architecture
  – active international community of plugin developers
• It’s a platform for other applications
  – Integration with Eclipse (Mayo Clinic)
  – A server and a client for (Semantic) Web Services
• Open source
Foundational Model of Anatomy

• Developed here at UW in the Department of Biological Structure by Prof. Cornelius Rosse and Dr. Onard Mejino and other team members (including me)

• Purpose was to provide a comprehensive framework for the study of the human body

• Can be used by students, doctors, medical researchers, even the general public
Motivating Hypothesis

“A sound ontological framework of biological structure (anatomy) provides a logical, comprehensive and efficient framework for organizing all types of information about biological organisms”
Why Anatomy?

Hypothesis 1: Manifestations of health and disease are attributes of anatomical structures.

Hypothesis 2: Representation of anatomy should facilitate representation of other domains and interoperability between biomedical domains.
Theory:

The FMA is a \textit{spatio-structural ontology} of the entities and relations which together form the \textit{phenotypic structure} of a biological organism at all salient \textit{levels of granularity}.
High level Objectives of the FMA theory

Foundational Model of Anatomy

declare the principles
  for including entities and relations
  that are implicitly assumed
  when knowledge of anatomy
  is applied in different contexts;

explicitly define
  entities and relations
  necessary and sufficient for consistently
  representing the structure of a biological organism.
Foundational Model of Anatomy Ontology
Anatomy Taxonomy (AT) - defines the essence of the entity through an inheritance hierarchy.
Anatomical Structural Abstraction (ASA) - declares the spatio-structural properties of an anatomical entity.
Foundational Model of Anatomy Ontology

Unifying theory of anatomy

High Level Scheme

$$FMA = (At, ASA, ATA, Mk)$$

where:

- $At$ = Anatomy taxonomy
- $ASA$ = Anatomical Structural Abstraction
- $ATA$ = Anatomical Transformation Abstraction
- $Mk$ = Metaknowledge
  (principles, rules, axioms)
Exploring the FMA

• The Foundational Model Explorer (FME)
  http://fme.biostr.washington.edu/FME/index.html

allows browsing through the frames following links.

• Emily Lite
allows relational queries
Query

Subject
Unknown  Auto Insert
Esophagus

Relation
Unknown  Auto Insert
has regional part
Closure

Object
Unknown  Auto Insert

Class Operations
Physical anatomical entity
Show in Explorer

Results
Delete
Set 1 (Esophagus is type of <unknown>)

What is regional part of Esophagus?
List  Tree

Abdominal part of esophagus
Cervical part of esophagus
Thoracic part of esophagus

Combine results
Set 1 (Esophagus is type of <unknown>)
or
Set 1 (Esophagus is type of <unknown>)

Combine

Java Application Window
Query
Subject: Esophagus
Relation: has constitutional part
Object: Closure

Class Operations
Physical anatomical entity
Show in Explorer

Explorer
Physical anatomical entity

Results
Delete
Set 1 (Esophagus is type of <unknown>)
Set 2 (Esophagus has regional part <unknown>)
Set 3 (Esophagus has regional part) + <unknown>
Set 4 (Esophagus has constitutional part) + <unknown>

Combine results
Set 1 (Esophagus is type of <unknown>)
or

What (is constitutional part of) + Esophagus...

List
Tree

Adventitia of esophagus
Basement membrane of epithelium proper of esophagus
Circular muscle layer of esophagus
Dense irregular connective tissue of adventitia
Dense regular collagenous tissue of submucosa
Dense regular elastic tissue of lamina propria
Diffuse mucosa-associated lymphoid tissue
Epithelium of esophagus
Lamina propria of esophagus
Longitudinal muscle layer of esophagus
Lumen of esophagus
Mucosa of esophagus

Java Application Window
What is the relation between Esophagus and Heart?

Set 1: Esophagus is type of <unknown>
Set 2: Esophagus has regional part <unknown>
Set 3: Esophagus has regional part <unknown>
Set 4: Esophagus has constitutional part <unknown>
Set 5: Esophagus <unknown> Stomach
Set 6: Esophagus <unknown> Heart

Combine results:

- Set 1: Esophagus is type of <unknown>
- or
- Set 1: Esophagus is type of <unknown>

Combine
What is the relation between Esophagus and Heart?

- (is type of) Organ with organ cavity
- (has regional part) Thoracic part of esophagus
- (is constitutional part of) Content of mediastinum
- (is constitutional part of) Content of superior mediastinum
- (is constitutional part of) Intrathoracic part of chest
  - (has constitutional part) Heart
- (has constitutional part) Wall of esophagus
- (is type of) Wall of organ
  - (has subtype) Wall of heart
    - (is constitutional part of) Heart