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.

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

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

• Example

  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

PATTERN = CIRCLE $ C1 $ CIRCLE $ C2 $
GT(VALU(C2,'RADIUS'), VALU(C1,'RADIUS')) $
AT(POINT(C2,'TOP'), POINT(C1,'BOT')) $
CIRCLE $ C3 $
GT(VALU(C3,'RADIUS'), VALU(C2,'RADIUS')) $
AT(POINT(C3,'TOP'), POINT(C2,'BOT'))

What is it?
Advantages of Production Rules

- Simpler than full predicate logic
- Still pretty expressive
- Simple backtracking search algorithms
- Easy for programmers to construct the rules
- Humans tend to understand the rules
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
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
Related Web Developments

• 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 datamodel for objects ("resources") and relations between them. These datamodels 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 (the OPB):

```xml
<?xml version="1.0"?>
<rdf:RDF
xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
xml:base="http://www.owl-ontologies.com/unnamed.owl">
    <owl:Ontology rdf:about=""
    </owl:Ontology>
    <owl:Class rdf:ID="Rotational_displacement">
        <rdfs:label rdf:datatype="http://www.w3.org/2001/XMLSchema#string" >Rotational displacement</rdfs:label>
        <rdfs:subClassOf>
            <owl:Class rdf:ID="Solid_displacement"/>
        </rdfs:subClassOf>
    </owl:Class>
    <protege:subclassesDisjoint rdf:datatype="http://www.w3.org/2001/XMLSchema#boolean" >true</protege:subclassesDisjoint>
    <owl:disjointWith>
        <owl:Class rdf:ID="Bending_displacement"/>
    </owl:disjointWith>
</rdf:RDF>
```
Semantic Web Stack

- User interface and applications
- Trust
- Proof
- Unifying logic
- Querying: SPARQL
- Ontologies: OWL
- Rules: RIF/SWRL
- Taxonomies: RDFS
- Data interchange: RDF
- Syntax: XML
- Identifiers: URI
- Character set: UNICODE
- Cryptography
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

• 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
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

San Jose Mercury News (Organization)

Name
San Jose Mercury News

Organization Chart

Manager
Columnist
Editor
Director
Salesperson
Reporter

Graph

George

Jocie

Sarah

Don

Kathy

Nancy

Mike

responsible_for
responsible_for
responsible_for
responsible_for
responsible_for
responsible_for

V C X
Some Applications within SMI 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 (FMA) Ontology

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 *spatio-structural ontology* of the entities and relations which together form the *phenotypic structure* of a biological organism at all salient *levels of granularity*. 
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.
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
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)
  

  allows browsing through the frames following links.

• Emily-Lite
  
  http://fma.biostr.washington.edu/emilylite/

  allows queries about entities and their relationships.
Query
Subject: Esophagus
Relation: has constitutional part
Object: Closure

Class Operations
Physical anatomical entity
Show in Explorer

Explorer
Physical anatomical entity

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

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

What (is constitutional part of)+ Esophagus...
Adventitia of esophagus
Basement membrane of epithelium proper of...
Circular muscle layer of esophagus
Dense irregular connective tissue of adventit...
Dense regular collagenous tissue of submuc...
Dense regular elastic tissue of lamina propri...
Diffuse mucosa-associated lymphoid tissue
Epithelium of esophagus
Lamina propria of esophagus
Longitudinal muscle layer of esophagus
Lumen of esophagus
Mucosa of esophagus
Query:
- Subject: Esophagus
- Relation: has constitutional part
- Object: Stomach

Class Operations:
- Physical anatomical entity
- Show in Explorer

Results:
- 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)

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

What is the relation between Esophagus...
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?

- Break down complex relations
- Show set dependencies

Esophagus
- (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