Ontologies

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What is an Ontology?

- Philosphy

  “Ontology is the study of what there is, an inventory of what exists. An ontological commitment is a commitment to an existence claim.”

  `http://www.artsci.wustl.edu/~philos/MindDict/ontology.html`

What is an Ontology?

- Artificial Intelligence

  "An ontology is an explicit specification of a conceptualization. [. . .] In such an ontology, definitions associate the names of entities in the universe of discourse (e.g., classes, relations, functions, or other objects) with human-readable text describing what the names mean, and formal axioms that constrain the interpretation and well-formed use of these terms. Formally, an ontology is the statement of a logical theory."

`http://www-ksl.stanford.edu/kst/what-is-an-ontology.html`

Why Ontologies?

- Philosphical issues. . .
- Modelling
  Using a well founded model of reality.
- Communication
  Knowing what we are talking about.
- Reasoning
  Drawing conclusion from the knowledge about what is.
- (At least) the last three items require formal ontologies!

Why Ontologies — Agent Perspective

- Explicit connection between agent's representation of knowledge and reality
- Share knowledge
- Translate between conceptualizations of the world
- Use and extend knowledge about the world

Agent Communication Languages

KQML (Knowledge Query and Manipulation Language)

- Example
- Weakness: No well defined semantics
- Declared dead

Agent Communication Languages

FIPA-ACL (Foundation for Intelligent Physical Agents)

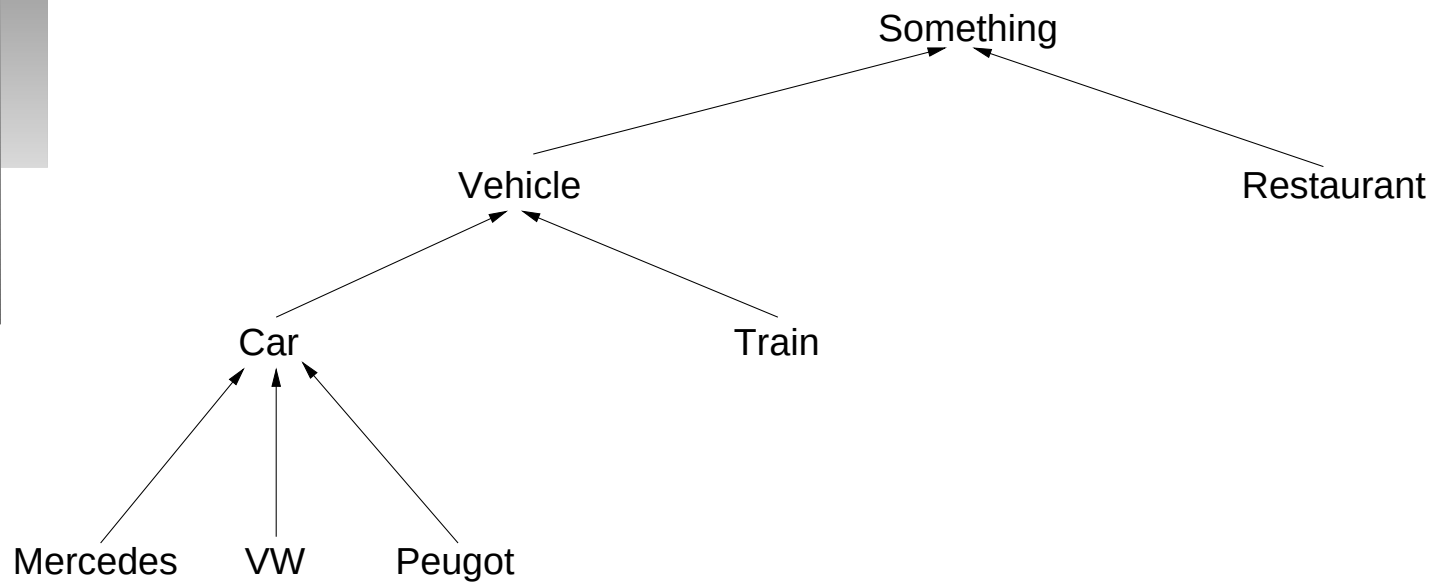
- Defines standard for agent communication
- Strong industry involvement
- Large set of specifications of all aspects of agent communication architecture.
- Basis for AgentCities
- Also defines an Ontology Agent communication interface

Univ. Koblenz AI Group Involvement

Using ontologies for. . .

- Web Search
  - Formalization of food domain
  - If the user is looking for “Pizza”, the agent knows to search for italian restaurants.
- Slicing book
  - Conceptualization of mathematical analysis
  - Depending on what the user want to learn, an individual book for her is created.

Formal Ontology - An Example



$$\forall x : \text{Mercedes}(x) \rightarrow \text{Car}(x)$$

$$\forall x : \text{Peugot}(x) \rightarrow \text{Car}(x)$$

$$\forall x : \text{Car}(x) \rightarrow \text{Vehicle}(x)$$

We need generic ontologies!

- Common representation of terms
- Shared set of ontology definitions
- Common logical theory

Formal Ontologies

- CycL
  - Used in CyC
  - Formalism for FOL
- KIF
  “Knowledge Interchange Format”
  Formalization of FOL in Lisp-notation.
- Goal of KIF: Allow the exchange of logical formulas

Ontolingua

- Based on KIF
- Goal: Allow the exchange of ontologies
- For this reason. . .
  - Using established representation mechanism
  - Very expressive: FOL + some second order constructs (invers,. . .)
  - Nice HTML interface
  - Translators for other representation formalisms.
  - Drawback: No efficient method for automated reasoning!

Description Logics

- Formal logics based on sets
- T-Box: Terminological knowledge

$$\begin{aligned} \text{Mercedes} &\sqsubseteq \text{Vehicle} \\ \text{Car} &\sqsubseteq \text{Vehicle} \\ \text{Vehicle} &\sqsubseteq \text{Something} \\ \text{CarOwner} &\equiv \text{Human} \sqcap \text{Owns.Car} \end{aligned}$$

(In FOL: $\text{CarOwner}(x) \equiv \text{Human}(x) \wedge \text{Owns}(x,y) \wedge \text{Car}(y)$)

Descripion Logics

- A-Box: Assertional Knowledge

Human(Fred)

Mercedes(Lilly)

Owns(Fred, Lilly)

Description Logics

- In between propositional logic and FOL
- Equivalent to FOL with arity of predicate restricted to 1 or 2.
- Equivalent to modal logics
- Worst case complexity still bad (PSPACE, NEXPTIME), but average case complexity O.K
- There are efficent implementations of inference engines.

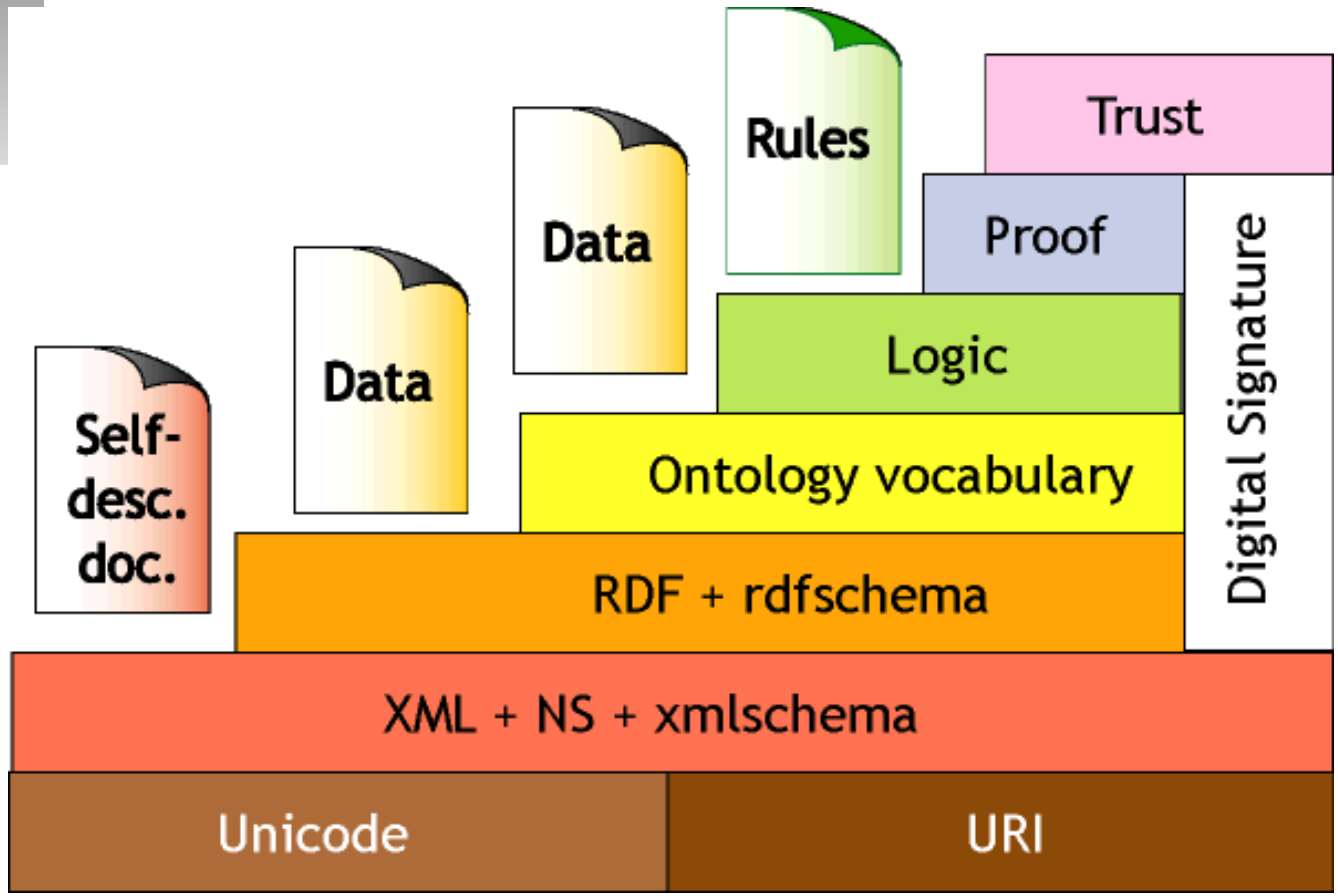
Semantic Web. . .

Description Logics incorporated in upcoming ontology standards.

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

  Tim Berners-Lee, James Hendler, Ora Lassila, The Semantic Web, Scientific American, May 2001
- W3C-Standard
- Based on XML and DL

Semantic Web Layers



(From http://www.w3.org/2000/Talks/1206-xml2k-tbl/slide10-0.html)

RDF

- Resource Description Framework
- Example
  “There is someone called Fred, with the email address fred@foo.org.”

```
<rdf:RDF>
  <Person>
    <mailbox rdf:resource="mailto:fred@foo.org"/>
    <name>Fred</name>
  </Person>
</rdf:RDF>
```

DAML+OIL

- DARPA Agent Markup Language (DAML)
- Ontology Inference Language (OIL)
- United in DAML+OIL
- Example:
  $Car \sqsubseteq Vehicle$

```
<daml:Class rdf:ID="Car">
  <rdfs:label>Car</rdfs:label>
  <daml:subClassOf rdf:resource="#Vehicle"/>
</daml:Class>
```

DAML+OIL — Another example

$$\text{CarOwner} = \text{Human} \sqcap \text{owns.Car}$$

```
<daml:ObjectProperty rdf:ID="owns">
  <rdfs:comment>
    Only humans can own something
  </rdfs:comment>
  <rdfs:domain rdf:resource="#Human"/>
</daml:ObjectProperty>
<daml:Class rdf:ID="CarOwner">
  <rdfs:label>CarOwner</rdfs:label>
  <daml:intersectionOf rdf:parseType="daml:collection">
    <daml:Class rdf:about="#Human"/>
    <daml:Restriction>
      <daml:onProperty rdf:resource="#owns"/>
      <daml:hasClass rdf:about="#Car"/>
    </daml:Restriction>
  </daml:intersectionOf>
</daml:Class>
```

DAML+OIL Ontologies

As of today, there are more than hundred DAML+OIL ontologies for various aspects of life defined:

```
...
airport
AirportCode
alias
annotation
Army
Art
assembly
association
Assorted
aviation
baseball
Beer
Bibliographies
BibTex
bioinformatics
Biology
boats
Brewers
...
```

. . . but none for our purposes.

There is no ontology to define the general properties of agents, and there are is no ontology for evolutionary computing.

$\rightarrow$ creating such an ontology should be interesting for BANG 3.

Example: Beer

```
* Beer (alcoholContent, madeFrom)
      o Ale ()
            + Bitter ()
            + BrownAle ()
            + Mild ()
            + PaleAle ()
      + ScotchAle ()
      o Bock ()
      o Lager ()
      o Pilsner ()
      o Porter ()
* Brewery (brews)
  o Microbrewery ()
```

```
* Ingredient ()
      o Hops ()
            + Cascade ()
            + Chinook ()
            + Galena ()
            + Hallertau ()
            + KentGoldings ()
            + Tettnang ()
            + Willamette ()
      o Malt ()
            + Black ()
            + Munich ()
            + Pale ()
      o Yeast ()
```

Example: Baseball

```
# Base ()
    * instance First
    * instance HomePlate
    * instance Second
    * instance Third
# Contract (player, team)
# Division (team)
# Employee (person, team)
    * Coach ()
    * Manager ()
    * Player ()
```

```
# Event ()
    * AggregateEvent ()
        o AtBat (player)
        o Game (date, innings)
            + AllStarGame ()
            + ExhibitionGame ()
            + PostSeasonGame ()
            # WorldSeriesGame ()
        o Inning (number)
    * BattingEvent ()
        o Ball ()
        o Bunt ()
        o Fly ()
        o Foul ()
        o Hit ()
            + Double ()
            + HomeRun ()
            + Single ()
            + Triple ()
        o HitByPitch ()
```

What to do?

- DAML+OIL ontology for the kind of agents used by BANG 3
- Implementation of agents using ontologies and an ontology agent
- Reasoning about ontologies / inference system
- Agents, ontologies and trust
- AgentCities and other agents out there. . .