Multiagent Systems (SMA-UPC)

2. Knowledge Representation and Communication

Part 1: Knowledge Representation

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Communicating Agents…

- Mutual understanding:
  - Translation between representation languages
  - Share the language's semantic content
- Three components in communication:
  - Interaction protocol
    - How are conversations/dialogues structured?
  - Communication Language
    - What does each message means?
  - Transport protocol
    - How messages are actually sent and received by agents?

2.(Part 1) Knowledge Representation

Communication and Knowledge Level

- Agents can be considered as (virtual) Knowledge Bases
- 3 representation levels
  - A language/formalism to represent domain knowledge
    - **Ontology**
  - A language to express propositions (to exchange knowledge)
    - **Content language** (for messages)
  - A language to express attitudes for those propositions
    - **Agent Communication Language** (for languages)

Multiagent Systems (SMA-UPC)

Knowledge Representation

- **Motivation**
- **Ontology Design**
- **Languages for Knowledge exchange**

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2.(Part 1) Knowledge Representation

Ontologies

- Ontology science aims to study the categories that exist in a given domain.
- The result of this study is an **ontology**.
  - A catalogue of the different kinds of objects that we assume as existing in a given domain D, from the perspective of someone that uses a language L in order to talk about D.
- Elements in ontologies represent predicates, constants, concepts and relationships
- An ontology can be seen as the vocabulary that agents need to use in order to talk about a given domain.

2.(Part 1) Knowledge Representation

Ontologies
Motivation

- To allow **sharing an interpretation** of information structure between people/agents
  - By creating an ontology about a domain, agents can understand each other (unambiguously) and know what the other means with each message
- To allow knowledge reuse
  - Create a domain description which can be used by other applications which should use/share knowledge about that domain
- To make explicit the interpretations about the domain
  - Interpretations about concepts, predicates… can be compared. If conflicts arise, a common interpretation can be agreed upon.

Ontologies
Motivation

- Ontologies divide domain knowledge from operational knowledge
  - Allows to independently develop the techniques and algorithms to solve a problem from the concrete knowledge about the problem
- They allow analysis over domain knowledge
  - Once we have a knowledge specification, it can be analysed by means of formal methods (correctness, completeness …)

Ontologies
Design and development

- Creating an ontology requires
  - To define the classes in the domain
  - To organize the classes in a taxonomic hierarchy
  - To define each class' properties and include any restriction on their values
  - To assign values for each property to create instances.
- Components in ontologies (for agents)
  - Classes (descriptions of the concepts in a domain)
  - Properties (attributes and relations in classes)
  - Restrictions (data type, cardinality…)
  - Instances (constitute the concrete items/individuals represented by the ontology)

Ontologies
Design and development

- There is no single standard methodology to develop ontologies
- There is no single correct method to model a domain. Best solution depends on given application/domain.
- In most methodologies the following 5 phases are present
  - Phase 1: Determine the domain and coverage for the ontology
  - Phase 2: Consider to re-use existing ontologies
  - Phase 3: Enumerate the important terms in the ontology
  - Phase 4: Define the classes and their hierarchy
  - Phase 5: Define the attributes for each class
- For more details, check the "Ontology 101" document.

Ontologies
Languages

2.(Part 1) Knowledge Representation

- Need to express ontologies in a machine-computable language (usable by agents in their messages and in their reasoning)
  - A language simple enough to make ontology development easier
  - A language with formal semantics
    - Formal semantics are needed in order to obtain deductions from the information in the ontology
  - A language allowing agents to reason with it
  - The computational cost should be reasonable

Description Logics

- FOL + new operators and symbols
  - $\doteq$ (if and only if), $\sqsubseteq$ (if)
  - $\sqcup$ union, $\sqcap$ intersection
  - $\top$ (universal set, theorem), $\perp$ (empty set, contradiction)
- Distinction between two kinds of predicates
  - Concepts (C)
  - Relations (R)
- Quantified formulae are rewritten:

$$\exists R.C \equiv \exists y(R(x,y) \wedge C(y))$$
$$\forall R.C \equiv \forall y(R(x,y) \rightarrow C(y))$$

Description Logics

Example

- A student, by def., is a person which has a name, an address and has registered for a course.

$$\textit{Student} \doteq \textit{Person} \sqcap \exists \textit{Name.String} \sqcap \exists \textit{Address.String} \sqcap \exists \textit{Registered.Course}$$

$$\equiv$$

$$\forall x(\textit{Student}(x) \rightarrow \textit{Person}(x) \wedge \exists y(\textit{Name}(x,y) \wedge \textit{String}(y)) \wedge \exists z(\textit{Address}(x,z) \wedge \textit{String}(z) \wedge \exists w(\textit{Registered}(x,w) \wedge \textit{Course}(w)))$$

- A person should be a man or a woman.

$$\textit{Person} \sqsubseteq \textit{Man} \sqcup \textit{Woman} \equiv \forall x(\textit{Person}(x) \rightarrow \textit{Man}(x) \vee \textit{Woman}(x))$$

Ontologies
Languages

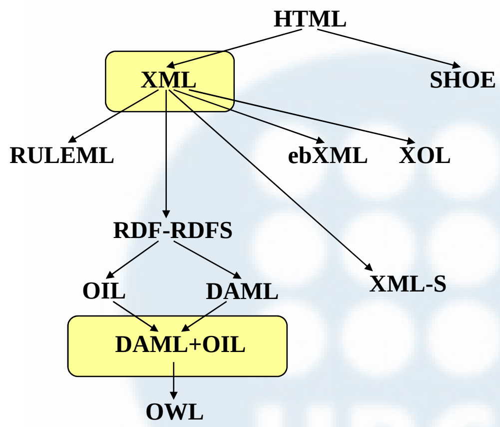
Generic Languages

CyCL – CP1

KIF – CP1 (Description Logic)

CLIPS – COOL (Object Oriented)

Markup languages



KIF
Knowledge Interchange Format

- Developed at Stanford University (1992)
- Idea: to have an exchange format between applications, independent from their internal representations.
- Based in First Order Logic (FOL)
  - Prefix notation + definitions
- Semantics: Description Logics (Definitions + needed conditions)

2.(Part 1) Knowledge Representation

KIF

- KIF has FOL's operators
  - Boolean values: **`true`**, **`false`**
  - Connectives:
    - **and**, **or**, **not**,
    - **=>** (if) **<=** (only if), **<=>** (definition)
  - Quantifiers: **`forall`**, **`exists`**
  - Vars: **?x** (individual var) **@x** (var group, as in PROLOG)
- E.g., **`(forall (?x)(> ?x 3))`**
- Lists can be built and used as basic data types (as LISP)

```
(listof 3 ''HOLA'' 2.34)
```

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2.(Part 1) Knowledge Representation

KIF

- Functions can be defined

```
(deffunction abs (?x) := ((if (>= ?x 0) ?x (- ?x))))
```

- Relations can be defined

```
(defrelation number (?x) :=
   (or (integer ?x) (real ?x) (complex ?x)))
≡
(<=> (number ?x)
   (or (integer ?x) (real ?x) (complex ?x)))
```

- Metaknowledge expressions

```
(believes john '(exists (?x) (> ?x 3)))
```

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KIF
example

- Class person

```
(defrelation name (?x) := (string ?x))

(defrelation age (?x) := (integer ?x))

(defrelation person (?x ?y) :=
   (listof (name ?x) (age ?y))

(defobject juan:= (person “Juan” 25))

(defrelation adult (?x) :=
   (and (= ?x (person ?x ?y))
        (> ?y 18)))
```


Markup Languages: XML

- Idea of a Semantic Web:
  - Information semantically annotated in a machine-parseable language
- HTML is not enough
  - Language oriented to presentation
- Idea: to use XML (derived from SGML)
- Advantages
  - allows to describe attributes in information
  - already used by industrial initiatives
  - allows integration from different data sources (by means of XSLT translation rules)
  - Non-proprietary language

XML

- An XML document can contain Data Type Definitions inside or can refer to a DTD file
- One can create repositories of reusable definitions (namespaces)
- E.g.:

```
<!Element direction (name, place)>
<!Element place (street, city)>
<!Element name (#PCDATA)>
...
<direction>
  <name> John </name>
  <place>
    <street> Oxford St. </street>
    <city> London </city>
  </place>
</direction>
```


From XML to DAML+OIL

- Problems:
  - XML is too rigid (tree-like structures)
  - Difficult to include relationships to the structures defined
  - Difficult to assert predicates
- Extension: RDF + RDFS
  - RDF allows to assert statements
  - RDFS declares classes, attributes and relations
  - RDFS definitions can be instantiated
- Even more powerful extension: DAML+OIL
  - DARPA agent markup language
  - Ontology Inference Layer

DAML+OIL
example

```
<daml:Ontology>
<daml:Class rdf:ID="Person"/>

<daml:ObjectProperty rdf: ID="Name">
 <daml:domain rdf:Resource="http://..." />
</daml:ObjectProperty>

<daml:ObjectProperty rdf: ID="Parent_of">
 <daml:domain rdf:Resource="#Person" />
 <daml:range rdf:Resource="#Person" />
 <daml:Restriction daml:Cardinality="2" />
</daml: ObjectProperty>

<daml:ObjectProperty rdf: ID="Son_of">
 <daml:InverseOf rdf:Resource="#Parent_of" />
</daml: ObjectProperty>

</daml:Class>
</daml:Ontology>
```


DAML+OIL
example

```
<Person rdf:ID="John"/>
<rdfs:comment> John is Peter's father </rdfs:comment>
<Age> 38 </Age>
<Parent_of:Resource="#Peter" />
</Person>

<Person rdf:ID="Peter"/>
<Age> 12 </Age>
<Son_of:Resource="#John" />
</Person>
```

- Further extension: OWL (Ontology Web Language)
  - Fusion of DAML+OIL, standard of W3C
  - 3 levels:
    - *OWL lite*: defines taxonomies and simple restrictions
    - *OWL DL*: provides expressiveness as Description Logic
    - *OWL full*: maximum expressiveness (but not available reasoners)

2.(Part 1) Knowledge Representation

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These slides are based mainly in W3C documents, [2], [5] and material from U. Cortés and J. Bejar.