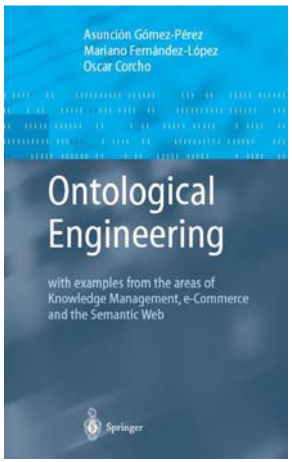
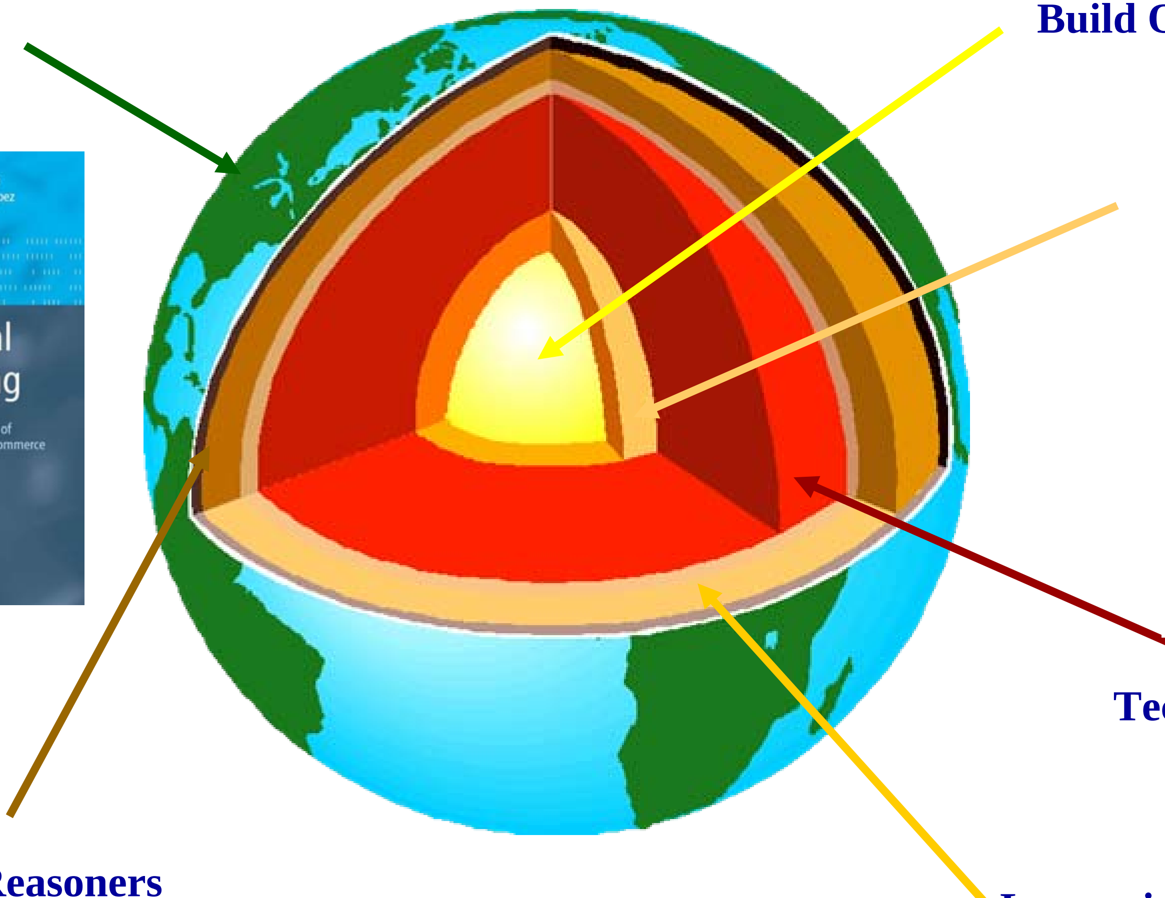
Main Components

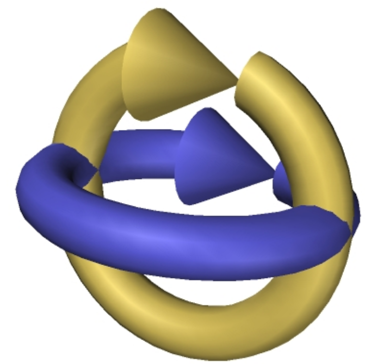
Applications





Build Ontologies

Methodologies and Methods



Technological Support

Reasoners

Languajes

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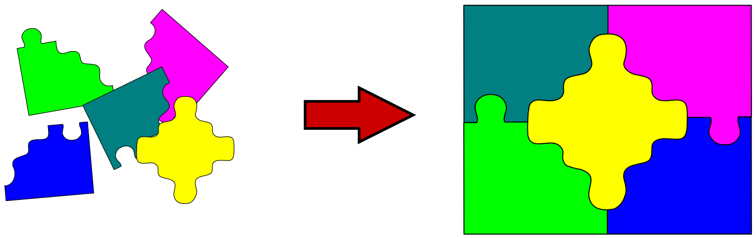
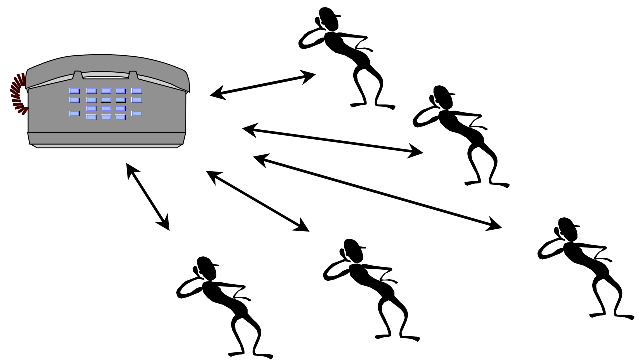
Reuse and Sharing

Reuse means to build new applications assembling components already built



Sharing is when different applications use the some resources



Advantages:

- **Less money**
- **Less time**
- **Less resources**

Areas:

- **Software**
- **Knowledge**
- **Communications**
- **Interfaces**
- **---**

The knowledge Sharing Initiative

"Building new Knowledge Based Systems today usually entails constructing new knowledge bases from scratch. It could instead be done by assembling reusable components. System developers would then only need to worry about creating the specialized knowledge and reasoners new to the specific task of their systems. This new system would interoperate with existing systems, using them to perform some of its reasoning. In this way, declarative knowledge, problem-solving techniques, and reasoning services could all be shared between systems. This approach would facilitate building bigger and better systems cheaply. The infraestructure to support such sharing and reuse would lead to greater ubiquity of these systems, potentially transforming the knowledge industry ..."

Neches, R.; Fikes, R.; Finin, T.; Gruber, T.; Patil, R.; Senator, T.; Swartout, W.R. *Enabling Technology for Knowledge Sharing*. **AI Magazine**. Winter 1991. 36-56.

Reusable Knowledge Components

Ontologies

Describe domain knowledge in a generic way and provide agreed understanding of a domain

Problem Solving Methods

Describe the reasoning process of a KBS in an implementation and domain-independent manner

Interaction Problem

Representing Knowledge for the purpose of solving some problem

is strongly affected by the nature of the problem

and the inference strategy to be applied to the problem [Bylander et al., 88

Bylander Chandrasekaran, B. **Generic Tasks in knowledge-based reasoning.: the right level of abstraction for knowledge acquisition.** In B.R. Gaines and J. H. Boose, EDs *Knowledge Acquisition for Knowledge Based systems*, 65-77, London: Academic Press 1988.

Ontological Engineering

It refers to the set of activities that concern

the ontology development process,

the ontology life cycle,

the methods and methodologies for building ontologies,

and the tool suites

and languages that support them.

Table of Content

Definitions of Ontologies (I)

1. "An ontology defines the basic terms and relations comprising the vocabulary of a topic area, as well as the rules for combining terms and relations to define extensions to the vocabulary"

Neches, R.; Fikes, R.; Finin, T.; Gruber, T.; Patil, R.; Senator, T.; Swartout, W.R. *Enabling Technology for Knowledge Sharing*. **AI Magazine**. Winter 1991. 36-56.

2. "An ontology is an explicit specification of a conceptualization"

Gruber, T. *A translation Approach to portable ontology specifications.* **Knowledge Acquisition**. Vol. 5. 1993. 199-220.

Definitions of Ontologies (II)

3. **An ontology is a hierarchically structured set of terms for describing a domain that can be used as a skeletal foundation for a knowledge base.**

B. Swartout; R. Patil; k. Knight; T. Russ. *Toward Distributed Use of Large-Scale Ontologies* **Ontological Engineering.** AAAI-97 Spring Symposium Series. 1997. 138-148.

4. **An ontology provides the means for describing explicitly the conceptualization behind the knowledge represented in a knowledge base.**

A. Bernaras;I. Laresgoiti; J. Correra. *Building and Reusing Ontologies for Electrical Network Applications* **ECAI96. 12th European conference on Artificial Intelligence.** Ed. John Wiley & Sons, Ltd. 298-302.

Definitions of Ontologies (III)

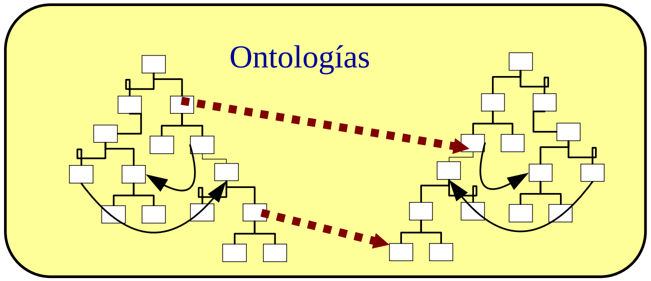
5. "An ontology is a formal, explicit specification of a shared conceptualization"

Machine-readable

Concepts, properties relations, functions, constraints, axioms, are explicitly defined

Consensual Knowledge

Abstract model and simplified view of some phenomenon in the world that we want to represent



Studer, Benjamins, Fensel. **Knowledge Engineering: Principles and Methods.** ***Data and Knowledge Engineering*. 25 (1998) 161-197**

Definitions of Ontologies (IV)

Lightweight Ontologies :

- **Include Concepts with properties and Taxonomies**
- **Do not include Axioms and constraints.**

Heavyweight Ontologies :

- **Include all the components**
- **Excellent!! If they have a lot of axioms.**

Table of Content

Components of an Ontology

Concepts are organized in **taxonomies**

Relations R: $C_1 \times C_2 \times \ldots \times C_{n-1} \times C_n$

> Subclass-of: Concept 1 x Concept2
> Connected to: Component1 x Component2

Functions F: $C_1 \times C_2 \times \ldots \times C_{n-1} \dashrightarrow C_n$

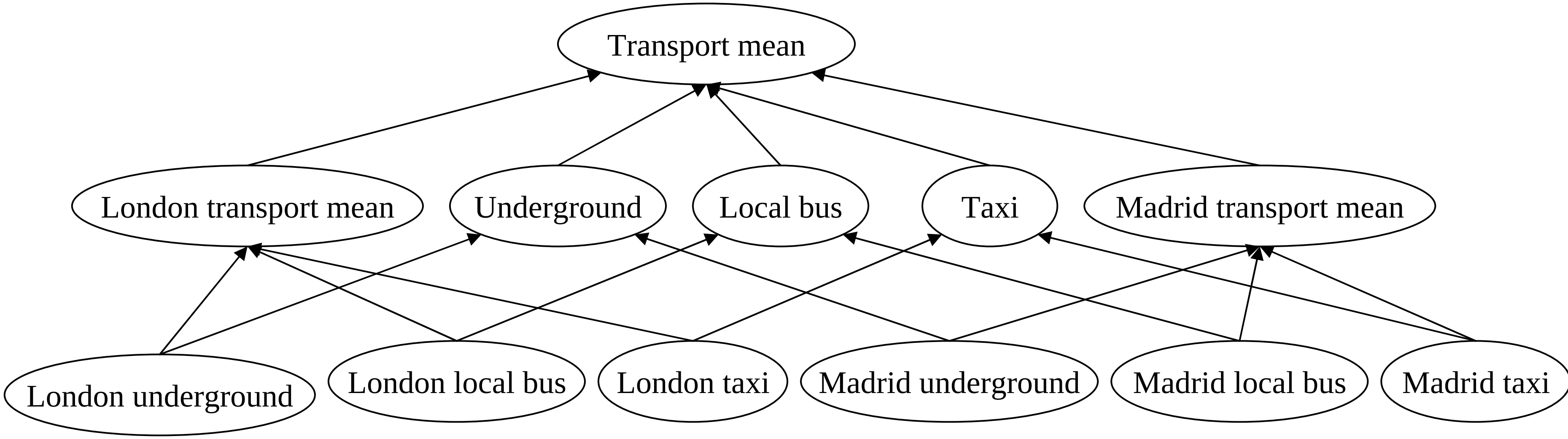
> Mother-of: Person --> Women
> Price of a used car: Model x Year x Kilometers --> Price

Instances Elements

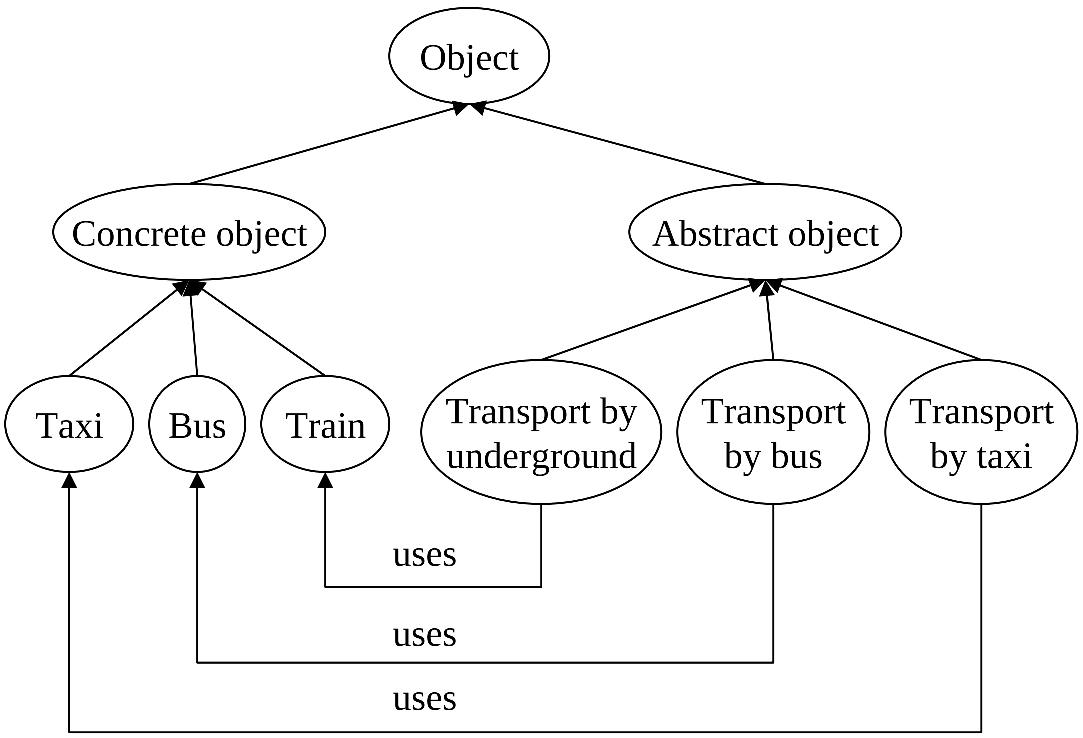
Axioms Sentences which are always true

Gruber, T. *A translation Approach to portable ontology specifications.* **Knowledge Acquisition**. Vol. 5. 1993. 199-220.

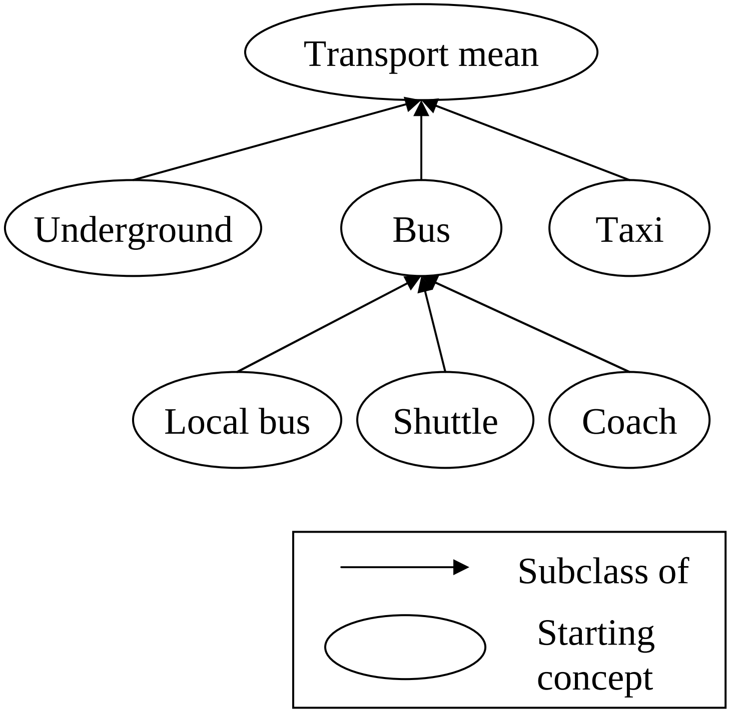
Strategies for building taxonomies: Botton up strategy



Strategies for building taxonomies: Top Down strategy



Strategies for building taxonomies: Middle out strategy



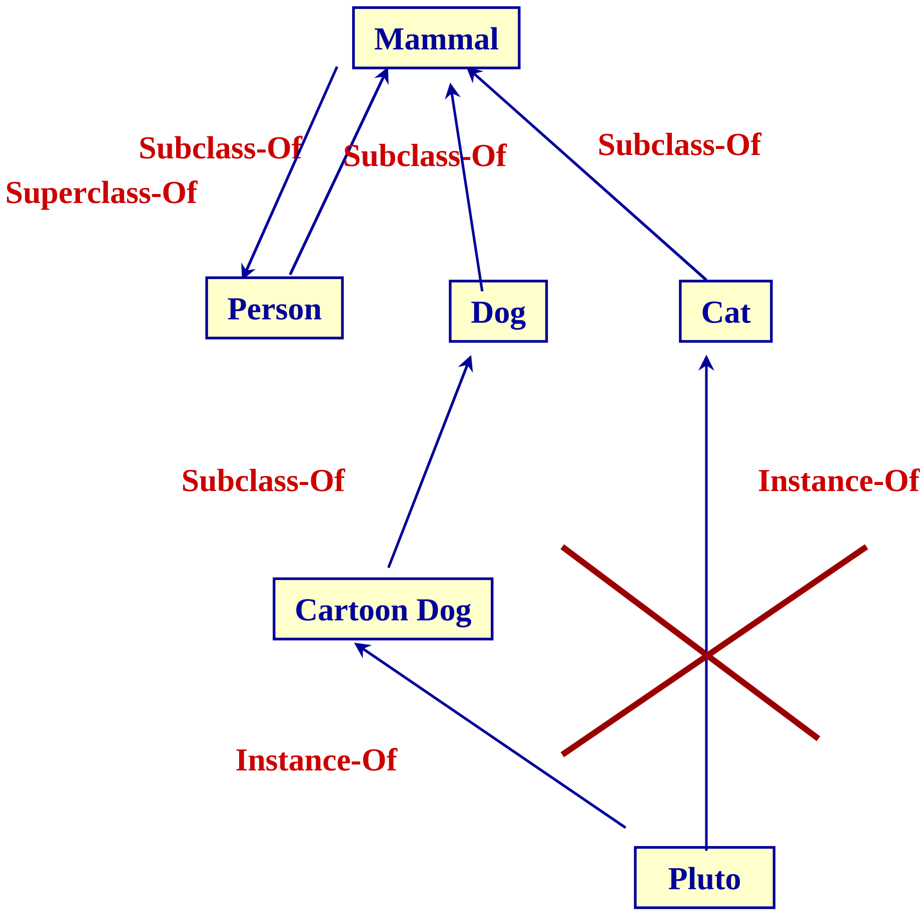
Primitivas necesarias para modelizar conocimientos disjuntos en taxonomías

class-Partition: **a set of disjoint classes**

Disjoint: **Defines the set of classes in the partition as subclasses of the parent class. This classification does not necessarily to be complete.**

Exhaustive-Disjoint: **Defines the set of classes in the partition as subclasses of the parent class. This classification is complete.**

Why disjoint knowledge is important (I)

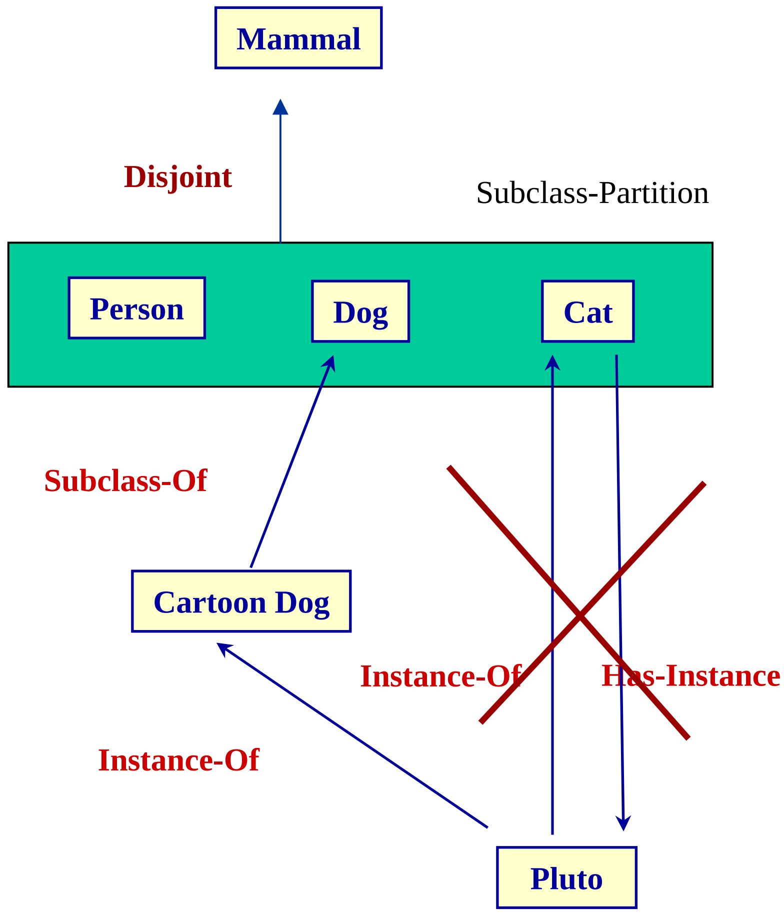


A. Gómez-Pérez. *Evaluation of Ontologies.* **International Journal of Intelligent Systems.** Vol. 16, Nº3. March 2001. PP391-410

Pluto could be an instance of cat and dog

Semantic Error

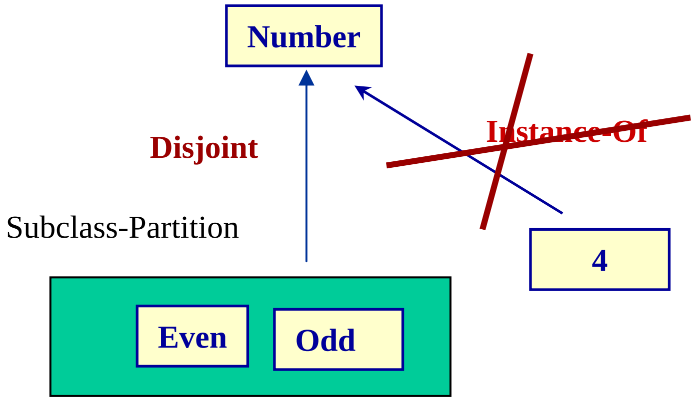
Why disjoint knowledge is important (II)

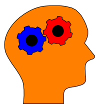


A. Gómez-Pérez. *Evaluation of Ontologies.* **International Journal of Intelligent Systems.** Vol. 16, Nº3. March 2001. PP391-410

Pluto can not be simultaneously a class of Cat and Dog because they are disjoint

Why disjoint knowledge is important (III)

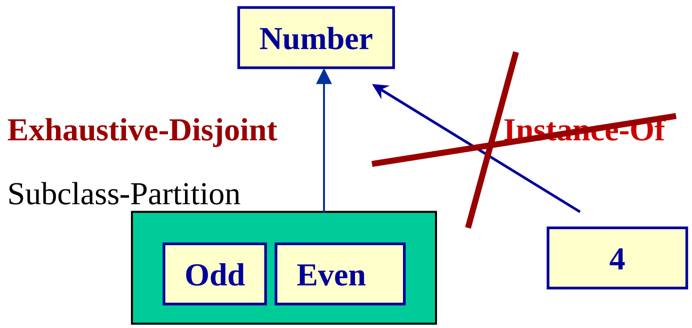


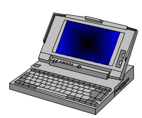


Four is an instance of Par

A. Gómez-Pérez. *Evaluation of Ontologies.* **International Journal of Intelligent Systems.** Vol. 16, Nº3. March 2001. PP391-410

Why disjoint knowledge is important (IV)



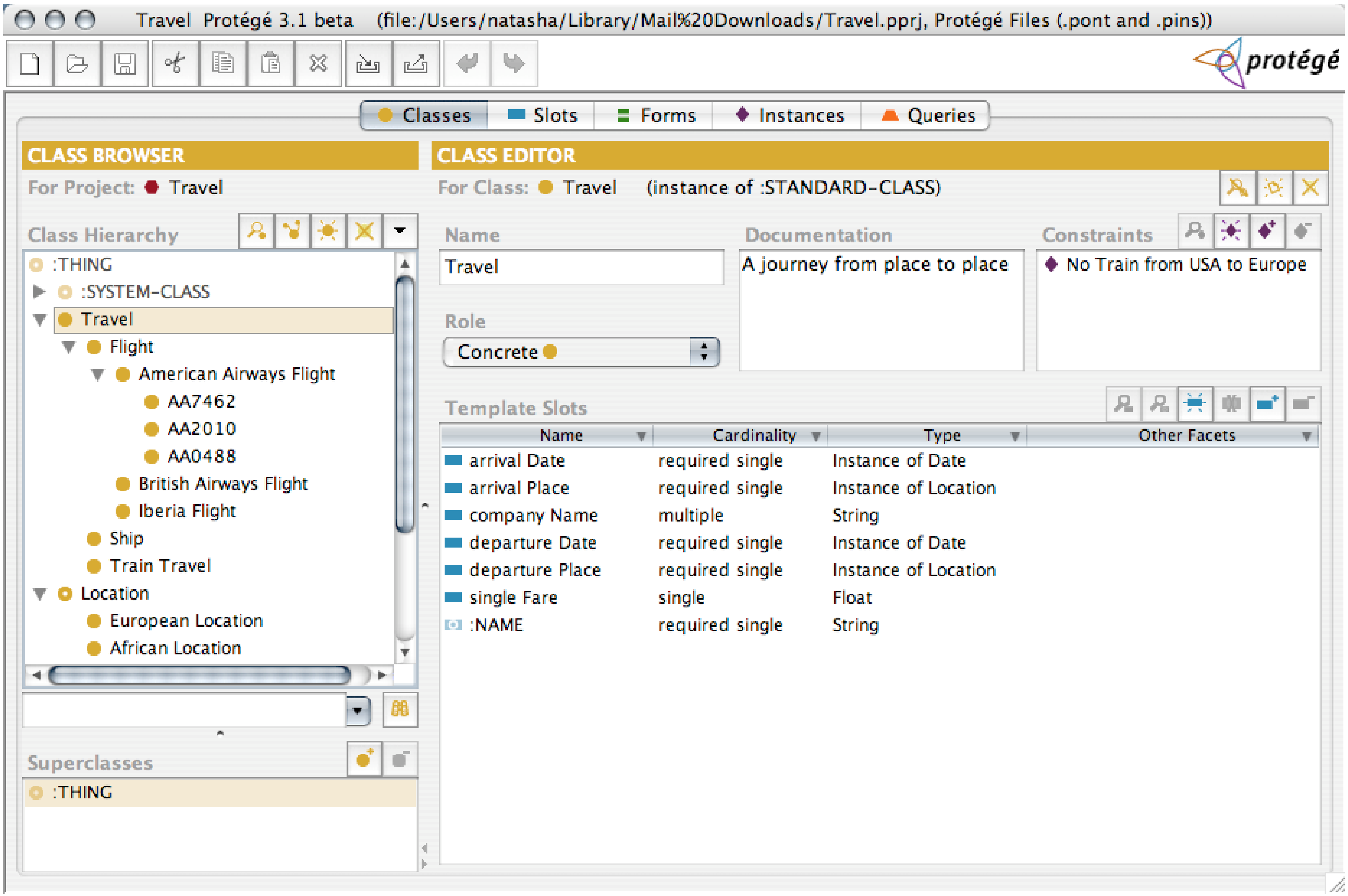


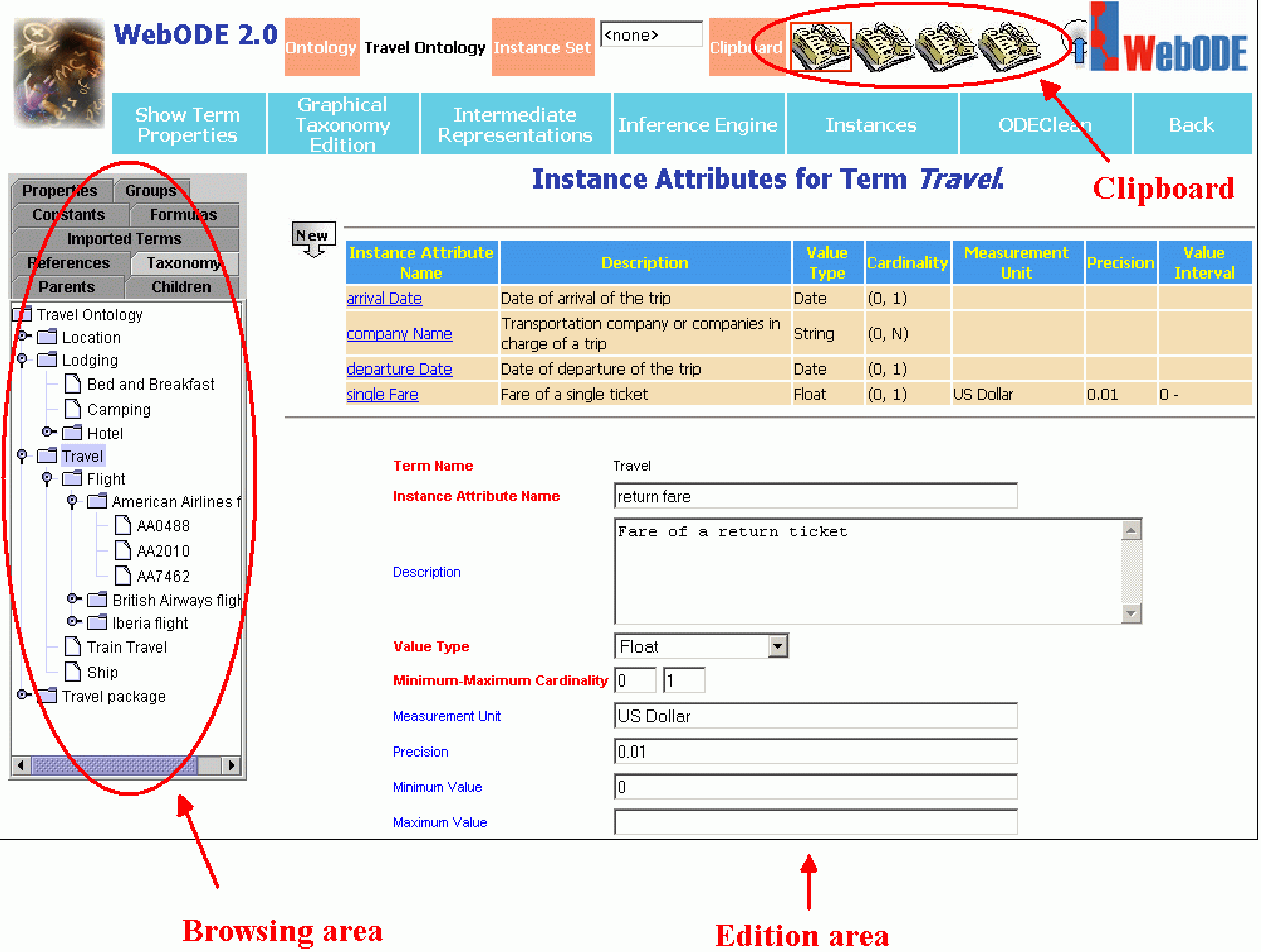
Four is an instance of something in the partition

Example of axioms

```
(define-axiom No-Train-from-USA-to-Europe
   "It is not possible to travel from the USA to Europe by train"
:= (forall (?travel)
    (forall (?city1)
     (forall (?city2)
       (=> (and (Travel ?travel)
                (arrivalPlace ?travel ?city1)
                (departurePlace ?travel ?city2)
                (EuropeanLocation ?city1)
                (USALocation ?city2))
           (not (TrainTravel ?travel)))))))


(define-axiom No-Train-between-USA-and-Europe
   "It is not possible to travel by train between the USA and Europe"
:= (forall (?travel)
    (forall (?city1)
     (forall (?city2)
      (=> (and (Travel ?travel)
               (arrivalPlace ?travel ?city1)
               (departurePlace ?travel ?city2)
               (or (and (EuropeanLocation ?city1)
                        (USALocation ?city2))
                   (and (EuropeanLocation ?city2)
                        (USALocation ?city1))))
          (not (TrainTravel ?travel)))))))
```


Travel Protégé 3.1 beta (file:/Users/natasha/Library/Mail%20Downloads/Travel.pprj, Protégé Files (.pont and .pins))
protégé
Classes
Slots
Forms
Instances
Queries
CLASS BROWSER
For Project: Travel
Class Hierarchy
:THING
:SYSTEM-CLASS
Travel
Flight
American Airways Flight
AA7462
AA2010
AA0488
British Airways Flight
Iberia Flight
Ship
Train Travel
Location
European Location
African Location
Superclasses
:THING
CLASS EDITOR
For Class: Travel (instance of :STANDARD-CLASS)
Name
Travel
Documentation
A journey from place to place
Constraints
No Train from USA to Europe
Role
Concrete
Template Slots
Name
Cardinality
Type
Other Facets
arrival Date required single Instance of Date
arrival Place required single Instance of Location
company Name multiple String
departure Date required single Instance of Date
departure Place required single Instance of Location
single Fare single Float
:NAME required single String


WebODE 2.0
Ontology
Travel Ontology
Instance Set
<none>
Clipboard
WebODE
Show Term Properties
Graphical Taxonomy Edition
Intermediate Representations
Inference Engine
Instances
ODEClean
Back
Clipboard
Instance Attributes for Term Travel
Properties
Groups
Constants
Formulas
Imported Terms
References
Taxonomy
Parents
Children
Travel Ontology
Location
Lodging
Bed and Breakfast
Camping
Hotel
Travel
Flight
American Airlines f
AA0488
AA2010
AA7462
British Airways fligh
Iberia flight
Train Travel
Ship
Travel package
New
Instance Attribute Name
Description
Value Type
Cardinality
Measurement Unit
Precision
Value Interval
arrival Date
Date of arrival of the trip
Date
(0, 1)
company Name
Transportation company or companies in charge of a trip
String
(0, N)
departure Date
Date of departure of the trip
Date
(0, 1)
single Fare
Fare of a single ticket
Float
(0, 1)
US Dollar
0.01
0 -
Term Name
Travel
Instance Attribute Name
return fare
Description
Fare of a return ticket
Value Type
Float
Minimum-Maximum Cardinality
0
1
Measurement Unit
US Dollar
Precision
0.01
Minimum Value
0
Maximum Value
Browsing area
Edition area

Using Frames and First Order Logic for Modeling Ontologies

```
(define-class Travel (?travel)
  "A journey from place to place"
:axiom-def
 (and (Superclass-Of Travel Flight)
     (Template-Facet-Value Cardinality
          arrivalDate Travel 1)
     (Template-Facet-Value Cardinality
          departureDate Travel 1)
     (Template-Facet-Value Maximum-Cardinality
          singleFare Travel 1))
:def
  (and (arrivalDate ?travel Date)
      (departureDate ?travel Date)
      (singleFare ?travel Number)
      (companyName ?travel String)))
```

```
(define-instance AA7462-Feb-08-2002 (AA7462)
:def ((singleFare AA7462-Feb-08-2002 300)
     (departureDate AA7462-Feb-08-2002 Feb8-2002)
     (arrivalPlace AA7462-Feb-08-2002 Seattle)))
```

```
(define-function Pays (?room ?discount) :-> ?finalPrice
  "Price of the room after applying the discount"
:def (and (Room ?room) (Number ?discount)
          (Number ?finalPrice)
          (Price ?room ?price))
:lambda-body
          (- ?price (/ (* ?price ?discount) 100)))
```

```
(define-relation connects (?edge ?source ?target)
  "This relation links a source and a target by an edge.
The source and destination are considered as spatial
points. The relation has the following properties: symmetry
and irreflexivity."
:def (and (SpatialPoint ?source)
          (SpatialPoint ?target)
          (Edge ?edge))
:axiom-def
((=> (connects ?edge ?source ?target)
    (connects ?edge ?target ?source)) ;symmetry
 (=> (connects ?edge ?source ?target)
    (not (or (part-of ?source ?target) ;irreflexivity
          (part-of ?target ?source))))))
```

Using Description Logics for Modeling Ontologies

```
(defconcept Travel
  "A journey from place to place"
:is-primitive
 (:and
   (:all arrivalDate Date)(:exactly 1 arrivalDate)
   (:all departureDate Date)(:exactly 1
departureDate)
   (:all companyName String)
   (:all singleFare Number)(:at-most singleFare 1)))
```

```
(defrelation Pays
:is
 (:function (?room ?Discount)
  (- (Price ?room) (/(*(Price ?room) ?Discount) 100)))
:domains (Room Number)
:range Number)
```

```
(defrelation connects
  "A road connects two different cities"
:arity 3
:domains (Location Location)
:range RoadSection
:predicate
 ((?city1 ?city2 ?road)
  (:not (part-of ?city1 ?city2))
  (:not (part-of ?city2 ?city1))
  (:or (:and (start ?road ?city1)(end ?road ?city2))
     (:and (start ?road ?city2)(end ?road ?city1)))))
```

```
(tellm (AA7462 AA7462-08-Feb-2002)
      (singleFare AA7462-08-Feb-2002 300)
      (departureDate AA7462-08-Feb-2002 Feb8-2002)
      (arrivalPlace AA7462-08-Feb-2002 Seattle))
```

Different Approaches to Build Ontologies

- The formalism and the language limit the kind of knowledge that can be represented

- All the aforementioned formalisms allow representing: classes, organized in class taxonomies, attributes, and binary relations

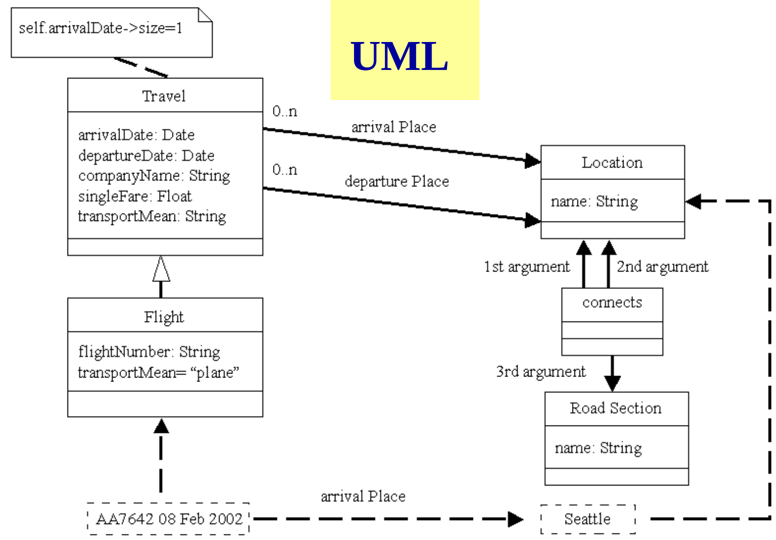
- Only AI formalisms are specially prepared to model formal axioms either as independent components in the ontology or embedded in other components

- A domain model is not necessarily an ontology only because it is written in Ontolingua or OWL, for the same reasons that we cannot say that a program is a knowledge-based system because it is written in Prolog

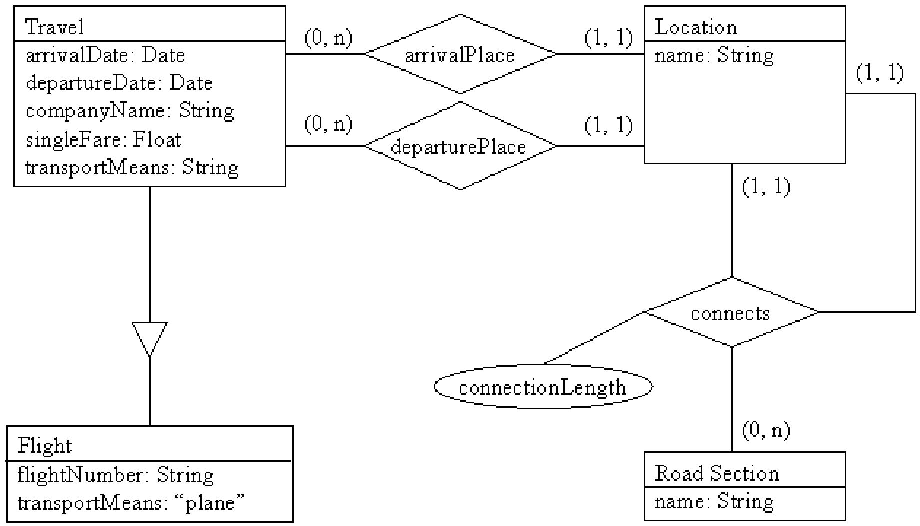
- Although some languages are more appropriate than others to represent ontologies, a model is an ontology only if it is agreed and machine readable

Approaches for building ontologies

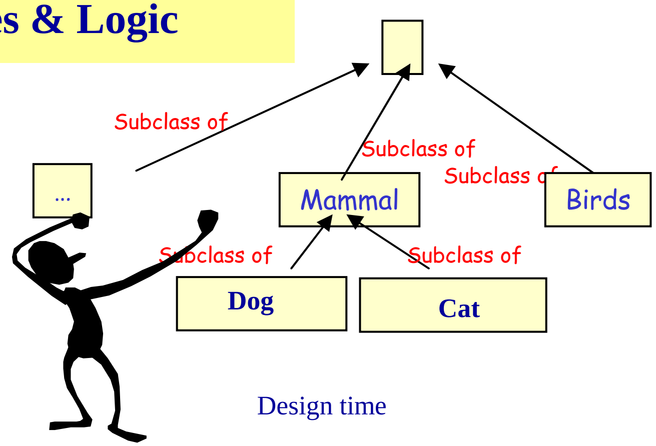
UML



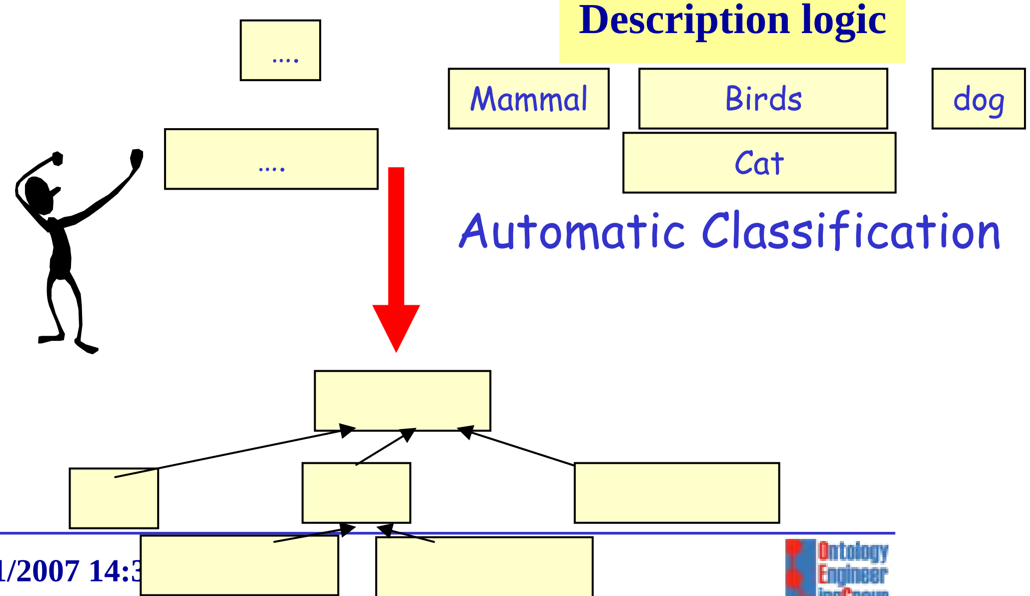
E/R Model



Frames & Logic



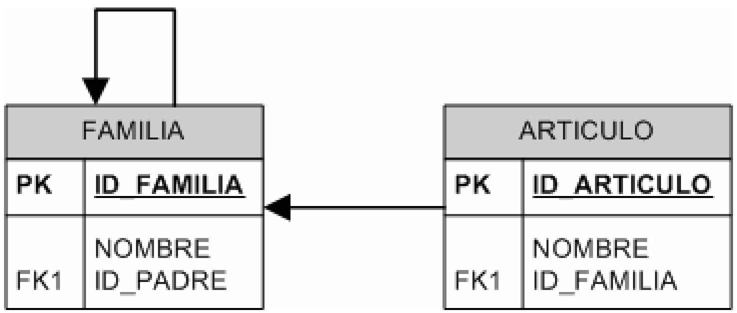
Description logic



Modelización y consulta con BB.DD. (ejemplo práctico)

PROBLEMA: se desea modelizar un catálogo de artículos informáticos. Los artículos se clasifican en familias (monitores, impresoras, consumibles, juegos, aplicaciones de productividad, etc.). Una familia puede ser subfamilia de otra dada (monitor e impresora de hardware, juegos y aplicaciones de software, etc.). Un artículo pertenece a una familia data. Diseñar un modelo y escribir la consulta que permite **obtener todos los productos de la familia Hardware.**

Esquema de la BB.DD.:



Contenido de ejemplo de las tablas:

ID_FAMILIA	NOMBRE	ID_PADRE
1	HARDWARE	
11	MONITOR	1
111	CRT	11
112	TFT	11
12	IMPRESORA	1
13	CONSUMIBLE	1
2	SOFTWARE	
...	...	...

ID_ARTICULO	NOMBRE	ID_FAMILIA
8947	SONY 15”	112
4233	HP LaserJet	12
4343	Toner Epson	13
4323	Tetris	21
7984	Microsoft Office	22
4455	AOC 17”	111
3454	Apple iLife	22
...	...	...

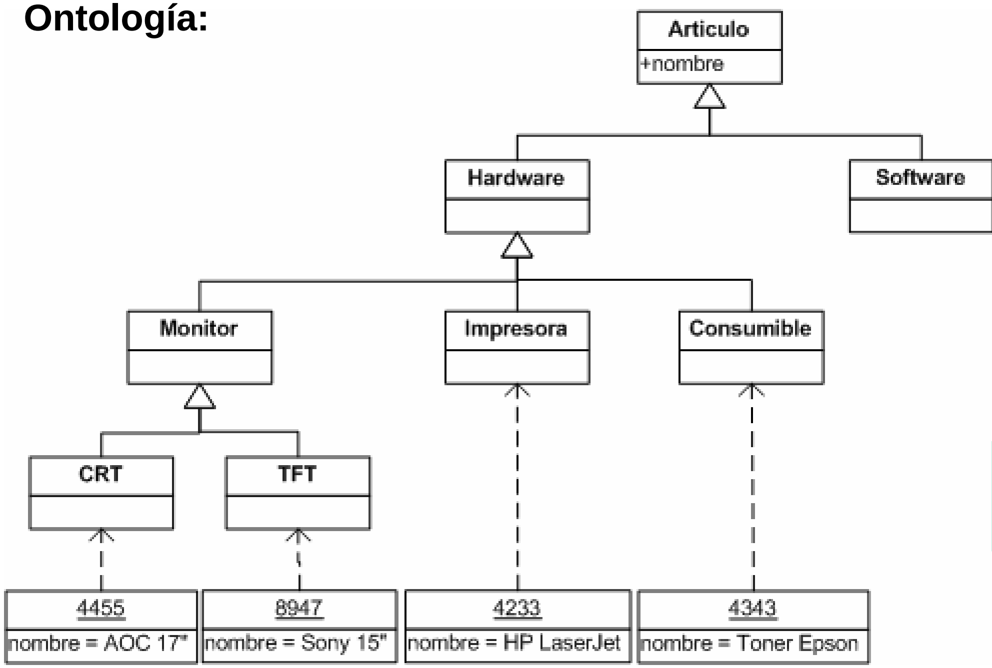
Solución usando consultas SQL:

```
pila.push(“Hardware”)                       // Añade a una pila vacía la famila por la cual se comienza la exploración
resultado = {}

while not pila.empty() do                   // Mientras la pila de familias por explorar no se encuentre vacía hacer:
   familia = pila.pop()                                                          // Se extrae una familia de la pila
   resultSet = SQL.execute(“SELECT HIJO.ID_FAMILA FROM FAMILIA AS HIJO LEFT JOIN FAMILIA AS PADRE ON HIJO.ID_PADRE =
      PADRE.ID_FAMILIA WHERE PADRE.ID_FAMILIA = ‘“ + familia + “’”)                  // Se obtienen las familias hijas
   pila.pushAllFrom(resultset)                                // Se añaden las familias padres obtenidas a la pila
   resultado.add(getArticulos(familia))                 // Se añade al resultado los artículos propios de esa familia
end

function getArticulos(familia)                                   // Función que obtiene los artículos de una familia dada
   resultSet = SQL.execute(“SELECT ARTICULO_ID FROM ARTICULO WHERE FAMILIA_ID = ‘” + familia + “’”)
   return resultSet
end
```

Ontología:



Solución usando consulta SPARQL:

```
resultado = SPARQL.execute("
   BASE http://delicias.dia.fi.upm.es/
   SELECT $articulo
   WHERE {$articulo a <Hardware>.}")
```

Ventajas con respecto a la aproximación con bases de datos:

1. **+** declarativo, **-** procedimental.
2.Los algoritmos de inferencia los implementa el razonador. El programador no se debe ocupar de ellos.
3.Al no tener que implementar el algoritmo se disminuye el riesgo de errores de programación.
4.La ontología se puede cambiar (p.e. ampliar) con mayor facilidad que el esquema de la base de datos.
5.Este ejemplo muestra únicamente la capacidad de inferencia con las taxonomías de clases. Existen otros tipos de inferencia dependiendo del formalismo elegido:

- Inferencia con taxonomías de propiedades.
- Clasificación automática.
- Equiparación.
- …

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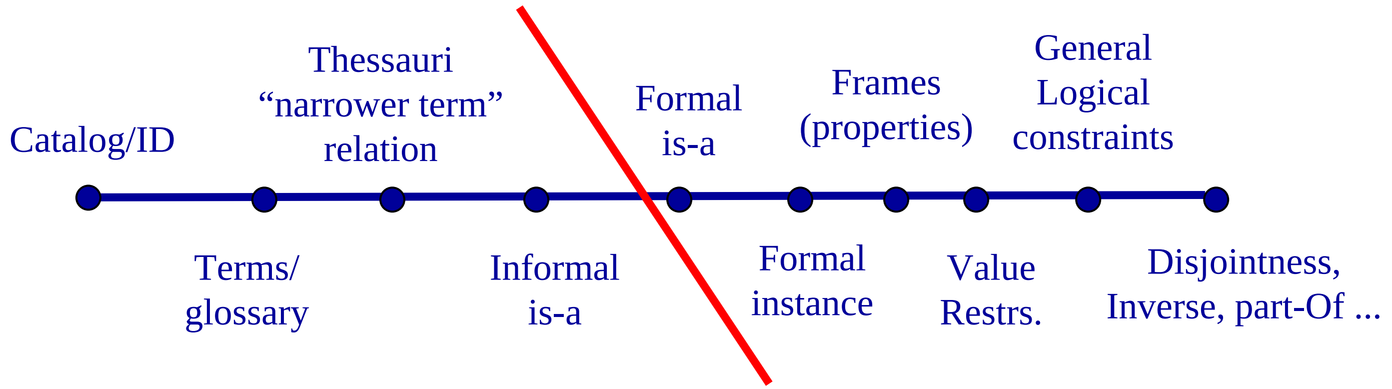
Types of Ontologies
Lassila and McGuiness Classification



Lassila O, McGuiness D. The Role of Frame-Based Representation on the Semantic Web. Technical Report. Knowledge Systems Laboratory. Stanford University. KSL-01-02. 2001.

Types of Ontologies

Content Ontologies

Domain O.
Scalpel, scanner
anesthetize, give birth

Task O.
goal, schedule
to assign, to classify

General/Common O.
Things, Events, Time, Space
Causality, Behavior, Function

Mizoguchi, R. Vanwelkenhuysen, J.; Ikeda, M.
Task Ontology for Reuse of Problem Solving Knowledge.
Towards Very Large Knowledge Bases:
Knowledge Building & Knowledge Sharing.
IOS Press. 1995. 46-59.

Issue of the Conceptualization

Representation O.
- Conceptualization of KR formalisms

Generic O.
- Reusable across D.

Domain O.
- Reusable

Application O.
- Non reusable
- Usable

Van Heist, G.; Schreiber, T.; Wielinga, B.
Using Explicit Ontologies in KBS
International Journal of Human-Computer Studies.
Vol. 46. (2/3). 183-292. 1997

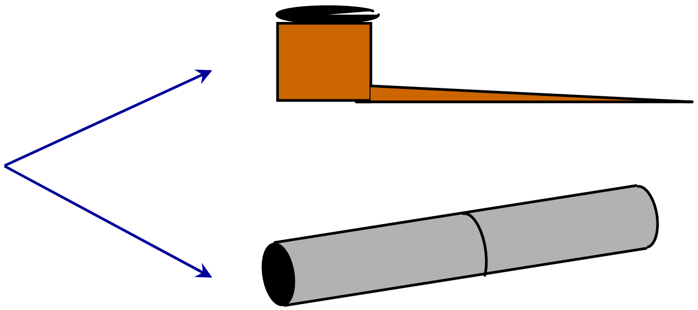
Ontological Commitments

Agreements to use the vocabulary in a coherent and consistent manner (Gruber)

Connection between the ontology vocabulary and the meaning of the terms of such vocabulary

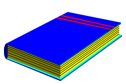
An agent commits (conforms) to an ontology if it "acts" consistently with the definitions

Example: What is a pipe?



9 definitions of the term flight from wordnet

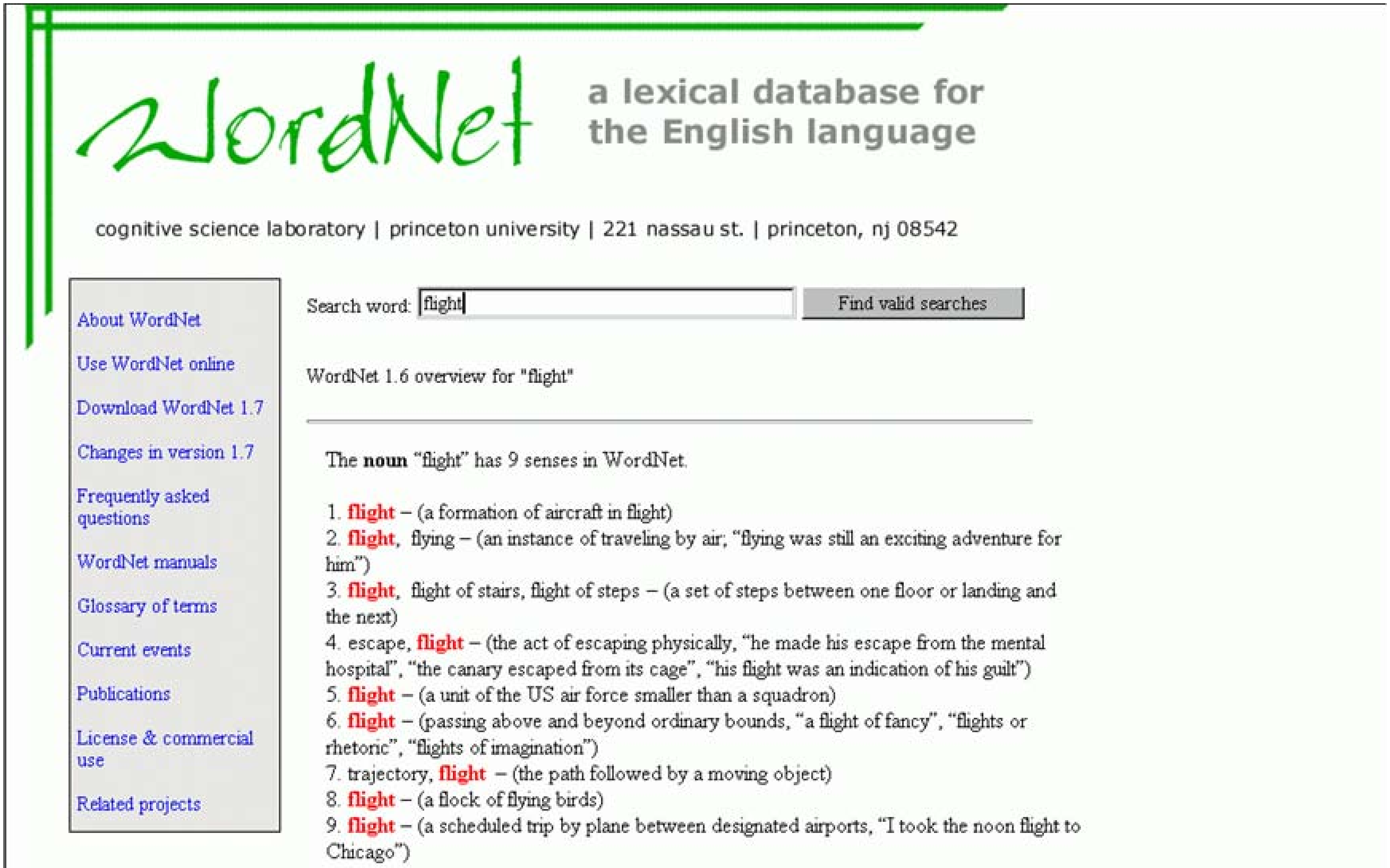
Identification of the ontological commitment



• Gruber, T.; Olsen, G. *An Ontology for Engineering Mathematics.* **Fourth International Conference on Principles of Knowledge Representation and Reasoning**. Ed by Doyle and Torasso. Morgan Kaufmann. 1994. Also as KSL-94-18.

• Guarino, N.; Carrara, M.; Giaretta, P. *Formalizing Ontological Commitments.* **12th National Conference on Artificial Intelligence. AAAI-**94. 1994. 560-567

Ontological Commitments



A formation of aircraft in flight

A scheduled trip by plane between designated airports

Vuelo	Salida		Llegada	
Iberia IB 545	Santiago (SCQ), Santiago, España	06:30	Barajas (MAD), Madrid, España	07:35
Iberia IB 6741	Barajas (MAD), Madrid, España	12:10	Eldorado (BOG), Bogotá, Colombia	16:45
Aces VX 7290	Eldorado (BOG), Bogotá, Colombia	18:00	Rafael Nunez (CTG), Cartagena, Colombia	19:18
Iberia IB 545	Santiago (SCQ), Santiago, España	06:30	Barajas (MAD), Madrid, España	07:35
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Aces VX 7290	Eldorado (BOG), Bogotá, Colombia	18:00	Rafael Nunez (CTG), Cartagena, Colombia	19:18

An instance of traveling by air

A flock of flying birds

OC_1

OC_2

OC_9

OC_8

flight

OC_3

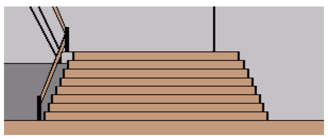
OC_4

OC_5

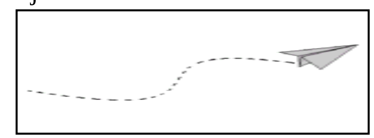
OC_6

OC_7

A set or steps between one floor or landing for him

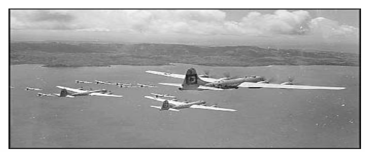


The path followed by a moving object



The act of escaping physically

A unit of the US air force smaller than a squadron



Passing above and beyond ordinary bounds

(**define-class** Flight (?X)
"A journey by plane"
:axiom-def
(**and** (**Subclass-Of** Flight Travel)
(**Template-Facet-Value** Cardinality
flightNumber Flight 1))
:class-slots ((transportMeans "plane")))

flight

Vuelo	Salida		Llegada	
Iberia IB 545	Santiago (SCQ), Santiago, España	06:30	Barajas (MAD), Madrid, España	07:35
Iberia IB 6741	Barajas (MAD), Madrid, España	12:10	Eldorado (BOG), Bogotá, Colombia	16:45
Aces VX 7290	Eldorado (BOG), Bogotá, Colombia	18:00	Rafael Nunez (CTG), Cartagena, Colombia	19:18
Iberia IB 545	Santiago (SCQ), Santiago, España	06:30	Barajas (MAD), Madrid, España	07:35
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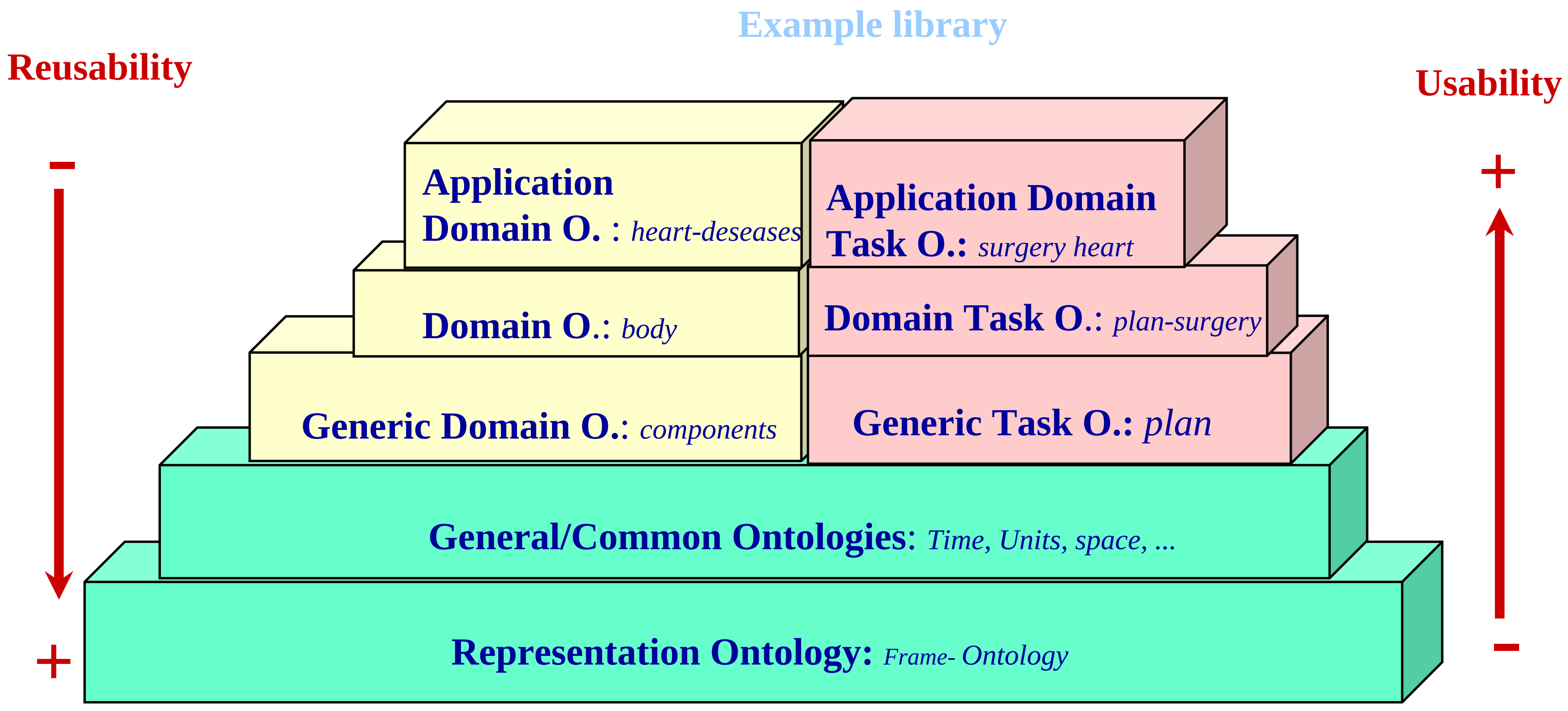
Table of Content

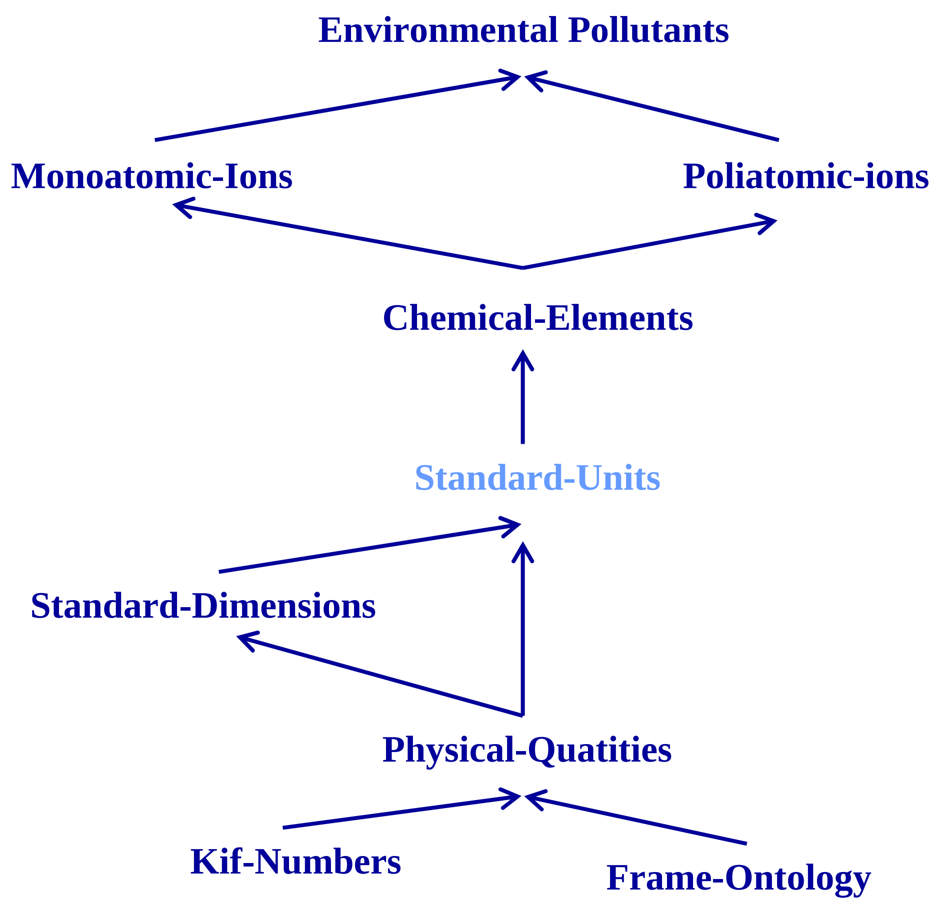
Ontologies

Libraries of Ontologies



http://delicias.dia.fi.upm.es/mirror-server/ont-serv.html

Relationship between Ontologies in the Library



Ontology Searching in Ontology Metadata Repositories

O. Searching
O. Assessment
O. Selection

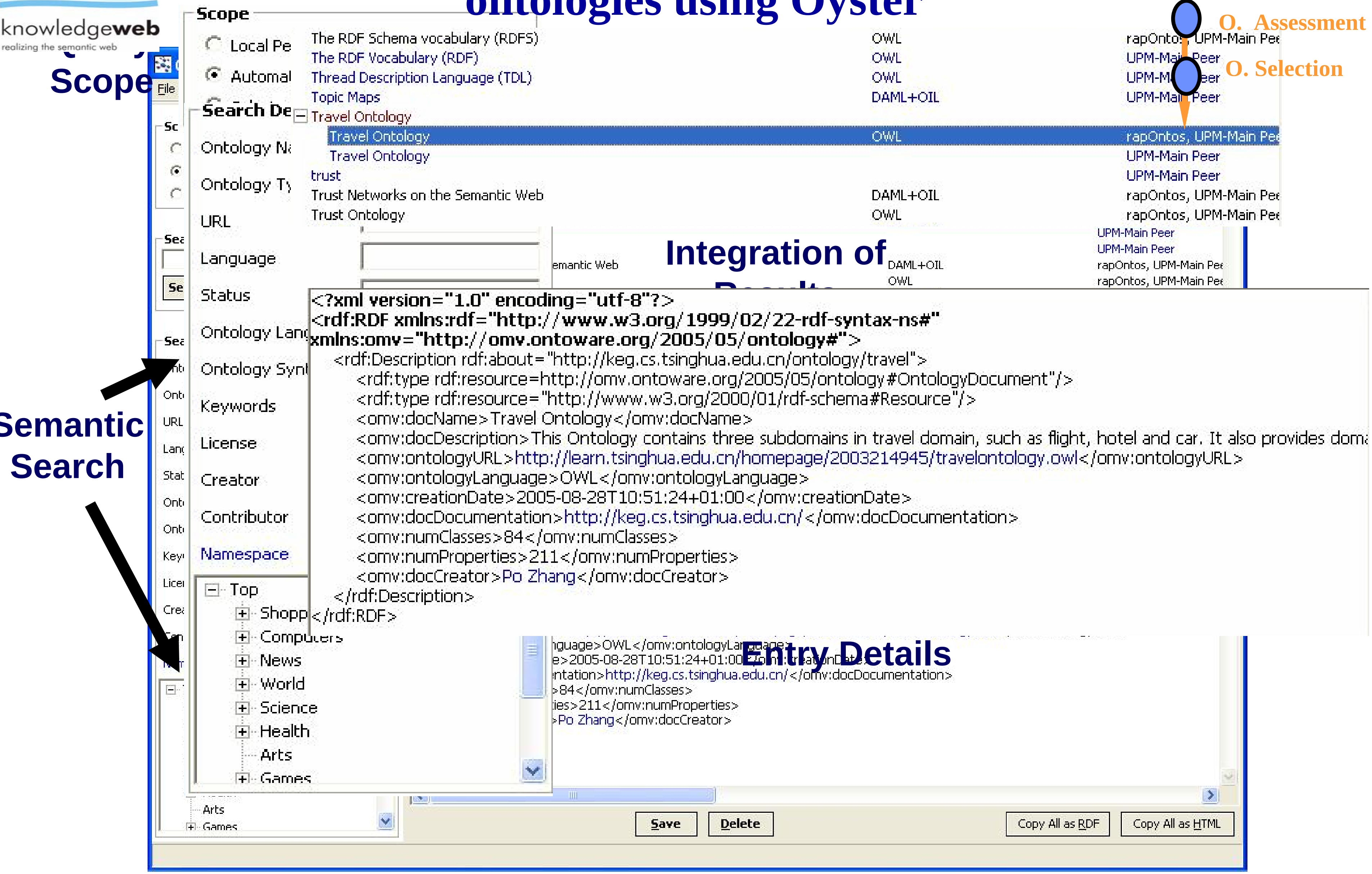
Ontology to describe ontology metadata information

- OMV – Ontology Metadata Vocabulary (http://ontoware.org/projects/omv)
- Knowledge Zone vocabulary (http://tinyurl.com/qfp2s)

4 Ontology Metadata Repositories

- Oyster (P2P system , http://oyster.ontoware.org)
- ONTHOLOGY.org (centralized, http://www.onthology.org/)
- Knowledge Zone (centralized, http://smiprotege.stanford.edu:8080/KnowledgeZone/)
- Swoogle (http://swoogle.umbc.edu/

Searching ontologies: Obtain the set of candidate ontologies using Oyster



Knowledge Representation Ontologies

•**The Frame Ontology and the OKBC Ontology**
(http://ontolingua.stanford.edu)

•Gruber TR (1993a) *A translation approach to portable ontology specification*. Knowledge Acquisition 5(2):199–220

•Chaudhri VK, Farquhar A, Fikes R, Karp PD, Rice JP (1998) *Open Knowledge Base Connectivity 2.0.3*. Technical Report. *http://www.ai.sri.com/~okbc/okbc-2-0-3.pdf*

•**RDF and RDF Schema knowledge representation ontologies**
(http://www.w3.org/1999/02/22-rdf-syntax-ns
http://www.w3.org/2000/01/rdf-schema)

Lassila O, Swick R (1999) *Resource Description Framework (RDF) Model and Syntax Specification*. W3C Recommendation. *http://www.w3.org/TR/REC-rdf-syntax/*

•**OIL knowledge representation ontology**
(http://www.ontoknowledge.org/oil/rdf-schema/2000/11/10-oil-standard)

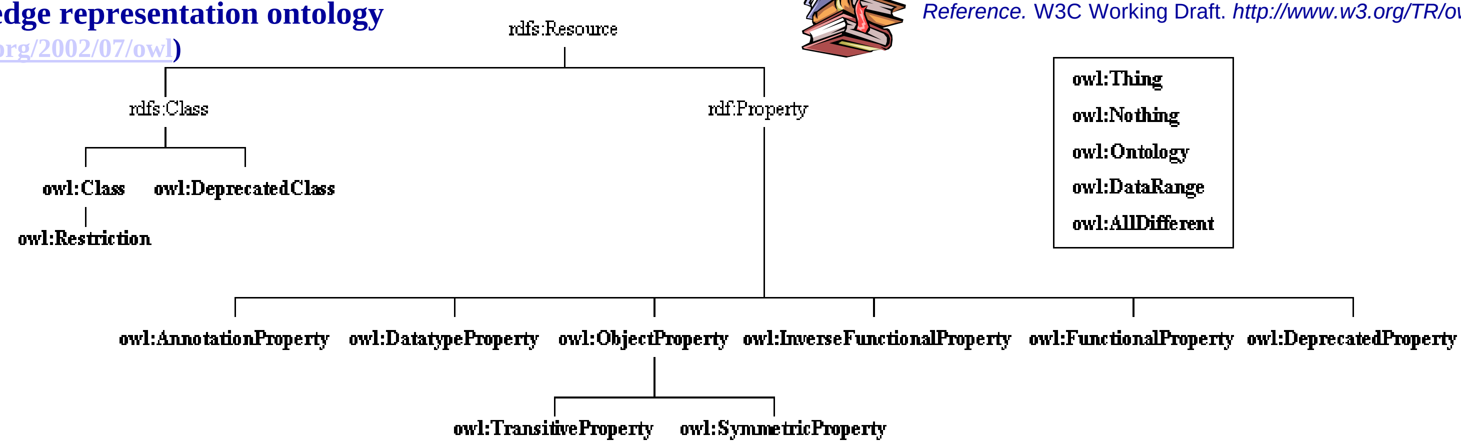
Horrocks I, Fensel D, Harmelen F, Decker S, Erdmann M, Klein M (2000) *OIL in a Nutshell*. In: Dieng R, Corby O (eds) 12th International Conference in Knowledge Engineering and Knowledge Management (EKAW'00). Juan-Les-Pins, France. (Lecture Notes in Artificial Intelligence LNAI 1937) Springer-Verlag, Berlin, Germany, pp 1–16

•**DAML+OIL knowledge representation ontology**
(http://www.daml.org/2001/03/daml+oil)

Horrocks I, van Harmelen F (eds) (2001) *Reference Description of the DAML+OIL (March 2001) Ontology Markup Language*. Technical report. *http://www.daml.org/2001/03/reference.html*

•**OWL knowledge representation ontology**
(http://www.w3.org/2002/07/owl)

Dean M, Schreiber G (2003) *OWL Web Ontology Language Reference.* W3C Working Draft. *http://www.w3.org/TR/owl-ref/*



Class hierarchy (23 classes defined):

- Binary-Relation
  - Antisymmetric-Relation
    - Asymmetric-Relation
    - Partial-Order-Relation
      - Total-Order-Relation
  - Irreflexive-Relation
    - Asymmetric-Relation
  - Many-To-Many-Relation
  - Many-To-One-Relation
  - One-To-Many-Relation
  - Reflexive-Relation
    - Equivalence-Relation
    - Partial-Order-Relation ...
  - Symmetric-Relation
    - Equivalence-Relation
  - Transitive-Relation
    - Equivalence-Relation
    - Partial-Order-Relation ...
  - Weak-Transitive-Relation
- Class
  - Root_Class
- Class-Partition
- Function
  - Many-To-One-Relation
- Individual-Thing
- Named-Axiom
- One-To-One-Relation
- Relation
- Unary-Relation

31 relations defined:

- Alias
- Composition-Of
- Default-Facet-Value
- Default-Slot-Value
- Default-Template-Facet-Value
- Default-Template-Slot-Value
- Disjoint-Decomposition
- Documentation
- Domain-Of
- Exhaustive-Decomposition
- Has-Author
- Has-Instance
- Has-Source
- Has-Subdefinition
- Has-Subrelation
- Inherited-Facet-Value
- Inherited-Slot-Value
- Nth-Argument-Name
- Nth-Domain
- Nth-Domain-Subclass-Of
- Obsolete-Same-Values
- Obsolete-Value-Type
- Onto
- Partition
- Range-Of
- Range-Subclass-Of
- Related-Axioms
- Single-Valued-Slot
- Slot-Documentation
- Subrelation-Of
- Total-On

13 functions defined:

- All-Instances
- All-Values
- Arity
- Compose
- Domain-Name
- Exact-Domain
- Exact-Range
- Function-Arity
- Obsolete-Slot-Cardinality
- Projection
- Range-Name
- Relation-Universe
- Subdefinition-Of

Definition of the relation SUBCLASS-OF in the Frame Ontology

```
(define-relation Subclass-Of (?child-class ?parent-class)

"Class C is a subclass of parent class P if and only if
every instance of C is also an instance of P.  A class
may have multiple superclasses and subclasses.
Subclass-of is transitive: if (subclass-of C1 C2) and
(subclass-of C2 C3) then (subclass-of C1 C3).
Object-centered systems sometimes distinguish
between a subclass-of relationship that is asserted
and one that is inferred. For example, (subclass-of
C1 C3) might be inferred from asserting (subclass-of
C1 C2) and (subclass-of C2 C3)..."

:iff-def
  (and (Class ?parent-class)
       (Class ?child-class)
       (forall (?instance)
         (=> (Instance-Of ?instance ?child-class)
             (Instance-Of ?instance ?parent-class))))
:axiom-constraints
  (Transitive-Relation Subclass-Of)
:issues
  ((:see-also direct-subclass-of)
   (:see-also "In CycL, subclass-of is called #%allGenls
because it is a slot from a collection to all of its
generalizations  (superclasses)."
              "In the KL-ONE literature, subclass
relationships are also called subsumption relationships
and ISA is sometimes used for subclass-of.")
   ("Why is it called Subclass-of instead of subclass or
superclass?"
    "Because the latter are ambiguous about the order of
their arguments. We are following the naming
convention that a binary relationship is read as an
English sentence `Domain-element Relation-name
Range-value'. Thus, `person subclass-of animal' rather
than `person superclass animal'.")))
```

http://www-ksl.stanford.edu

Top-level Ontologies

- **Top-level ontologies of universals and particulars** (http://webode.dia.fi.upm.es/)

•Guarino N, Welty C (2000) *A Formal Ontology of Properties*. In: Dieng R, Corby O (eds) 12th International Conference in Knowledge Engineering and Knowledge Management (EKAW'00). Juan-Les-Pins, France. (Lecture Notes in Artificial Intelligence LNAI 1937) Springer-Verlag, Berlin, Germany, pp 97–112

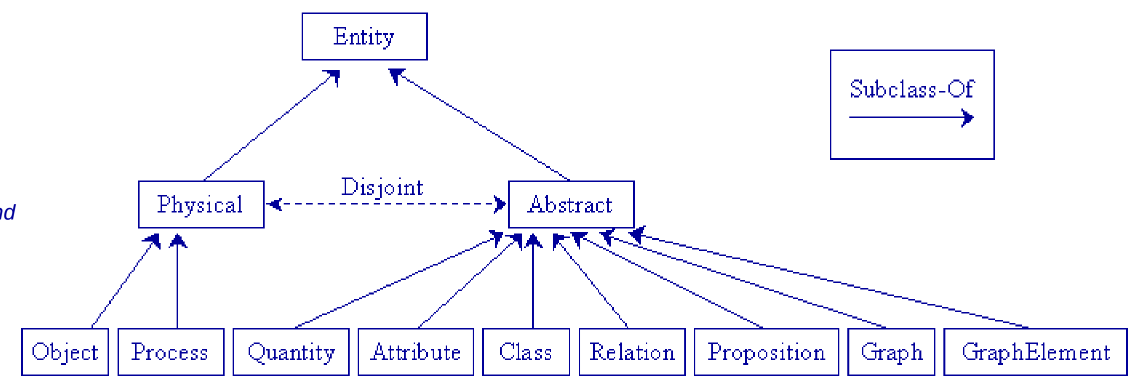
•Gangemi A, Guarino N, Oltramari A (2001) *Conceptual analysis of lexical taxonomies: the case of Wordnet top-level*. In: Smith B, Welty C (eds) International Conference on Formal Ontology in Information Systems (FOIS'01). Ogunquit, Maine. ACM Press, New York, pp 3–15

- **Sowa's top-level ontology** (http://www.jfsowa.com/ontology/toplevel.htm)

Sowa JF (1999) *Knowledge Representation: Logical, Philosophical, and Computational Foundations*. Brooks Cole Publishing Co., Pacific Grove, California

- **Cyc's upper ontology** (http://www.cyc.com/cyc-2-1/cover.html)

Lenat DB, Guha RV (1990) *Building Large Knowledge-based Systems: Representation and Inference in the Cyc Project*. Addison-Wesley, Boston, Massachusetts

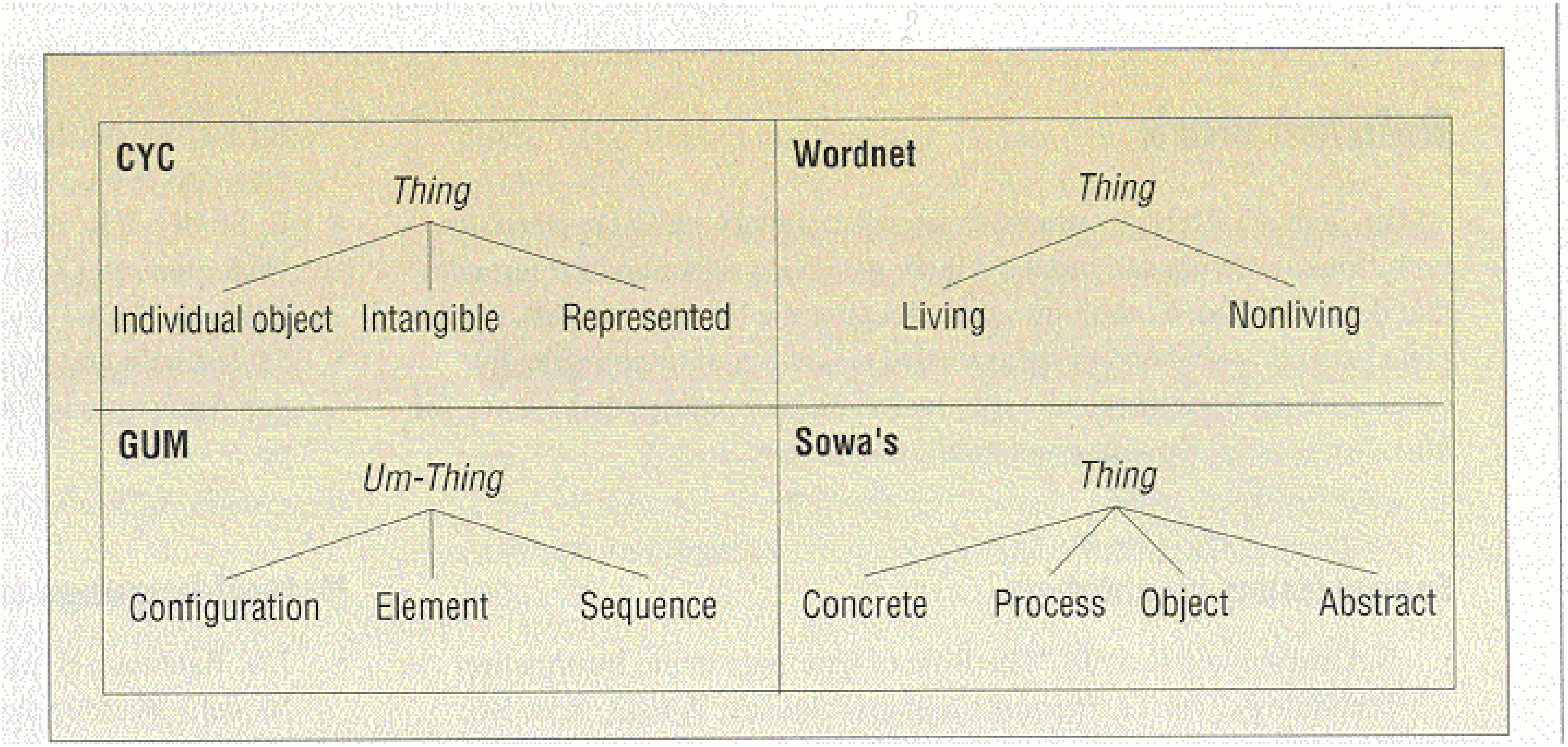


- **The Standard Upper Ontology (SUO)** (http://suo.ieee.org/)

Pease RA, Niles I (2002) *IEEE Standard Upper Ontology: A Progress Report*. The Knowledge Engineering Review 17(1):65–70

One Unique Top-Level Ontology?

Various proposals



Linguistic Ontologies

•WordNet (http://www.hum.uva.nl/~ewn/gwa.htm)

•Miller GA (1995) *WordNet: a lexical database for English*. Communications of the ACM 38(11):39–41

•Miller GA, Beckwith R, Fellbaum C, Gross D, Miller K (1990) *Introduction to WordNet: An on-line lexical database*. International Journal of Lexicography 3(4):235–244

•EuroWordNet (http://www.hum.uva.nl/~ewn/)

•Vossen P (ed) (1999) *EuroWordNet General Document. Version 3*. http://www.hum.uva.nl/ewn/

•Vossen P (ed) (1998) *EuroWordNet: A Multilingual Database with Lexical Semantic Networks*. Kluwer Academic Publishers, Dordrecht, The Netherlands

•The Generalized Upper Model (http://www.darmstadt.gmd.de/publish/komet/gen-um/newUM.html)

Bateman JA, Fabris G, Magnini B (1995) *The Generalized Upper Model Knowledge Base: Organization and Use*. In: Mars N (ed) Second International Conference on Building and Sharing of Very Large-Scale Knowledge Bases (KBKS '95). University of Twente, Enschede, The Netherlands. IOS Press, Amsterdam, The Netherlands, pp 60–72

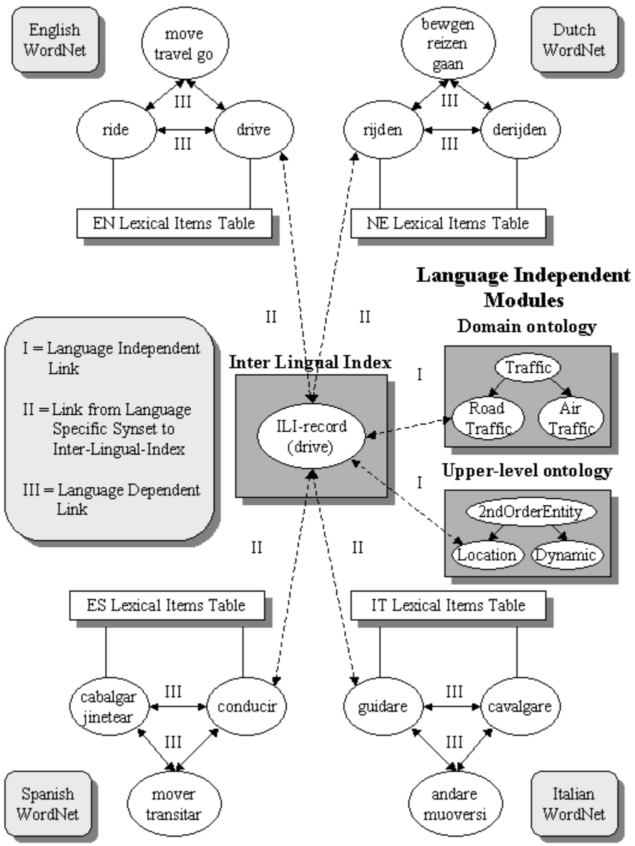
•The Mikrokosmos ontology (http://crl.nmsu.edu/mikro [user and password are required])

•Mahesh K (1996) *Ontology development for machine translation: Ideology and Methodology*. Technical Report MCCS-96-292. Computing Research Laboratory, New Mexico State University, Las Cruces, New Mexico. http://citeseer.nj.nec.com/mahesh96ontology.html

•Mahesh K, Nirenburg S (1995) *Semantic classification for practical natural language processing*. In: Schwartz RP, Kwasnik BH, Beghtol C, Smith PJ, Jacob E (eds) 6th ASIS SIG/CR Classification Research Workshop: An Interdisciplinary Meeting. Chicago, Illinois, pp 79–94

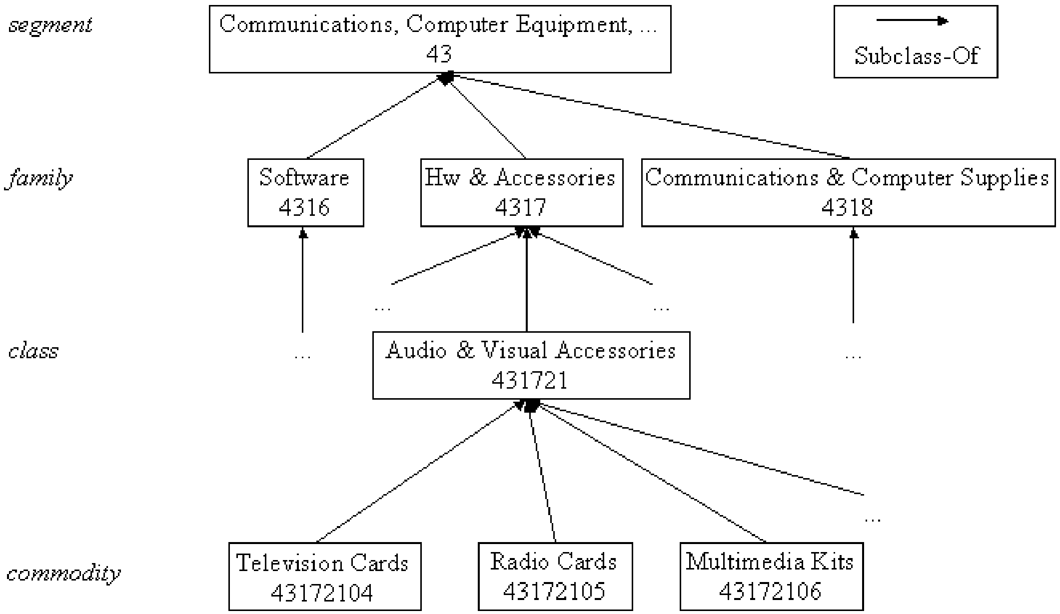
•SENSUS (http://www.isi.edu/natural-language/projects/ONTOLOGIES.html)

Swartout B, Ramesh P, Knight K, Russ T (1997) *Toward Distributed Use of Large-Scale Ontologies*. In: Farquhar A, Gruninger M, Gómez-Pérez A, Uschold M, van der Vet P (eds) AAAI'97 Spring Symposium on Ontological Engineering. Stanford University, California, pp 138–148



Domain Ontologies: e-Commerce Ontologies

- •The United Nations Standard Products and Services Codes (UNSPSC) (http://www.unspsc.org/)
- •NAICS (North American Industry Classification System) (http://www.census.gov/epcd/www/naics.html)
- •SCTG (Standard Classification of Transported Goods) (http://www.statcan.ca/english/Subjects/Standard/sctg/sctg-menu.htm)
- •E-cl@ss (http://www.eclass.de/)
- •RosettaNet (http://www.rosettanet.org)



Domain Ontologies: Medical Ontologies

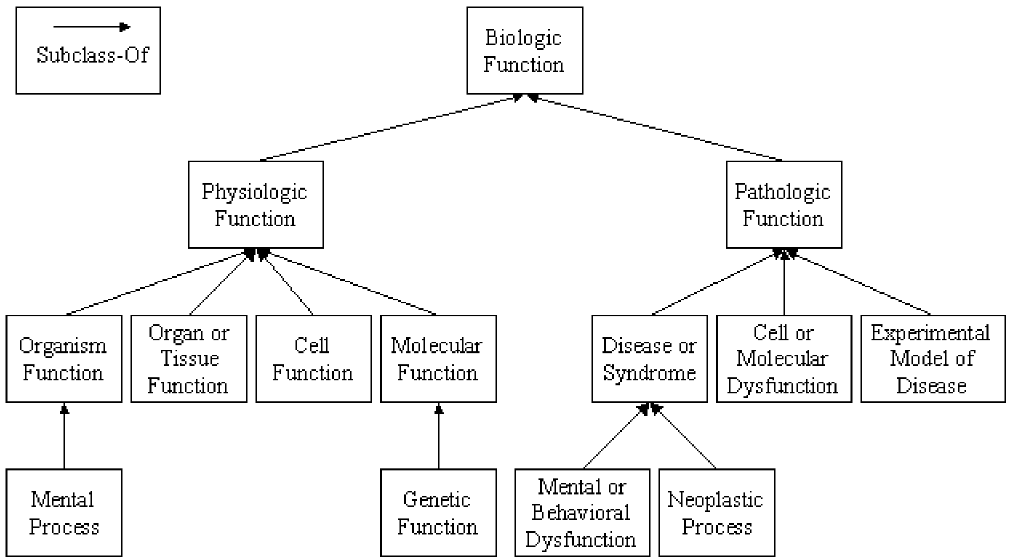
•**GALEN** **http://www.co-ode.org/galen/**

Rector AL, Bechhofer S, Goble CA, Horrocks I, Nowlan WA, Solomon WD (1997) *The GRAIL concept modelling language for medical terminology*. Artificial Intelligence in Medicine 9:139–171

•**UMLS (Unified Medical Language System)**
(http://www.nih.gov/research/umls/)

•**ON9** (http://saussure.irmkant.rm.cnr.it/ON9/index.html)

Gangemi A, Pisanelli DM, Steve G (1998) *Some Requirements and Experiences in Engineering Terminological Ontologies over the WWW*. In: Gaines BR, Musen MA (eds) 11th International Workshop on Knowledge Acquisition, Modeling and Management (KAW'98). Banff, Canada, SHARE10:1–20



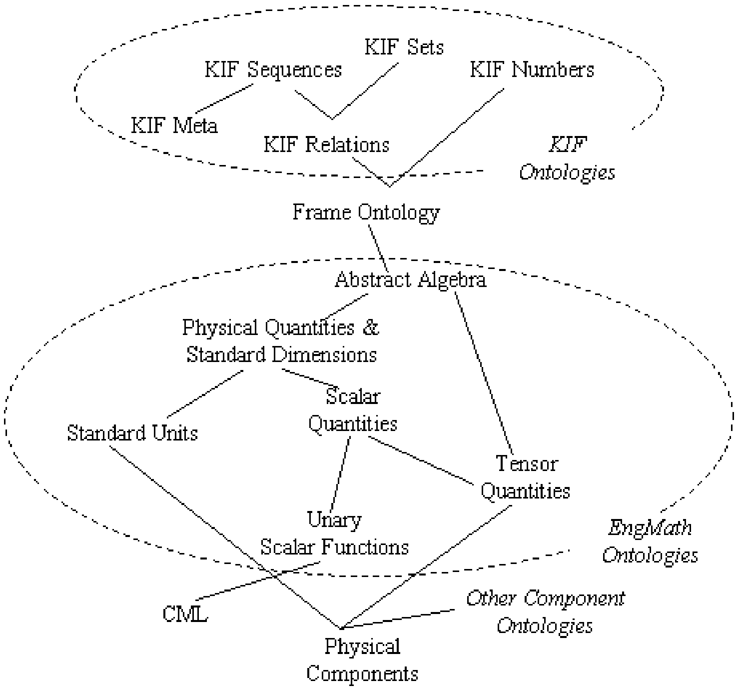
Domain Ontologies: Engineering Ontologies

•**EngMath**

Gruber TR, Olsen G (1994) *An ontology for Engineering Mathematics*. In: Doyle J, Torass Sandewall E (eds) Fourth International Conference on Principles of Knowledge Representation and Reasoning. Bonn, Germany. Morgan Kaufmann Publishers, San Francisco, California, pp 258–269

•**PhysSys**

Borst WN (1997) *Construction of Engineering Ontologies*. Centre for Telematica and Information Technology, University of Tweenty. Enschede, The Netherlands



Domain Ontologies: Enterprise Ontologies

•**Enterprise Ontology** (http://www.aiai.ed.ac.uk/~entprise/enterprise/ontology.html)

Uschold M, King M, Moralee S, Zorgios Y (1998) *The Enterprise Ontology*. The Knowled
Engineering Review 13(1):31–89

•**TOVE** (http://www.eil.utoronto.ca/tove/toveont.html)

Fox MS (1992) *The TOVE Project: A Common-sense Model of the Enterprise*. In: Belli F, Radermacher FJ (eds) Industrial and Engineering Applications of Artificial Intelligence and Expert Systems. (Lecture Notes in Artificial Intelligence LNAI 604) Springer-Verlag, Berlin, Germany, pp 25–34

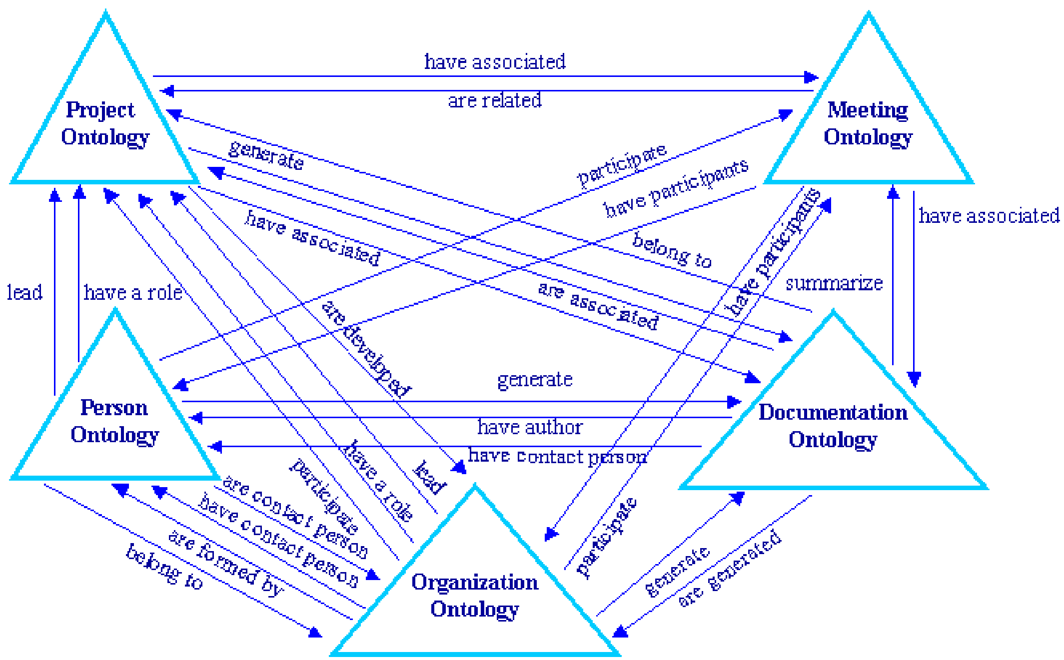
- Enterprise Ontologies
  - Enterprise Design Ontology
  - Project Ontology
  - Material Flow Ontology
  - Business Process Ontology
- Derivative Ontologies
  - Transportation Ontology
  - Inventory Ontology
  - Quality Ontology
  - Product Design Ontology
  - Goals Ontology
  - Scheduling Ontology
  - Operating Strategies Ontology
  - Product Requirements Ontology
  - Information Resource Ontology
  - Intended Action Ontology
  - Electro Mechanical Product Ontology
- Core Ontologies
  - Product Ontology
  - Service Ontology
  - Activity Ontology
  - Organization Ontology
  - Resource Ontology

Domain Ontologies: Knowledge Management Ontologies

- (KA)[2] ontologies (http://ka2portal.aifb.uni-karlsruhe.de)

Decker S, Erdmann M, Fensel D, Studer R (1999) *Ontobroker: Ontology Based Access to Distributed and Semi-Structured Information*. In: Meersman R, Tari Z, Stevens S (eds) Semantic Issues in Multimedia Systems (DS-8), Rotorua, New Zealand. Kluwer Academic Publisher, Boston, Massachusetts. pp 351–369

- **R&D projects** (http://www.esperonto.net/)



What is an Ontology?

Shared understanding of a domain

Repository of vocabulary

- Formal definitions
- Informal definitions