KDI
SOA Solutions: Ontologies

Fausto Giunchiglia and Mattia Fumagallli
University of Trento

What is an Ontology?

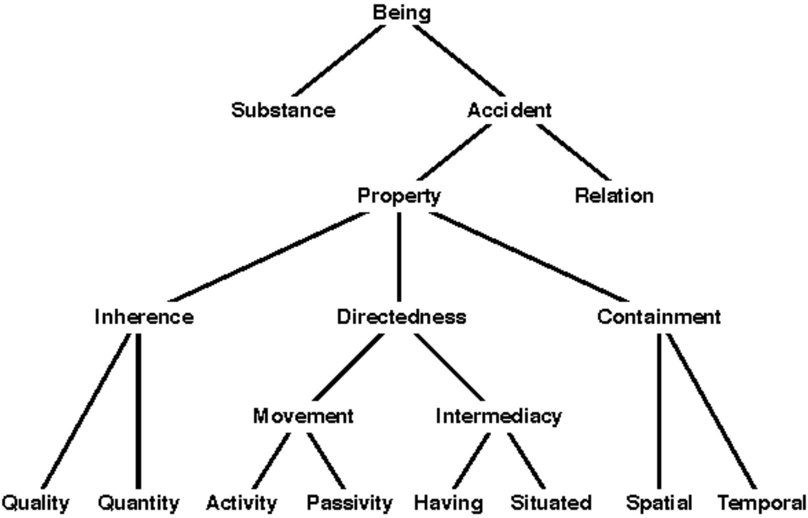
What is an Ontology?

"Ontology" has different meaning in different communities...

Ontology: philosophical discipline which deals with the nature and structure of "reality."

- the science of "being qua being," i.e., the study of attributes that belong to things because of their very nature (Aristotle), which focuses on the nature and structure of things per se,
- independently of any further considerations, and even independently of their actual existence
  - e.g. Ontology of unicorns and other fictitious entities

What is an Ontology?



What is an Ontology?

- **An ontology: in computer science, a special kind of information object or computational artifact**
  - **formally model the structure of a system, i.e., the relevant entities and relations that emerge from its observation, and which are useful to our purposes.**
- **Example: Provide an ontological representation of a company with all its employees and their interrelationships**
  - **entities organized in concepts (unary predicates) and relations (binary predicates) a taxonomy of concepts (generalization/specialization hierarchy)**

    E.g.:

    - **Person, Manager, and Researcher**
      - **Person "super concept" of Manager, and Researcher**
    - **Cooperates-with can be considered a relevant relation holding between persons.**
    - **A concrete person (e.g. Mario Rossi) working in a company would then be an instance of its corresponding concept.**
    - **Cooperates-with(Mario Rossi, Giorgio Bianchi) states that Mario Rosso cooperates with Giorgio Bianchi in its work.**

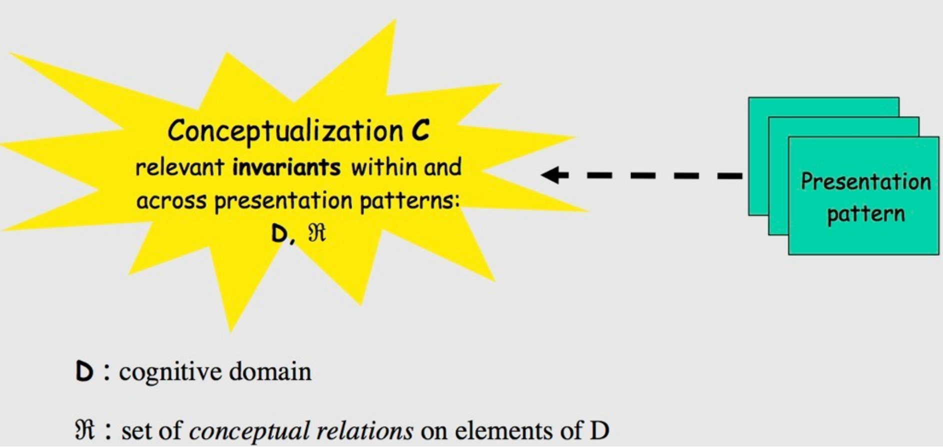
Several definitions

- "explicit specification of a conceptualization" [Gruber, 1993]
- "formal specification of a shared conceptualization" [Borst, 1997]
- "An ontology is a formal, explicit specification of a shared conceptualization" [Studer et al., 1998]
- But….
  - What is a conceptualization?
  - What is a proper formal, explicit specification?
  - Why is 'shared' of importance?

What is a conceptualization?

- Formal structure of (a piece of) reality as perceived and organized by an agent, independently of:
  - the vocabulary used
  - the actual occurence of a specific situation
- Different situations involving same objects, described by different vocabularies, may share the same conceptualization.
- "mela", "apple": different terms for the same conceptualization...

What is a conceptualization?



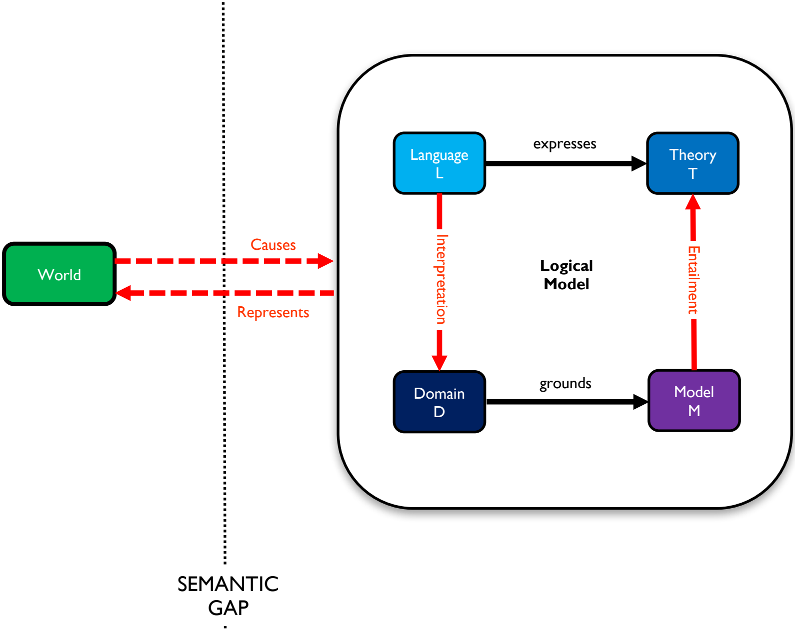
Formal, Explicit Specification

- We need to use a language to refer to the elements of a conceptualization
  - the language **commits** to a conceptualization
- Problem: a logical signature can be interpreted in arbitrarily many different ways
- Once we commit to a certain conceptualization, we have to make sure to only admit those **models** which are **intended** according to the conceptualization.
  - the intended models of a relation predicate will be those such that the interpretation of the predicate returns one of the various possible extensions (one for each possible world) of the conceptual relation denoted by the predicate.

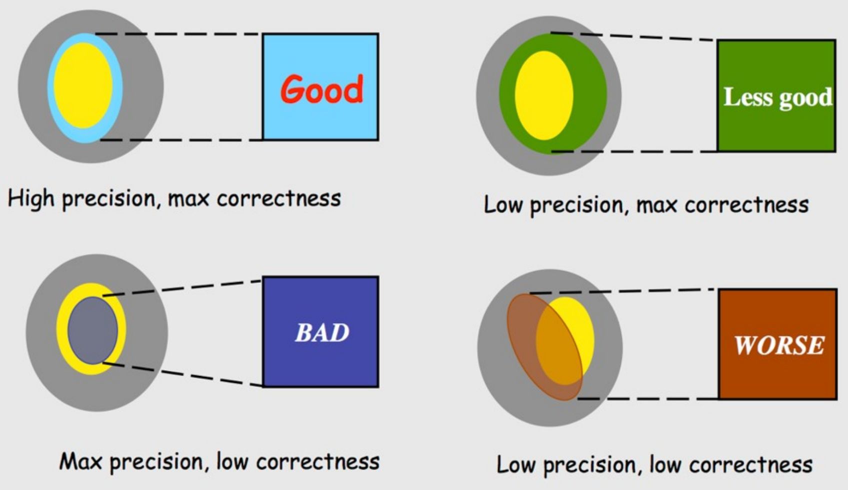
Formal, Explicit Specification

- Conceptualization can be explicitly specified in two ways:
  - extensionally: listing the extensions of every (conceptual) relation for all possible worlds (**unfeasible**)
  - intensionally: fix a language, and constrain the interpretations of the language in an intensional way, by means of suitable axioms
- An ontology: a logical theory (set of axioms) designed to **capture the intended models** corresponding to a certain conceptualization and to **exclude the unintended ones**.
- Axioms can be given in an informal (e.g. natural language) or formal language (i.e. machine processable)
  - we need a formal language!

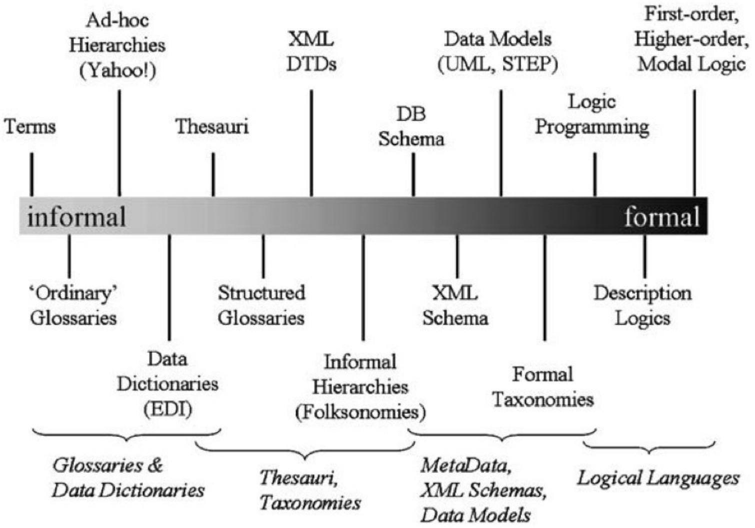
What is an Ontology?



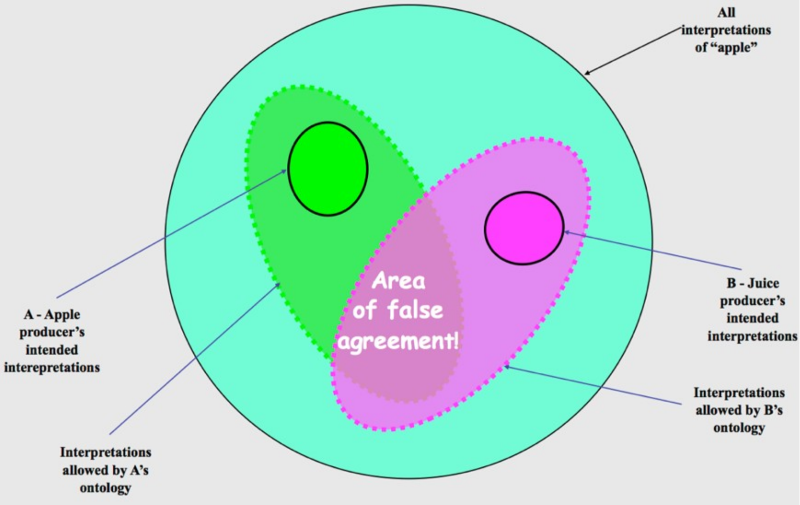
Ontology Quality : Precision and Correctness



Ontological Precision: Language Expressivness



Ontological Precision: Importance of Ontological Precision



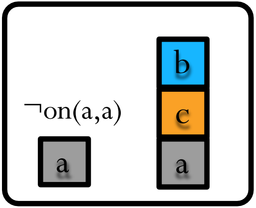
Ontological Precision: Lack of Precision

- Only one binary predicate in the language: on
- Only three blocks in the domain: a, b, c.
- Axioms (for all x,y,z):
  - $on(x,y) \rightarrow \neg on(y,x)$
  - $on(x,y) \rightarrow \neg \exists z\,(on(x,z) \wedge on(z,y))$

Ontological Precision: Lack of Precision

- Only one binary predicate in the language: on
- Only three blocks in the domain: a, b, c.
- Axioms (for all x,y,z):
  - $on(x,y) \rightarrow \neg on(y,x)$
  - $on(x,y) \rightarrow \neg \exists z (on(x,z) \wedge on(z,y))$

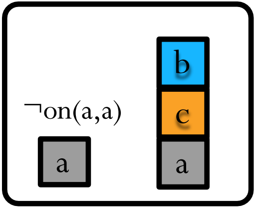
Excluded $\neg on(b,a)$

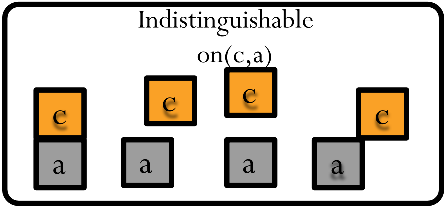


Ontological Precision: Lack of Precision

- Only one binary predicate in the language: on
- Only three blocks in the domain: a, b, c.
- Axioms (for all x,y,z):
  - on(x,y) → ¬on(y,x)
  - on(x,y) → ¬∃z (on(x,z) ∧ on(z,y))

Excluded ¬on(b,a)





Precision and accuracy

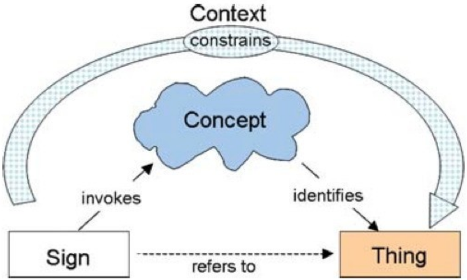
- Capturing all intended models is not sufficient for a "perfect" ontology
  - Precision: non-intended models are excluded
  - Accuracy: negative examples are excluded
- When is a precise and accurate ontology useful?
  - When subtle distinctions are important
  - When recognizing disagreement is important
  - When general abstractions are important
  - When careful explanation and justification of ontological commitment is important
  - When mutual understanding is more important than interoperability.

Why is Shared of Importance?

- Sharing whole conceptualizations may not be possible (private to the mind of the individuals)
- Sharing approximations of conceptualizations based on a limited set of examples, and showing the actual circumstances where a certain conceptual relation holds
- Without such minimal sharing, the benefits of having an ontology are limited
  - ontology may turn out useless if it is used in a way that runs counter the understanding of the primitive terms in the appropriate way.
- Any ontology will always be less complete and less formal than it would be desirable in theory.

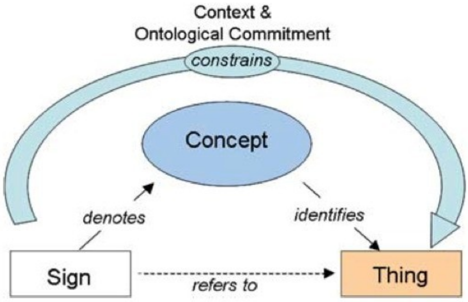
Why is Shared of Importance?

- Ontologies to facilitate the communication between the human and the machine
  - set of possible correspondences between signs, concepts and real-world entities is strongly reduced (message becomes completely unambiguous)

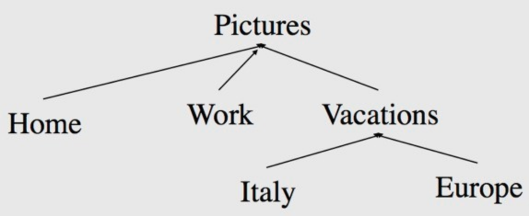


Why is Shared of Importance?

- Ontologies to facilitate the communication between the human and the machine
  - set of possible correspondences between signs, concepts and real-world entities is strongly reduced (message becomes completely unambiguous)

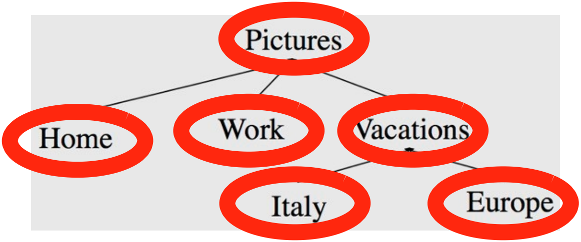


Ontologies vs. classifications



- Classifications focus on:
  - access, based on pre-determined criteria (encoded by syntactic keys)
- Ontologies focus on:
  - Meaning of terms
  - Nature and structure of a domain

Ontologies vs. classifications



- Classification focus on:
  - access, based on pre-determined criteria (encoded by syntactic keys)
- Ontologies focus on:
  - Meaning of terms
  - Nature and structure of a domain

Ontology Building Blocks

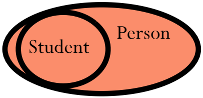
- Concept (DL) / Class (OWL)
  - something that characterizes a set of individuals
  - corresponds to an unary predicate in FOL
  - e.g. Animal, Person, Pizza
- Relation / Role (DL) / Property (OWL)
  - something that relates two or more individuals
  - corresponds to an n-ary ($n \geq 2$) predicate in FOL
    - DL/OWL only allows binary ($n=2$) predicates
  - e.g. Loves, MarriedWith, Eat
- Object / Individual (OWL,DL)
  - the element of the domain, concrete entities of the world
  - corresponds to constants/variables in FOL
  - e.g. Fausto Giunchiglia, UniTN

Ontology Building Blocks: Concept vs Individual

- Deciding if something is a concept or is an individual may not be always trivial
- Some criteria:
  - Concepts can (but not necessarily) have instances / Individuals do not have instances
    - e.g. Person / FaustoGiunchiglia
  - Concepts are typically abstract entities / Individuals can be concrete objects of the world or abstract objects
    - e.g. Superheroes / Batman,
  - Intuition: if it recalls a set of entities, go for a concept

Is-a Relation

- **is-a relation**: binary relation between concepts (not individuals)
- Examples: Student is-a Person, Air Pollutant is-a Pollutant
  - Informal meaning: all the students are persons (or all the individuals that are students are also persons); if something is an air pollutant, itis also a pollutant
- In set-theoretical terms:



- In FOL terms:
  - $\forall x(\text{student}(x) \rightarrow \text{person}(x))$
- In DL terms:
  - $\text{Student} \sqsubseteq \text{Person}$

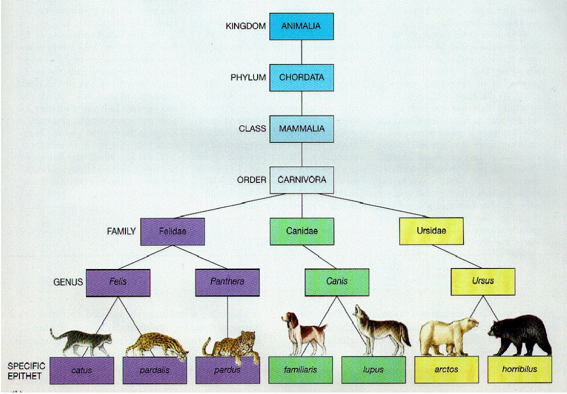
Ontology Building Blocks: Properties of Is-a relation

- Reflexivity:
  - A is-a A
- Antisymmetry:
  - if A is-a B and B is-a A, then A = B
- Transitivity:
  - if A is-a B and B is-a C, then A is-a C

- That is, is-a is a partial order

Is-a hierarchy

- **taxonomy**: a hierarchical organized subject-based classification system
  - typically depicted in a tree-like structure
- **is-a hierarchy**: taxonomy of concepts organized according to the is-a relation.



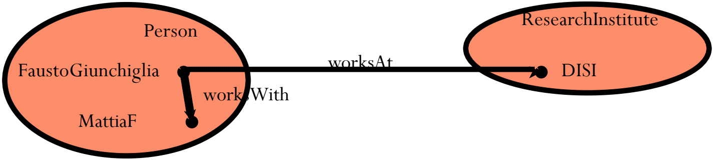
Instance-of

- **instance-of**: associates an individual (~~or evena concept~~) to a concept
- Examples: faustoGiunchiglia instance-of Person,FBK instance-of Institute
- In set-theoretical terms:

- In FOL terms:
  - Person(FaustoGiunchiglia)
- In DL terms:
  - Person(FaustoGiunchiglia)

Relations

- **relations**: allows to predicate on the individuals of concepts
- Examples: FaustoGiunchiglia worksAt DISI, FaustoGiunchiglia worksWith MattiaF
- In set-theoretical terms:



- In FOL/DL terms:
  - WorksAt(FaustoGiunchiglia, DISI), WorksWith(FaustoGiunchiglia, MattiaF)

An important example of relation: parthood

- Part–whole relations and meronomies (hierarchy that deals with part– whole relationships)
- A meronomy is a partial ordering of concepts by the part–whole relation
- A "set" of relations:
  - Member / collection
    - This cow / the herd, John / the orchestra
  - Sub-collection / collection
    - Benelux / EU (but not USA / NATO)
  - Component-Integral Whole
    - The handle / the door, the engine / my car
  - Portion-Whole
    - A piece of cake
  - Substance-Whole
    - Some sugar / this cake
  - Piece-Whole
    - The left half of this table

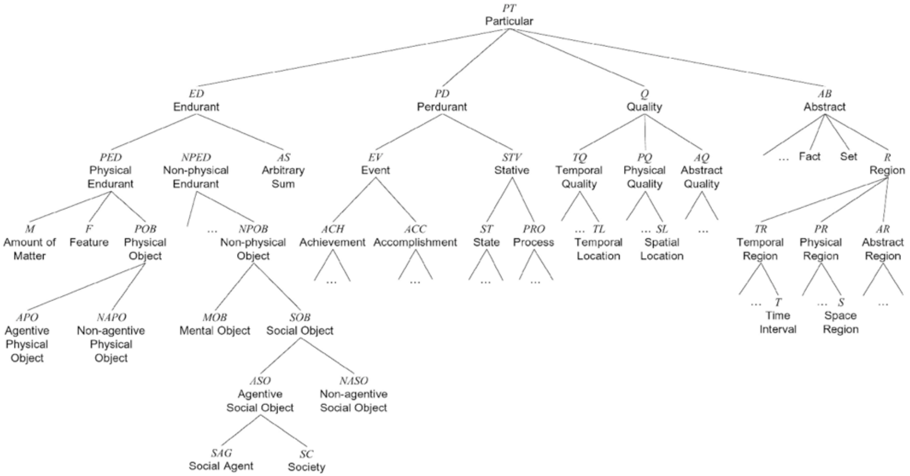
Ontology Typologies: Top-level (or foundational) Ontologies

- Aim: provide a broad view of the world suitable for many different target domains (cross-domain knowledge)
  - to provide a coherent formal description of entities (e.g. event, object) and relationships (e.g. part-of) that are common across domains

Top-level Ontologies: DOLCE

- DOLCE: a Descriptive Ontology for Linguistic and Cognitive Engineering
  - Developed in FOL but some DL approximations exist
  - Cognitive bias: descriptive (as opposite to prescriptive) attitude.
  - Emphasis on cognitive invariants.
  - Categories as conceptual containers: no `deep' metaphysical implications.
  - Clear branching points to allow easy comparison with different ontological options.
  - Rich axiomatization.
  - Available at: http://www.loa-cnr.it/DOLCE.html

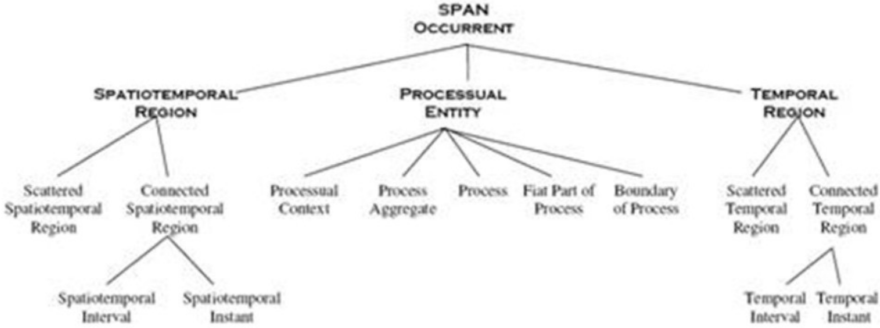
Ontology Typologies: Top-level Ontologies: DOLCE taxonomy



Top-level Ontologies: BFO

- BFO: Basic Formal Ontology
  - Philosophical and Realistic bias Consists
  - in a series of sub-ontologies two main
  - ingredients:
    - SNAPs: continuant (or snapshot) ontologies
      - 3-dimensional entities (no temporal information)
      - Substantial Entities, Tropes, Spatial Regions
      - An inventory of all entities existing at a time
    - SPANs: occurrent ontologies
      - 4-dimensional entities (temporal information)
      - Processual Entities, Temporal Regions, Spatio-temporal Regions
      - An inventory (processory) of all the processes unfolding through a given interval of time
  - Available at: http://code.google.com/p/bfo/

Top-level Ontologies: SPAN taxonomy in BFO

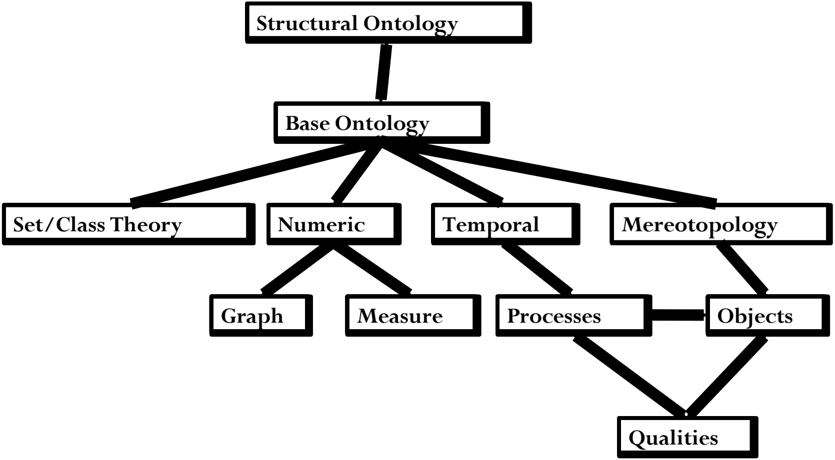


Top-level Ontologies: SUMO

- SUMO:The Suggested Upper Merged Ontology
  - A large, open source,formal ontology stated in first-order logic
  - Richly axiomatized, not just a taxonomy.
    - All terms are formally defined.
    - Meanings are not dependent on a particular inference implementation.
  - Mapped to all of the WordNet lexicon
  - Available at: http://www.ontologyportal.org/SUMO.owl

Ontology Typologies

Top-level Ontologies: SUMO taxonomy



Domain Ontologies

- Aim: define the meanings of terms as they apply to the domain under consideration
  - definition of a term may be different in ontologies describing different domains
- Examples:
  - Gene Ontology: ontology of terms representing gene product properties
    - covers three domains: cellular component, molecular function, and biological process,
    - http://www.geneontology.org/
  - Wine ontology: ontology describing the domain of wine
    - http://www.w3.org/TR/owl-guide/wine.rdf

Application Ontologies

- Aim: an ontology engineered for a specific use or application focus and whose scope is specified through testable use cases
  - focus is not on the domain, rather on supporting some application tasks (e.g. via reasoning)
- Examples:
  - BPMN Ontology: describes the business process modeling notation language
    - https://dkm.fbk.eu/index.php/BPMN_Related_Resources
  - PESCaDO Ontology: an ontology supporting the processing of environmental data for decision support
    - https://ontohub.org/fois-ontology-competition/PESCaDO_Ontology

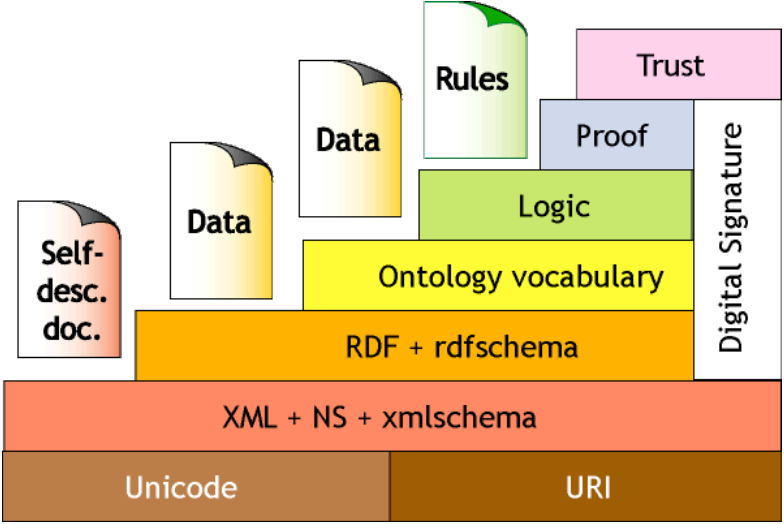
Why Developing Ontologies?

- To share common understanding of the structure of information among people or software agents
- To enable reuse of domain knowledge
- To make domain assumptions explicit
- To separate domain knowledge from the operational knowledge
- To analyze domain knowledge

Typical Application of Ontologies in Computer Science

- Naming "things"
- As a data exchange format
- Define a knowledge base schema
- Computer reasoning over data
- Driving NLP
- Information integration

The Semantic Web Cake



Acknowledgements

Parts of these slides have been inspired by (or reuse) (possibly adapted) content included in the following material:

- Nicola Guarino, Daniel Oberle, and Steffen Staab: What is an ontology?
- Nicola Guarino: Introduction to Applied Ontology and Ontological Analysis
- Stefano Borgo, Carola Eschenbach, Laure Vieu: Modeling in Knowledge Representation: the Parthood Relation
- Claudio Masolo: An introduction to formal ontological distinctions (in DOLCE)
- Marco Rospocher: Slides