Introduction to Ontologies

Gilles Falquet
Université de Genève,
Centre universitaire d'informatique

Outline

- Philosophical and terminological aspects
- Ontologies in computing science:
  - NLP, AI, IS, Semantic Web
- Ontological Languages

Ontology and Ontologies

Ontology (philo.) The branch of metaphysics dealing with the nature of being. In particular:

- Categories of being
- Entities and types of entities
- Relationships between entities

An ontology. Enumeration/description/organisation of existing entities.

- Hierarchies of concepts
- General vs. Local ontologies (for a particular field of knowledge)

An ontology: Some Definitions

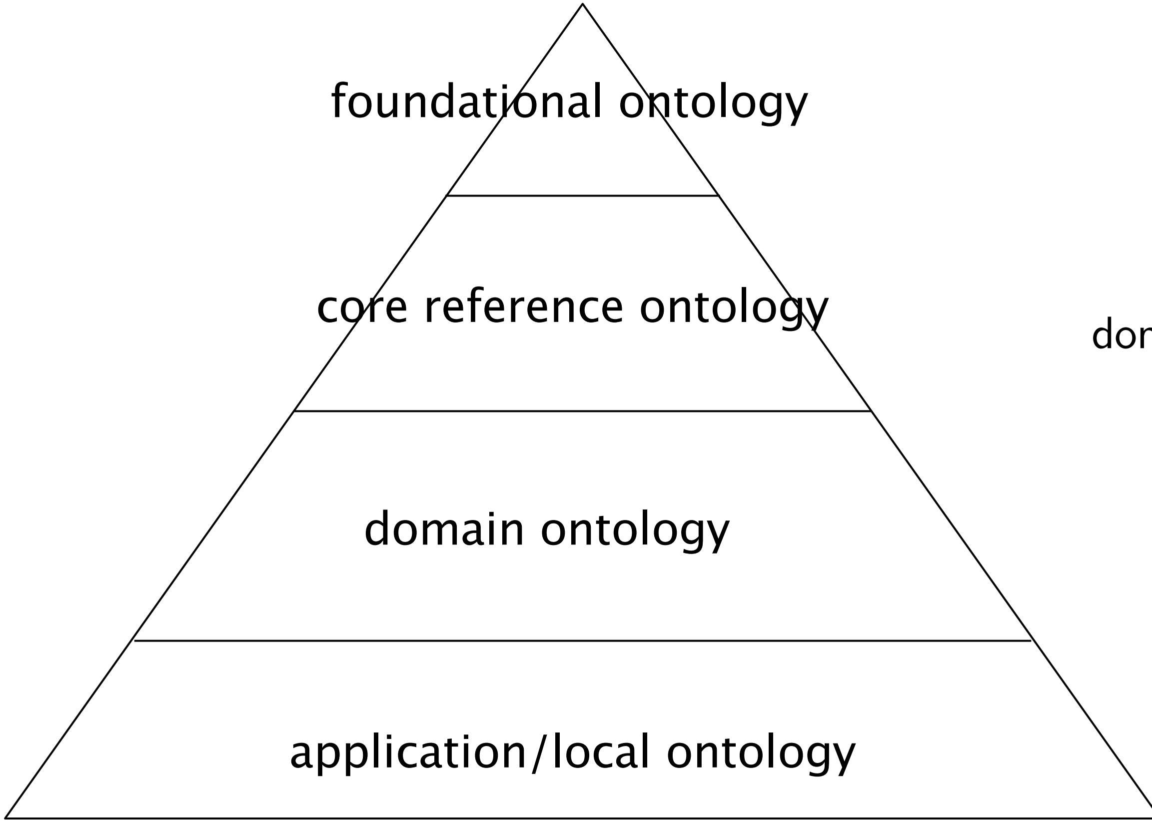
- an explicit specification of a conceptualization (Gruber)
- a formal specification of a shared conceptualization
- a formal, explicit specification of a shared conceptualization
- a logical theory accounting for the intended meaning of a formal vocabulary, i.e. its ontological commitment to a particular conceptualization of the world (Guarino)

Conceptualization

- create concepts
  - idea/mental image that corresponds to some entity or class of entity

- relate concepts
  - typical relations
    - “generic/specific”, “instance/class”, “part/whole”, ...

A classification of ontologies



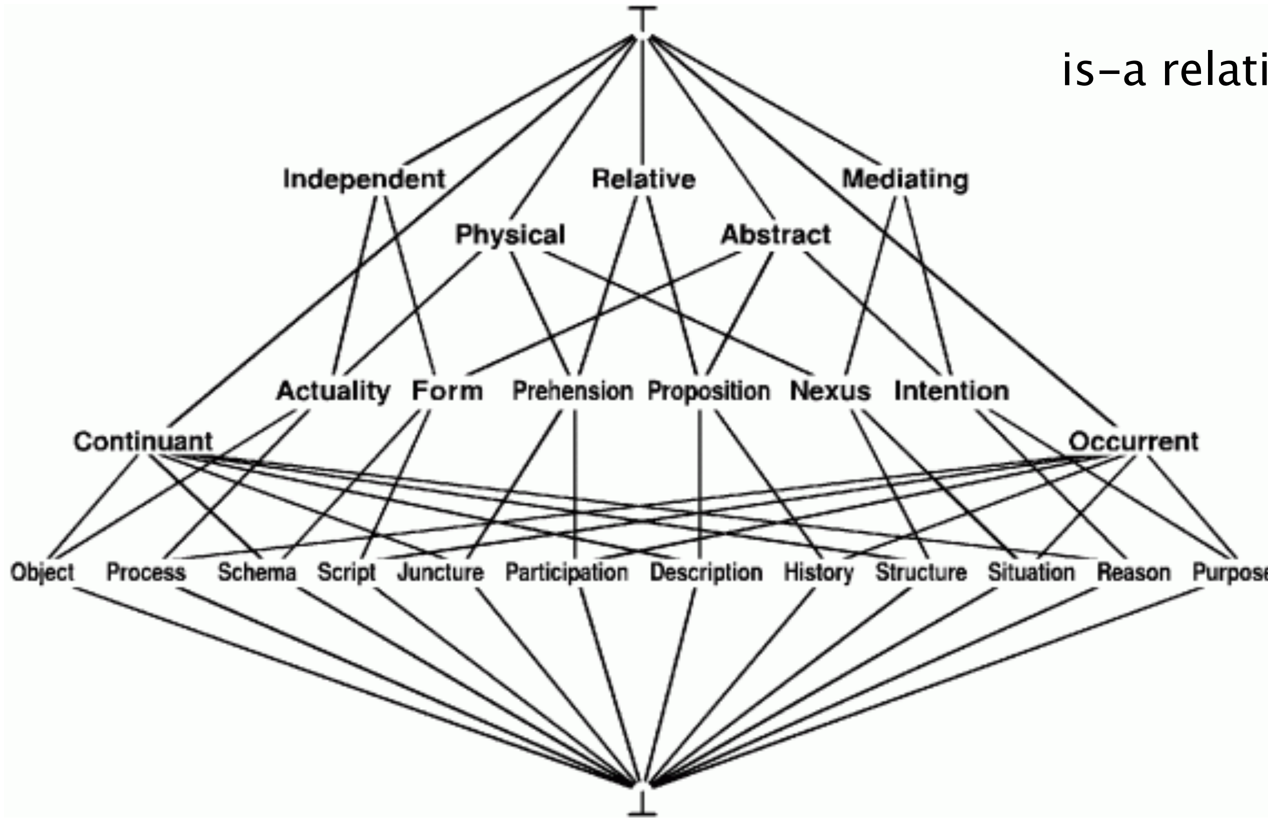
define basic notions: objects, relations, events, processes

central concepts and relations of a domain, integrate different viewpoints

applicable to a domain with a specific viewpoint

no consensus or knowledge sharing, specific to a task

A Top Level Ontology



is-a relations

John F. Sowa. *Knowledge Representation*

A core reference ontology

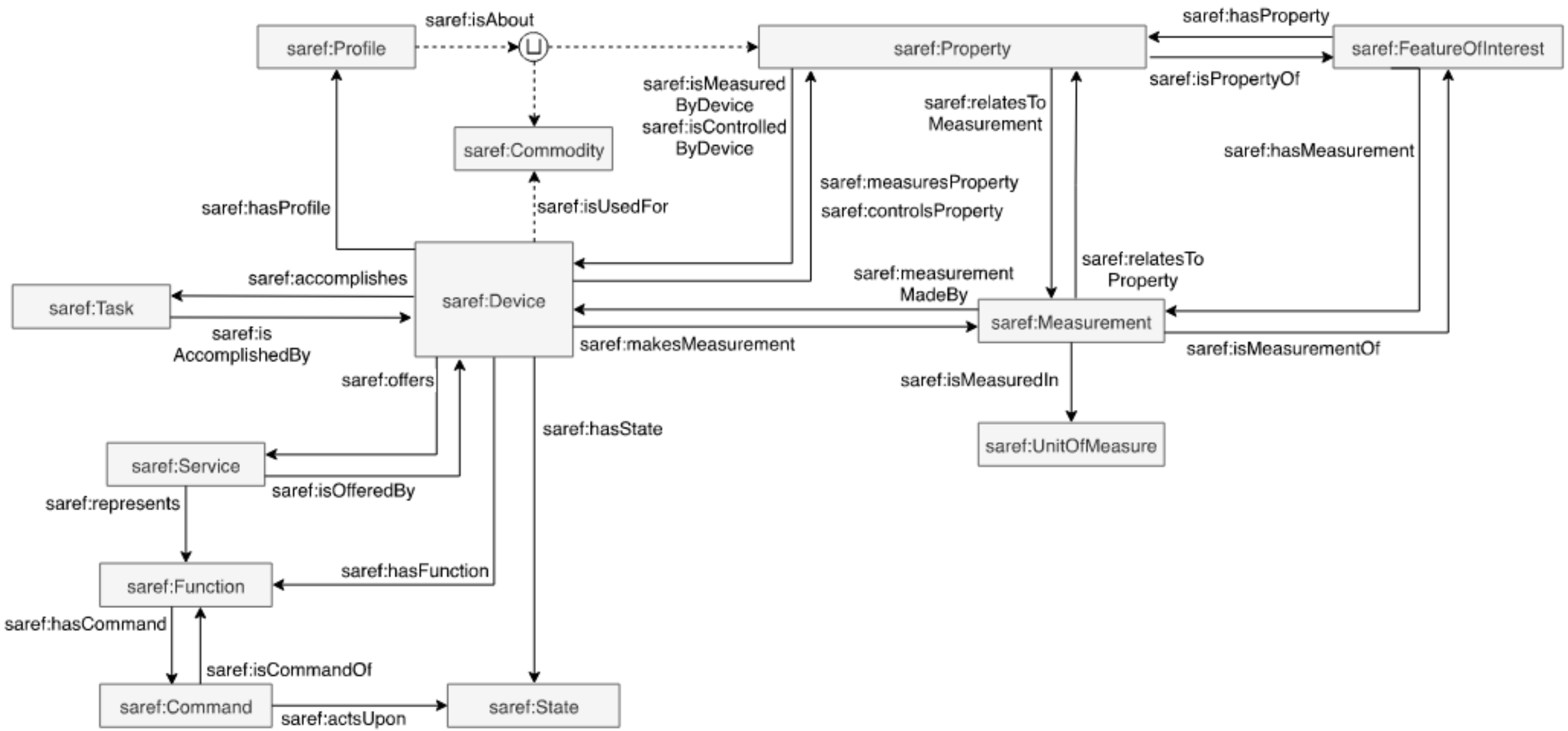
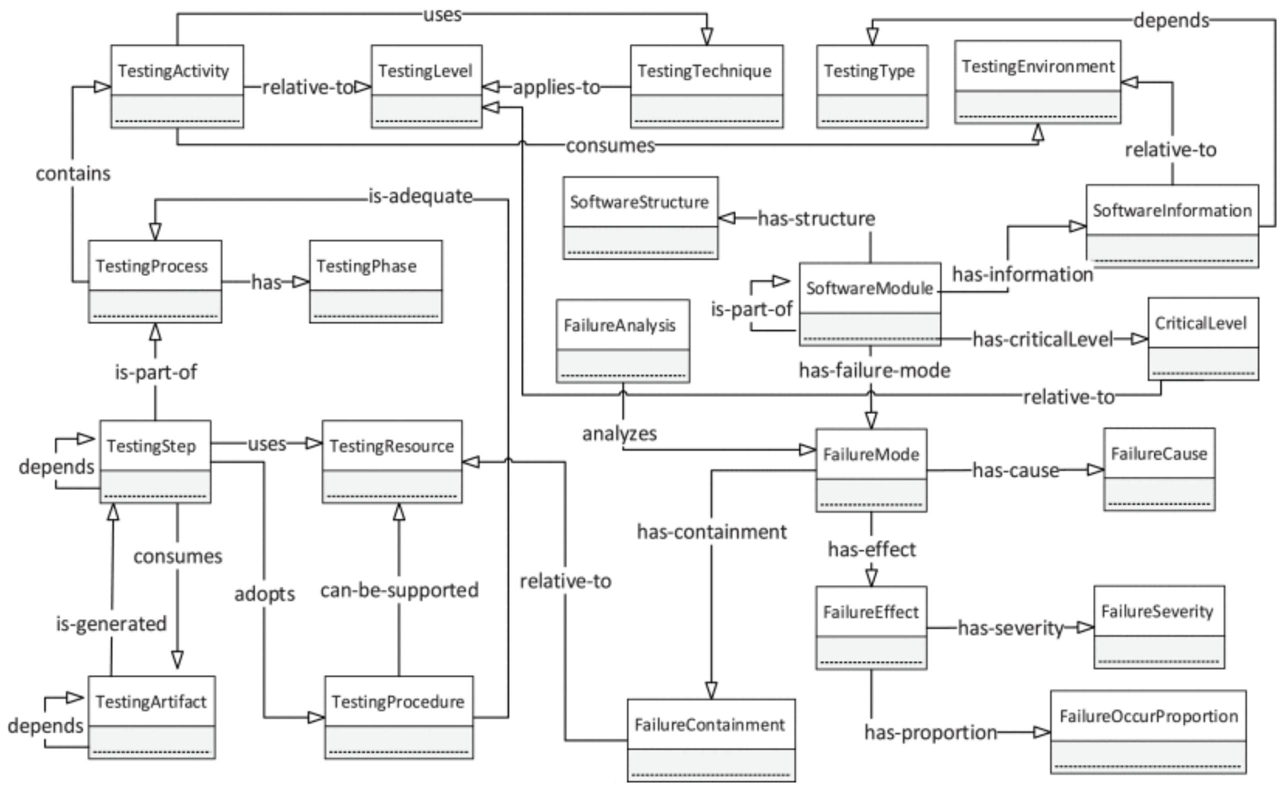


Figure 2: Overview of the SAREF ontology

https://www.etsi.org/deliver/etsi_ts/103200_103299/103264/03.01.01_60/ts_103264v030101p.pdf

Domain ontology:
Entire Process Ontology on Software Testing



https://ieeexplore.ieee.org/document/9253652

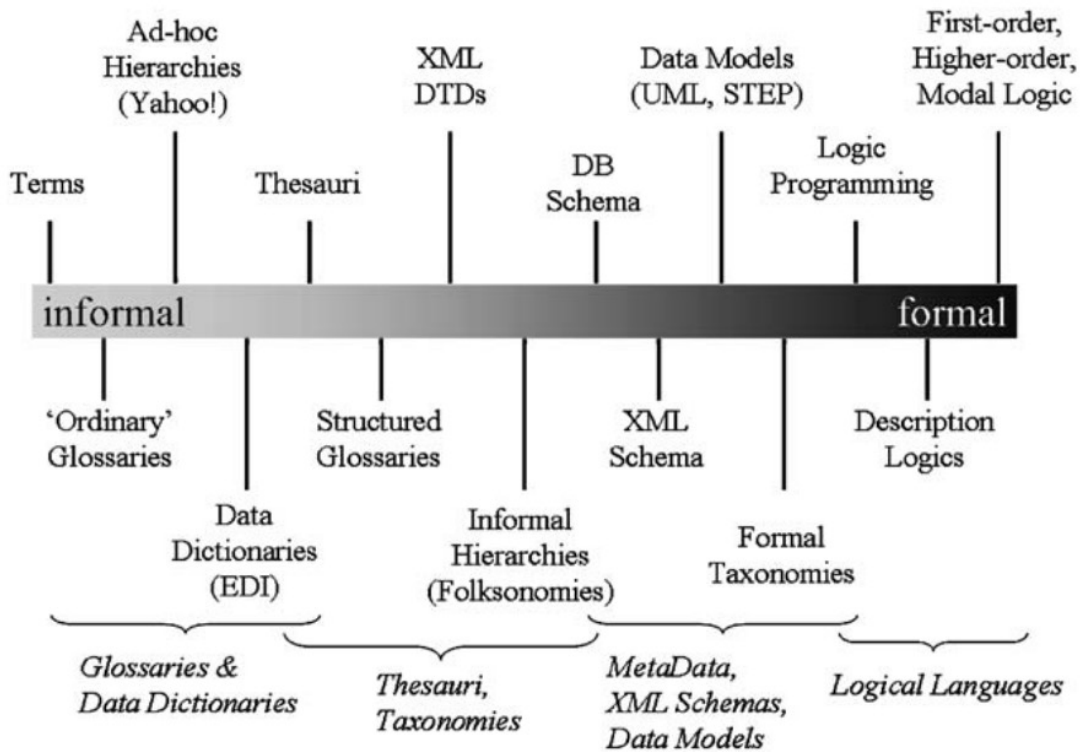
Specification of a conceptualization

- Expression of the specification in a **language**
  - textual
  - graphical
  - ...

- Syntax
  - rules for writing correct expressions

- Semantics
  - explicitly defined in mathematical terms $\rightarrow$ formal language
  - explicitly defined in natural language(+math) $\rightarrow$ semi-formal
  - not defined, suggested, implicit $\rightarrow$ informal

Ontology expression



https://www.iaoa.org/isc2012/docs/Guarino2009_What_is_an_Ontology.pdf

Some semi-formal languages

language	concept expression	relation expression	complex relations
XML schema	element type definition	subtype, element inclusion, reference attributes	number restrictions (min/max occurs)
relational DB schema	not explicit some tables (in general)	not explicit, foreign keys, some tables	integrity constraints expressed in SQL Datalog rules
UML	class	association, inheritance, composition	number restrictions (min/max occurs) + Object Constraint Language

Formal Languages for Ontologies

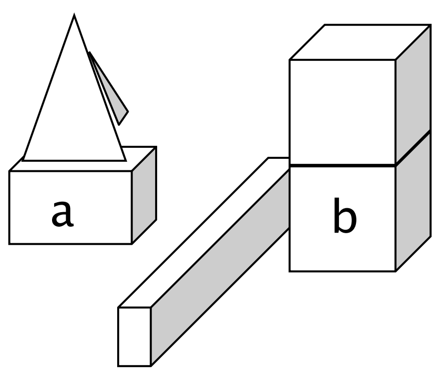
- First order logic
  - propositional logic
  - predicate logic

- Description logics
  - a family of logics
  - designed to formalize class diagrams and other class-oriented and frame-based languages

Why Formal Expressive Ontology Languages ?

- to formally express complex relationships / domain rules
  - "a vegan pizza is a pizza whose ingredients are all vegan"
  - if Parent(x, y) and Parent(y, z) then GrandParent(x, z)
- the notion of consistency is well defined
- the notion of logical entailment is well defined
- if the language is not too expressive
  - consistency and entailment can be automatically checked

- A cube is an object
- A tetrahedron is an object
- Two objects cannot be at the same place
- A cube cannot stand on a tetrahedron
- An object cannot be moved if there is another object on top of it

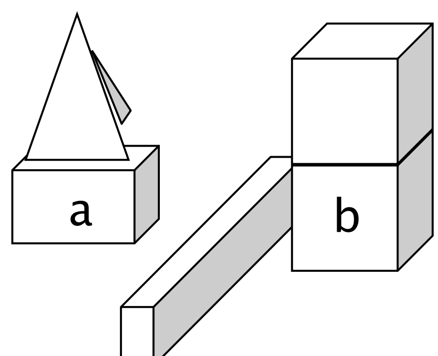


"Put a on b !"

First Order Logic

Axioms

1. $\forall x \ \mathrm{Cube}(x) \Rightarrow \mathrm{Object}(x)$
2. $\forall x \ \forall y \ \mathrm{Object}(x) \wedge \mathrm{Object}(y) \wedge x \neq y$
   $\Rightarrow \mathrm{location}(x) \neq \mathrm{location}(y)$
3. $\forall x \ \forall y \ \mathrm{On}(x, y) \Rightarrow \neg \ \mathrm{Movable}(y)$



First Order Logic

- Highly expressive
  - e.g. every algorithm is expressible in FOL
- Difficult to understand and master the formalism
- Not decidable
  - no algorithm to decide (always in finite time) if
    - a formula is equivalent to another one
    - a formula is a consequence of another formula
    - a set of formulae contains a contradiction
- "Semi decidable"
  - algorithms answer “yes”, “no”, or run forever

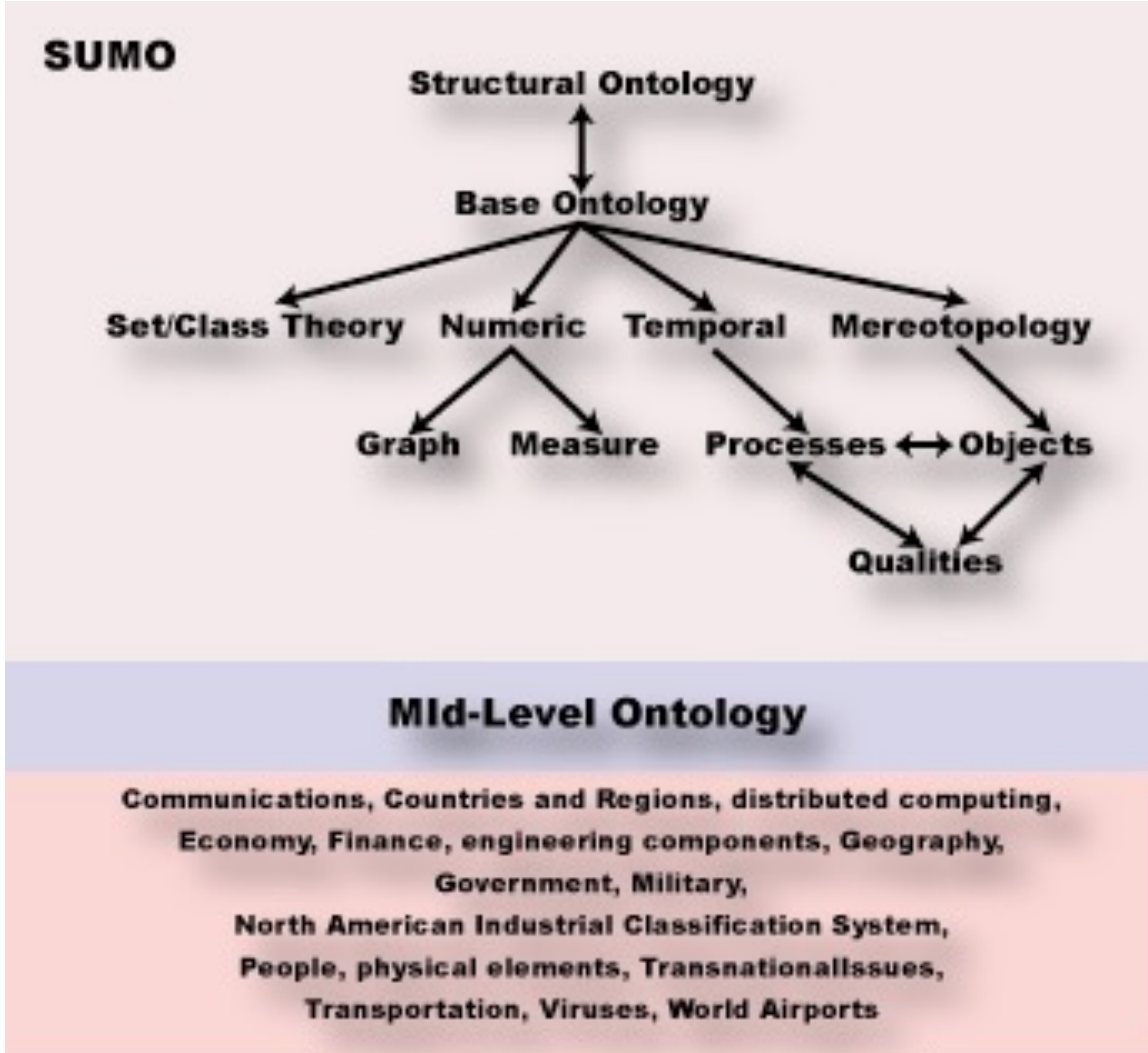
Well known ontologies in FOL

- Foundational ontologies / Top level ontologies/ Upper Level Ontologies
  - generic ontologies applicable to various domains
  - define basic notions like objects, relations, events, processes, ...

  - SUMO
  - CyC
  - DOLCE

SUMO

- Foundational ontology
- Largest free, formal ontology available, with ~25,000 terms and ~80,000 axioms
- Language: SUO-KIF <-> First order logic


SUMO
Structural Ontology
Base Ontology
Set/Class Theory
Numeric
Temporal
Mereotopology
Graph
Measure
Processes
Objects
Qualities
Mid-Level Ontology
Communications, Countries and Regions, distributed computing,
Economy, Finance, engineering components, Geography,
Government, Military,
North American Industrial Classification System,
People, physical elements, TransnationalIssues,
Transportation, Viruses, World Airports

http://virtual.cvut.cz/kifb/en/toc/root.html

- entity
  - physical
  - abstract
    - quantity
    - attribute
      - internal attribute
      - relational attribute
        - truth value
        - positional attribute
        - time zone
        - social role
          - occupational role
            - position
            - unemployed
        - normative attribute
    - set or class
    - relation
    - proposition
    - graph
    - graph element

Axioms related to 'entity'

- There exists thing so that thing is an instance of entity.

$$\exists T \text{ instance}(T, \text{Entity})$$

- If class is an instance of class, then class is a subclass of entity.

$$\text{instance}(C, \text{Class}) \Rightarrow \text{subclass}(C, \text{Entity})$$

The CyC Project

Build a theory of commonsense, to add AI to all computer programs

- In first order logic
- Currently millions of axioms
- Grouped in coherent "microtheories": geometry, physics, movement, transport, ...(some freely available)
- Partial reasoning system

DOLCE

WonderWeb Deliverable D17 The WonderWeb Library of Foundational Ontologies

Preliminary Report

Claudio Masolo, Stefano Borgo, Aldo Gangemi, Nicola Guarino, Alessandro Oltramari, Luc Schneider ISTC-CNR c/o ISIB-CNR, C.so Stati Uniti, 4 35127 Padova Italy

DOLCE

"We do not commit to a strictly referentialist metaphysics related to the intrinsic nature of the world"

"[Our categories] are just *descriptive* notions that assist in making *already formed* conceptualizations explicit. [...]. In other words, our categories describe entities in an *ex post* way, reflecting more or less the surface structures of language and cognition."

"DOLCE is an ontology of *particulars*, in the sense that its domain of discourse is restricted to them. [...] particulars are entities which have no instances; universals are entities that can have instances. Properties and relations (corresponding to predicates in a logical language) are usually considered as universals. "

Main categories

Endurants

- can "genuinely" change in time
- the very same endurant as a whole can have incompatible properties at different times;
  - my computer was working yesterday
  - my computer is down today
- statements about what parts it has must be made relative to some time or other
  - my computer has a 1Tb hard disk, but I will replace it tomorrow

Perdurants

- events, processes, ...
- endurants need a time- indexed parthood, while perdurants do not
  - “my youth is part of my life”
  - "Italy is the winner of the worldcup 2020"
  - "Algol 68 is a programming language"

  do not require a time specification

Qualities

- Qualities *inhere* to entities: every entity comes with certain qualities, which exist as long as the entity exists.
- a quality
  - the color of a specific rose

  must be distinguished from its quale (value)
  - a particular shade of red.
- a *quale* describes the position of an individual quality within a certain *conceptual space* (*quality space*)

Relations in DOLCE

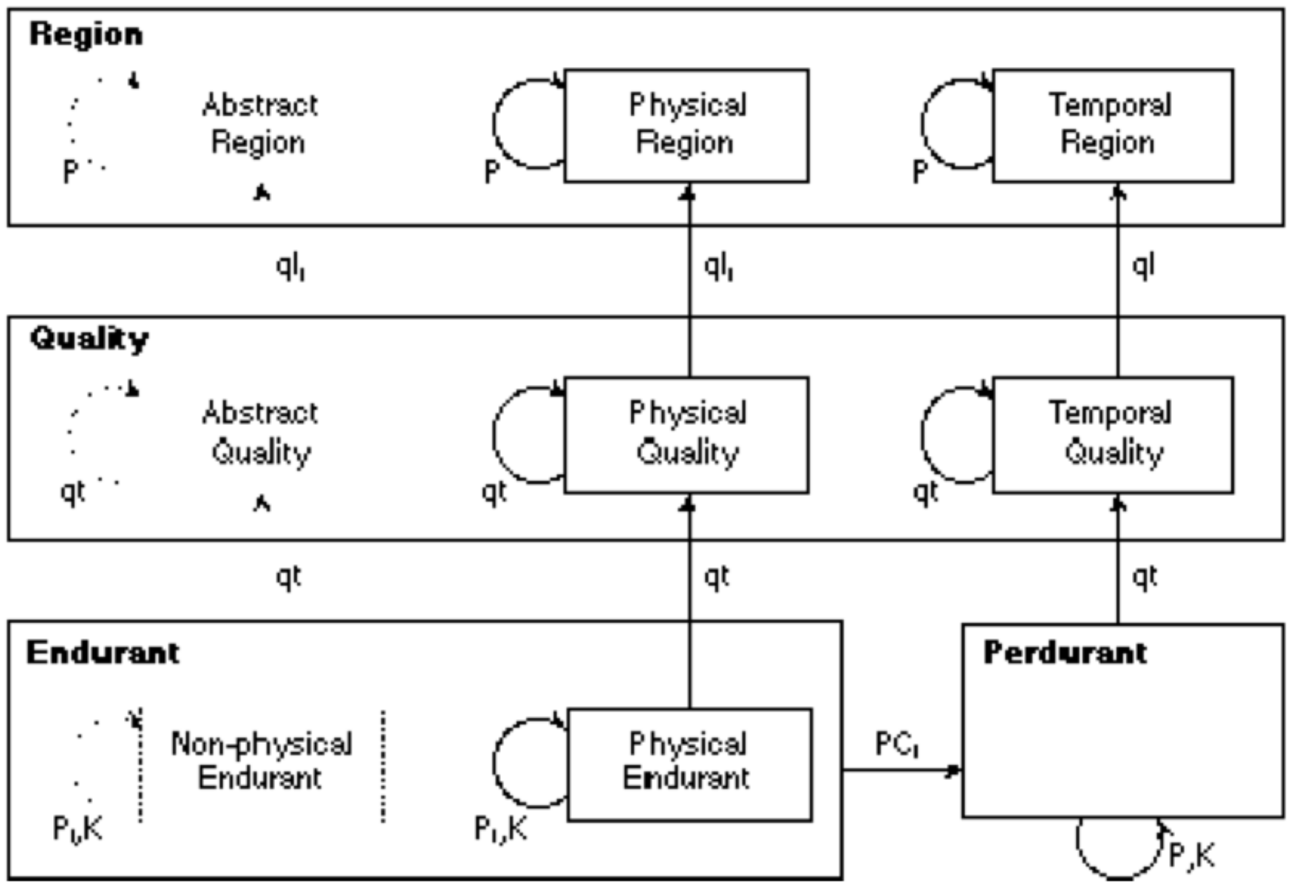


Figure 4. Primitive relations between basic categories.[1]

Axioms (sample)

Mereological Definitions

(D14)	$\mathrm{PP}(x, y) =_{\mathrm{df}} \mathrm{P}(x, y) \wedge \neg \mathrm{P}(y, x)$	*(Proper Part)*
(D15)	$\mathrm{O}(x, y) =_{\mathrm{df}} \exists z(\mathrm{P}(z, x) \wedge \mathrm{P}(z, y))$	*(Overlap)*
(D16)	$\mathrm{At}(x) =_{\mathrm{df}} \neg \exists y(\mathrm{PP}(y, x))$	*(Atom)*
(D17)	$\mathrm{AtP}(x, y) =_{\mathrm{df}} \mathrm{P}(x, y) \wedge \mathrm{At}(x)$	*(Atomic Part)*
(D18)	$x + y =_{\mathrm{df}} \iota z \forall w(\mathrm{O}(w, z) \leftrightarrow (\mathrm{O}(w, x) \vee \mathrm{O}(w, y)))$	*(Binary Sum)*
(D19)	$\sigma x \phi(x) =_{\mathrm{df}} \iota z \forall y(\mathrm{O}(y, z) \leftrightarrow \exists w(\phi(w) \wedge \mathrm{O}(y, w)))$[1]	*(Sum of φ's)*
(D20)	$\mathrm{PP}(x, y, t) =_{\mathrm{df}} \mathrm{P}(x, y, t) \wedge \neg \mathrm{P}(y, x, t)$	*(Temporary Proper Part)*
(D21)	$\mathrm{O}(x, y, t) =_{\mathrm{df}} \exists z(\mathrm{P}(z, x, t) \wedge \mathrm{P}(z, y, t))$	*(Temporary Overlap)*
(D22)	$\mathrm{At}(x, t) =_{\mathrm{df}} \neg \exists y(\mathrm{PP}(y, x, t))$	*(Temporary Atom)*
(D23)	$\mathrm{AtP}(x, y, t) =_{\mathrm{df}} \mathrm{P}(x, y, t) \wedge \mathrm{At}(x, t)$	*(Temporary Atomic Part)*
(D24)	$x \equiv_t y =_{\mathrm{df}} \mathrm{P}(x, y, t) \wedge \mathrm{P}(y, x, t)$	*(Coincidence)*
(D25)	$\mathrm{CP}(x, y) =_{\mathrm{df}} \exists t(\mathrm{PRE}(y, t)) \wedge \forall t(\mathrm{PRE}(y, t) \rightarrow \mathrm{P}(x, y, t))$	*(Constant Part)*
(D26)	$x +_t y =_{\mathrm{df}} \iota z \forall w,t(\mathrm{O}(w, z, t) \leftrightarrow (\mathrm{O}(w, x, t) \vee \mathrm{O}(w, y, t)))$	
(D27)	$\sigma_t x \phi(x) =_{\mathrm{df}} \iota z \forall y,t(\mathrm{O}(y, z, t) \leftrightarrow \exists w(\phi(w) \wedge \mathrm{O}(y, w, t)))$[2]	

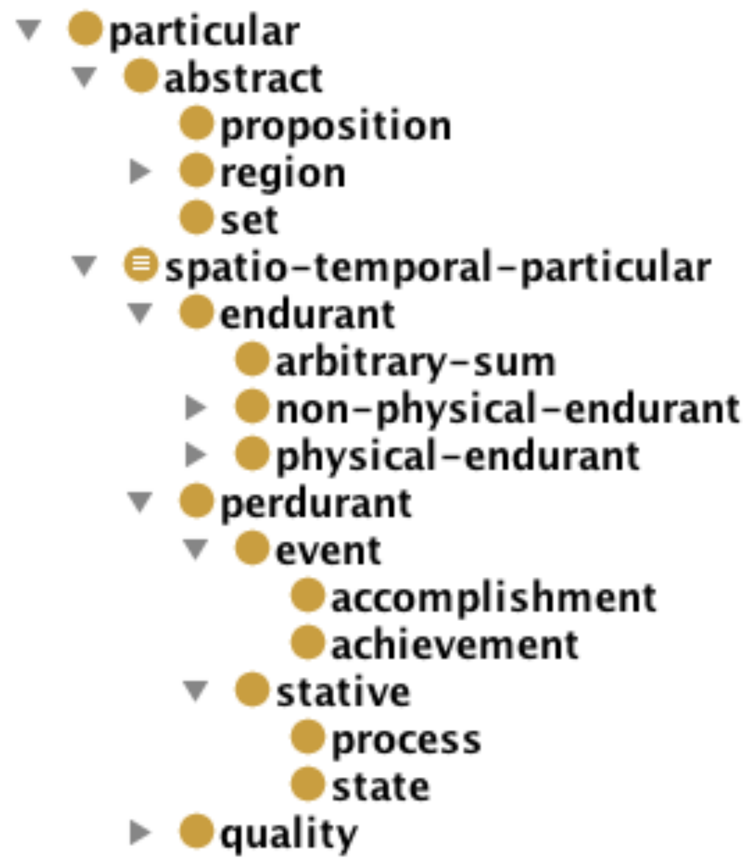
Concept hierarchy

∀x abstract(x)→particular(x)

∀x proposition(x)→abstract(x)

etc.

DOLCE Light in OWL



- particular
  - abstract
    - proposition
    - region
    - set
  - spatio-temporal-particular
    - endurant
      - arbitrary-sum
      - non-physical-endurant
      - physical-endurant
    - perdurant
      - event
        - accomplishment
        - achievement
      - stative
        - process
        - state
    - quality

Description Logics (DL)

A family of logic languages (fragments of FOL)

- "Reasonably" expressive
  - Less expressive than predicate logics
  - More expressive than UML class diagrams
  - Reasoning can be automated in many DLs

Ontology

- vocabulary of classes, properties, and individuals
- axioms
  - concept definitions and inclusions
  - concept instances (individuals)

Ontologies in DL

Top level foundational ontologies

- BFO
- DOLCE (Light)
- CCO

Core ontologies

- FMA (foundational model of anatomy, 104721 classes)
- OWL-S (web services)
- CityGML, IFCOWL (translated from other models)

Specific (application) ontologies

- see for instance https://bioportal.bioontology.org/ontologies/

Common Core Ontologies

Realism: an ontology should be designed to model not only data, but also, more importantly, the entities in the world that data refers to.

- Conviction: disparate ways of capturing data are best rendered interoperable by rendering them conformant to the ways things actually are in reality.
- Any given assertion in an ontology can be evaluated on the basis of an objective criterion: Is the assertion true?
- A distinction between representations of **real entities** and representations of **information entities**. For example, it allows one to distinguish explicitly between
  - a representation of a patient John Doe (repr. of a real person) and
  - a representation of the electronic medical records that are about John Doe ((fallible) repr. of data about the real person).

https://github.com/CommonCoreOntology/CommonCoreOntologies

Reasoning in DL

- Most DLs are decidable fragments of FOL
- Decidable reasoning tasks
  - consistency
  - subsumption (C subclass of D?)
  - instance checking (x instance of C?)
- Restricted DLs for efficient reasoning
  - OWL2-RL (rule-based reasoners)
  - OWL2-QL (SQL reasoners)

Rule extensions

- To increase the expressive power of the language
- Not in the standard DL semantics
- SWRL rule language
- SPARQL DL:
  - OWL inference
  - SPARQL on the inferred RDF graph