Laboratory for Applied Ontology

Institute of Cognitive Science and Technology
Italian National Research Council

Making Basic Ontological Assumptions: *The DOLCE Experience*

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Thanks to all LOA people!

www.loa-cnr.it

Summary

1. Role of axiomatic, foundational ontologies
2. Towards a library of foundational ontologies
3. Formal Ontology: basic choices available
4. The DOLCE choices
5. DOLCE axioms
6. DOLCE applications and extensions

- Research activities at LOA
- A new journal: Applied Ontology (www. applied-ontology.org)

The importance of *subtle distinctions*

"Trying to engage with ***too many partners too fast*** is one of the main reasons that ***so many online market makers have foundered***. The transactions they had viewed as simple and routine actually involved many ***subtle distinctions in terminology and meaning***"

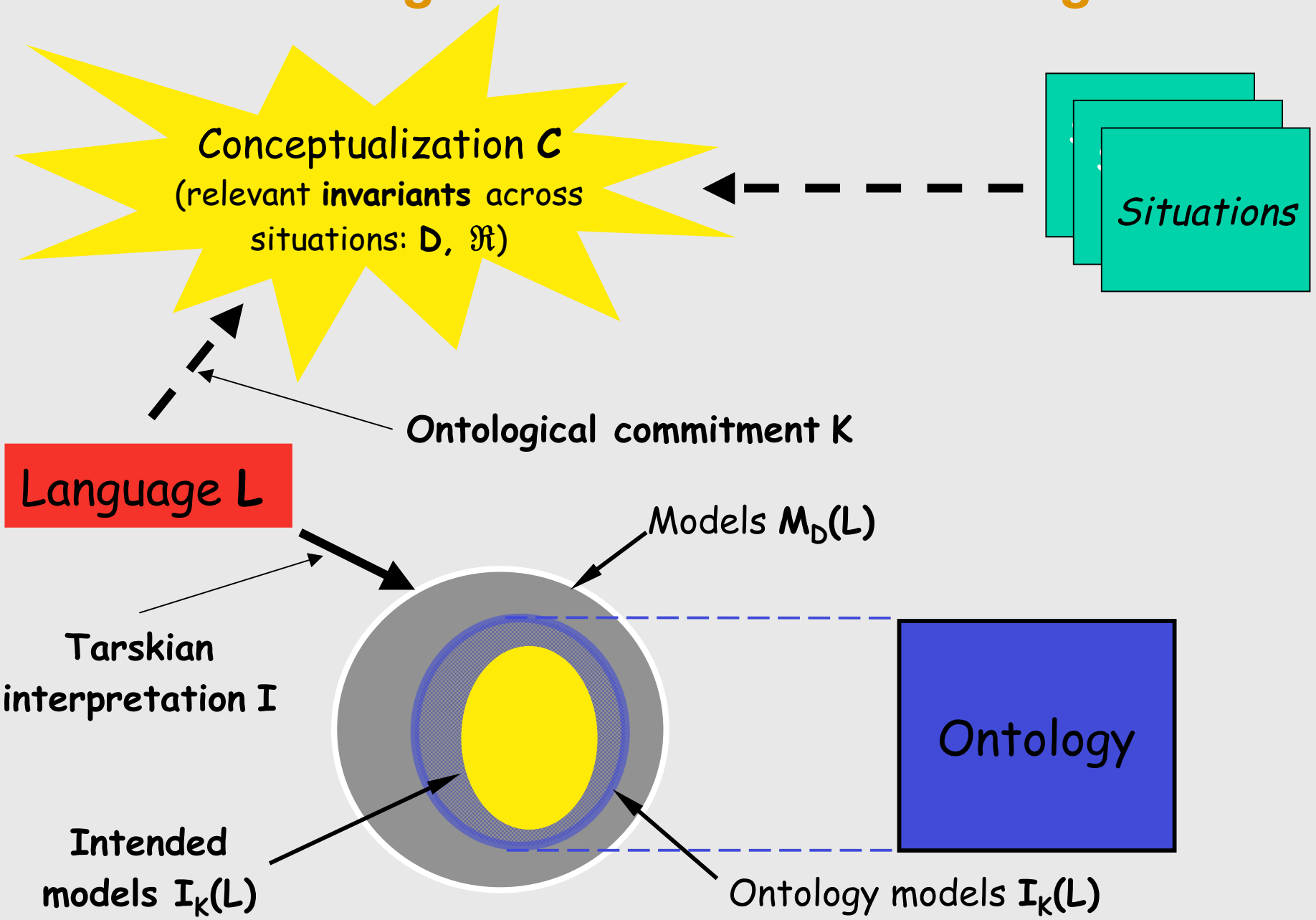
Harvard Business Review, October 2001

Where subtle distinctions in meaning are important

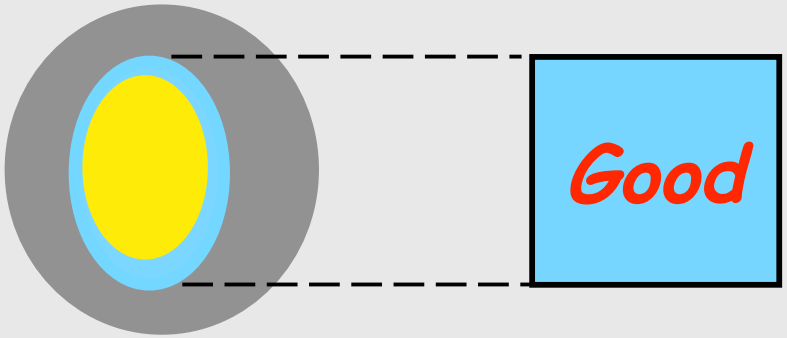
- 2000 US Presidential elections: is there a ***hole***?
- Twin towers catastrophe:
  how many ***events****?*

…only ***ontological analysis*** solves these problems!!

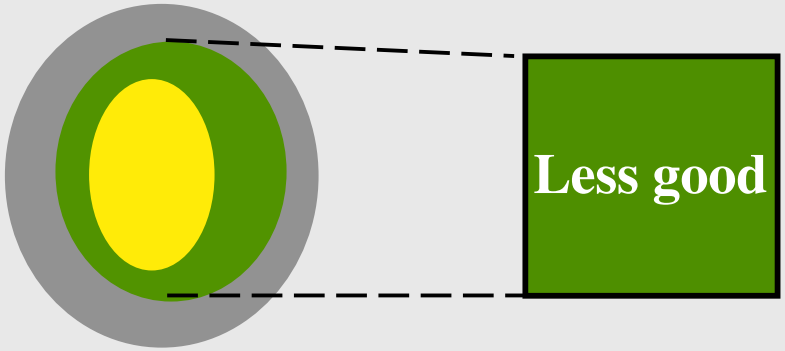
Ontologies and intended meaning



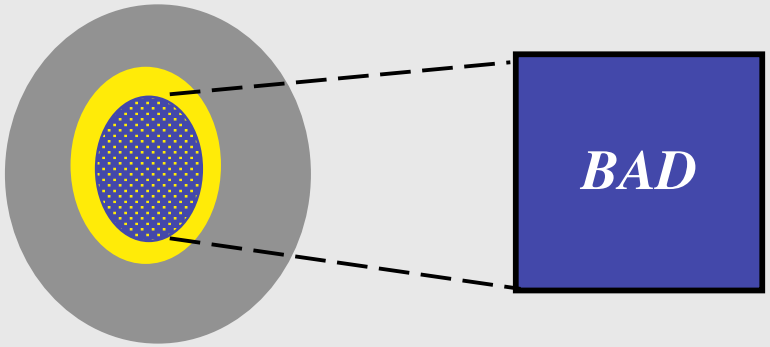
Ontology Quality: Precision and Coverage



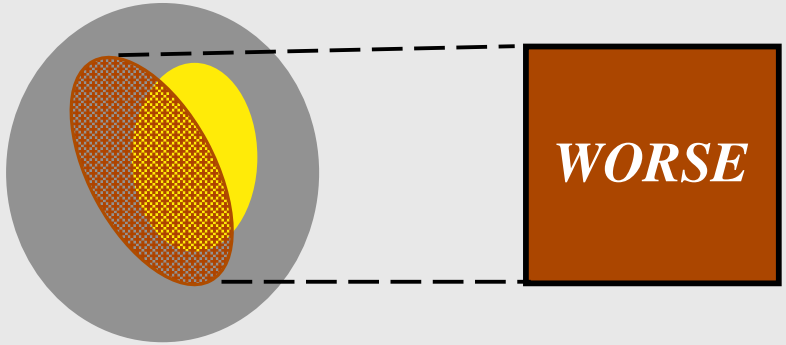
High precision, max coverage



Low precision, max coverage

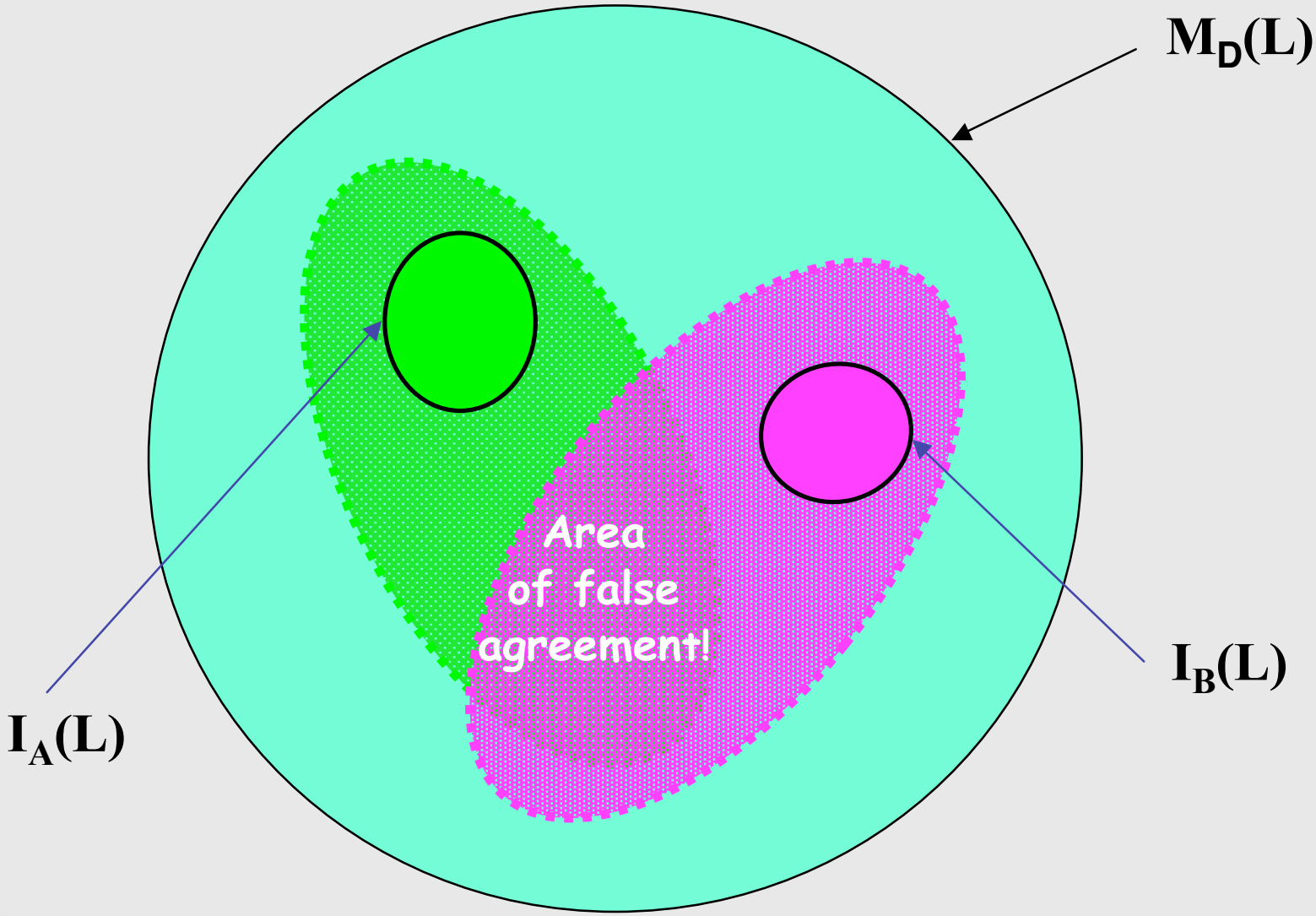


Max precision, limited coverage



Low precision, limited coverage

Why precision is important



When is a foundational ontology useful?

1. When *subtle distinctions* are important
2. When *recognizing disagreement* is important
3. When *rigorous referential semantics* is important
4. When *general abstractions* are important
5. When *careful explanation and justification* of ontological commitment is important
6. When ***mutual understanding*** is more important than interoperability.

Community-based Access vs. Global Knowledge Access

different roles of ontologies

- **Community-based access**
  - Intended meaning of terms ***known in advance***
  - ***Taxonomic reasoning*** is the main ontology service
  - ***Limited expressivity***
  - ***On-line reasoning*** (stringent computational requirements)

- **Global knowledge access**
  - ***Negotiate meaning*** across different communities
  - ***Establish consensus*** about meaning of a new term within a community
  - ***Explain meaning*** of a term to somebody new to community
  - ***Higher expressivity*** required to express intended meaning
  - ***Off-line reasoning*** (only needed ***once***, before cooperation process starts)

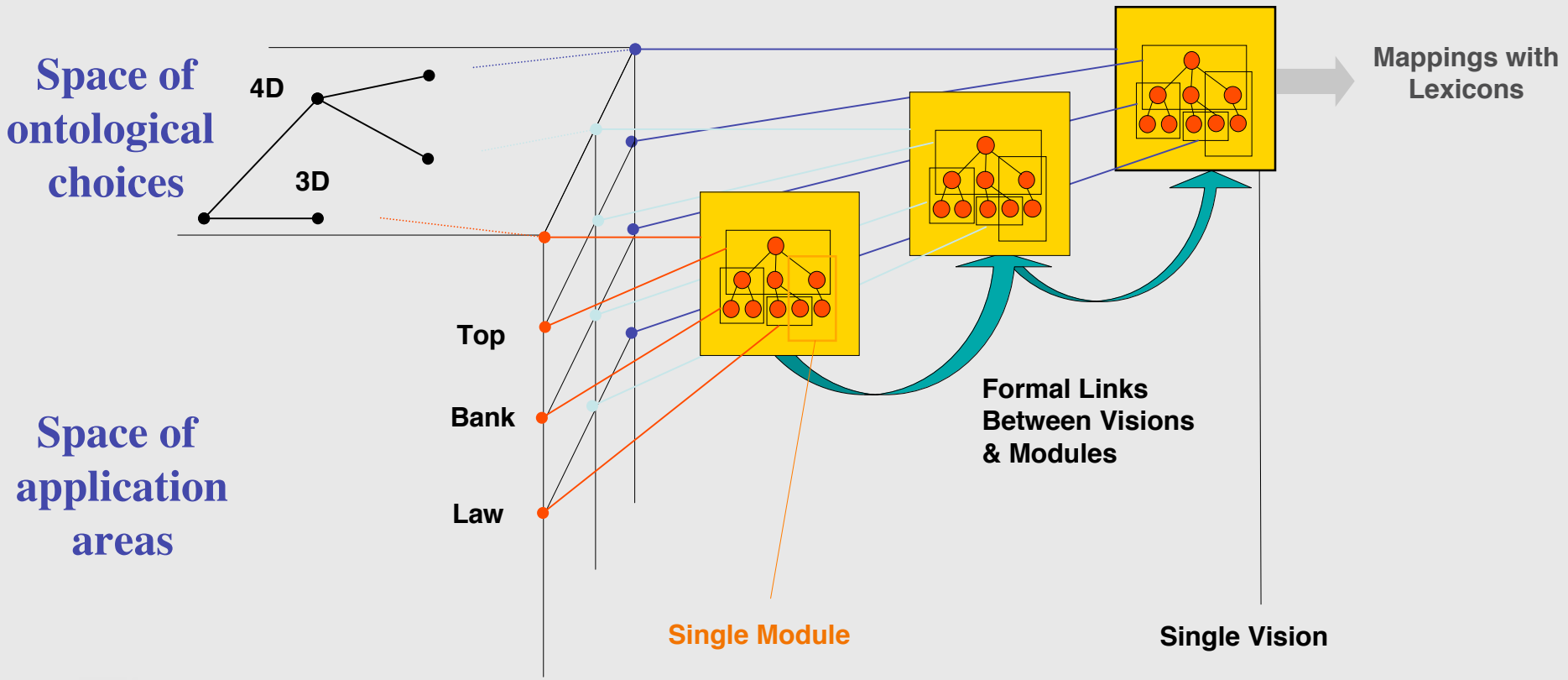
The WonderWeb Foundational Ontologies Library (WFOL)

- No single upper level
- Rather, a (small) set of ***foundational ontologies*** carefully ***justified*** and ***positioned*** with respect to the space of possible choices, reflecting different commitments and purposes
- ***Basic options*** clearly documented
- Clear ***branching points*** to allow for easy comparison of ontological options

- A ***starting point*** for building new ontologies
- A ***reference point*** for easy and rigorous comparison among different ontological approaches
- A ***common framework*** for analyzing, harmonizing and integrating existing ontologies and metadata standards

The WFOL architecture (*WonderWeb FP5 project*)

(the library of formal ontologies)

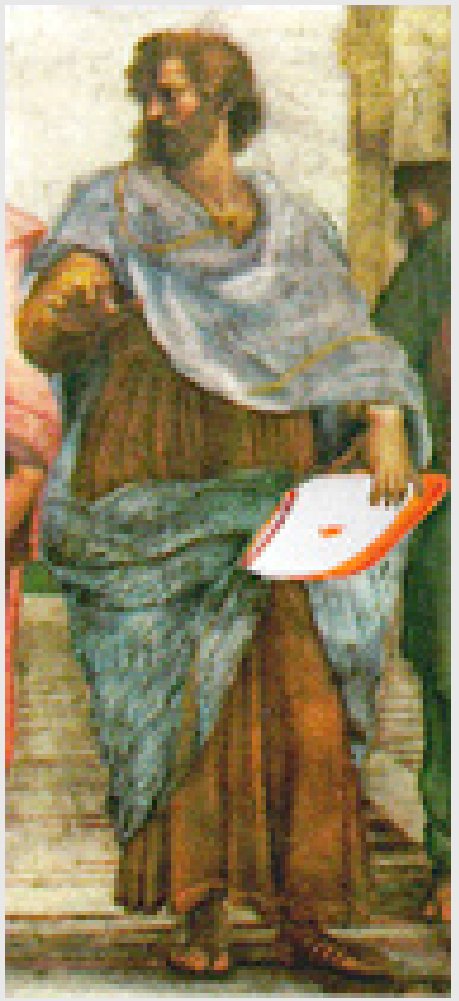


Formal Ontology

- Theory of ***formal distinctions and connections*** within:
  - entities of the world, as we perceive it (***particulars***)
  - categories we use to talk about such entities (***universals***)
- Why ***formal****?*
  - Two meanings: ***rigorous*** and ***general***
  - Formal logic: connections between truths - neutral wrt ***truth***
  - Formal ontology: connections between things - neutral wrt ***reality***

Formal Ontological Analysis

- Theory of Essence and Identity
- Theory of Parts (Mereology)
- Theory of Wholes
- Theory of Dependence
- Theory of Composition and Constitution
- Theory of Properties and Qualities



The basis for a common ontology vocabulary

Mereology

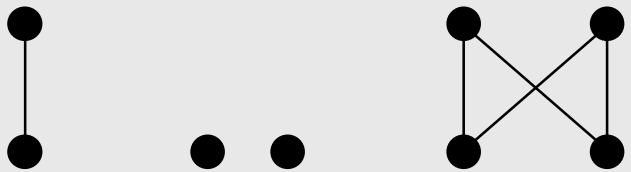
- Primitive: ***proper part-of*** relation (PP)
  - asymmetric
  - transitive
  - **Pxy =$_{def}$ PPxy ∨ x=y**
  - **Oxy =$_{def}$ ∃ z(Pzx ∧ Pzy)**
- Axioms:

supplementation: **PPxy → ∃z (PPzy ∧ ¬ Ozx)**

principle of sum: **∃z ∀w (Owz ↔ (Owx ∨ Owy))**

extensionality: **x = y ↔ ∀w(Pwx ↔ Pwy)**

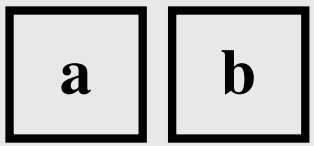
Excluded models:



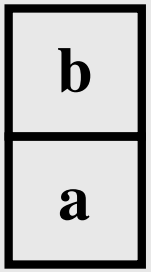
Part, Constitution, and Identity

- ***Structure*** may change identity
- ***Mereological extensionality*** is lost

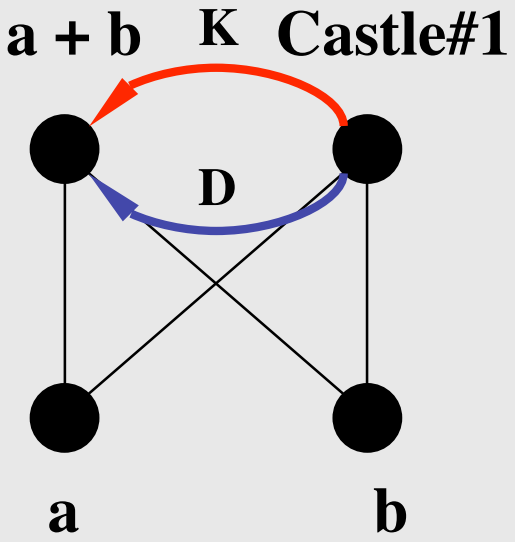
- ***Constitution*** links the two entities
- **Constitution is** asymmetric (implies ***dependence***)



Two blocks



A castle



Some Ontological Choices (1)

- **Universals, Particulars and Individual Properties**
  - Properties
    a) repeatable *universals*, belonging to different entities
    b) non-repeatable *tropes*, inhering only in a specific entity"
  - Particulars
    a) Aggregations *(bundles)* of properties
    b) Properties inhering to some substrate *(bare particular)*

- **Persistence of entities**
  - How do entities persist?
  - How do entities *change* in time?
    - Due to different phases (similar to change in space)
    - Due to (whole) instantiation of different properties at different times?
  - How are change and persistence related?

Some Ontological Choices (2)

- **Space and Time**
  - Absolute or relative?
  - Atomic or not?
- **Localization**
  - Are there entities that are not in space/time (*abstract*)?
  - Is it possible to have different entities spatially or spatio-temporally co-localized?

DOLCE: motivating its ontological distinctions

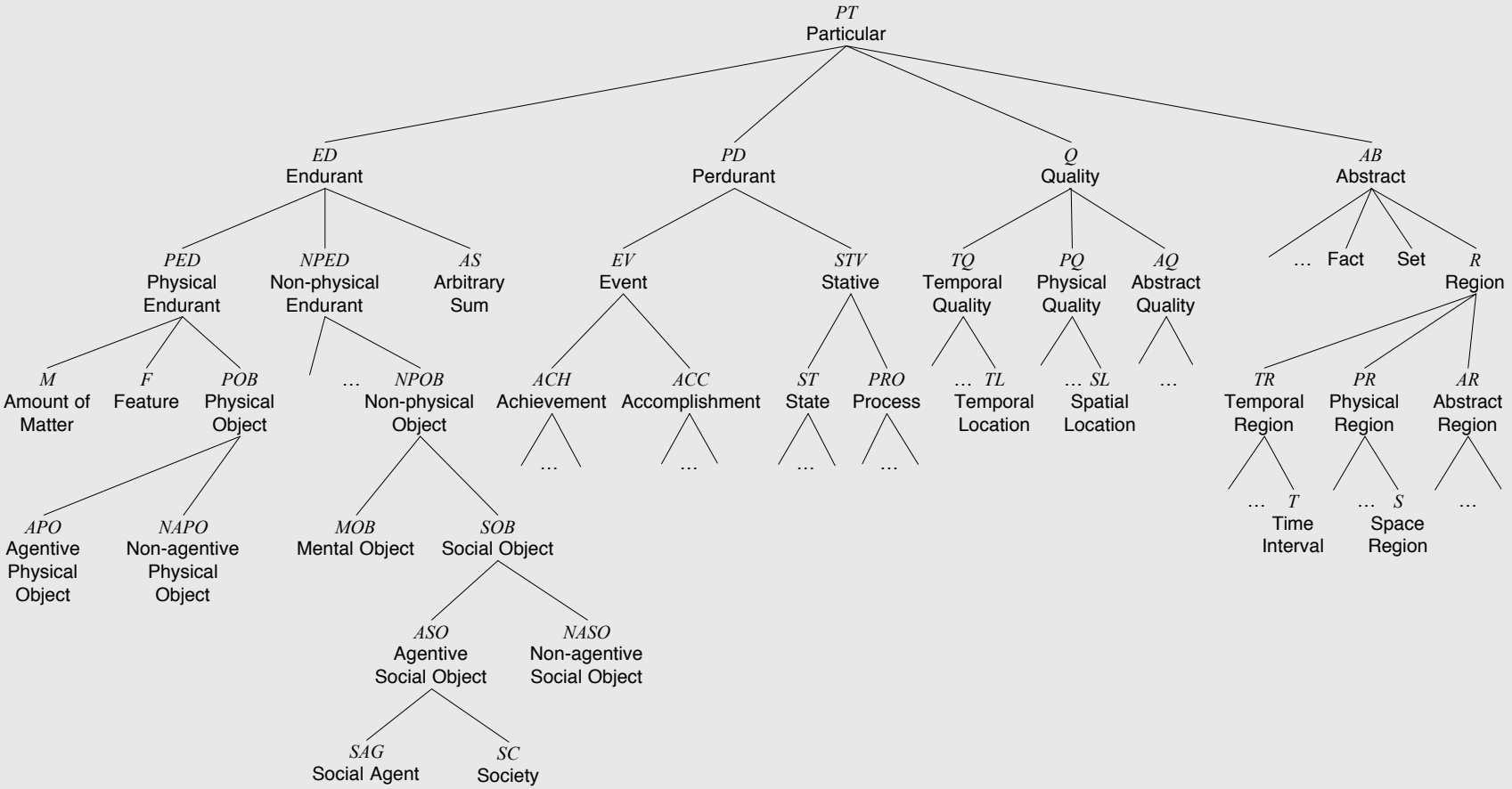
DOLCE
a Descriptive Ontology for Linguistic and Cognitive Engineering

- Strong cognitive/linguistic bias:
  - ***descriptive*** (as opposite to *prescriptive*) attitude
  - Categories mirror cognition, common sense, and the lexical structure of natural language.
- Emphasis on ***cognitive invariants***
- Categories as ***conceptual containers***: no “deep” metaphysical implications
- Focus on ***design rationale*** to allow easy comparison with different ontological options
- Rigorous, systematic, interdisciplinary approach
- ***Rich axiomatization***
  - *37 basic categories*
  - *7 basic relations*
  - *80 axioms, 100 definitions, 20 theorems*
- Rigorous quality criteria
- Documentation

DOLCE's basic taxonomy

- Endurant
  - Physical
    - Amount of matter
    - Physical object
    - Feature
  - Non-Physical
    - Mental object
    - Social object
  - …
- Perdurant
  - Static
    - State
    - Process
  - Dynamic
    - Achievement
    - Accomplishment
- Quality
  - Physical
    - Spatial location
    - …
  - Temporal
    - Temporal location
    - …
  - Abstract
- Abstract
  - Quality region
    - Time region
    - Space region
    - Color region
    - …
  - …

DOLCE taxonomy



DOLCE's Basic Ontological Choices

- **Endurants** (aka *continuants* or *objects*) and **Perdurants** (aka *occurrences* or *events*)
  - distinct categories connected by the relation of *participation*.

- **Qualities**
  - Individual entities *inhering in* Endurants or Perdurants
  - can live/change with the objects they inhere in
  - Instance of *quality kinds,* each associated to a **Quality Space** representing the *"values" (qualia)* that qualities (of that kind) can assume. Quality Spaces are neither in time nor in space.

- **Multiplicative approach**
  - Different Objects/Events can be spatio-temporally co-localized: the relation of *constitution* is considered.

Endurants and Perdurants

- Endurants (3D *continuants*)
  - Need a time-indexed parthood relation
  - Exist in time
  - Can genuinely change in time
  - May have non-essential parts
  - All proper parts are present whenever they are present (wholly presence, no temporal parts)

- Perdurants (4D *occurrences*[1]) [*Occurrents* are *occurrence-types*]
  - Do not need a time-indexed parthood relation
  - Happen in time
  - Do not change in time *(as a whole...)*
  - All parts are essential
  - Only some proper parts are present whenever they are present (partial presence,temporal parts)

- Endurants *participate to* Perdurants

(1)

1 - The physical view

- Basic ***qualities*** ascribed to atomic spacetime regions (e.g., mass, electric charge…)
- ***Fields*** (physical processes) are spatiotemporal distributions of qualities

2 - The *cognitive view*

- Humans isolate ***relevant invariances*** on the basis of:
  - Perception (as resulting from evolution)
  - Cognition and cultural experience
  - Language
- A set of ***atomic percepts*** is associated to each situation
- Synchronic level: ***spatial invariants***
  - Unity properties are ascribed to percepts patterns: topological and morphological ***wholes*** emerge
- Diachronic level: ***temporal invariants***
  - ***Endurants***: equivalence relationships among percepts patterns belonging to different situations
  - ***Perdurants:*** unity properties are ascribed to percepts patterns belonging to different situations

3 - The linguistic view

and the *multiplicative choice*

substitutivity tests :

- I am talking here
- *This bunch of molecules is talking
- *What's here now is talking

- This statue is looking at me
- *This piece of marble is looking at me
- This statue has a strange nose
- *This piece of marble has a strange nose

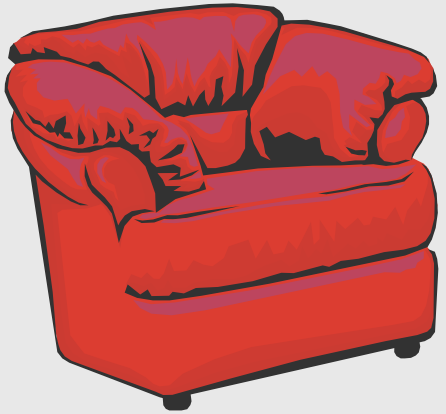
- There is a fly on the nose of this statue
- *There is a fly on the nose of this piece of marble
- There is a fly on this piece of marble

Qualities and qualia

- Linguistic evidence
  - *This rose is red*
  - *Red is a color*
  - *This rose has a color*
  - *The color of this rose turned to brown in one week*
  - *Red is opposite to green and close to brown*
  - *The patient's temperature is increasing*
  - *The doctor measured the patient's temperature*

- Each endurant and perdurant comes with certain qualities that permanently ***inhere*** to it and are ***unique*** of it
- Qualities are perceptually mapped into ***qualia***, which are regions of ***quality spaces***.
- Properties hold because qualities have certain locations in their quality spaces.
- Each quality type has its own quality space

Qualities

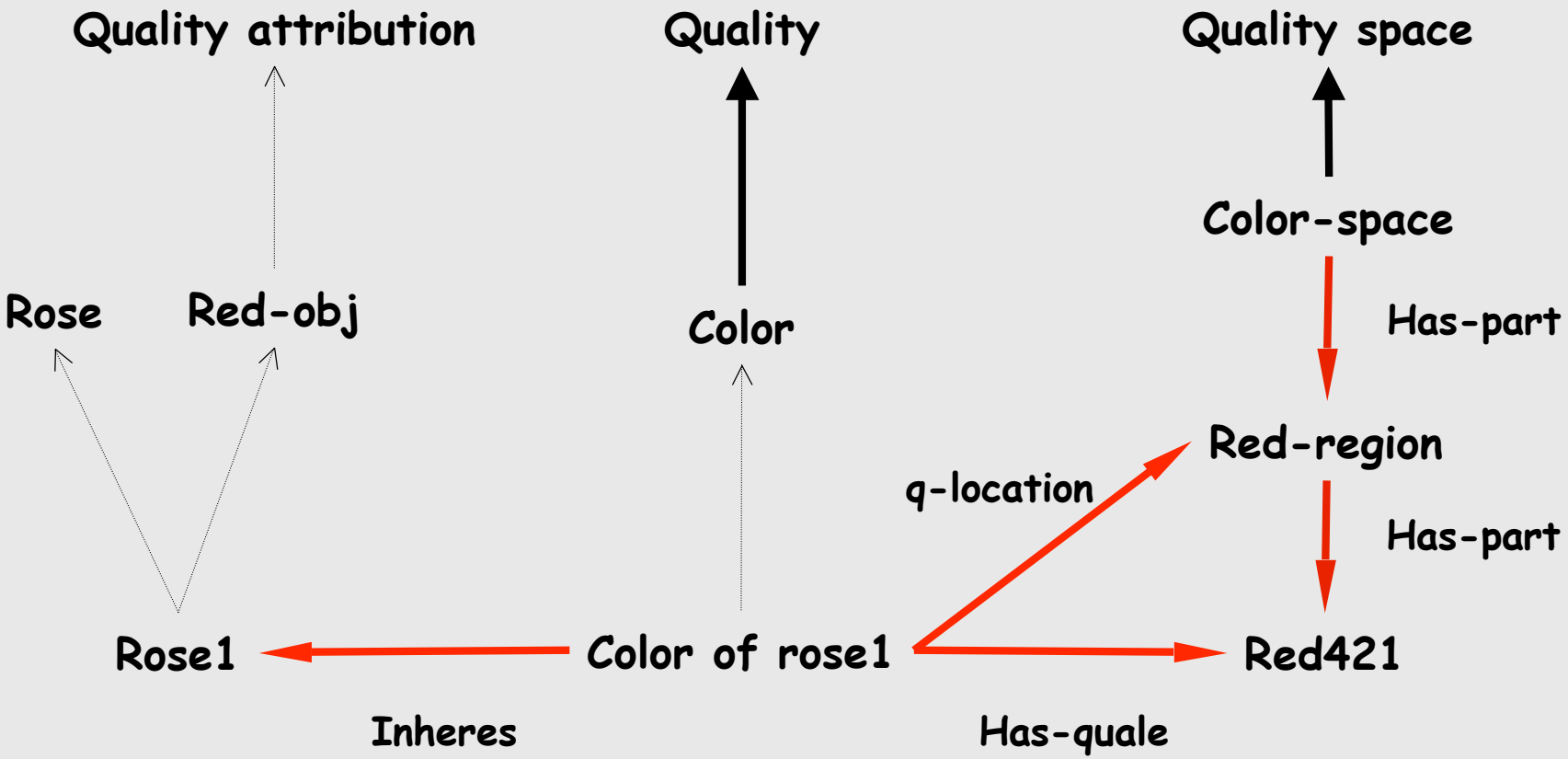


The rose and the chair have *the same color*:

- different color qualities inhere to the two objects
- they are located in the same quality region

Therefore, the same color attribute (red) is ascribed to the two objects

Qualities


Quality attribution
Quality
Quality space
Color-space
Rose
Red-obj
Color
Has-part
Red-region
q-location
Has-part
Rose1
Color of rose1
Red421
Inheres
Has-quale

Qualities vs. Features

- **Features**: “parasitic” physical entities.
- **relevant parts** of their host…
  … or **places**
- Features have qualities, qualities have no features.

Abstract vs. Concrete Entities

- Concrete:
  - located (at least) in time
- Abstract - two meanings:
  - Result of an abstraction process (something common to multiple exemplifications)
  - ☛ ***Not located in space-time*** (no inherent spatial or temporal location)

- Examples: ***propositions***, ***sets***, ***symbols***, ***regions***, etc.
  - ***Quality regions*** and ***quality spaces*** are abstract entities
  - Mereological sums (of concrete entities) are concrete, the corresponding sets are abstract...

Physical vs. Non-physical Endurants

- Physical endurants
  - Inherent spatial localization
  - Not necessarily dependent on other objects

- Non-physical endurants
  - No inherent spatial localization
  - Dependent on agents
    - mental (depending on singular agents)
    - social (depending on communities of agents)
  - Agentive: a company, an institution
  - Non-agentive: a law, the Divine Comedy, a linguistic system…
    - Descriptions, an extension of DOLCE

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Formalizing DOLCE

Basic Relations

- Parthood
  - Between quality regions (immediate)
  - Between arbitrary objects (temporary)
- Dependence
  - Specific/generic constant dependence
- Constitution
- Inherence (between a quality and its host)
- Quale
  - Between a quality and its region (immediate, for unchanging entities)
  - Between a quality and its region (temporary, for changing entities)
- Participation
- Representation

Axiomatizing basic relations

- Domain restrictions
- Ground axioms (mainly algebraic)
- Links to other relations
- Dependence on time

Domain restrictions on basic relations

Parthood: "*x is part of y*" $\mathrm{P}(x, y) \rightarrow (AB(x) \vee PD(x)) \wedge (AB(y) \vee PD(y))$
Temporary Parthood: "*x is part of y during t*" $\mathrm{P}(x, y, t) \rightarrow (ED(x) \wedge ED(y) \wedge T(t))$
Constitution: "*x constitutes y during t*" $\mathrm{K}(x, y, t) \rightarrow ((ED(x) \vee PD(x)) \wedge (ED(y) \vee PD(y)) \wedge T(t))$
Participation: "*x participates in y during t*" $\mathrm{PC}(x, y, t) \rightarrow (ED(x) \vee PD(y) \wedge T(t))$
Quality: "*x is a quality of y*" $\mathrm{qt}(x, y) \rightarrow (Q(x) \wedge (Q(y) \vee ED(y) \vee PD(y)))$
Quale: "*x is the quale of y* (*during t*)" $\mathrm{ql}(x, y) \rightarrow (TR(x) \wedge TQ(y))$ $\mathrm{ql}(x, y, t) \rightarrow ((PR(x) \vee AR(x)) \wedge (PQ(y) \vee AQ(y)) \wedge T(t))$

Kinds of dependence

(D1) $SD(x, y) =_{df} o(\exists t(PR(x, t)) \wedge \forall t(PR(x, t) \rightarrow PR(y, t)))$ (*Specific Const. Dep.*)

(D2) $SD(\phi, \psi) =_{df} DJ(\phi, \psi) \wedge o\forall x(\phi(x) \rightarrow \exists y(\psi(y) \wedge SD(x, y)))$ (*Specific Const. Dep.*)

(D3) $GD(\phi, \psi) =_{df} DJ(\phi, \psi) \wedge o(\forall x(\phi(x) \rightarrow \exists t(PR(x, t)) \wedge$
$\forall x,t((\phi(x) \wedge At(t) \wedge PR(x, t)) \rightarrow \exists y(\psi(y) \wedge PR(y, t))))$ (*Generic Const. Dep.*)

(D4) $D(\phi, \psi) =_{df} SD(\phi, \psi) \vee GD(\phi, \psi))$ (*Constant Dependence*)

(D5) $OD(\phi, \psi) =_{df} D(\phi, \psi) \wedge \neg D(\psi, \phi)$ (*One-sided Constant Dependence*)

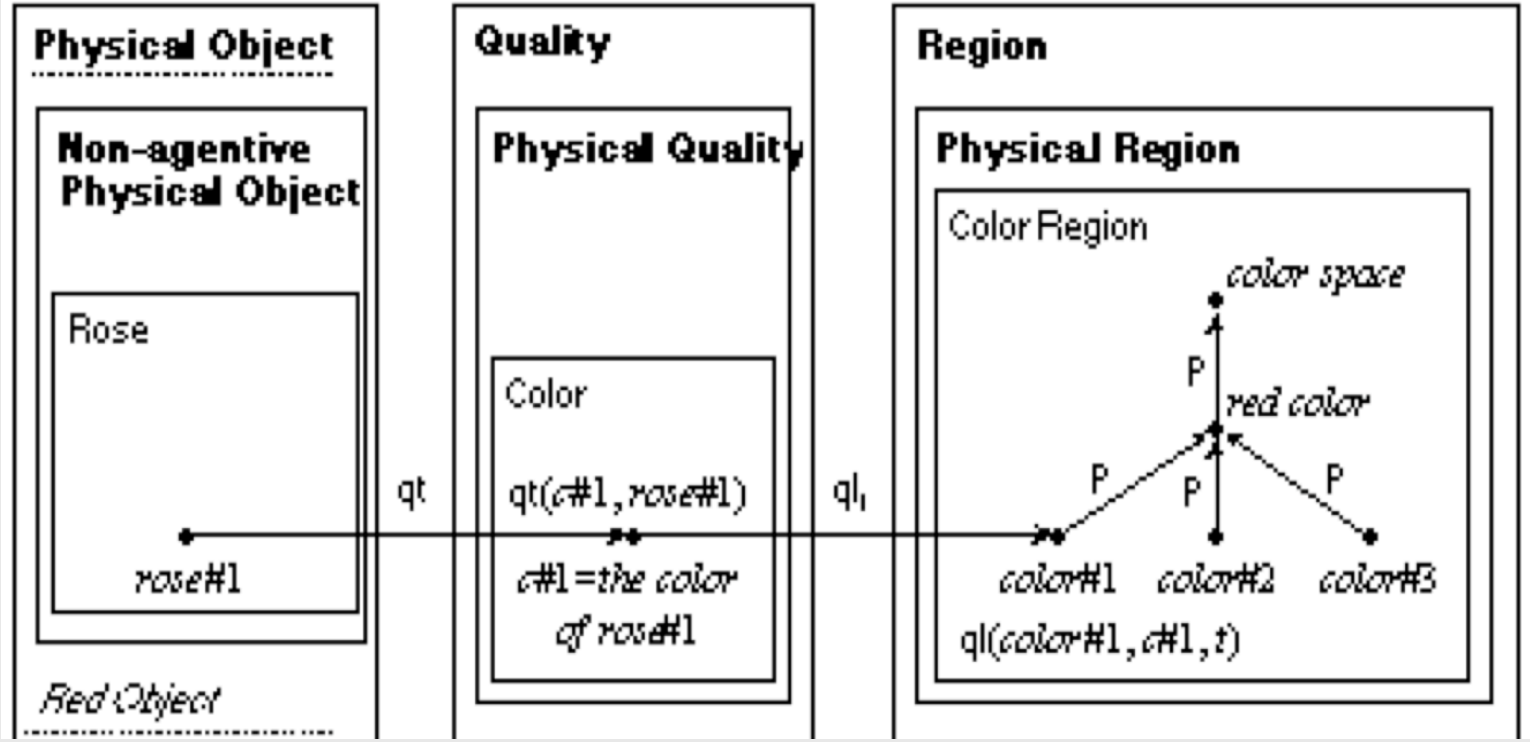
(D6) $OSD(\phi, \psi) =_{df} SD(\phi, \psi) \wedge \neg D(\psi, \phi)$ (*One-sided Specific Constant Dependence*)

(D7) $OGD(\phi, \psi) =_{df} GD(\phi, \psi) \wedge \neg D(\psi, \phi)$ (*One-sided Generic Constant Dependence*)

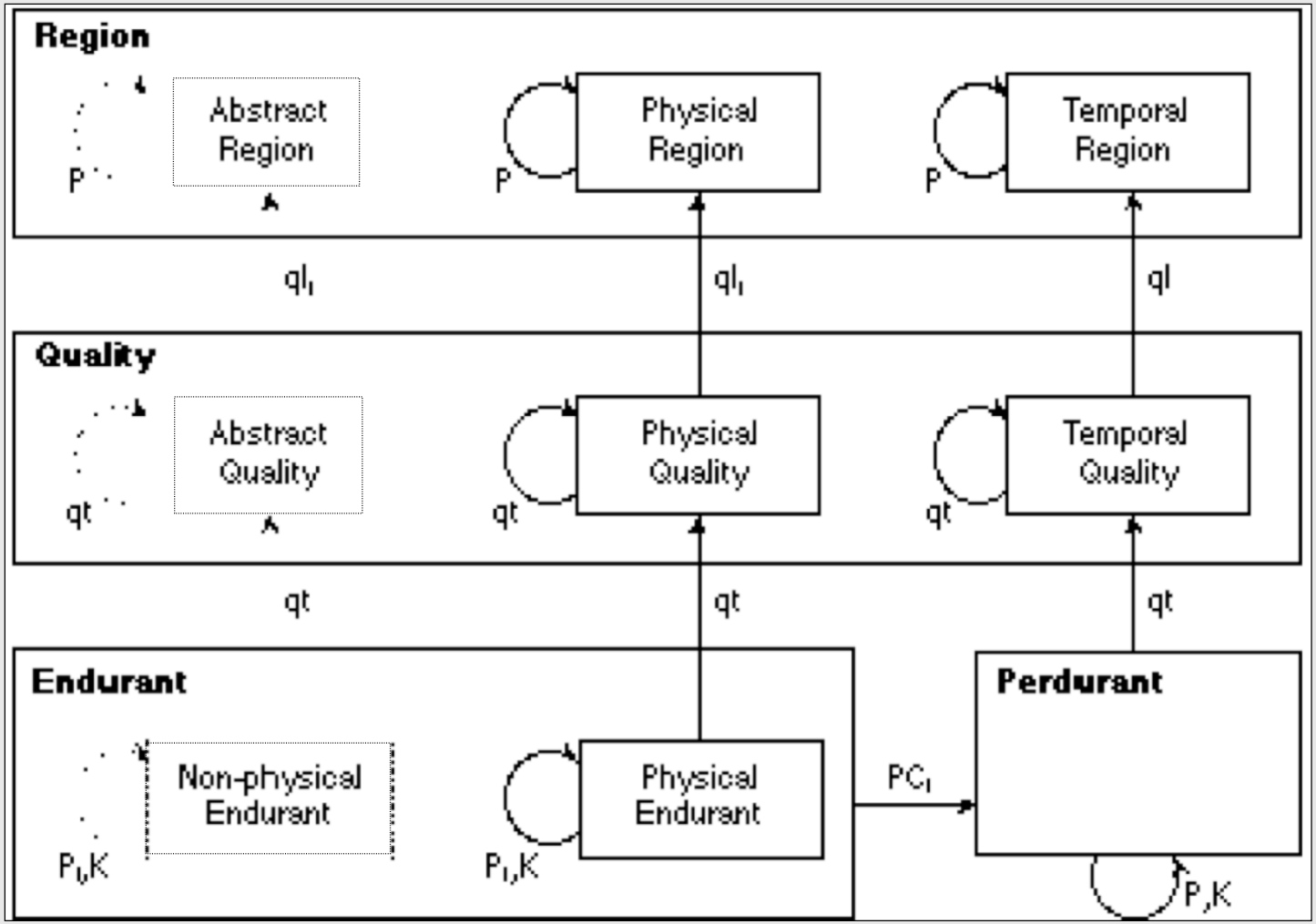
(D8) $MSD(\phi, \psi) =_{df} SD(\phi, \psi) \wedge SD(\psi, \phi)$ (*Mutual Specific Constant Dependence*)

(D9) $MGD(\phi, \psi) =_{df} GD(\phi, \psi) \wedge GD(\psi, \phi)$ (*Mutual Generic Constant Dependence*)

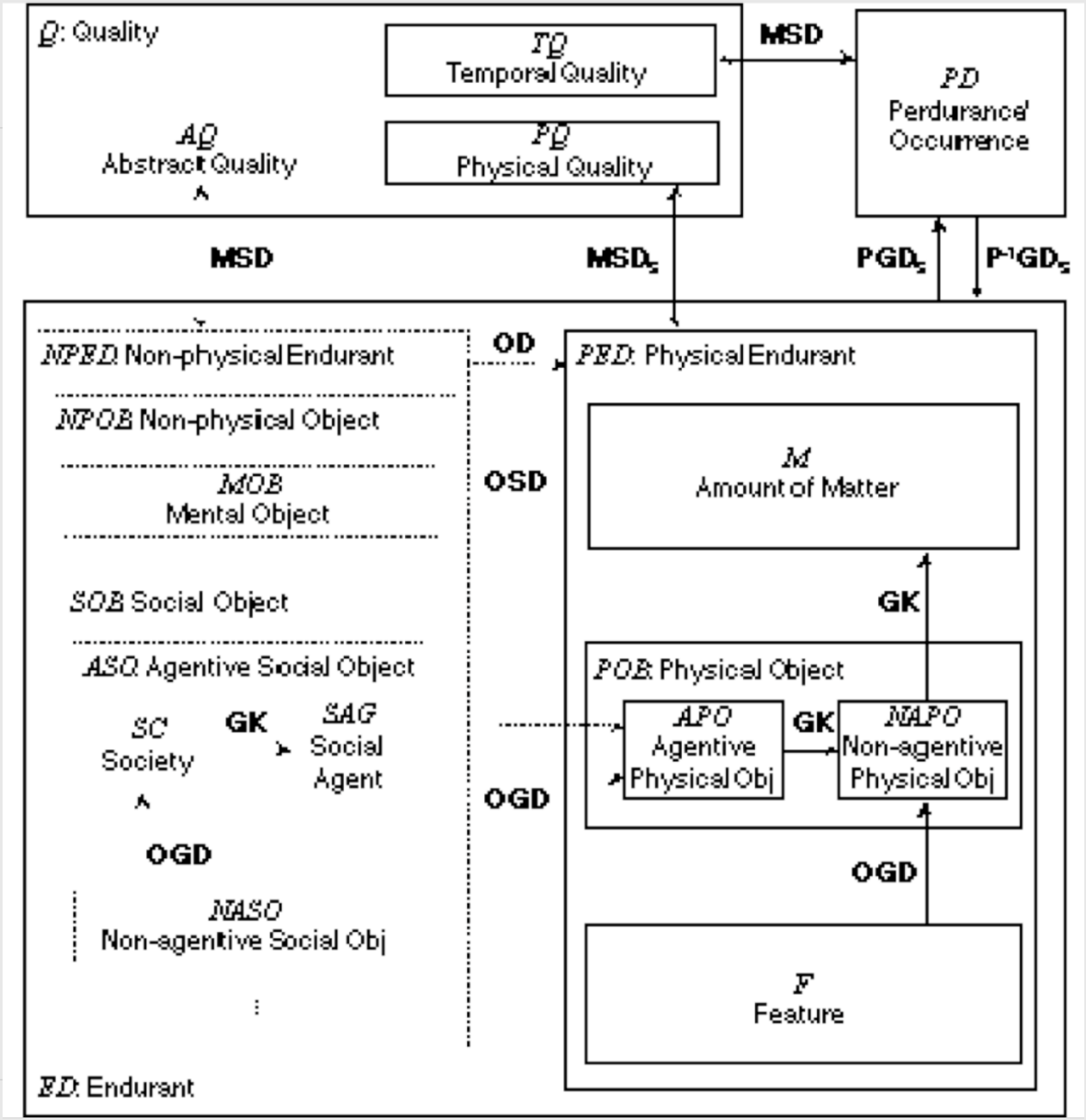
Quality relations



Primitive relations and basic categories



Dependence relations



Participation relations

- Hold between a perdurant and its involved endurants
- Extremely relevant for domain modelling
- Current axiomatization covers:
  - constant vs. temporary
  - complete vs. partial
- Further distinctions are currently primitive (thematic roles)
  - *Agent, Theme, Substrate, Instrument, Product*
  - More is needed on event structure, intentionality, and artifacts to produce analytic definitions

DOLCE Extensions and Applications

DOLCE Extensions

(mainly by Aldo Gangemi @LOA-RM)

- Allen-based ontology of time for events
- Ontology of common-sense locations
- Descriptions and Situations (D&S) ontology (reified relations and relationships)
- Ontology of Functional Participation (cf. *thematic roles*)
- Ontology of Plans and Tasks (DDPO) (Metokis project)
- Ontology of Information Objects (DDIO (Metokis project)
- Ontology of Knowledge Content Objects (KCO), from Metokis, for multimedia description and negotiation
- Ontology of Services, based on DDPO (with UKA, VUA)
- Ontology of Semantic Middleware (by Daniel Oberle at UKA)
- Core Legal Ontology (CLO, with ITTIG-CNR)
- Metaontology of ontology as semiotic object (O2)
- Ontology of ontology evaluation and quality (oQual)
- Ontology of design patterns
- Ontology of social entities and organizations (MOSTRO project @LOA-TN)

Mapping with lexicons: the OntoWordNet project

(Aldo Gangemi, Alessandro Oltramari, Massimiliano Ciaramita)

- 809 synsets from WordNet1.6 directly subsumed by a DOLCE+ class
  - Whole WordNet linked to DOLCE+
  - Lower WordNet levels still need revision
- Glosses being transformed into DOLCE+ axioms
  - Machine learning applied jointly with foundational ontology
- WordNet “domains” being used to create a modular, general purpose domain ontology
- Ongoing work on ontological analysis of specific WordNet domains (cognition, emotion, psychological feature)
- Ongoing cooperation with Princeton University.

The OntoWordNet methodology

1. **Populate** a general ontology (DOLCE) by adding single synsets (or whole taxonomy branches) from a c. lexicon (upon suitable classification)
2. **Restructure** a c. lexicon by checking ontological constraints (e.g. *OntoClean* meta-properties) throughout the branches
3. **Merge** an ontology and a c. lexicon (includes 1. and 2.)
4. **Enrich** the resulting structure by extracting relationships from the glosses.

A Selection of Most Relevant Projects (2003-2006)

- **WonderWeb** (FP5): Ontology Infrastructure for the Semantic Web (LOA: foundational ontologies for the Semantic Web)
- **OntoWeb** (FP5 - NoE): Ontology-based information exchange for knowledge management and electronic commerce (LOA: *SIG on Content Standards*)
- **METOKIS** (FP6): Methodologies and tools infrastructure for the development of multimedia knowledge units
- **SEMANTIC MINING** (FP6 - NoE): Semantic Interoperability and Data Mining in Biomedicine
- **TICCA** (PAT&CNR): Tecnologie cognitive per l'interazione e la cooperazione con agenti artificiali (LOA: ontology of social interaction)
- **MOSTRO** (PAT); Modelling Security and Trust Relationships in Organizations
- **IKF** : Intelligent Knowledge Fusion (Eureka Project)
  - *Ontology of banking transactions* (*with* ELSAG Banklab_)
  - *Ontology of Service-Level Agreement and IS monitoring* (*with* SELESTA_)
  - *Ontology of Insurance Services (with Nomos SpA)*
- **FOS** (UN/FAO): Alignment of legacy fishery ontologies

- **NEON** (FP6) - Networked Ontologies
- **ONTOGEO** (FP6) - Geo-spatial Semantic Web

Conclusion

- Subtle meaning distinctions do matter
- Formal ontological analysis provides a rigorous methodology to obtain robust and coherent theories
- A humble interdisciplinary approach is essential

…Is this hard?

Of course yes!

(Why should it be easy??)

A new journal: *Applied Ontology*

Editors in chief:

Nicola Guarino
ISTC-CNR

Mark Musen
Stanford University

IOS Press

Amsterdam, Berlin,
Washington, Tokyo, Beijing

www.applied-ontology-org

FOIS-2006

International Conference on Formal Ontology in Information Systems

http://www.formalontology.org/

November 9-11, 2006
Baltimore, Maryland (USA)

Extra slides

A missing extension: unity and plurality

Unity

- A tentative formulation: *x* ***is a whole*** under ω iff ω is an equivalence relation that binds together all the parts of *x*, such that

$$P(y,x) \rightarrow (P(z,x) \leftrightarrow \omega(y,z))$$

but not

$$\omega(y,z) \leftrightarrow \exists x(P(y,x) \wedge P(z,x))$$

- P is the ***part-of*** relation
- ω can be seen as a ***generalized indirect connection***

Kinds of Wholes

- Depending on the nature of ω, we can distinguish:
  - ***Topological wholes*** (a piece of coal, a lump of coal)
  - ***Morphological wholes*** (a constellation)
  - ***Functional wholes*** (a hammer, a bikini)
  - ***Social wholes*** (a population)

* a whole can have parts that are ***themselves wholes*** (with a different ω)

Parts vs. components

- A part x of y is a ***component*** of y iff it is a whole
- We can have topological components, morphological components, functional components….
- ***Members*** of collections are special kinds of components

Unity and Plurality

- *Ordinary objects:* ***wholes or sums of wholes***
  - *Singular*: ***no wholes as proper parts***
  - *Plural*: ***sums of wholes***
    - *Plural wholes* (the sum is ***also a whole***)
    - *Collections* (the sum is not a whole)

- "Fiat" objects: everything else

- Role of *topological wholes* in perception

Further issues about qualities

- Do qualities endure or perdure?
- What about qualities of events?
- Do qualities have parts?
  - Homogenous parts?
  - Heterogeneous parts?
- Do qualities have locations (i.e, other qualities)?
- What does it mean to measure a quality?

DOLCE vs. other axiomatic top-level ontologies

- SUMO
- CYC
- BFO
- GOL
- OCHRE
- Domain-oriented logical theories of space, time, law…
- CIDOC-CRM
- **See UoBremen paper**

Extensions of DOLCE
Plans and task models

- Using D&S, some other extensions are being developed
- A preliminary plan ontology has been defined by starting from the harmonizing of existing clinical guidelines standards
- Basic distinction between plans as contexts (*methods*), and plan execution as configuration
- Typical attributes of plans are different from those of an execution (e.g. “approved” vs. “started”)
- A plan is composed by *tasks*, *roles*, and *parameters*
- Tasks *sequence* actions or processes
  - Succession relations applicable that mirrors temporal relations
  - Task≠Action (cf. “alternative” vs. “running”)
  - Distinction btw action tasks and rational tasks (branching, joining)
- Roles are *played by* objects or substances
- Parameters *select* regions within quality spaces
- Plan representation is also addressed by using an ontology of *communication*