Laboratory for Applied Ontology
Institute of Cognitive Science and Technology
Italian National Research Council
Research Institute for Computer Science of Toulouse - CNRS

Formal Ontology for Semanticists

Stefano Borgo, Nicola Guarino, Laure Vieu

Lesson 5

www.loa-cnr.it

Outline of this lesson

- A glimpse of OntoClean
  - useful distinctions among properties
- DOLCE
  - just a few further motivations and clarifications
- OntoWordNet
  - formal ontology and lexical resources

1 - OntoClean: useful distinctions among properties

Essential properties and rigidity

- Certain entities must have some properties in order to exist;
  - John must have a brain
  - John must be a person.
- Certain properties are essential to ***all*** their instances (compare ***being a person*** with ***having a brain***).
- These properties are ***rigid*** - if an entity is ever an instance of a rigid property, it must necessarily be such.

Note: what does "exist" mean?
For concrete objects, being present at t...

Formal Rigidity

- ϕ is rigid (+R): $\forall x\ (\mathbf{pos}\ \phi(x) \rightarrow \mathbf{nec}\ \phi(x))$
  - e.g. Person, Apple
- ϕ is non-rigid (-R): $\exists x\ (\mathbf{pos}\ \phi(x) \wedge \neg\ \mathbf{nec}\ \phi(x))$
  - e.g. Red, Male
- ϕ is anti-rigid (~R): $\forall x\ (\mathbf{pos}\ \phi(x) \rightarrow \neg\ \mathbf{nec}\ \phi(x))$ e.g. Student, Agent

Meta-properties

Formal rigidity - variations

- **Taking time and actual existence into account:**

$$\mathbf{nec}\forall xt((E(x,t) \wedge \phi(x,t)) \rightarrow \mathbf{nec}\forall t'(E(x,t') \rightarrow \phi(x)))$$

- *Welty, C. and Andersen, W. Towards OntoClean 2.0: A framework for rigidity (to appear soon on Applied Ontology)*

Carrying essential properties

- A property P *carries* a (relevant) essential property Q (different from P) iff Q is essential to all instances of P, and still Q is not rigid:
  - Every person must have a brain.
- Compare with:
  - Every person must be a mammal.

Unity as an essential property

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

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

but not

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

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

Unity Refined

$\delta_U(x) =_{df} U(x, x)$ *(x belongs to the domain of U)*

$U_U(x) =_{df} \Sigma_{\delta_U}(x) \wedge \forall y,z((\delta_U(y) \wedge \delta_U(z) \wedge P(y, x) \wedge P(z, x)) \rightarrow U(y, z))$

(x is unified by U)

$W_U(x) =_{df} Max_{U_U}(x)$ *(x is a whole under U)*

$\Sigma_\phi(x) =_{df} \forall y(P(y, x) \rightarrow \exists z(\phi(z) \wedge P(z, x) \wedge O(z, y))$ *(sum of ϕs)*

Kinds of Whole

- Depending on the ***nature of U***, 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 **U**)
* Being a whole of a certain kind is an *essential property:* things cannot change their own unity conditions

Unity Disjointness Constraint

Classes with incompatible UCs are ***disjoint***

Example: Object and Matter

Identity criteria

- *Classic formulation:*

$$\phi(x) \wedge \phi(y) \rightarrow (\rho(x,y) \leftrightarrow x = y)$$

(ϕ *carries the identity criterion* ρ)

- *Generalization:*

$$\phi(x,t) \wedge \phi(y,t') \rightarrow (\Gamma(x,y,t,t') \leftrightarrow x = y)$$

(synchronic: $t = t'$; diachronic: $t \neq t'$)

- In most cases, Γ is based on the ***sameness*** of certain ***characteristic features***:

$$\Gamma(x,y,t,t') = \forall z\,(\chi(x,z,t) \wedge \chi(y,z,t'))$$

- **Non-triviality condition:**
  - $\Gamma(x, y, t, t')$ must not contain an identity statement between x and y!

Sortals and other properties

- **Sortals** (*horse, triangle, amount of matter, person, student...)*
  - Carry (non-trivial) identity conditions
  - Usually correspond to ***nouns***
  - High organizational utility
- **Non-sortals** *(red, big, old, decomposable, dependent...)*
  - No identity
  - Usually correspond to ***adjectives***
  - Span across different sortals
  - Limited organizational utility (but high semantic value)
- **Categories** *(universal, particular,object, event, substance...)*
  - No identity
  - Useful generalizations for sortals
  - Characterized by a set of (only necessary) formal properties
  - Good organizational utility

Carrying vs. Supplying Identity

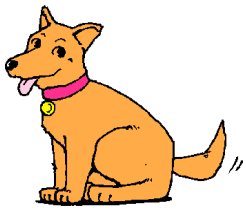
- ***Supplying*** (global) identity (**+O**)
  - Carrying an IC (or essential property) that doesn't hold for *all* directly subsuming properties
- ***Carrying*** identity (**+I**)
  - Not supplying identity, while being subsumed by a property that does.
- ***Common sortal principle***: x=y -> there is a common sortal supplying their identity
- Theorem: only rigid properties supply identity

Heuristics for Identity

- Finding necessary *and* sufficient ICs for a given property may be ***very hard***.
- Heuristic 1: ***at least a sufficient IC***.
- Heuristic 2: ***some essential parts or qualities***
- Heuristic 3: ***some essential (non-rigid) properties***

Unity, Identity, and Essence

- **Unity**: is the collar part of my dog?
  - ***Being a topological whole*** is an essential property of my dog
- **Identity**: is this my dog?
  - Essential properties allow us to keep track of my dog across time
    - Individual essential properties of ***my dog***
    - **Generic essential properties of *dogs***



Identity Disjointness Constraint

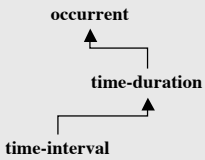
ICs impose ***constraints*** on sortals, making their ontological nature explicit:

Properties with incompatible ICs are ***disjoint***

Examples:
- sets vs. ordered sets
- persons and passengers
- amounts of matter vs. assemblies

Example - Identity

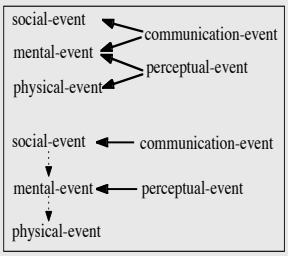
- Is *time-interval* a subclass of *time-duration*?
  - Initial answer: yes
- IC for *time-duration*
  - Same-length
- IC for *time-interval*
  - Same start & end



IS-A overloading

- ***Reduction of sense:***
  1. A *physical object* is an *amount of matter* (Pangloss)
  2. An *association* is a *group* (WordNet)
- ***Overgeneralization:***
  3. An *amount of matter* is a *physical object* (WordNet)
  4. A *place* is a *physical object* (μKosmos, WordNet)
- ***Clash of senses:***
  5. A *window* is both an *artifact* and a *place* (μKosmos)
  6. A *person* is both a *physical object* and a *living thing* (Pangloss)
  7. A *communicative event* is a *physical*, a *mental*, and a *social event* (μKosmos, Pangloss)

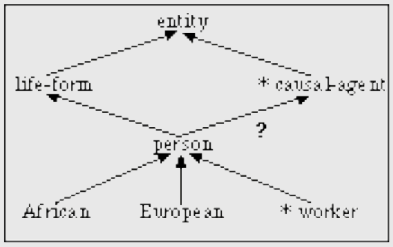
How ontological levels simplify taxonomies



Sortal specialization

- ***Type*** specialization (e.g. Living being → Person)
  - New features (especially essential properties) ***affect identity***
  - Both necessary and sufficient ICs can be added while specializing types
    - Polygon: same edges, same angles
      - Triangle: two edges, one angle
    - Living being: same DNA, etc…?
      - Zebra: same stripes?
- ***Role*** specialization (e.g. Person → Student)
  - New features ***don't affect identity***

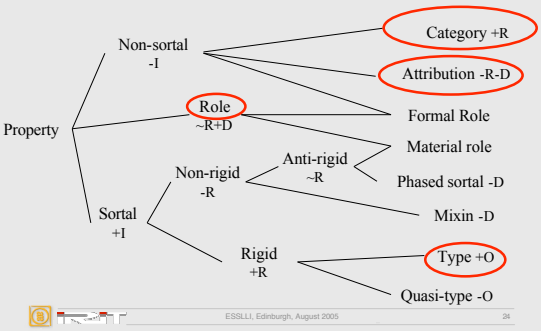
Types and Roles



Dependence

- Between particulars
  - ***Existential dependence*** (specific/generic)
    - Hole/host, person/brain, person/heart
  - Historical dependence
    - Person/parent
  - Causal dependence
    - Heat/fire
- Between universals
  - ***Definitional dependence***
    - *P* depends on *Q* iff *Q* is involved in the **definition** of *P*.
    - Metaproperties: +D/-D

A formal ontology of properties



Why bother with this?

- ***Formal ontological analysis*** requires analyzing all properties according to their meta-properties – This is a ***lot*** of work!
- Why perform this analysis?
  - Makes ***modeling assumptions*** clear, which:
    - Helps resolving known conflicts
    - Helps recognizing unkown conflicts
  - Imposes ***constraints*** on standard modeling primitives (*generalization, aggregation, association*)
  - Elicits ***natural distinctions***
  - …results in more ***reusable ontologies***

Taxonomic Constraints

- +R ⊄ ~R
- -I ⊄ +I
- -U ⊄ +U
- +U ⊄ ~U
- -D ⊄ +D

- Incompatible IC's are disjoint
- Incompatible UC's are disjoint

Resolving Ontological Conflicts

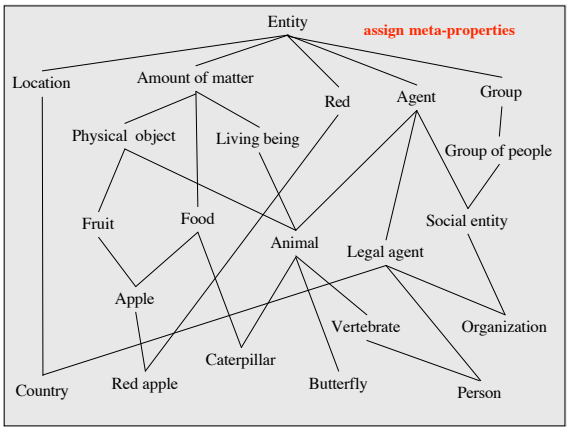
- Two well-known linguistic ontologies define:
  - ***Physical Object is-a Amount of Matter*** (WordNet)
  - ***Amount of Matter is-a Physical Object*** (Pangloss)

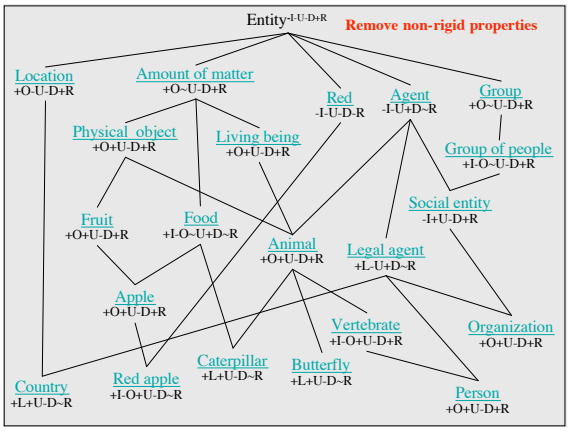
- Amount of Matter
  - unstructured /scattered "stuff"
  - Identity: mereologically extensional
  - Unity: intrinsically none (anti-unity)

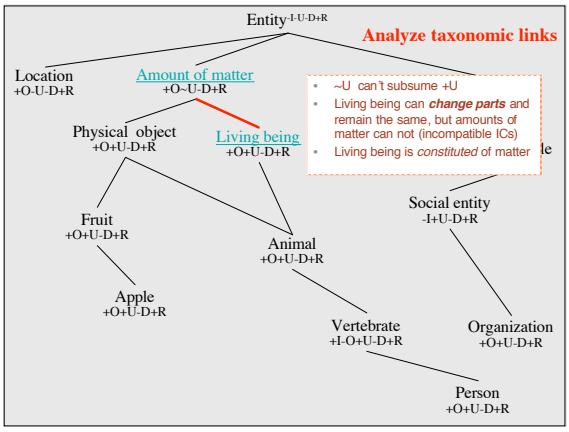
- Physical Object
  - Isolated material body
  - Identity - three options:
    - None
    - Non-extensional
    - Extensional
  - Unity: Topological

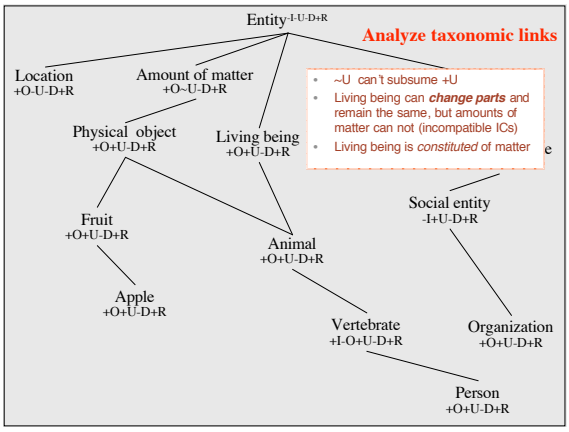
Conclusion: the two concepts are ***disjoint***. Physical objects are ***constituted*** by amounts of matter

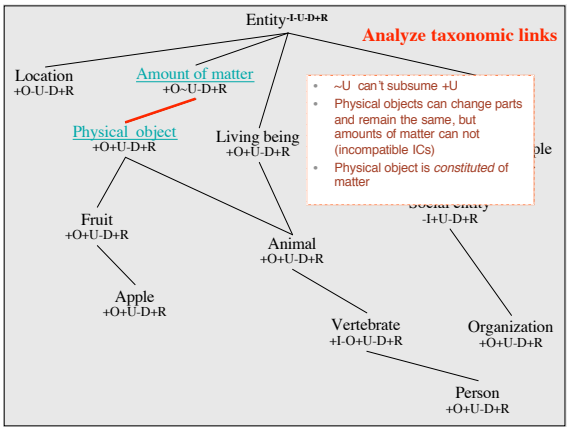
A taxonomy cleaning example

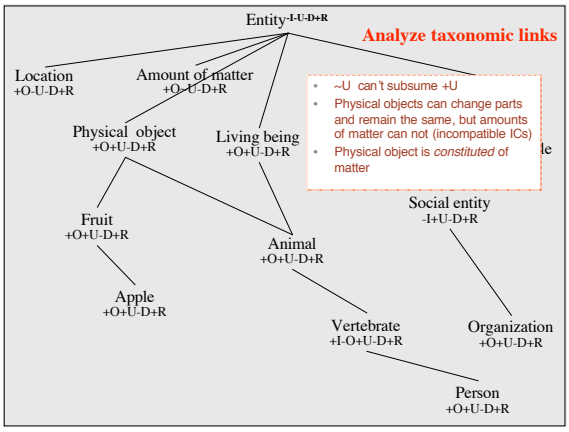


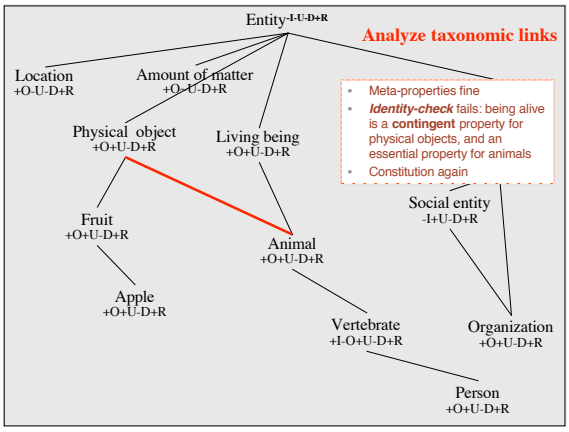


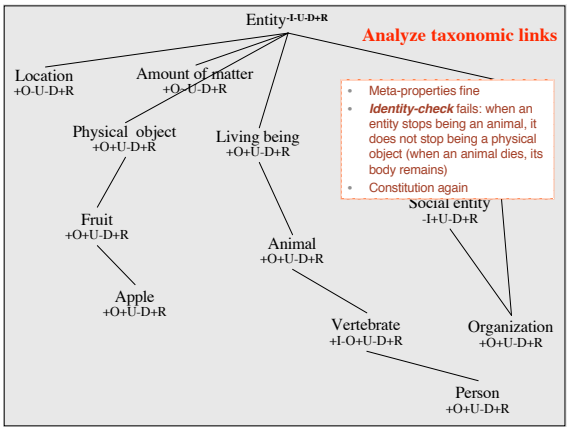

Entity -I-U-D+R
Analyze taxonomic links
Location +O-U-D+R
Amount of matter +O~U-D+R
Physical object +O+U-D+R
Living being +O+U-D+R
~U can't subsume +U
Living being can change parts and remain the same, but amounts of matter can not (incompatible ICs)
Living being is constituted of matter
Social entity -I+U-D+R
Fruit +O+U-D+R
Animal +O+U-D+R
Apple +O+U-D+R
Vertebrate +I-O+U-D+R
Organization +O+U-D+R
Person +O+U-D+R

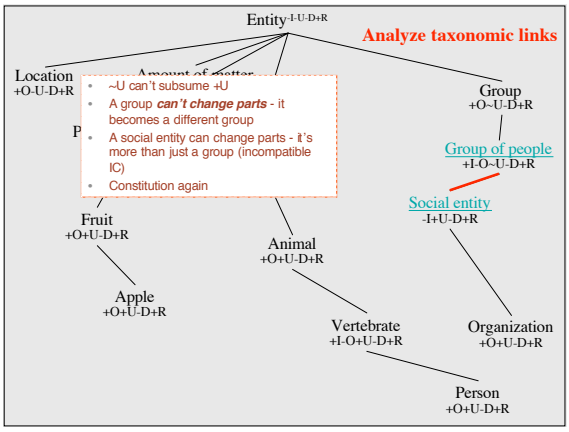

Entity -I-U-D+R
Analyze taxonomic links
Location +O-U-D+R
Amount of matter +O~U-D+R
Physical object +O+U-D+R
Living being +O+U-D+R
~U can't subsume +U
Living being can change parts and remain the same, but amounts of matter can not (incompatible ICs)
Living being is constituted of matter
Social entity -I+U-D+R
Fruit +O+U-D+R
Animal +O+U-D+R
Apple +O+U-D+R
Vertebrate +I-O+U-D+R
Organization +O+U-D+R
Person +O+U-D+R

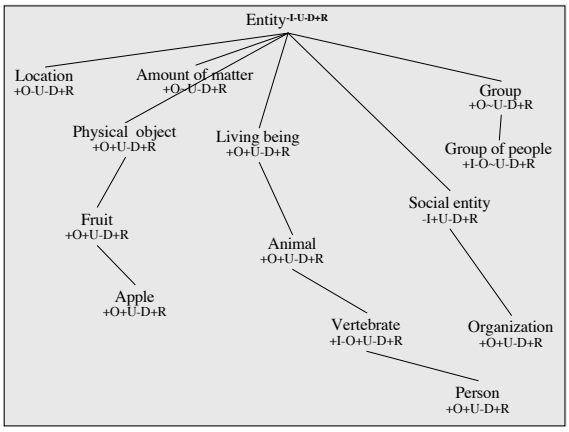

Entity -I-U-D+R
Analyze taxonomic links
Location +O-U-D+R
Amount of matter +O~U-D+R
Physical object +O+U-D+R
Living being +O+U-D+R
~U can't subsume +U
Physical objects can change parts and remain the same, but amounts of matter can not (incompatible ICs)
Physical object is constituted of matter
Fruit +O+U-D+R
Animal +O+U-D+R
Apple +O+U-D+R
Vertebrate +I-O+U-D+R
Organization +O+U-D+R
Person +O+U-D+R

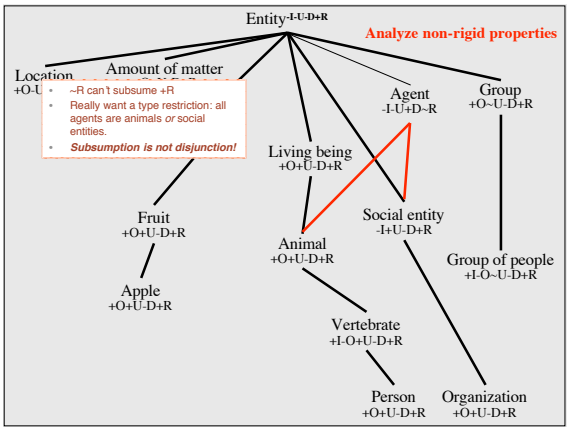

Entity-I-U-D+R
Analyze taxonomic links
Location
+O-U-D+R
Amount of matter
+O-U-D+R
Physical object
+O+U-D+R
Living being
+O+U-D+R
Fruit
+O+U-D+R
Animal
+O+U-D+R
Apple
+O+U-D+R
Social entity
-I+U-D+R
Vertebrate
+I-O+U-D+R
Organization
+O+U-D+R
Person
+O+U-D+R
~U can't subsume +U
Physical objects can change parts and remain the same, but amounts of matter can not (incompatible ICs)
Physical object is constituted of matter

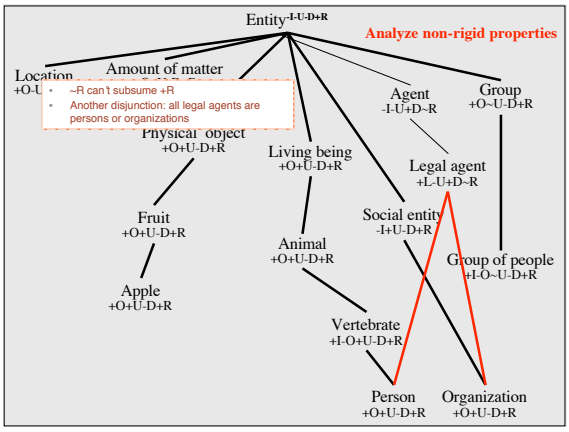

Entity-I-U-D+R
Analyze taxonomic links
Location
+O-U-D+R
Amount of matter
+O-U-D+R
Physical object
+O+U-D+R
Living being
+O+U-D+R
Fruit
+O+U-D+R
Animal
+O+U-D+R
Apple
+O+U-D+R
Social entity
-I+U-D+R
Vertebrate
+I-O+U-D+R
Organization
+O+U-D+R
Person
+O+U-D+R
Meta-properties fine
Identity-check fails: being alive is a contingent property for physical objects, and an essential property for animals
Constitution again

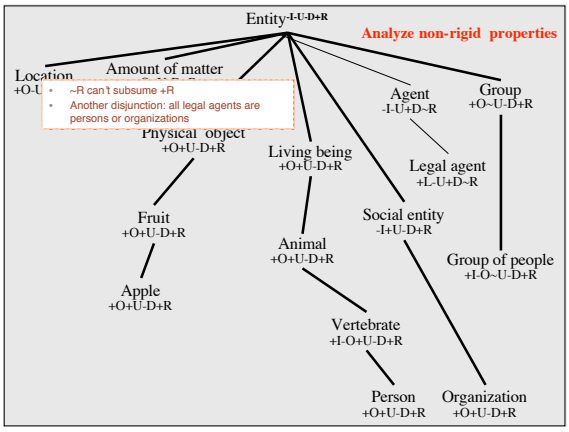

Entity-I-U-D+R
Analyze taxonomic links
Location
+O-U-D+R
Amount of matter
+O-U-D+R
Physical object
+O+U-D+R
Living being
+O+U-D+R
Fruit
+O+U-D+R
Animal
+O+U-D+R
Apple
+O+U-D+R
Social entity
-I+U-D+R
Vertebrate
+I-O+U-D+R
Organization
+O+U-D+R
Person
+O+U-D+R
Meta-properties fine
Identity-check fails: when an entity stops being an animal, it does not stop being a physical object (when an animal dies, its body remains)
Constitution again

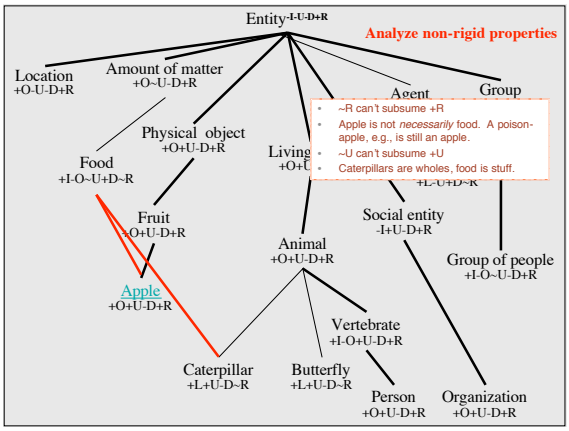

Entity-I-U-D+R
Analyze taxonomic links
Location
+O-U-D+R
Group
+O~U-D+R
~U can't subsume +U
A group can't change parts - it becomes a different group
A social entity can change parts - it's more than just a group (incompatible IC)
Constitution again
Group of people
+I-O~U-D+R
Social entity
-I+U-D+R
Fruit
+O+U-D+R
Animal
+O+U-D+R
Apple
+O+U-D+R
Vertebrate
+I-O+U-D+R
Organization
+O+U-D+R
Person
+O+U-D+R

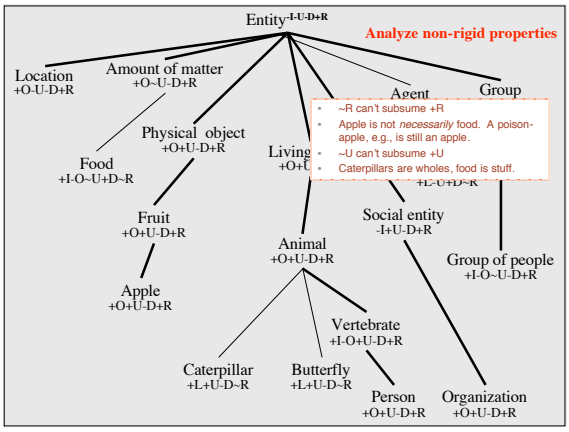

Entity-I-U-D+R
Location
+O-U-D+R
Amount of matter
+O-U-D+R
Group
+O~U-D+R
Physical object
+O+U-D+R
Living being
+O+U-D+R
Group of people
+I-O~U-D+R
Social entity
-I+U-D+R
Fruit
+O+U-D+R
Animal
+O+U-D+R
Apple
+O+U-D+R
Vertebrate
+I-O+U-D+R
Organization
+O+U-D+R
Person
+O+U-D+R

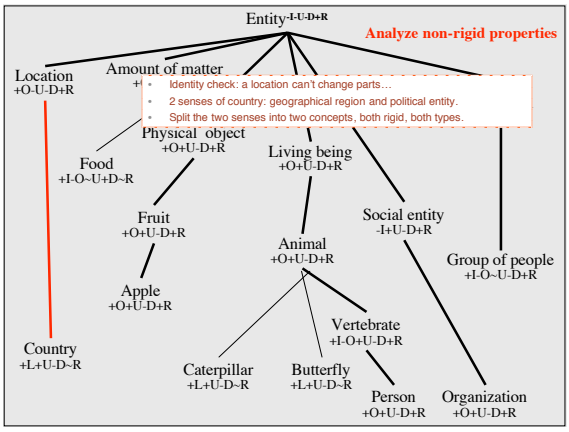

Entity-I-U-D+R
Analyze non-rigid properties
Amount of matter
~R can't subsume +R
Really want a type restriction: all agents are animals or social entities.
Subsumption is not disjunction!
Agent
-I-U+D~R
Group
+O~U-D+R
Living being
+O+U-D+R
Fruit
+O+U-D+R
Social entity
-I+U-D+R
Animal
+O+U-D+R
Group of people
+I-O~U-D+R
Apple
+O+U-D+R
Vertebrate
+I-O+U-D+R
Person
+O+U-D+R
Organization
+O+U-D+R

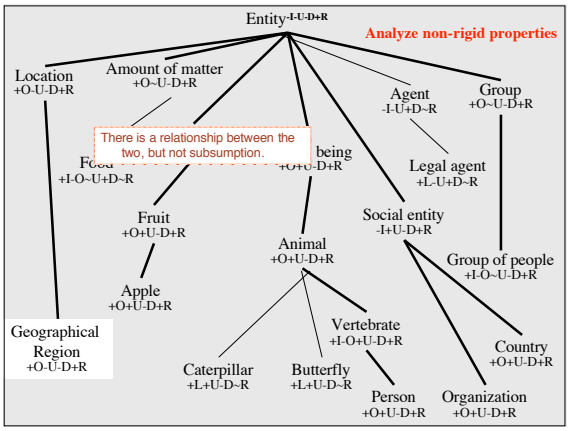

Entity-I-U-D+R
Analyze non-rigid properties
Location +O-U
Amount of matter
~R can't subsume +R
Another disjunction: all legal agents are persons or organizations
Agent -I-U+D-R
Group +O~U-D+R
Physical object +O+U-D+R
Living being +O+U-D+R
Legal agent +L-U+D~R
Fruit +O+U-D+R
Social entity -I+U-D+R
Animal +O+U-D+R
Group of people +I-O~U-D+R
Apple +O+U-D+R
Vertebrate +I-O+U-D+R
Person +O+U-D+R
Organization +O+U-D+R

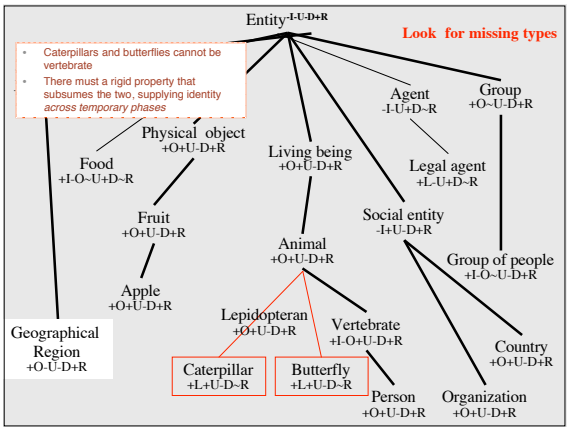

Entity-I-U-D+R
Analyze non-rigid properties
Location +O-U
Amount of matter
~R can't subsume +R
Another disjunction: all legal agents are persons or organizations
Agent -I-U+D-R
Group +O~U-D+R
Physical object +O+U-D+R
Living being +O+U-D+R
Legal agent +L-U+D~R
Fruit +O+U-D+R
Social entity -I+U-D+R
Animal +O+U-D+R
Group of people +I-O~U-D+R
Apple +O+U-D+R
Vertebrate +I-O+U-D+R
Person +O+U-D+R
Organization +O+U-D+R

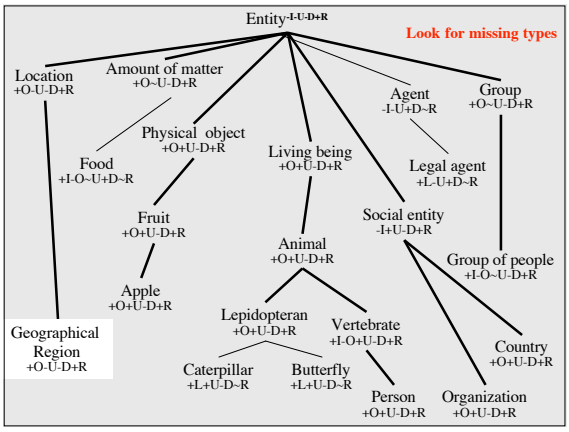

Entity-I-U-D+R
Analyze non-rigid properties
Location +O-U-D+R
Amount of matter +O~U-D+R
~R can't subsume +R
Apple is not necessarily food. A poison-apple, e.g., is still an apple.
~U can't subsume +U
Caterpillars are wholes, food is stuff.
Agent
Group
Physical object +O+U-D+R
Food +I-O~U+D~R
Living +O+U
Fruit +O+U-D+R
Social entity -I+U-D+R
Animal +O+U-D+R
Group of people +I-O~U-D+R
Apple +O+U-D+R
Vertebrate +I-O+U-D+R
Caterpillar +L+U-D~R
Butterfly +L+U-D~R
Person +O+U-D+R
Organization +O+U-D+R

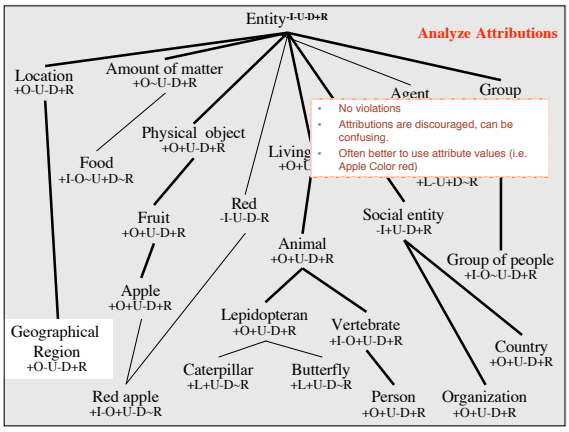

Entity-I-U-D+R
Analyze non-rigid properties
Location +O-U-D+R
Amount of matter +O~U-D+R
Agent
Group
~R can't subsume +R
Apple is not necessarily food. A poison-apple, e.g., is still an apple.
~U can't subsume +U
Caterpillars are wholes, food is stuff.
Physical object +O+U-D+R
Food +I-O~U+D~R
Living +O+U
Fruit +O+U-D+R
Social entity -I+U-D+R
Animal +O+U-D+R
Group of people +I-O~U-D+R
Apple +O+U-D+R
Vertebrate +I-O+U-D+R
Caterpillar +L+U-D~R
Butterfly +L+U-D~R
Person +O+U-D+R
Organization +O+U-D+R

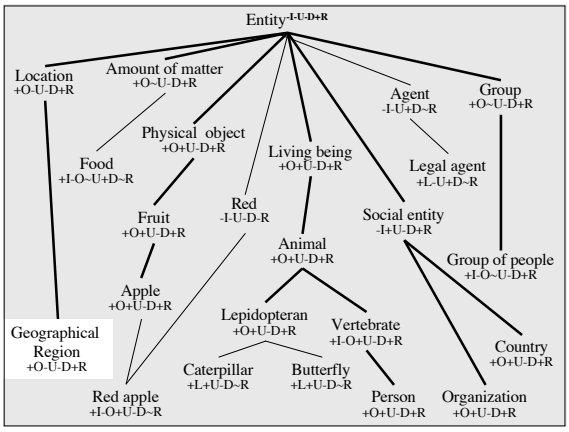

Entity-I-U-D+R
Analyze non-rigid properties
Location +O-U-D+R
Identity check: a location can't change parts…
2 senses of country: geographical region and political entity.
Split the two senses into two concepts, both rigid, both types.
Physical object +O+U-D+R
Food +I-O~U+D~R
Living being +O+U-D+R
Fruit +O+U-D+R
Social entity -I+U-D+R
Animal +O+U-D+R
Group of people +I-O~U-D+R
Apple +O+U-D+R
Vertebrate +I-O+U-D+R
Country +L+U-D~R
Caterpillar +L+U-D~R
Butterfly +L+U-D~R
Person +O+U-D+R
Organization +O+U-D+R

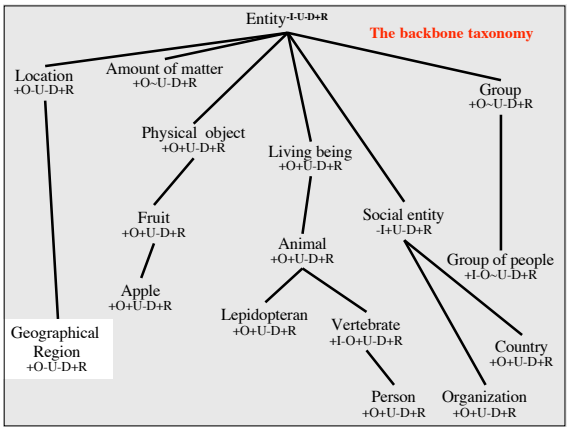

Entity-I-U-D+R
Analyze non-rigid properties
Location +O-U-D+R
Amount of matter +O~U-D+R
Agent -I-U+D~R
Group +O~U-D+R
There is a relationship between the two, but not subsumption.
Legal agent +L-U+D~R
Food +I-O~U+D~R
Fruit +O+U-D+R
Social entity -I+U-D+R
Animal +O+U-D+R
Group of people +I-O~U-D+R
Apple +O+U-D+R
Vertebrate +I-O+U-D+R
Geographical Region +O-U-D+R
Country +O+U-D+R
Caterpillar +L+U-D~R
Butterfly +L+U-D~R
Person +O+U-D+R
Organization +O+U-D+R

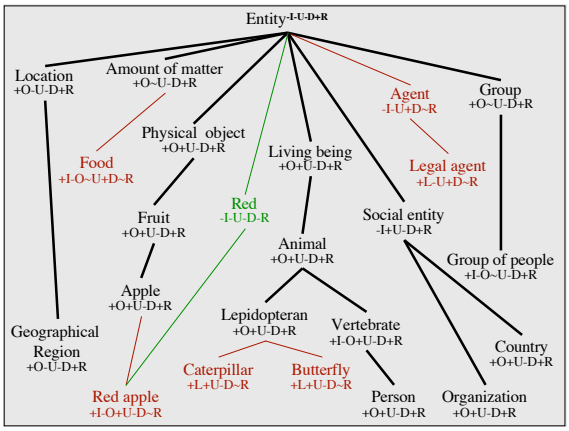

Entity-I-U-D+R
Look for missing types
Caterpillars and butterflies cannot be vertebrate
There must a rigid property that subsumes the two, supplying identity *across temporary phases*
Agent -I-U+D-R
Group +O~U-D+R
Physical object +O+U-D+R
Food +I-O~U+D~R
Living being +O+U-D+R
Legal agent +L-U+D~R
Fruit +O+U-D+R
Social entity -I+U-D+R
Animal +O+U-D+R
Group of people +I-O~U-D+R
Apple +O+U-D+R
Lepidopteran +O+U-D+R
Vertebrate +I-O+U-D+R
Geographical Region +O-U-D+R
Caterpillar +L+U-D~R
Butterfly +L+U-D~R
Country +O+U-D+R
Person +O+U-D+R
Organization +O+U-D+R

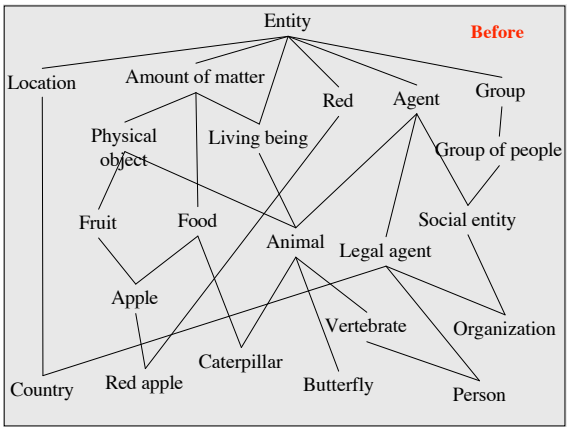

Entity-I-U-D+R
Look for missing types
Location +O-U-D+R
Amount of matter +O~U-D+R
Agent -I-U+D~R
Group +O~U-D+R
Physical object +O+U-D+R
Food +I-O~U+D~R
Living being +O+U-D+R
Legal agent +L-U+D~R
Fruit +O+U-D+R
Social entity -I+U-D+R
Animal +O+U-D+R
Group of people +I-O~U-D+R
Apple +O+U-D+R
Lepidopteran +O+U-D+R
Vertebrate +I-O+U-D+R
Geographical Region +O-U-D+R
Caterpillar +L+U-D~R
Butterfly +L+U-D~R
Country +O+U-D+R
Person +O+U-D+R
Organization +O+U-D+R

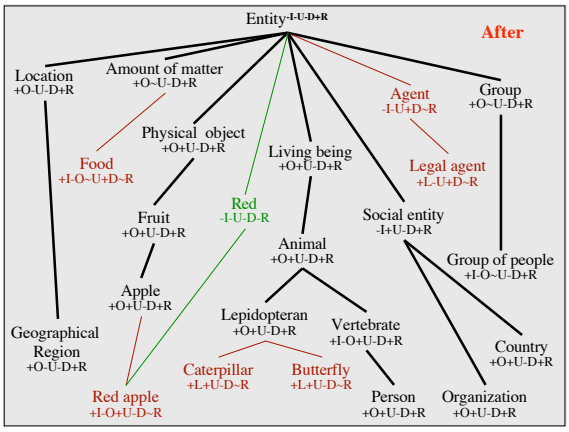

Entity-I-U-D+R
Analyze Attributions
No violations
Attributions are discouraged, can be confusing.
Often better to use attribute values (i.e. Apple Color red)
Location +O-U-D+R
Amount of matter +O~U-D+R
Group
Physical object +O+U-D+R
Food +I-O~U+D~R
Red -I-U-D-R
Fruit +O+U-D+R
Social entity -I+U-D+R
Animal +O+U-D+R
Group of people +I-O~U-D+R
Apple +O+U-D+R
Lepidopteran +O+U-D+R
Vertebrate +I-O+U-D+R
Geographical Region +O-U-D+R
Caterpillar +L+U-D~R
Butterfly +L+U-D~R
Country +O+U-D+R
Red apple +I-O+U-D~R
Person +O+U-D+R
Organization +O+U-D+R


Entity -I-U-D+R
Location +O-U-D+R
Amount of matter +O~U-D+R
Agent -I-U+D-R
Group +O~U-D+R
Physical object +O+U-D+R
Food +I-O~U+D~R
Living being +O+U-D+R
Legal agent +L-U+D~R
Fruit +O+U-D+R
Red -I-U-D-R
Social entity -I+U-D+R
Animal +O+U-D+R
Group of people +I-O~U-D+R
Apple +O+U-D+R
Lepidopteran +O+U-D+R
Vertebrate +I-O+U-D+R
Geographical Region +O-U-D+R
Country +O+U-D+R
Caterpillar +L+U-D~R
Butterfly +L+U-D~R
Red apple +I-O+U-D~R
Person +O+U-D+R
Organization +O+U-D+R


Entity -I-U-D+R
The backbone taxonomy
Location +O-U-D+R
Amount of matter +O~U-D+R
Group +O~U-D+R
Physical object +O+U-D+R
Living being +O+U-D+R
Fruit +O+U-D+R
Social entity -I+U-D+R
Animal +O+U-D+R
Group of people +I-O~U-D+R
Apple +O+U-D+R
Lepidopteran +O+U-D+R
Vertebrate +I-O+U-D+R
Geographical Region +O-U-D+R
Country +O+U-D+R
Person +O+U-D+R
Organization +O+U-D+R


Entity -I-U-D+R
Location +O-U-D+R
Amount of matter +O~U-D+R
Agent -I-U+D-R
Group +O~U-D+R
Physical object +O+U-D+R
Food +I-O~U+D~R
Living being +O+U-D+R
Legal agent +L-U+D~R
Fruit +O+U-D+R
Red -I-U-D-R
Social entity -I+U-D+R
Animal +O+U-D+R
Group of people +I-O~U-D+R
Apple +O+U-D+R
Lepidopteran +O+U-D+R
Vertebrate +I-O+U-D+R
Geographical Region +O-U-D+R
Caterpillar +L+U-D~R
Butterfly +L+U-D~R
Country +O+U-D+R
Red apple +I-O+U-D~R
Person +O+U-D+R
Organization +O+U-D+R





2 - DOLCE: motivating its ontological distinctions

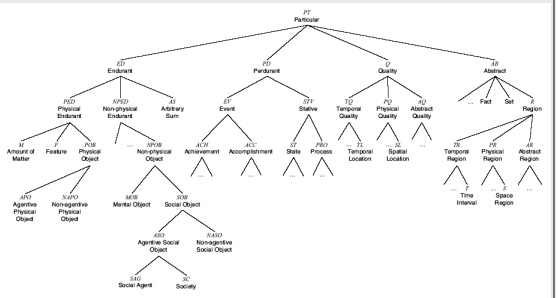
DOLCE
a Descriptive Ontology for Linguistic and Cognitive Engineering

- Strong cognitive bias: descriptive (as opposite to prescriptive) attitude
  - Emphasis on cognitive invariants
  - Categories as conceptual containers: no "deep" metaphysical implications wrt "true" reality
- Clear branching points to allow easy comparison with different ontological options
- Rich axiomatization
  - 37 basic categories
  - 7 basic relations
  - 80 axioms, 100 definitions, 20 theorems

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
    - …
  - …

A representation of DOLCE's upper levels



Qualities and qualia

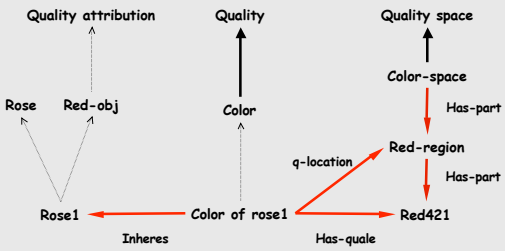
- Linguistic evidence
  - *This rose is red*
  - *Red is a color*
  - *This rose has a color*
  - *The color of this rose turned to brown in one week*
  - *Red is opposite to green and close to brown*
  - *The patient's temperature is increasing*
  - *The doctor measured the patient's temperature*
-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



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***

Physical vs. Non-physical Objects

- Physical objects
  - Inherent spatial localization
  - Not necessarily dependent on other objects
- Non-physical objects
  - 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

Endurants and Perdurants

- Endurants (3D "objects", e.g., a written text)
  - All proper parts are present whenever they are present (wholly presence, no temporal parts)
  - Exist in time
  - Can genuinely change in time
  - Need a time-indexed parthood relation
- Perdurants (4D "eventualities", e.g., an utterance)
  - Only some proper parts are present whenever they are present (partial presence,temporal parts)
  - Happen in time
  - Do not change in time
  - Do not need a time-indexed parthood relation
- Participation

Physical vs. *Non-physical Object*

FIAT SpA

- Physical objects:
  - *inherent spatial localization*
  - *not dependent* on other objects (**physical objects, like cars**) or no inherent localization and be dependent on *agents* (**non-physical objects, like laws and institutions**).

•Non-physical objects can also be divided into *mental* (depending on *singular* agents) and *social* (depending on *communities* of agents).

3 - Ontologies and computational lexicons

Ontologies and computational lexicons

- In the simplest case, both ontologies and computational lexicons are hierarchical structures of "terms" used for describing entities in a given domain. Nevertheless:
  - a lexicon contains only lexicalised concepts and linguistic relations
    (i.e. substance, synonymy)
  - an ontology provides also structure for non-lexicalised concepts and semantic relations
    (i.e. amount-of-matter, subsumption)
  - linguistic relationship may not correspond to ontological relationships

Ontological problems with WordNet (1)

- Unclear semantic interpretation of has-hypernym relation
  - Instantiation vs. subsumption
  - Object-level vs. meta-level
  - Multiple hypernyms to account for polisemy
- Unclear taxonomic structure
  - Glosses not consistent with taxonomic structure
  - Heterogeneous leves of generality
  - Formal constraints violations (especially concerning roles)
- Polysemous use of antonymy (child/parent vs. daughter/son)
- Poor ontology of adjectives and qualities
- Shallow taxonomy of verbs

Ontological problems with WordNet (2)

- **Multiple hypernyms to account for polisemy**
  cure
  HAS-HYPERNYM (medicinal_drug,treatment)

  Ontological insight (DOLCE-based):
  medicinal_drug : amount of matter
  treatment: perdurant

- **Heterogeneity (mixed roles & types)**
  animal
  HAS-HYPONYM
  (work_animal, domestic_animal, mate, captive, prey, chordate, larva, fictional_animal)
  Red: roles; Blue: types

Ontological problems with WordNet (3)

- **Concepts** Vs. **Instances**
  {Fall, social_event, …} HAS-HYPERNYM event
  {Macao, trust_territory, …} HAS-HYPERNYM territorial_dominion
  {Bach, songwriter, …} HAS-HYPERNYM composer
  {Red_cross, company, …} HAS-HYPERNYM organization

  Green: instances
  …but: forthcoming releases will supply INSTANCE-OF relation

- **Object-level** Vs. **Meta-level**
  abstraction HAS-HYPONYM
  (attribute, relation, quantity, set, time, space)

  Purple: meta-level

Aligning computational lexicons and ontologies

- Comparative analysis of the homonymous and/or synonymous terms (if any) between the ontology and the c. lexicons.

  METHODOLOGIES:

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.

Application of DOLCE (1)
WordNet alignment and OntoWordNet

- 809 synsets from WordNet1.6 directly subsumed by a DOLCE+D&S class
  - Whole WordNet linked to DOLCE+D&S
  - Lower taxonomy levels in WordNet 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)

Applications of DOLCE (2)
Core Ontologies

based on DOLCE, D&S, and OntoWordNet

- Core ontology of plans and guidelines
- Core ontology of (Web) services
- Core ontology of service-level agreements
- Core ontology of (bank) transactions (anti-money-laundering)
- Core ontology for the Italian legal lexicon
- Core ontology of regulatory compliance
- Core ontology of fishery (FAO's Agriculture Ontology Service)
- Core ontology of biomedical terminologies (UMLS)

Conclusion

- Subtle meaning distinctions do matter
- General ontological primitives help making intended meaning explicit
- Formal ontology 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??