COMP718: Ontologies and Knowledge Bases

Lecture 6: Top-down Ontology Development II

Maria Keet
email: keet@ukzn.ac.za
home: http://www.meteck.org

School of Mathematics, Statistics, and Computer Science
University of KwaZulu-Natal, South Africa

13 March 2012

Outline

Some questions and problems (not exhaustive...)

- Is Tshwane a more specific instance of Gauteng, or a part of it?
- Is a tunnel part of the mountain?
- What is the difference, if any, between how `Cell nucleus` and `Cell` are related and how `Receptor` and `Cell wall` are related?
- And w.r.t. `Brain part of Human` and/versus `Hand part of Boxer`? (assuming boxers must have their own hands)
- A classical example: hand is part of musician, musician part of orchestra, but clearly, the musician's hands are not part of the orchestra. Is part-of then not transitive, or is there a problem with the example?

Analysis of the issues from diverse angles

- Mereological theories (Varzi, 2004), usage & extensions (e.g. mereotopology, relation with granularity, set theory)
- Early attempts with direct parthood, SEP triples, and other outstanding issues, some still remaining
- Cognitive & linguistic issues from meronymy
- Usage in conceptual modelling and ontology engineering
- Subject domains: thus far, mainly geo, bio, medicine

Ground Mereology

Reflexivity (everything is part of itself)

$$\forall x(part\_of(x, x)) \quad (1)$$

Antisymmetry (two distinct things cannot be part of each other, or: if they are, then they are the same thing)

$$\forall x, y((part\_of(x, y) \land part\_of(y, x)) \rightarrow x = y) \quad (2)$$

Transitivity (if x is part of y and y is part of z, then x is part of z)

$$\forall x, y, z((part\_of(x, y) \land part\_of(y, z)) \rightarrow part\_of(x, z)) \quad (3)$$

Proper parthood

$$\forall x, y(proper\_part\_of(x, y) \equiv part\_of(x, y) \land \neg part\_of(y, x)) \quad (4)$$

Ground Mereology

Proper parthood

$$\forall x, y(proper\_part\_of(x, y) \equiv part\_of(x, y) \land \neg part\_of(y, x)) \quad (5)$$

Asymmetry (if x is part of y then y is not part of x)

$$\forall x, y(part\_of(x, y) \rightarrow \neg part\_of(y, x)) \quad (6)$$

Irreflexivity (x is not part of itself)

$$\forall x \neg(part\_of(x, x)) \quad (7)$$

Defining other relations with *part_of*

Overlap (x and y share a piece z)

$$\forall x, y(overlap(x, y) \equiv \exists z(part\_of(z, x) \land part\_of(z, y))) \quad (8)$$

Underlap (x and y are both part of some z)

$$\forall x, y(underlap(x, y) \equiv \exists z(part\_of(x, z) \land part\_of(y, z))) \quad (9)$$

Over- & undercross (over/underlap but not part of)

$$\forall x, y(overcross(x, y) \equiv overlap(x, y) \land \neg part\_of(x, y)) \quad (10)$$

$$\forall x, y(undercross(x, y) \equiv underlap(x, y) \land \neg part\_of(y, x)) \quad (11)$$

Proper overlap & Proper underlap

$$\forall x, y(p\_overlap(x, y) \equiv overcross(x, y) \land overcross(y, x)) \quad (12)$$

$$\forall x, y(p\_underlap(x, y) \equiv undercross(x, y) \land undercross(y, x)) \quad (13)$$

- With x as part, what to do with the remainder that makes up y?
  - Weak supplementation: every proper part must be supplemented by another, disjoint, part. **MM**
  - Strong supplementation: if an object fails to include another among its parts, then there must be a remainder. **EM**
- Problem with EM: non-atomic objects with the same proper parts are identical, because of this (extensionality principle), but sameness of parts may not be sufficient for identity E.g.: two objects can be distinct purely based on arrangement of its parts, differences statue and its marble (multiplicative approach)

General Extensional Mereology

- Strong supplementation [EM]

$$\neg part\_of(y,x) \rightarrow \exists z(part\_of(z,y) \wedge \neg overlap(z,x)) \quad (14)$$

- And add unrestricted fusion [GEM]. Let ϕ be a property or condition, then for every satisfied ϕ there is an entity consisting of all entities that satisfy ϕ. [1] Then:

$$\exists x \phi \rightarrow \exists z \forall y(overlap(y,z) \leftrightarrow \exists x(\phi \wedge overlap(y,x))) \quad (15)$$

- Note that in EM and upward we have identity, from which one can prove acyclicity for ppo
- There are more mereological theories, and the above is not uncontested (more about that later)

[1] Need to refer to classes, but desire to stay within FOL. Solution: axiom schema with only predicates or open formulas

Relations between common mereological theories

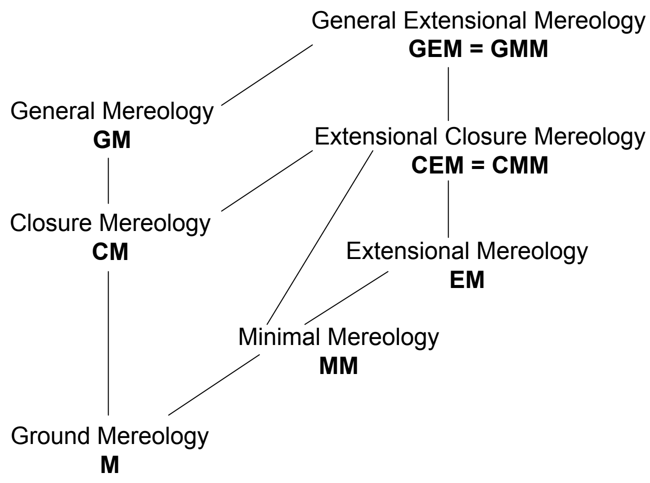


Fig. 1: Hasse diagram of mereological theories; from weaker to stronger, going uphill (after [44]).

Can any of this be represented in a decidable fragment of first order logic for use in ontologies and (scalable) software implementations?

Things are improving...

- Early days (90s) and simplest options: DL-role `R` as `partof`, or `has-part` added as primitive role as $\succeq$, model it as the transitive closure of a parthood relation (16) and define e.g. `Car` as having wheels that in turn have tires (17):

$$\succeq \doteq (\texttt{primitive-part})* \quad (16)$$

$$\texttt{Car} \doteq \exists \succeq .(\texttt{Wheel} \sqcap \exists \succeq .\texttt{Tire}) \quad (17)$$

  Then $\texttt{Car} \sqsubseteq \exists \succeq .\texttt{Tire}$
- SEP triples with $\mathcal{ALC}$
- What $\mathcal{SHIQ}$ fixes cf. $\mathcal{ALC}$: Transitive roles, Inverse roles (to have both part-of and has-part), Role hierarchies (e.g. for subtypes of part-of), qualified Number restrictions (e.g. to represent that a bycicle has-part 2 wheels)
- Build-your-own DL-language

What we can(not) implement now with DL-based ontology languages

Table: Properties of parthood and proper parthood compared to their support in $\mathcal{DLR}_\mu$, $\mathcal{SHOIN}$ and $\mathcal{SROIQ}$. *: properties of the parthood relation (in M); ‡: properties of the proper parthood relation (in M).

Language ⇒ **Feature** ⇓	$\mathcal{DLR}_\mu$	$\mathcal{SHOIN}$ (∼ OWL-DL)	$\mathcal{SROIQ}$ (∼ OWL 2 DL)	DL-Lite$_A$ (∼ OWL 2 QL)
Reflexivity *	+	–	+	–
Antisymmetry *	–	–	–	–
Transitivity * ‡	+	+	+	–
Asymmetry ‡	+	+	+	+
Irreflexivity ‡	+	–	+	–
Acyclicity	+	–	–	–

Definitions in OBO Relations Ontology

- Instance-level relations
  - c **part_of** c_1 at t - a primitive relation between two continuant instances and a time at which the one is part of the other
  - p **part_of** p_1, r **part_of** r_1 - a primitive relation of parthood, holding independently of time, either between process instances (one a subprocess of the other), or between spatial regions (one a subregion of the other)
  - c **contained_in** c_1 at $t \triangleq c$ **located_in** c_1 at t and not c **overlap** c_1 at t
  - c located_in r at t - a primitive relation between a continuant instance, a spatial region which it occupies, and a time

Definitions in OBO Relations Ontology

- Class-level relations
  - C *part_of* $C_1 \triangleq$ for all c, t, if Cct then there is some c_1 such that $C_1 c_1 t$ and c **part_of** c_1 **at** t.
  - P *part_of* $P_1 \triangleq$ for all p, if Pp then there is some p_1 such that: $P_1 p_1$ and p **part_of** p_1.
  - C *contained_in* $C_1 \triangleq$ for all c, t, if Cct then there is some c_1 such that: $C_1 c_1 t$ and c **contained_in** c_1 at t
- Need to commit to a foundational ontology. Recently, linked to BFO http://obofoundry.org/ro/#mappings (test release)
- Same labels, different relata and only a textual constraint: Label the relations differently

Linguistic use of part-whole relations

- Part of?
  ⋆ Centimeter part of Decimeter
  ⋆ Decimeter part of Meter
  — *therefore* Centimeter part of Meter
  ⋆ Meter part of SI
  — but *not* Centimeter part of SI
- Transitivity?
  ⋆ Person part of Organisation
  ⋆ Organisation located in Bolzano
  — therefore Person located in Bolzano?
  — but *not* Person part of Bolzano

Linguistic use of part-whole relations (meronymy)

- Part of?
  ⋆ Centimeter part of Decimeter
  ⋆ Decimeter part of Meter
  — *therefore* Centimeter part of Meter
  ⋆ Meter part of SI
  — but *not* Centimeter part of SI
- Transitivity?
  ⋆ Person member of Organisation
  ⋆ Organisation located in Bolzano
  — therefore Person located in Bolzano?
  — but *not* Person member of Bolzano

Linguistic use of part-whole relations

- Which part of?
  ⋆ CellMembrane structural part of RedBloodCell
  ⋆ RedBloodCell part of Blood
  — but *not* CellMembrane structural part of Blood
  ⋆ Receptor structural part of CellMembrane
  — *therefore* Receptor structural part of RedBloodCell

Linguistic use of part-whole relations

- Which part of?
  ⋆ CellMembrane structural part of RedBloodCell
  ⋆ RedBloodCell contained in? Blood
  — but *not* CellMembrane structural part of Blood
  ⋆ Receptor structural part of CellMembrane
  — *therefore* Receptor structural part of RedBloodCell

Addressing the issues

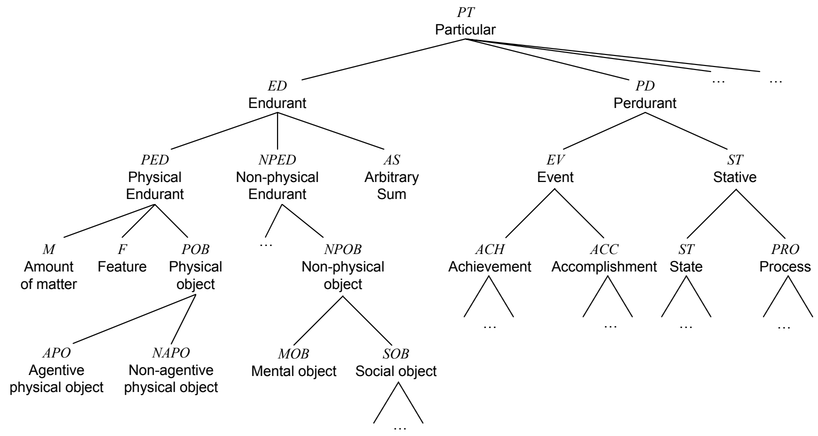
- Efforts to disambiguate this confusion; e.g. an informal taxonomy by Winston et al (1987), list of 6 types motivated by UML conceptual modeling (Odell) ontology-inspired conceptual modelling (Guizzardi)
- Location, containment, membership of a collective, quantities of a mass
- Relatively well-settled debate on transitivity, or not

Overview

- Mereological *part_of* (and subtypes) versus ‘other’ part-whole relations
- Categories of object types of the part-whole relation changes
- Structure these relations by (non/in)transitivity and kinds of relata
- Simplest mereological theory, **M**.
- Commit to a foundational ontology: DOLCE (though one also could choose, a.o., BFO, OCHRE, GFO, ...)

Parts, mereology, meronymy | Taxonomy of types of part-whole relations | Extensions | Ontology Design Patterns | Summary

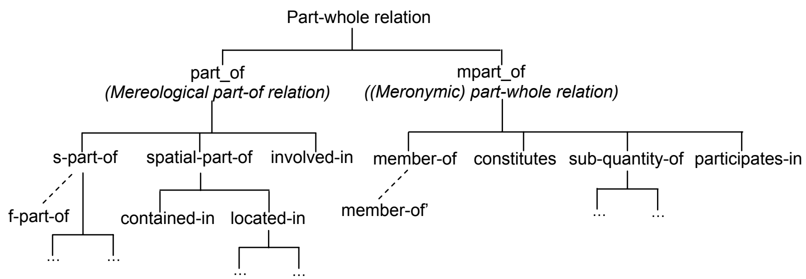
DOLCE categories



Parts, mereology, meronymy | Taxonomy of types of part-whole relations | Extensions | Ontology Design Patterns | Summary

The taxonomy

Part-whole relations



Parts, mereology, meronymy | Taxonomy of types of part-whole relations | Extensions | Ontology Design Patterns | Summary

The taxonomy

Part-whole relations

“member-bunch”, collective nouns (e.g. `Herd`, `Orchestra`) with their members (`Sheep`, `Musician`)

$$\forall x, y(member\_of_n(x, y) \triangleq mpart\_of(x, y) \land (POB(x) \lor SOB(x)) \land SOB(y))$$

“material-object”, that what something is made of (e.g., `Vase` and `Clay`)

$$\forall x, y(constitutes_{it}(x, y) \equiv constituted\_of_{it}(y, x) \triangleq mpart\_of(x, y) \land POB(y) \land M(x))$$

Part-whole relations

"quantity-mass", "portion-object", relating a smaller (or sub) part of an amount of matter to the whole. Two issues (glass of wine & bottle of wine vs. `Salt` as subquantity of `SeaWater`)

$$\forall x, y(sub\_quantity\_of_n(x, y) \triangleq mpart\_of(x, y) \wedge M(x) \wedge M(y))$$

"noun-feature/activity", entity participates in a process, like `Enzyme` that participates in `CatalyticReaction`

$$\forall x, y(participates\_in_{it}(x, y) \triangleq mpart\_of(x, y) \wedge ED(x) \wedge PD(y))$$

Part-whole relations

processes and sub-processes (e.g. `Chewing` is involved in the grander process of `Eating`)

$$\forall x, y(involved\_in(x, y) \triangleq part\_of(x, y) \wedge PD(x) \wedge PD(y))$$

Object and its 2D or 3D region, such as `contained_in(John's address book, John's bag)` and `located_in(Pretoria, South Africa)`

$$\forall x, y(contained\_in(x, y) \triangleq part\_of(x, y) \wedge R(x) \wedge R(y) \wedge \exists z, w(has\_3D(z, x) \wedge has\_3D(w, y) \wedge ED(z) \wedge ED(w)))$$

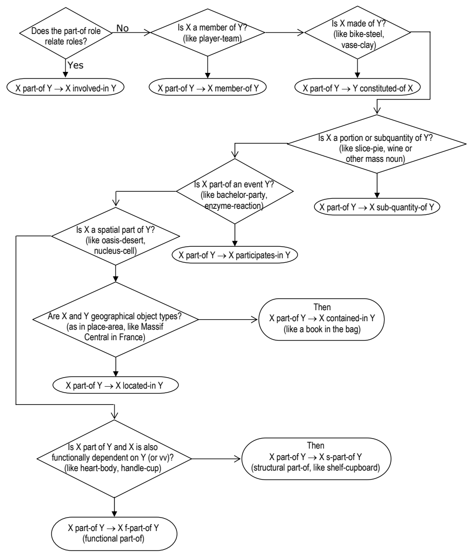
$$\forall x, y(located\_in(x, y) \triangleq part\_of(x, y) \wedge R(x) \wedge R(y) \wedge \exists z, w(has\_2D(z, x) \wedge has\_2D(w, y) \wedge ED(z) \wedge ED(w)))$$

$$\forall x, y(s\_part\_of(x, y) \triangleq part\_of(x, y) \wedge ED(x) \wedge ED(y))$$

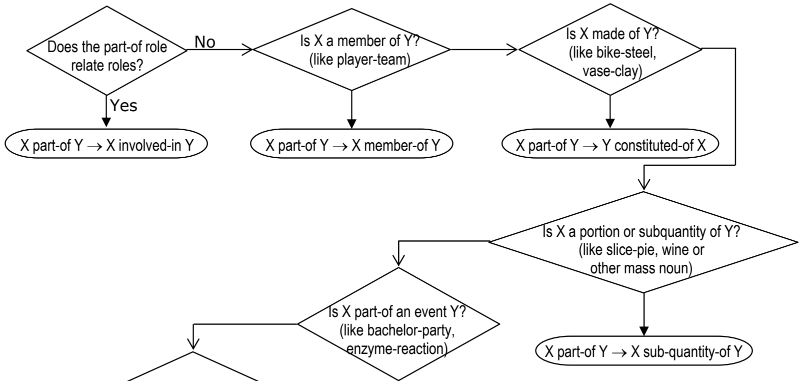
Using the taxonomy of part-whole relations

- Representing it correctly in ontologies and conceptual data models
  - Decision diagram
  - Using the categories of the foundational ontology
  - Examples
  - *Software application* that simplifies all that
- Reasoning with a taxonomy of relations
  - The *RBox reasoning service* to pinpoint errors

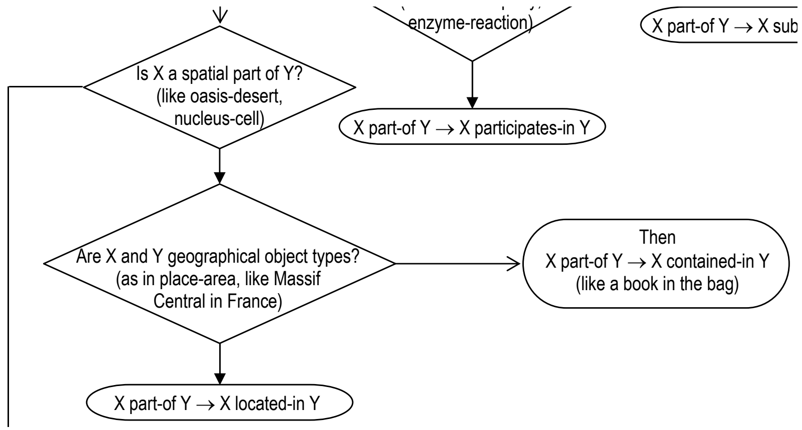
Decision diagram



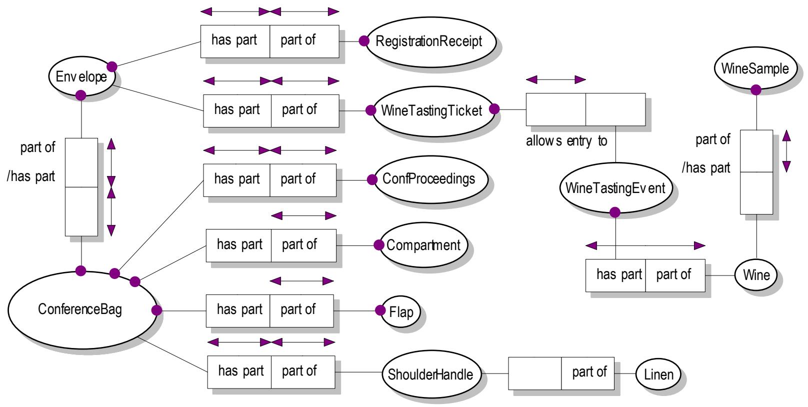
Decision diagram



Decision diagram



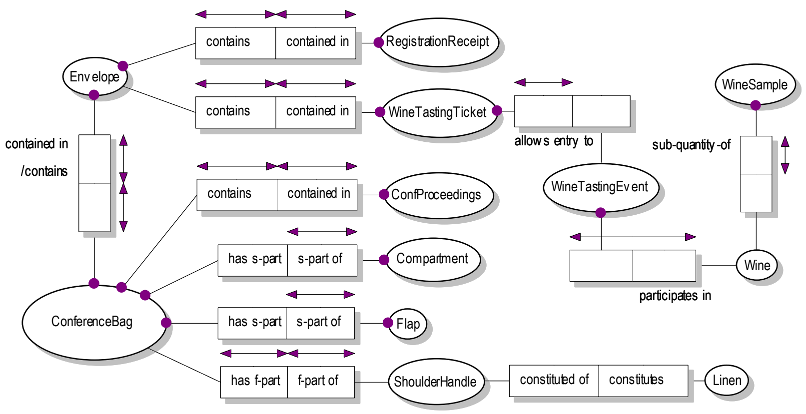
Example - before



Example - after

- Envelope is not involved-in, not a member-of, does not constitute, is not a sub-quantity of, does not participate-in, is not a geographical object, but instead is contained-in the ConferenceBag.
- Transitivity holds for the mereological relations: derived facts are automatically correct, like RegistrationReceipt contained-in ConferenceBag.
- Intransitivity of Linen and ConferenceBag, because a conference bag is not wholly constituted of linen (the model does not say what the Flap is made of).
- Completeness, i.e. that *all* parts make up the whole, is implied thanks to the closed-world assumption. ConferenceBag directly contains the ConfProceedings and Envelope *only*, and does not contain, say, the Flap.

Example - after



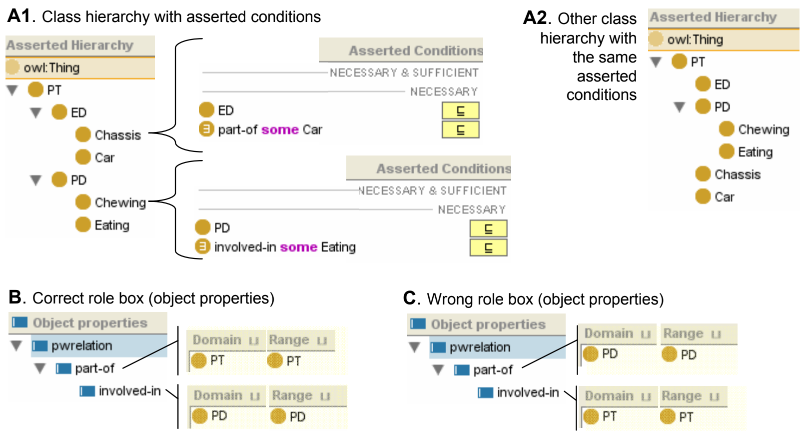
Using DOLCE's categories

- The participating objects instantiate some category (*ED*, *PD*, etc)
- Given the formalization, one immediately can exclude/identify appropriate relations, taking a shortcut in the decision diagram
  - E.g.: *Chewing* and *Eating* are both a kind of (a subtype of) *PD*, hence *involved_in*
  - E.g.: *Alcohol* and *Wine* are both mass nouns, or *M*, hence *sub_quantity_of*
- Demo of OntoPartS

Requirements for reasoning over the hierarchy

- Represent at least Ground Mereology,
- Express ontological categories and their taxonomic relations,
- Having the option to represent transitive and intransitive relations, and
- Specify the domain and range restrictions (/relata/entity types) for the classes participating in a relation.

Current behaviour of reasoners

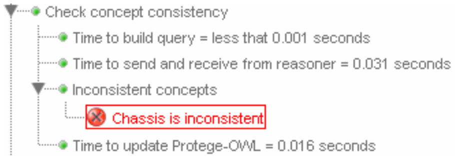


Current behaviour of reasoners

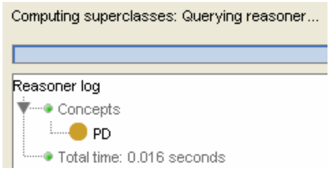
1. A1+B+racer: *ontology OK*

2. A2+B+racer: *ontology OK*

3. A1+C+racer: class hierarchy is inconsistent



4. A2+C+racer: Chassis reclassified as PD



The *RBox Compatibility* service – definitions

Definition (Domain and Range Concepts)

Let R be a role and $R \sqsubseteq C_1 \times C_2$ its associated Domain & Range axiom. Then, with the symbol D_R we indicate the *User-defined Domain* of R—i.e., $D_R = C_1$—while with the symbol R_R we indicate the *User-defined Range* of R—i.e., $R_R = C_2$.

Definition (RBox Compatibility)

For each pair of roles, R, S, such that $\langle \mathcal{T}, \mathcal{R} \rangle \models R \sqsubseteq S$, check:

Test 1. $\langle \mathcal{T}, \mathcal{R} \rangle \models D_R \sqsubseteq D_S$ and $\langle \mathcal{T}, \mathcal{R} \rangle \models R_R \sqsubseteq R_S$;

Test 2. $\langle \mathcal{T}, \mathcal{R} \rangle \not\models D_S \sqsubseteq D_R$;

Test 3. $\langle \mathcal{T}, \mathcal{R} \rangle \not\models R_S \sqsubseteq R_R$.

An RBox is said to be compatible iff `Test 1` and (*2* or *3*) hold for all pairs of role-subrole in the RBox.

The *RBox Compatibility* service – behaviour

- If `Test 1` does not hold: warning that domain & range restrictions of either R or S are in conflict with the role hierarchy proposing either
  (i) To change the role hierarchy or
  (ii) To change domain & range restrictions or
  (iii) If the test on the domains fails, then propose a new axiom $R \sqsubseteq D'_R \times R_R$, where $D'_R \equiv D_R \sqcap D_S$[2], which subsequently has to go through the RBox compatibility service (and similarly when `Test 1` fails on range restrictions).

[2] The axiom $C_1 \equiv C_2$ is a shortcut for the axioms: $C_1 \sqsubseteq C_2$ and $C_2 \sqsubseteq C_1$.

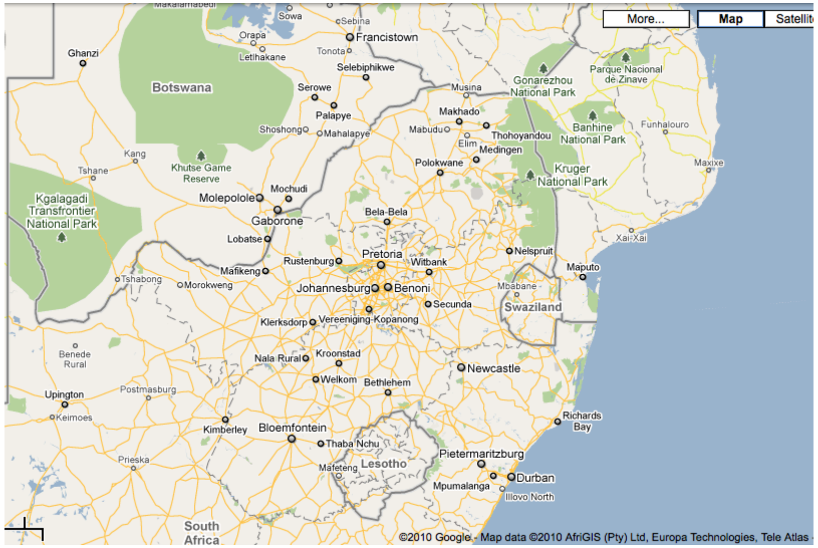
The *RBox Compatibility* service – behaviour

- If `Test 2` and `Test 3` fail: warn that R cannot be a proper subrole of S but that the two roles can be equivalent. Then, either:
  (a) Accept the possible equivalence between the two roles or
  (b) Change domain & range restrictions.
- Ignoring all warnings is allowed, too

Extensions in various directions

- Mereotopology, with location, GIS, Region Connection Calculus (http://www.comp.leeds.ac.uk/qsr/rcc.html)
- Mereogeometry
- Mereology and/vs granularity
- Temporal aspects of part-whole relations

Knowledge and Google & AfriGIS



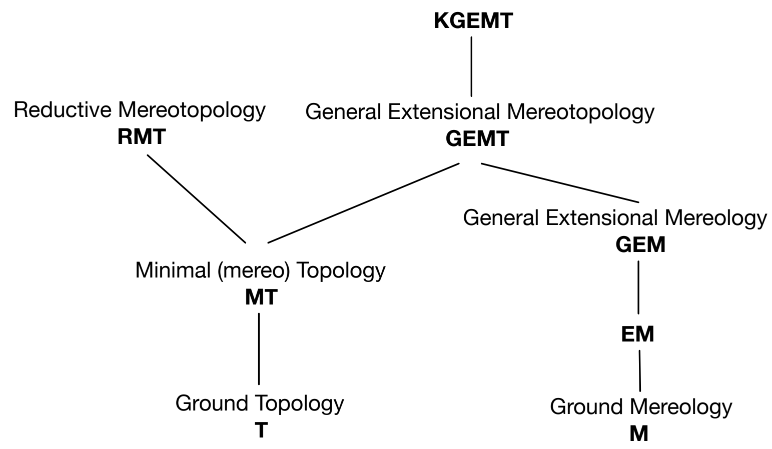
Knowledge and Google & AfriGIS

- How can we represent
  - The Kruger Park *overlaps* with South Africa
  - Durban is a *tangential proper part* of South Africa
  - Gauteng is a *non-tangential proper part* of South Africa
  - Botswana is *connected to* South Africa (do they *share* a border?)
  - Lesotho is *spatially located within* the area of South Africa (but not part of)?
- Can we do all that with mereology? Use only spatial relations? Combining mereo+spatial?

Mereology with spatial notions

- Another primitive: Connected, which is reflexive and symmetric
- More and more expressive theories, e.g.:
  - T: $C(x,x)$ and $C(x,y) \rightarrow C(y,x)$
  - MT: T and $P(x,y) \rightarrow E(x,y)$ where E is enclosure $(E(x,y) =_{def} \forall z(C(z,x) \rightarrow C(z,y)))$
- Two primitives, P and C, or *part* in terms of C?
  - $P =_{def} \forall z(C(z,x) \rightarrow C(z,y))$
- or perhaps "x and y are connected parts of z" as primitive, $CP(x,y,z)$, then:
  $P(x,y) =_{def} \exists z\ CP(x,z,y)$ and
  $C(x,y) =_{def} \exists z\ CP(x,y,z)$

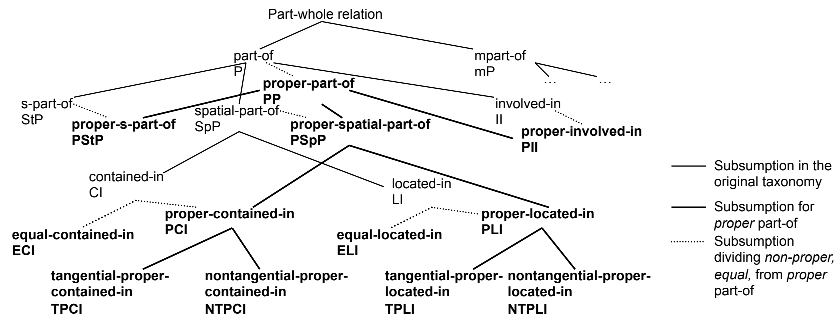
Some of the mereo- and topological theories



Note: one can add explicit variations with Atom/Atomless and Boundary/Boundaryless

Figure: Diagram of mereo- and mereotopological theories; from weaker to stronger, going uphill (after descriptions in Varzi (2007))

Extension to the taxonomy of part-whole relations



Extension to the taxonomy of part-whole relations

$$\forall x,y \quad (ECI(x,y) \equiv CI(x,y) \wedge P(y,x) \tag{18}$$

$$\forall x,y \quad (PCI(x,y) \equiv PPO(x,y) \wedge R(x) \wedge R(y) \wedge \exists z,w(has\_3D(z,x) \wedge has\_3D(w,y) \wedge ED(z) \wedge ED(w))) \tag{19}$$

$$\forall x,y \quad (NTPCI(x,y) \equiv PCI(x,y) \wedge \forall z(C(z,x) \rightarrow O(z,y))) \tag{20}$$

$$\forall x,y \quad (TPCI(x,y) \equiv PCI(x,y) \wedge \neg NTPCI(x,y)) \tag{21}$$

$$\forall x,y \quad (ELI(x,y) \equiv LI(x,y) \wedge P(y,x) \tag{22}$$

$$\forall x,y \quad (PLI(x,y) \equiv PPO(x,y) \wedge R(x) \wedge R(y) \wedge \exists z,w(has\_2D(z,x) \wedge has\_2D(w,y) \wedge ED(z) \wedge ED(w))) \tag{23}$$

$$\forall x,y \quad (NTPLI(x,y) \equiv PLI(x,y) \wedge \forall z(C(z,x) \rightarrow O(z,y))) \tag{24}$$

$$\forall x,y \quad (TPLI(x,y) \equiv PLI(x,y) \wedge \neg NTPLI(x,y)) \tag{25}$$

Implementability

- KGEMT requires second order logic
- No definitions of relations in OWL
- Recollect object property characteristics in the different OWL species
- What do we loose exactly regarding representation and, consequently, reasoning?
- See ESWC'12 paper

Rationale

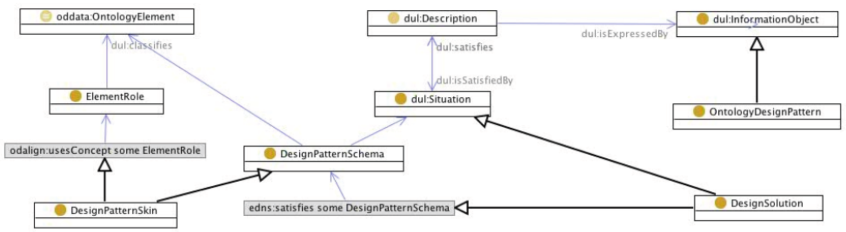
- It is hard to reuse only the "useful pieces" of a comprehensive (foundational) ontology, and the cost of reuse may be higher than developing a new ontology from scratch
- Need for small (or cleverly modularized) ontologies with explicit documentation of design rationales, and best reengineering practices
- Hence, in analogy to software design patterns: **ontology design patterns**
- ODPs summarize the good practices to be applied within design solutions
- ODPs keep track of the design rationales that have motivated their adoption

content of slides based on Presutti et al, 2008

ODP definition

- An ODP is an information object
- A design pattern schema is the description of an ODP, including the roles, tasks, and parameters needed in order to solve an ontology design issue
- *An ODP is a modeling solution to solve a recurrent ontology design problem. It is an Information Object that expresses a Design Pattern Schema (or skin) that can only be satisfied by DesignSolutions. Design solutions provide the setting for Ontology Elements that play some ElementRole(s) from the schema.* (Presutti et al, 2008)

ODP types



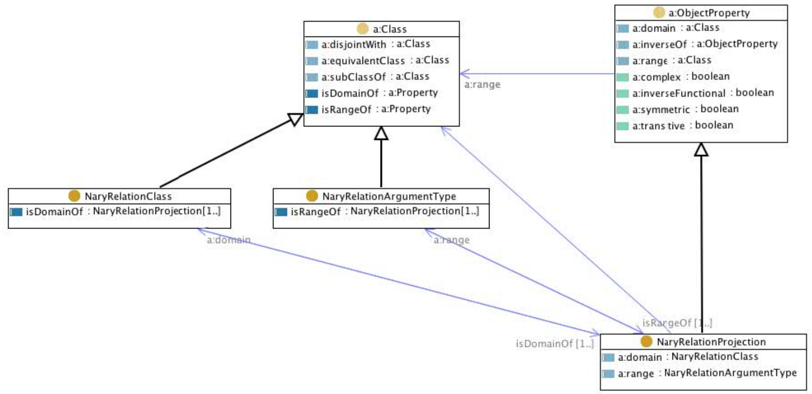
Types of Patterns

- Six families of ODPs: Structural OPs, Correspondence OPs, Content OPs (CPs), Reasoning OPs, Presentation OPs, and Lexico-Syntactic OPs
- CPs can be distinguished in terms of the domain they represent
- Correspondence OPs (for reengineering and mappings—next lecture)
- Reasoning OPs are typical reasoning procedures
- Presentation OPs relate to ontology usability from a user perspective; e.g., we distinguish between Naming OPs and Annotation OPs
- Lexico-Syntactic OP are linguistic structures or schemas that permit to generalize and extract some conclusions about the meaning they express

Structural OPs

- Logical OPs:
  - Are compositions of logical constructs that solve a problem of expressivity in OWL-DL (and, in cases, also in OWL 2 DL)
  - Only expressed in terms of a logical vocabulary, because their signature (the set of predicate names, e.g. the set of classes and properties in an OWL ontology) is empty
  - Independent from a specific domain of interest
  - **Logical macros** compose OWL DL constructs; e.g. the universal+existential OWL macro
  - **Transformation patterns** translate a logical expression from a logical language into another; e.g. n-aries

Example: n-ary relation Logical OP



Architectural OPs

- Architectural OPs are defined in terms of composition of Logical OPs that are used in order to affect the overall shape of the ontology; i.e., an Architectural OP identifies a composition of Logical OPs that are to be exclusively used in the design of an ontology
- Examples of Architectural OPs are: Taxonomy, Modular Architecture, and Lightweight Ontology
- E.g., **Modular Architecture** Architectural OP consists of an ontology network, where the involved ontologies play the role of modules, which are connected by the *owl:import* operation with one root ontology that imports all the modules

Lexico-Syntactic OPs

- linguistic structures or schemas that consist of certain types of words following a specific order and that permit to generalize and extract some conclusions about the meaning they express; *verbalisation* patterns
- E.g., "subClassOf" relation, NP<subclass> be NP<superclass>, a Noun Phrase should appear before the verb—represented by its basic form or lemma, be in this example—and the verb should in its turn be followed by another Noun Phrase
- Other Lexical OPs provided for OWL's equivalence between classes, object property, subpropertyOf relation, datatype property, existential restriction, universal restriction, disjointness, union of classes
- Mainly for English language only, thus far
- Similar to idea of ORM's verbalization templates

Summary

1. Parts, mereology, meronymy
   - Introduction
   - Mereology
   - Implementation
   - Meronymy
2. Taxonomy of types of part-whole relations
   - The taxonomy
   - Using the taxonomy of part-whole relations
   - RBox Compatibility
3. Extensions
4. Ontology Design Patterns