Ontology Engineering

Lecture 7: Top-down (and middle-out) Ontology Development II

Maria Keet

email: mkeet@cs.uct.ac.za

home: http://www.meteck.org

Department of Computer Science
University of Cape Town, South Africa

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Outline

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1. Parts
   - Meronymy
   - Mereology
   - Implementation
2. Taxonomy of types of part-whole relations
   - The taxonomy
   - Using the taxonomy of part-whole relations
   - RBox Compatibility
3. Extending the foundations for broader use
4. Ontology Design Patterns

Some questions and problems (not exhaustive)

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- And w.r.t. `Brain part of Human` and/versus `Hand part of Boxer`? (assuming boxers must have their own hands)

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- 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?

Part-whole relations in natural language (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

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  - ⋆ Person part of Organisation
  - ⋆ Organisation located in Rondebosch
  - — therefore Person located in Rondebosch?
  - — but *not* Person part of Rondebosch

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Part-whole relations in natural language (meronymy)

- 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

Part-whole relations in natural language (meronymy)

- 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

Analysis of the issues from diverse angles

- Mereological theories (Varzi, 2004), usage & extensions (e.g. mereotopology, relation with granularity, set theory) – Ontology
- Early attempts with direct parthood, SEP triples, and other outstanding issues, some still remaining
- Cognitive & linguistic issues from meronymy
- Their use in conceptual modelling and ontology engineering (e.g. UML's aggregation)
- Subject domains: everywhere

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)

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

Irreflexivity (x is not part of itself)

$$\forall x \neg(proper\_part\_of(x, x)) \quad (7)$$

Transitivity

$$\forall x, y, z((proper\_part\_of(x, y) \land proper\_part\_of(y, z)) \rightarrow proper\_part\_of(x \quad (8)$$

Defining other relations with *part_of*

- Overlap (x and y share a piece z)

$$\forall x, y(overlap(x, y) \equiv \exists z(part\_of(z, x) \wedge part\_of(z, y))) \quad (9)$$

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

$$\forall x, y(underlap(x, y) \equiv \exists z(part\_of(x, z) \wedge part\_of(y, z))) \quad (10)$$

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- The 'other direction': has part

$$\forall x, y(has\_part(x, y) \equiv part\_of^{-}(x, y)) \quad (11)$$

- 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**

- With x as part, what to do with the 'remainder' that makes up y?
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  - 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 (extra)

- Strong supplementation [EM]

$$\neg part\_of(y,x) \rightarrow \exists z(part\_of(z,y) \land \neg overlap(z,x)) \quad (12)$$

- 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:

$$\exists x\phi \rightarrow \exists z\forall y(overlap(y,z) \leftrightarrow \exists x(\phi \land overlap(y,x))) \quad (13)$$

- 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

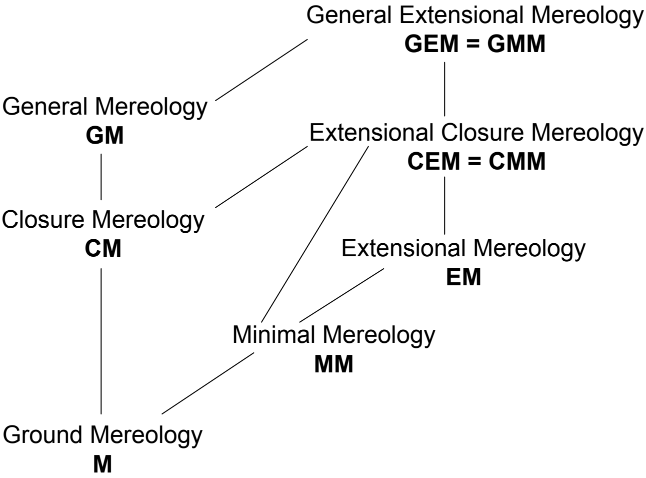

Fig. 1: Hasse diagram of mereological theories; from weaker to stronger, going uphill (after [44]).

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

What we can(not) implement with DLs

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

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  - *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.
- Same labels, different relata and only a textual constraint: Label the relations differently

Outline

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

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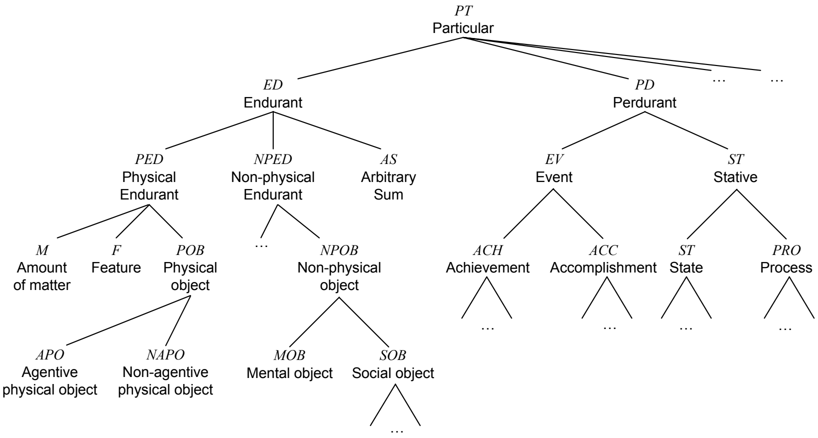
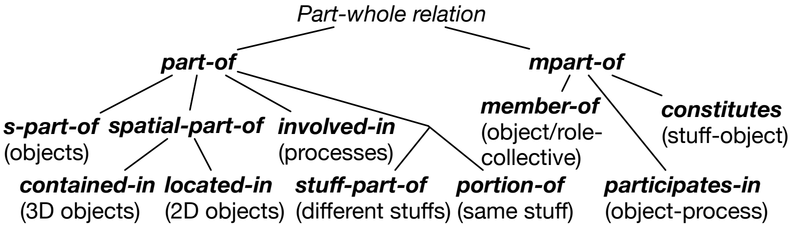
- Mereological *part_of* (and subtypes) versus ‘other’ part-whole relations
- Categories of object types of the part-whole relation changes
- Structure these relations by (non/in)transitivity and kinds of relata
- Simplest mereological theory, **M**.
- Commit to a foundational ontology: DOLCE (though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

DOLCE categories



Part-whole relations (small version)



Part-whole relations (meronymic ones)

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

$$\forall x, y(member\_of_n(x, y) \triangleq mpart\_of(x, y) \wedge (POB(x) \vee SOB(x)) \wedge SOB(y))$$

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

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

"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 (mereology)

"quantity-mass", e.g., `Salt` as subquantity of `SeaWater`—different types of amounts of matter. partial formalisation:

$$\forall x, y(sub\_quantity\_of_n(x, y) \triangleq part\_of(x, y) \land M(x) \land M(y))$$

"portion-object", relating a smaller (or sub) part of an amount of matter to the whole; same type of stuff; e.g. glass of wine & bottle of wine. partial formalisation:

$$\forall x, y(portion\_of(x, y) \triangleq part\_of(x, y) \land M(x) \land M(y))$$

Part-whole relations (mereology)

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

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

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

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

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

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

Using the taxonomy of part-whole relations

- Representing it correctly in ontologies and conceptual data models
- Reasoning with a taxonomy of relations

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

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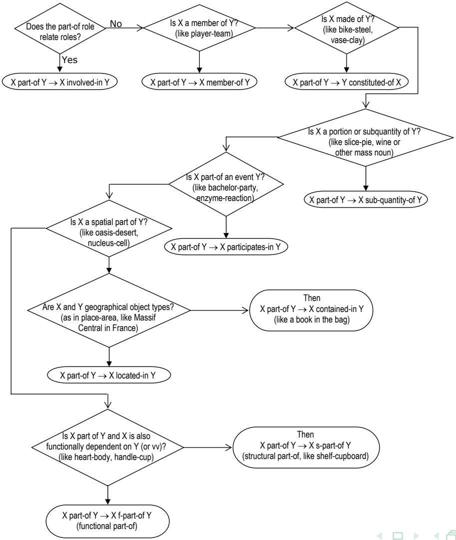
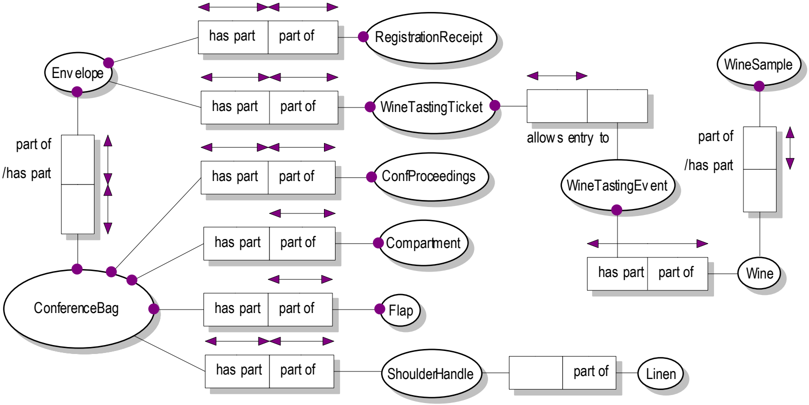
  - The *RBox reasoning service* to pinpoint errors

Decision diagram



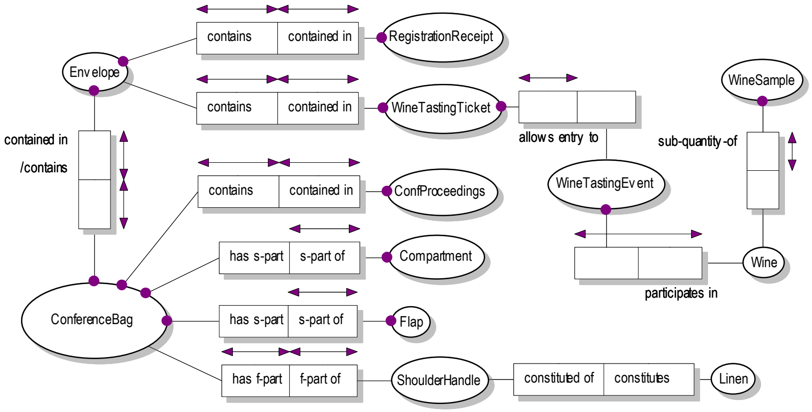
Example - before



Example - decisions

- 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 - revised



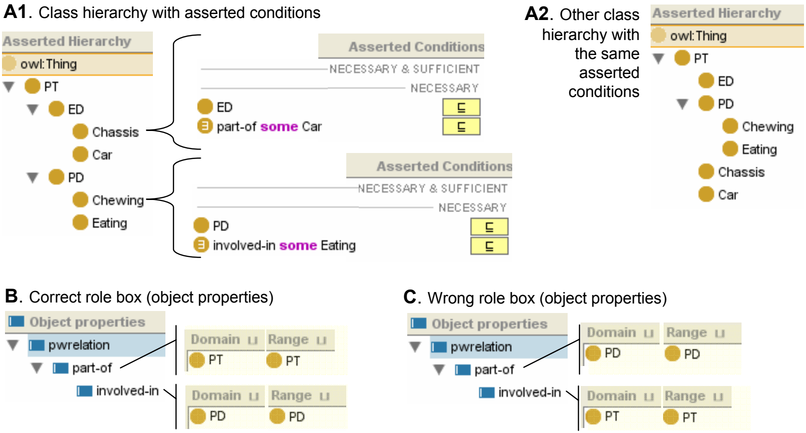
Using DOLCE's categories

- The participating objects instantiate some category (*ED*, *PD*, etc)
- Given the formalisation, 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 `http://www.meteck.org/files/ontopartssup/supindex.html`

Requirements for reasoning over the hierarchy

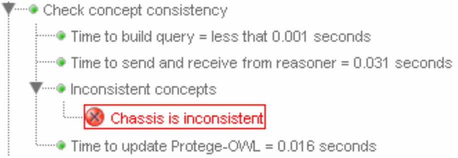
- Represent at least Ground Mereology,
- Express ontological categories and their taxonomic relations,
- Having the option to represent transitive and intransitive relations, and
- Specify the domain and range restrictions (/relata/entity types) for the classes participating in a relation.

Current behaviour of reasoners

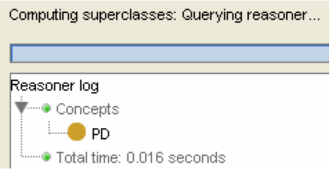


Current behaviour of reasoners

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

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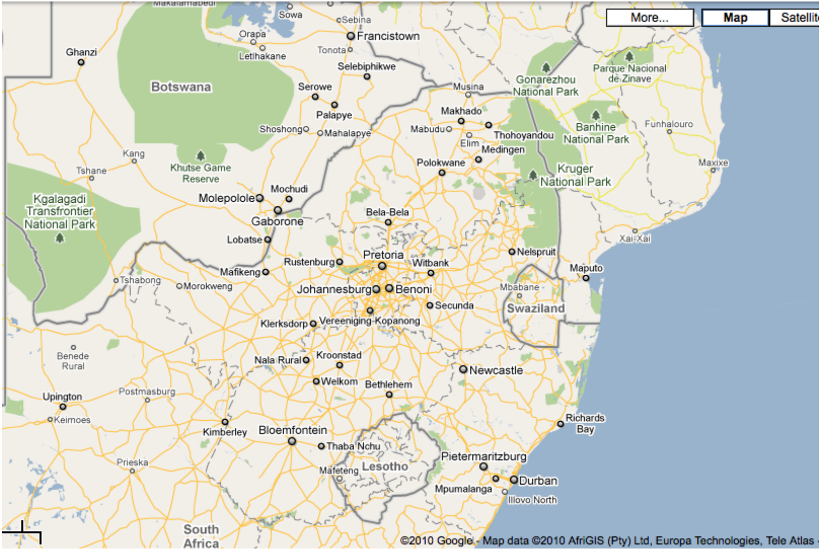
Extensions in various directions

- Mereotopology, with location, GIS, Region Connection Calculus
- Mereogeometry
- Mereology and/vs granularity
- Temporal aspects of part-whole relations
- Any linguistic and/or cultural specifics

Example (1/2)


More...
Map
Satellit
Sowa
Sebina
Francistown
Orapa
Letlhakane
Tonota
Ghanzi
Selebiphikwe
Botswana
Serowe
Palapye
Musina
Gonarezhou National Park
Parque Nacional de Zinave
Makhado
Shoshong
Mahalapye
Mabudu
Thohoyandou
Elim
Medingen
Banhine National Park
Funhalouro
Kang
Tshane
Khutse Game Reserve
Polokwane
Kruger National Park
Maxixe
Kgalagadi Transfrontier National Park
Molepolole
Mochudi
Gaborone
Bela-Bela
Lobatse
Xai-Xai
Nelspruit
Pretoria
Rustenburg
Witbank
Mafikeng
Maputo
Tshabong
Morokweng
Johannesburg
Benoni
Mbabane
Secunda
Swaziland
Klerksdorp
Vereeniging-Kopanong
Benede Rural
Nala Rural
Kroonstad
Newcastle
Welkom
Bethlehem
Upington
Postmasburg
Keimoes
Richards Bay
Kimberley
Bloemfontein
Thaba Nchu
Pietermaritzburg
Prieska
Mafeteng
Lesotho
Durban
Mpumalanga
Illovo North
South Africa
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Exercise – Representation needs

- How to represent that:
  - 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)

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- Can we do all that with mereology? Use only spatial relations? Combining mereo+spatial?

Mereology with spatial notions

- Another primitive: *C*onnected, which is reflexive and symmetric

Mereology with spatial notions

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- 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 ($E(x,y) =_{def} \forall z(C(z,x) \rightarrow C(z,y))$)

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  - $P =_{def} \forall z(C(z, x) \rightarrow C(z, y))$

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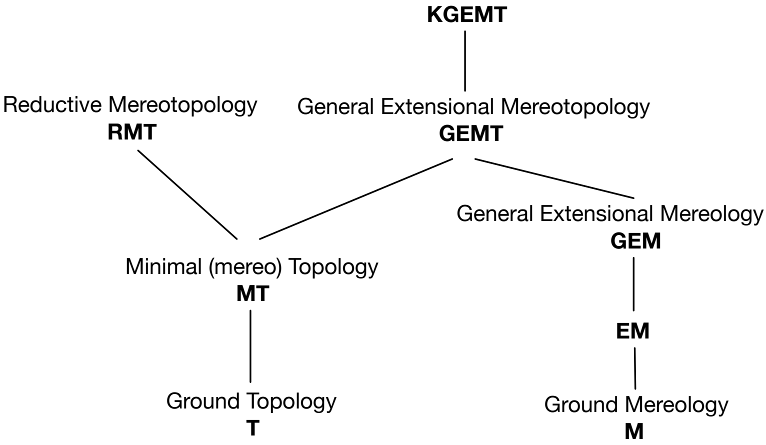
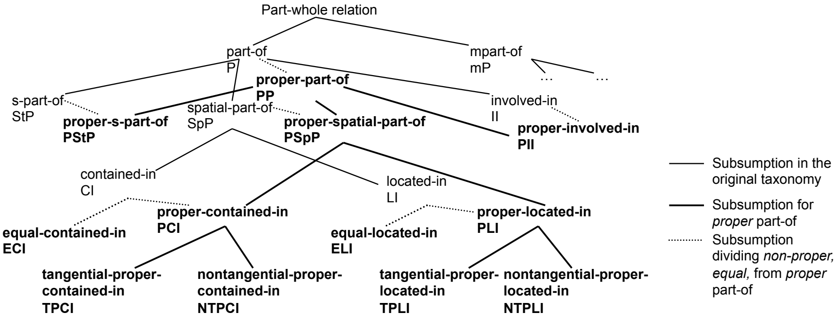
- Two primitives, P and C, or *part* in terms of C?
  - $P =_{def} \forall z(C(z,x) \rightarrow C(z,y))$
- or perhaps "x and y are connected parts of z" as primitive, $CP(x,y,z)$, then:
  $P(x,y) =_{def} \exists z \; CP(x,z,y)$ and
  $C(x,y) =_{def} \exists z \; CP(x,y,z)$

Some of the mereo- and topological theories



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

Extension to the taxonomy of part-whole relations



Extension to the taxonomy of part-whole relations

$$\forall x, y \quad (ECI(x, y) \equiv CI(x, y) \land P(y, x) \tag{14}$$

$$\forall x, y \quad (PCI(x, y) \equiv PPO(x, y) \land R(x) \land R(y) \land \exists z, w(has\_3D(z, x) \land has\_3D(w, y) \land ED(z) \land ED(w))) \tag{15}$$

$$\forall x, y \quad (NTPCI(x, y) \equiv PCI(x, y) \land \forall z(C(z, x) \rightarrow O(z, y))) \tag{16}$$

$$\forall x, y \quad (TPCI(x, y) \equiv PCI(x, y) \land \neg NTPCI(x, y)) \tag{17}$$

$$\forall x, y \quad (ELI(x, y) \equiv LI(x, y) \land P(y, x) \tag{18}$$

$$\forall x, y \quad (PLI(x, y) \equiv PPO(x, y) \land R(x) \land R(y) \land \exists z, w(has\_2D(z, x) \land has\_2D(w, y) \land ED(z) \land ED(w))) \tag{19}$$

$$\forall x, y \quad (NTPLI(x, y) \equiv PLI(x, y) \land \forall z(C(z, x) \rightarrow O(z, y))) \tag{20}$$

$$\forall x, y \quad (TPLI(x, y) \equiv PLI(x, y) \land \neg NTPLI(x, y)) \tag{21}$$

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- Is there a way to avoid this?
- Yes, but computationally costly and not ‘easy’ yet: e.g., OWL + Common Logic within DOL (recall Ch4)

Outline

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 modularised) ontologies with explicit documentation of design rationales, and best engineering practices
- Hence, in analogy to software design patterns: **ontology design patterns**
- ODPs summarise the good practices to be applied within design solutions
- ODPs keep track of the design rationales that have motivated their adoption

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)
- OPs have their own metadata

Another OP/ODP hierarchy

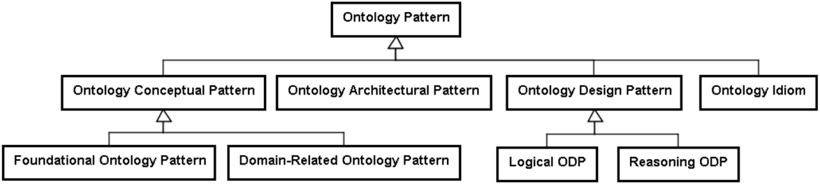


Fig. 2. Ontology Pattern Types

Types of Patterns

- Structural OPs, Correspondence OPs, Content OPs (CPs), Reasoning OPs, Presentation OPs, 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., 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 (more in next lecture)

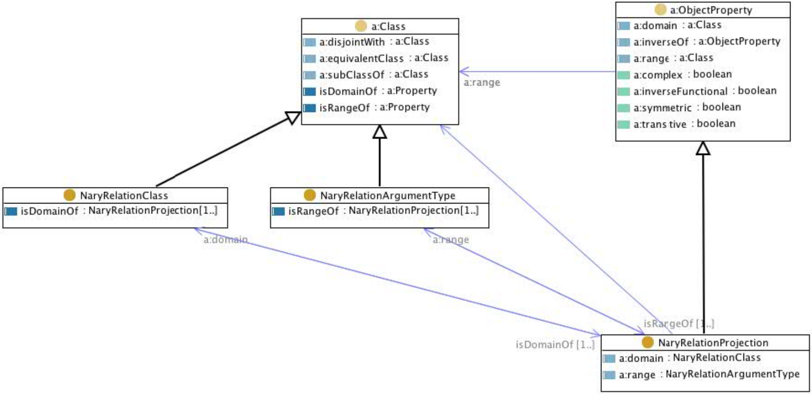
Structural OPs

- 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" idea

- Reify the n-ary R into a class R'
- Create n binaries between the classes and R'
- Declare 1:1 cardinality constraints
- Declare identifier across the n new binaries (often omitted)

Example: n-ary relation “Logical OP”



Architectural OPs

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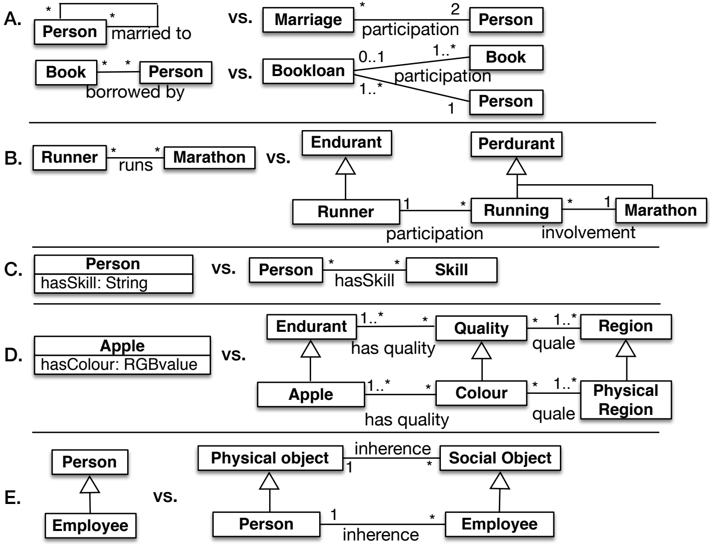
- Examples of Architectural OPs are: Taxonomy, Modular Architecture, and Lightweight Ontology
- E.g., **Modular Architecture** Architectural OP consists of an ontology network, where the involved ontologies play the role of modules, which are connected by the *owl:import* operation with one root ontology that imports all the modules

Correspondence and reengineering OPs



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- Mainly for English language only, thus far

Summary

1. Parts
   - Meronymy
   - Mereology
   - Implementation
2. Taxonomy of types of part-whole relations
   - The taxonomy
   - Using the taxonomy of part-whole relations
   - RBox Compatibility
3. Extending the foundations for broader use
4. Ontology Design Patterns