Semantic Web Technologies

Lecture 6: Ontology engineering: parts, wholes, and time

Maria Keet

email: keet -AT- inf.unibz.it

home: http://www.meteck.org

blog:

http://keet.wordpress.com/category/computer-science/72010-semwebtech/

KRDB Research Center
Free University of Bozen-Bolzano, Italy

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Outline

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The landscape

- OWL 2 DL is quite expressive, but this does not mean one can represent everything
- Trade-offs between expressiveness and computational complexity
- One can choose for different combinations of the trade-offs
  - properties of the object properties
  - other operators
  - settle for 'workarounds' w.r.t. modelling
- For instance, parthood in its full glory, temporalizations, fuzzy, probabilistic

Examples

- SNOMED CT: "Concussion with loss of consciousness for less than one hour", where the loss of consciousness still can be before or after the concussion
- Difference between how the brain and a heart are part of your body
- Classifying "ripe" apples or "the set of all individuals that mostly buy low calorie food"
- "Butterfly is a transformation of Caterpillar"
- The wall that is shared by the adjacent—overlaps with the—semi-detached houses

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- 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?

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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
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Ground Mereology

Reflexivity (everything is part of itself)

$$\forall x(part\_of(x, x)) \tag{1}$$

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

$$\forall x, y((part\_of(x, y) \wedge part\_of(y, x)) \rightarrow x = y) \tag{2}$$

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

$$\forall x, y, z((part\_of(x, y) \wedge part\_of(y, z)) \rightarrow part\_of(x, z)) \tag{3}$$

Proper parthood

$$\forall x, y(proper\_part\_of(x, y) \equiv part\_of(x, y) \wedge \neg part\_of(y, x)) \tag{4}$$

Ground Mereology

Proper parthood

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

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)

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

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

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

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

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

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

Proper overlap & Proper underlap

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

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

- 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)

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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. [2] 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)

[2] 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

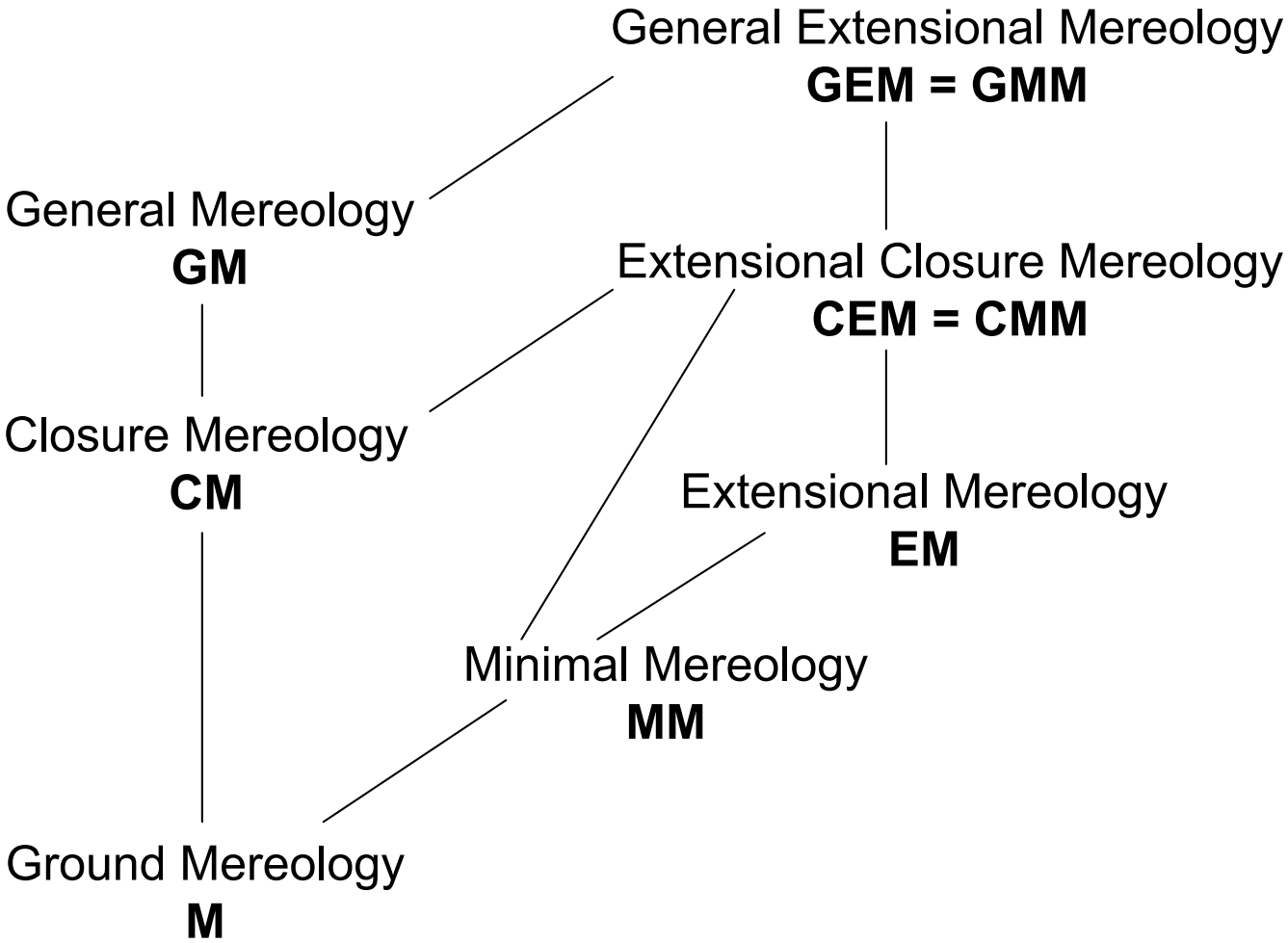

Fig. 1: Hasse diagram of mereological theories; from weaker to stronger, going uphill (after [44]).

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):

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

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

  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

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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 $\Rightarrow$ **Feature** $\Downarrow$	$\mathcal{DLR}_\mu$	$\mathcal{SHOIN}$ ($\sim$ OWL-DL)	$\mathcal{SROIQ}$ ($\sim$ OWL 2 DL)	DL-Lite$_A$
Reflexivity *	+	−	+	−
Antisymmetry *	−	−	−	−
Transitivity $^{*\ \ddagger}$	+	+	+	−
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

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

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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 (1987), list of 6 types motivated by CMing (Odell) ontology-inspired conceptual modelling (Guizzardi)
- Location, containment, membership of a collective, quantities of a mass
- Relatively well-settled debate on transitivity, or not

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
- Simplest mereological theory, **M**.
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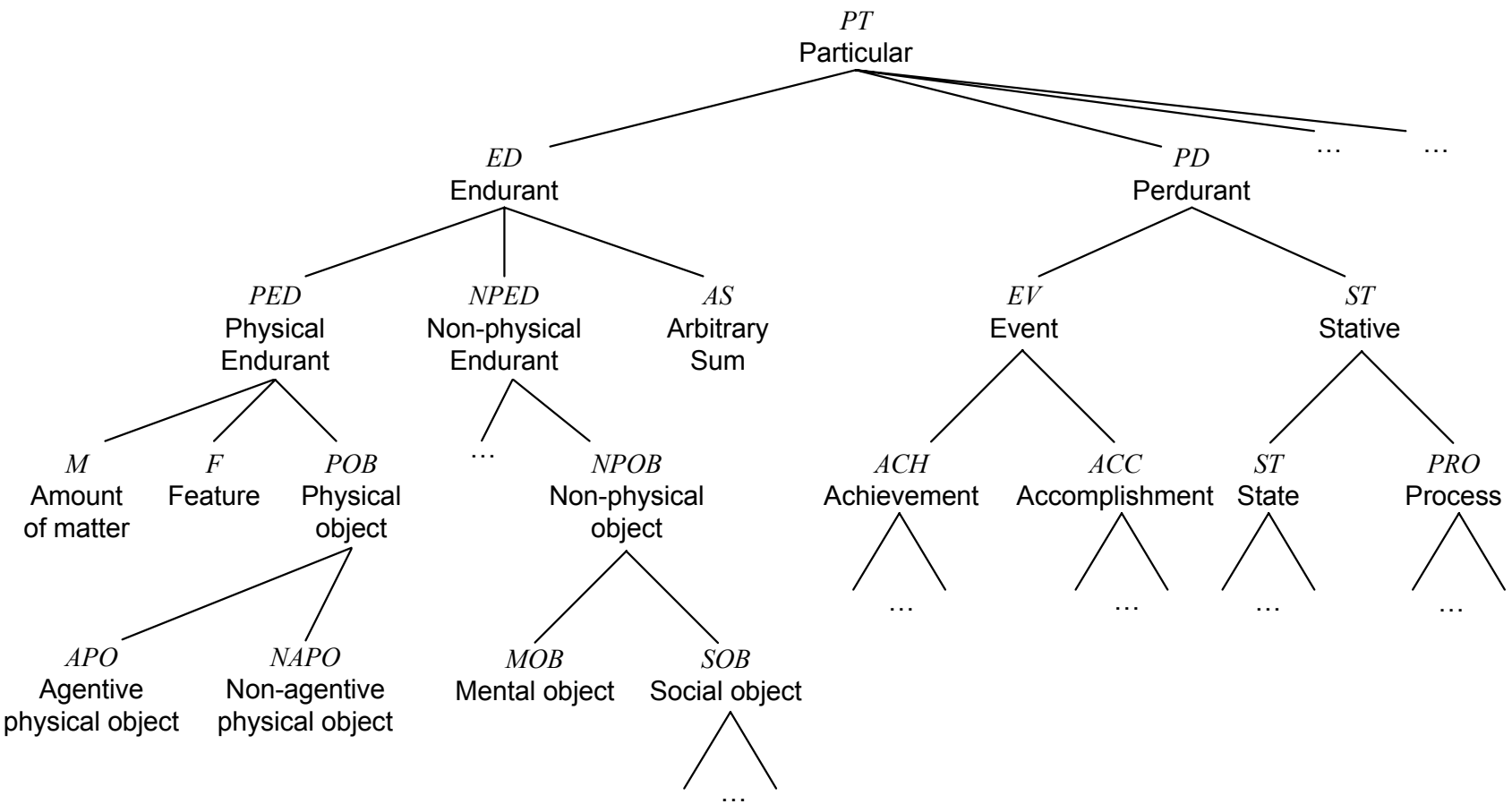
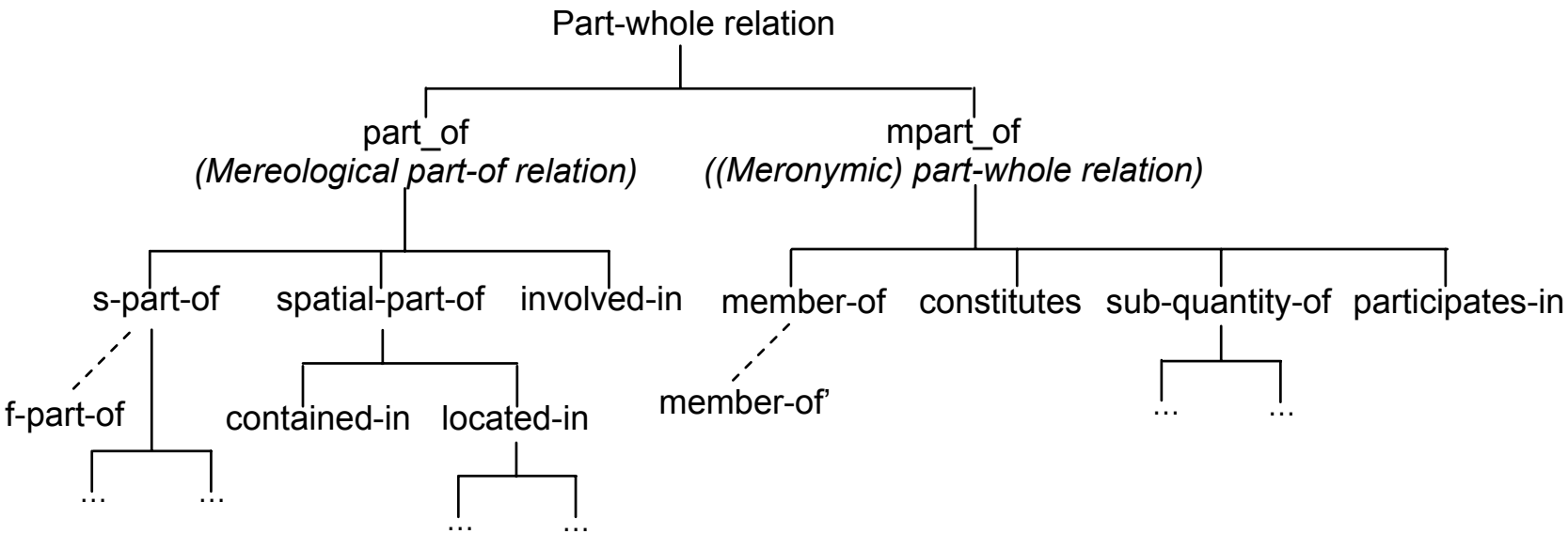
DOLCE categories



Part-whole relations



Part-whole relations

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

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

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

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

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)`

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

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

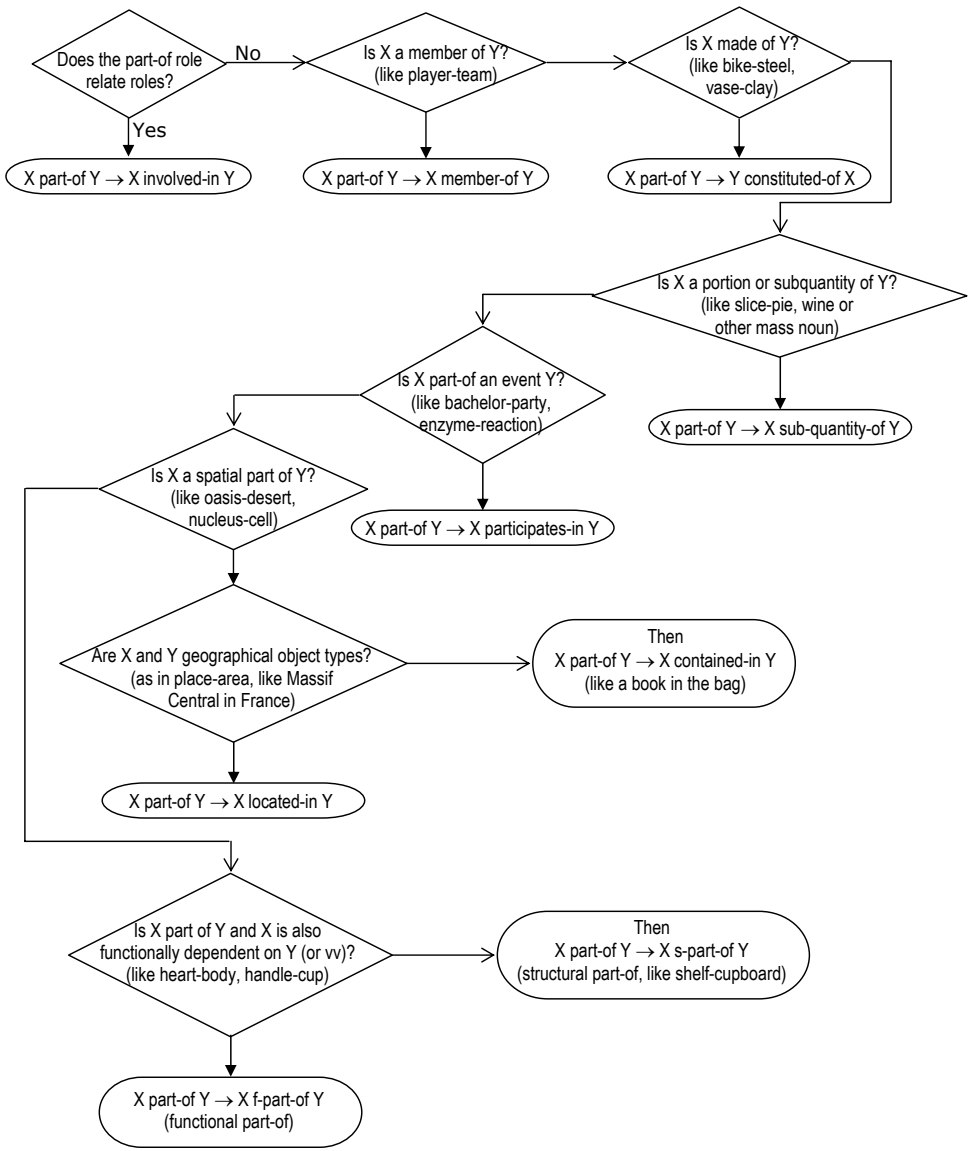
$$\forall x, y(s\_part\_of(x, y) \triangleq part\_of(x, y) \wedge ED(x) \wedge ED(y))$$

Outline

Using the taxonomy of part-whole relations

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

Decision diagram



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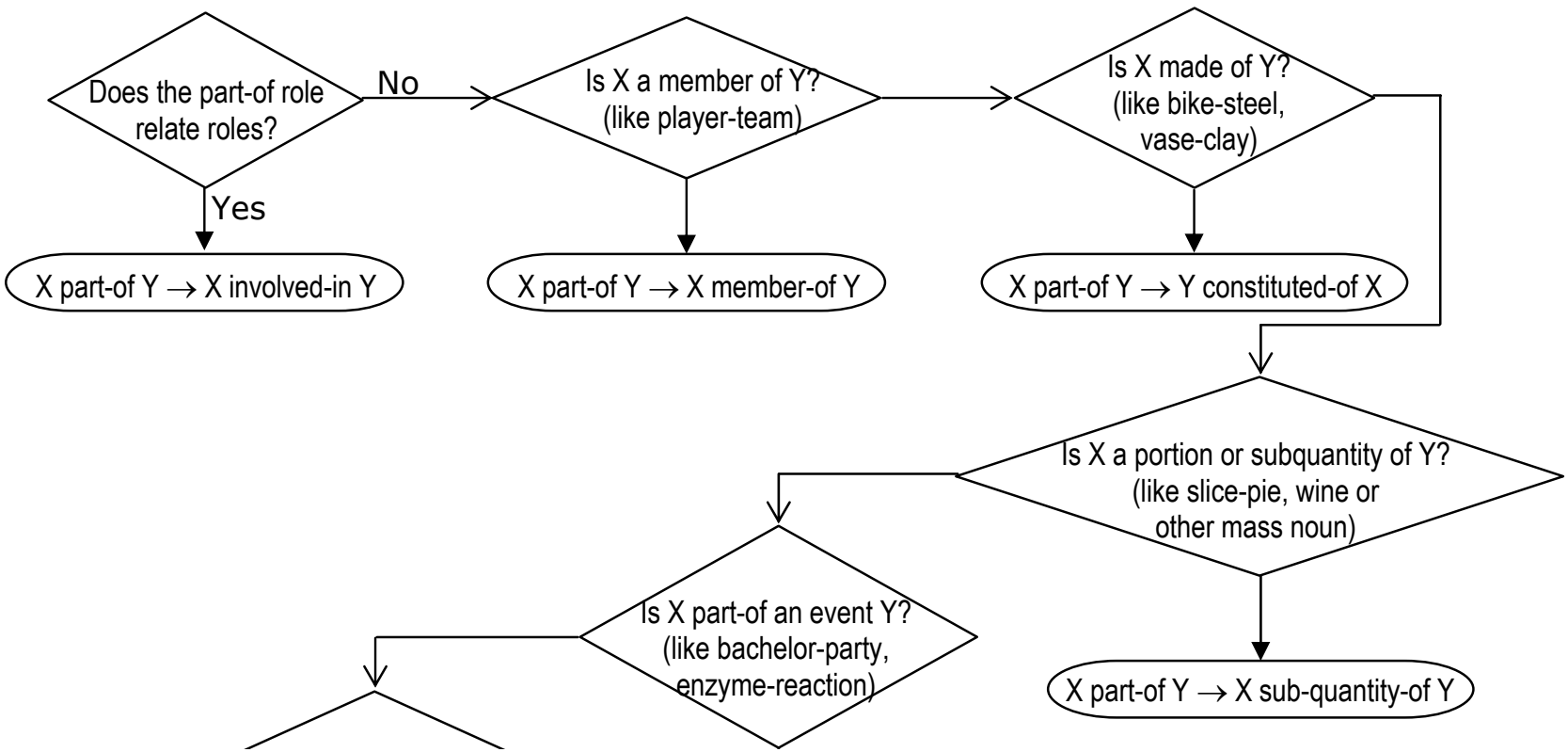

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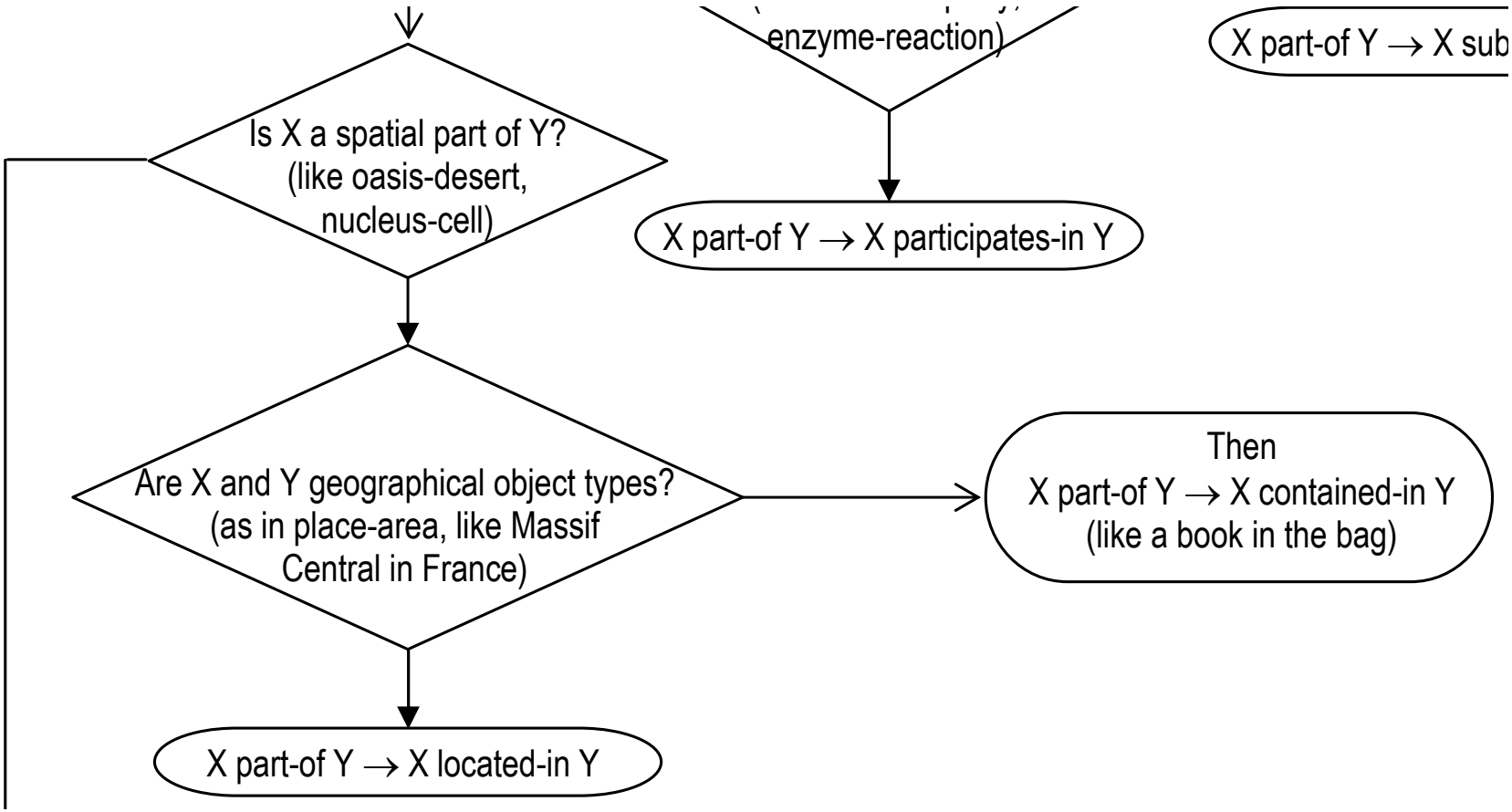
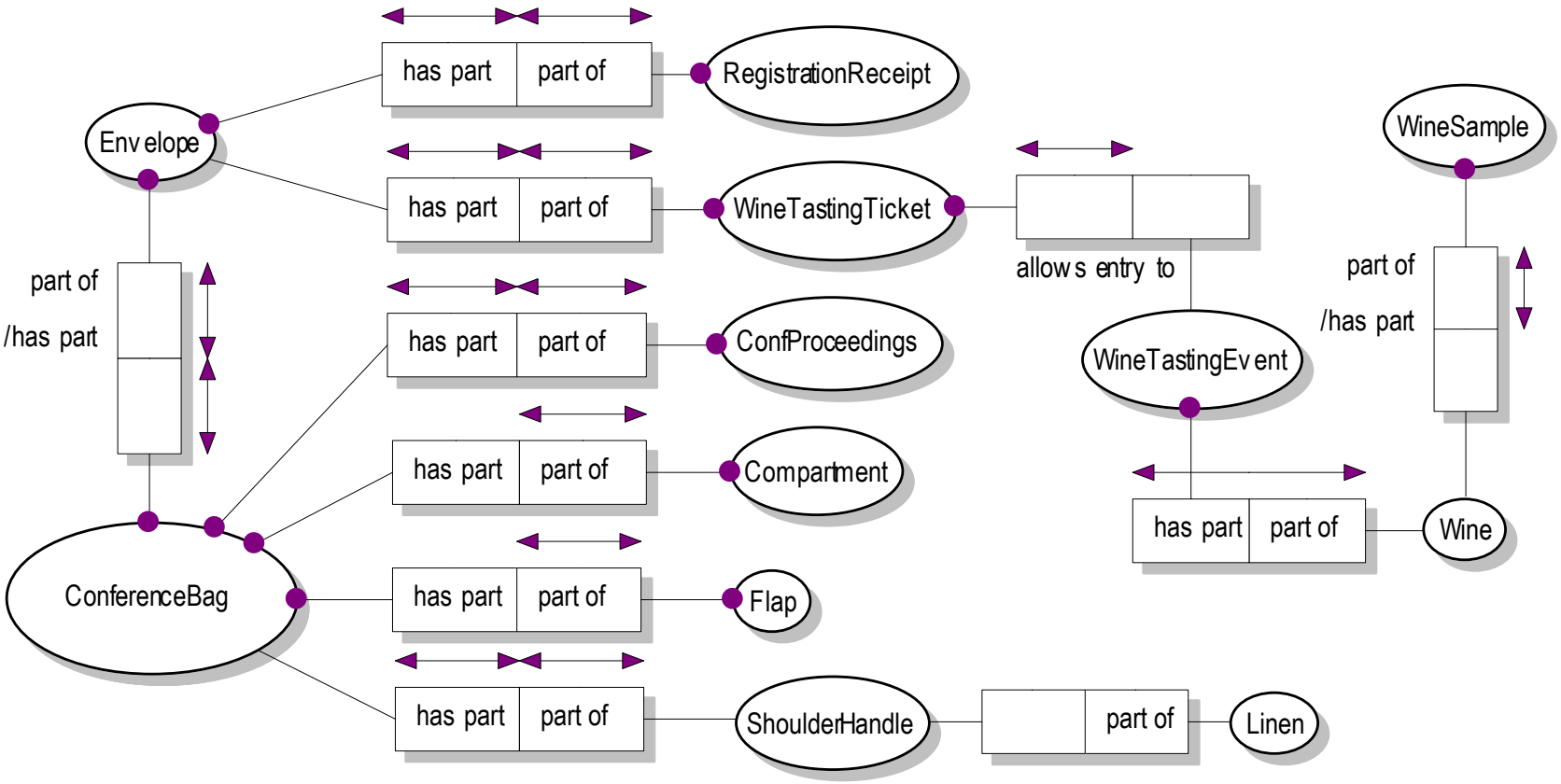


Example - before



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.

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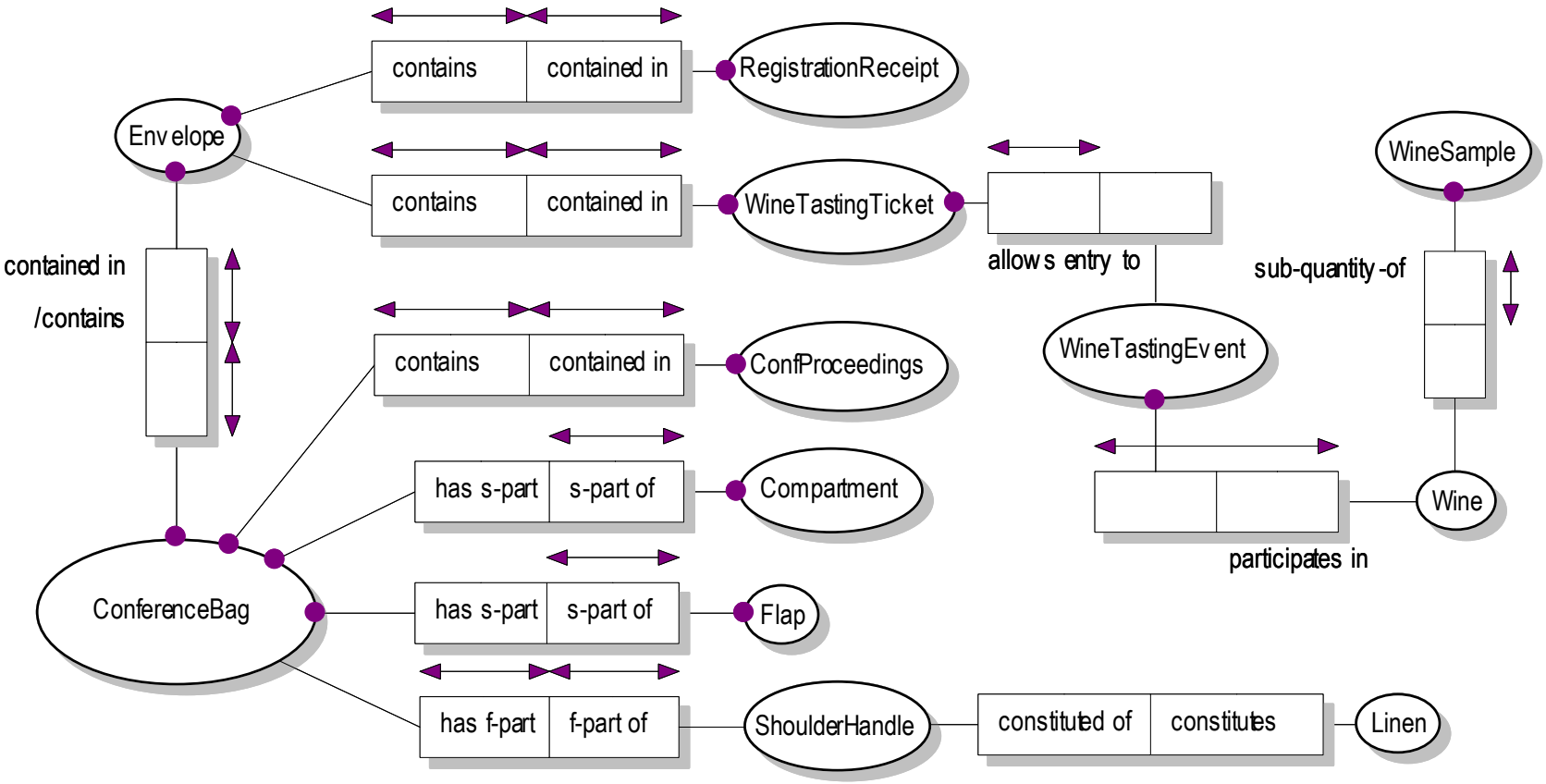
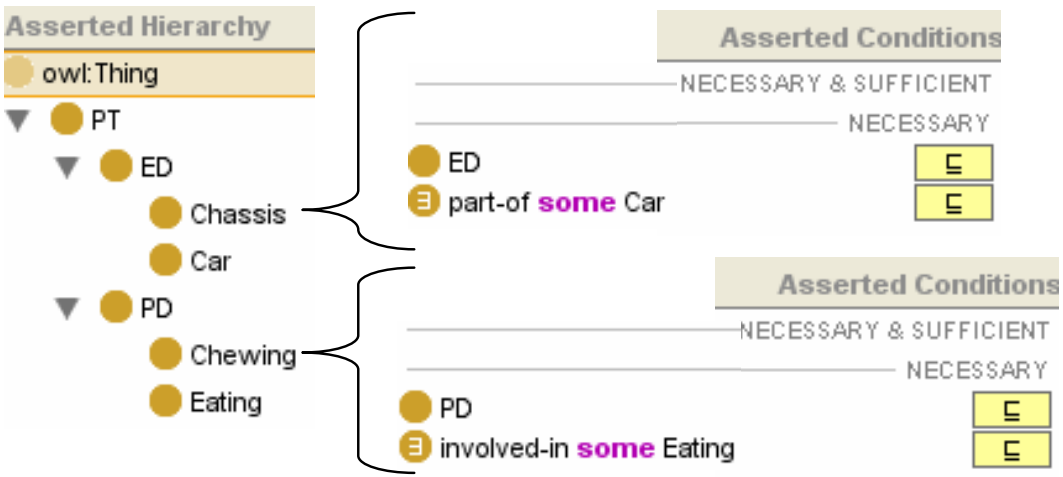


Requirements

- 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.

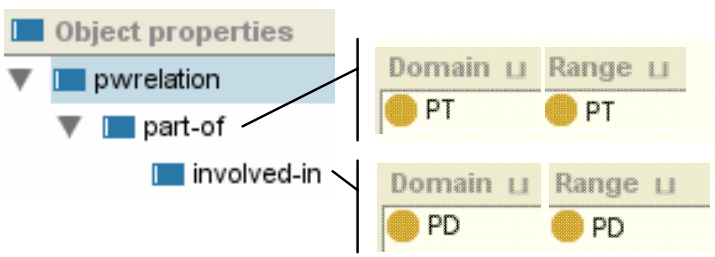
Current behaviour of reasoners

A1. Class hierarchy with asserted conditions

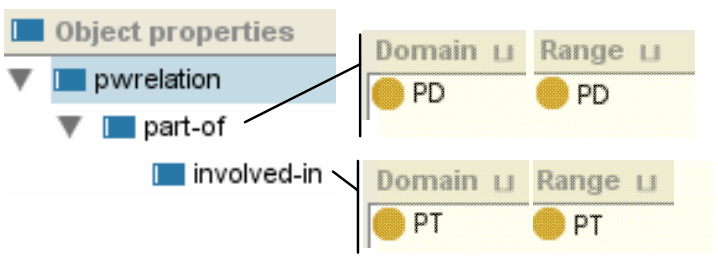


A2. Other class hierarchy with the same asserted conditions

B. Correct role box (object properties)



C. Wrong role box (object properties)

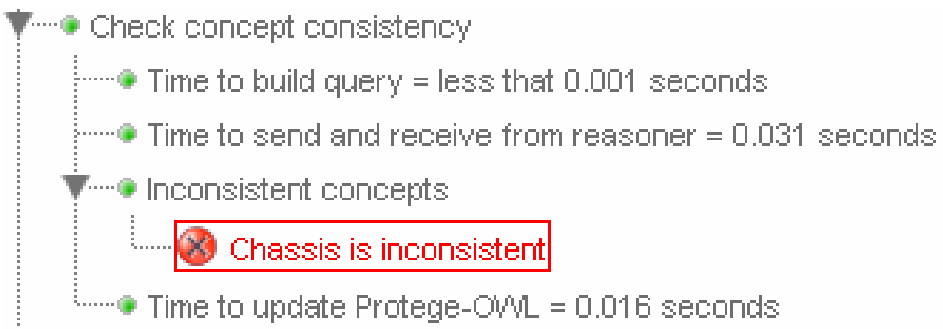


Current behaviour of reasoners

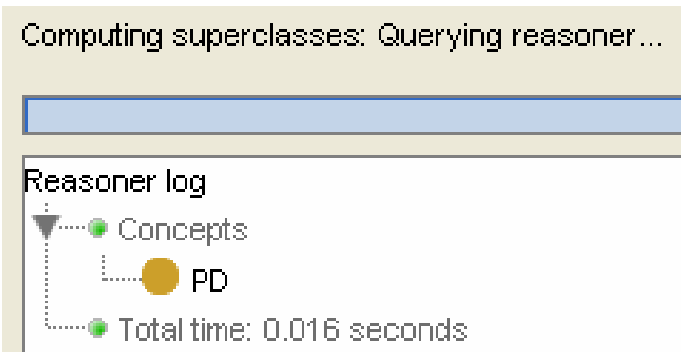
1. A1+B+racer: *ontology OK*

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 $D'_R \equiv D_R \sqcap D_S$[3], which subsequently has to go through the RBox compatibility service (and similarly when `Test 1` fails on range restrictions).

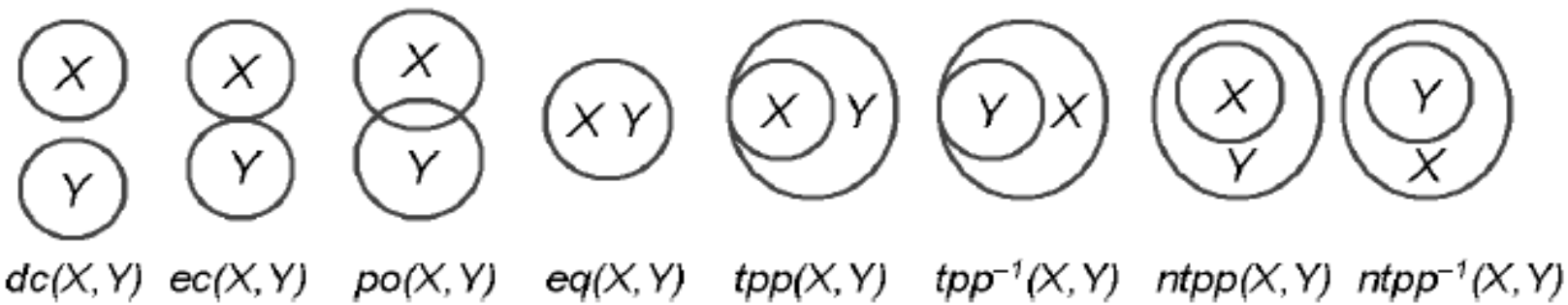
[3] The axiom $C_1 \equiv C_2$ is a shortcut for the axioms: $C_1 \sqsubseteq C_2$ and $C_2 \sqsubseteq C_1$.

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

Post-script: 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
- Temporalising the part-whole relations

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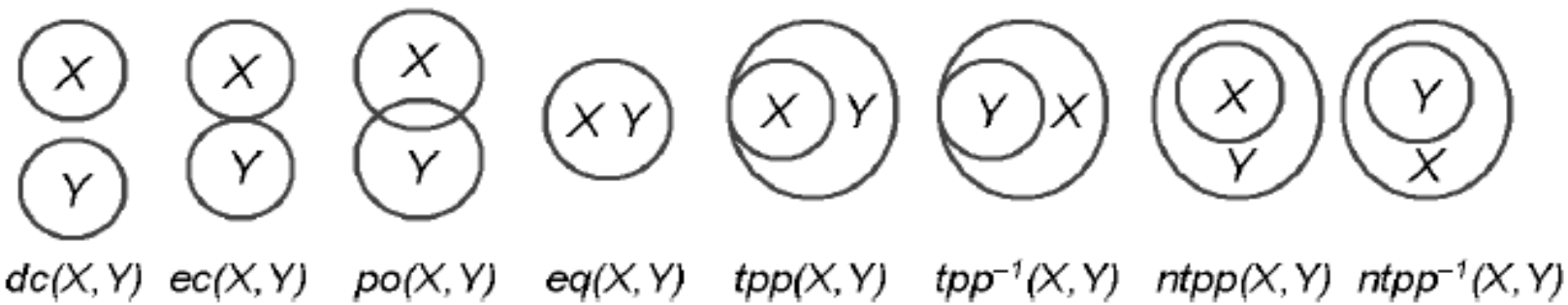

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- Mereology and/vs granularity
- Temporalising the part-whole relations

Outline

Outline

Which kind of temporal things?

- Actual dates, time, intervals
- Qualitative temporal relations, such as: before, after, during, while, meet (Allen temporal relations)
- More advanced relations (that possibly can be dealt with with simpler ones): e.g., transformation_of, developed_from, derived_from
- Temporalising classes (cf. 'object migration' in databases)
- Temporalising relations; e.g. 'during the lifetime of x, it always has y as part'

Examples

- Buttery is a transformation of Caterpillar, using both LTL and the phased sortals of OntoClean (Keet, 2009)
- Brain is specific dependent part of Human body, using temporalisation of the parthood relation (AGK 2008)
- Bypass sometimes comes after the grafting, using CTL then we have E[grafting U bypass]
  - Note shorthand CTL notations: E 'exists a path', A 'in all paths', F 'some time in the future', G 'globally in the future', X 'next time', and U 'for a until q'

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Reasoning services

- The usual ones (satisfiability, subsumption, etc.)
- Querying temporal knowledge bases
  - "In which year in the previous century was the great flooding (watersnoodramp) in the Netherlands?"
  - "Who was the Italian prime minister before Berlusconi?"
- Logical implications; e.g. given $B \sqsubseteq A$, then
  - objects active in B must be active in A (e.g., if one is a student (B) then one is also a person (A)),
  - objects scheduled to become active in B must exist in A (e.g., an employee (A) is up for promotion to become a manager (B))
- A range of other examples, a.o.:
  - Reasoning with a calendar hierarchy and across calendars
  - Finding a solution satisfying a set of constraints (scheduling the lecture hours of a study programme)

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Outline

Overview

- An ontology to describe the temporal content of Web pages and the temporal properties of Web services
- Vocabulary for expressing facts about topological relations among instants and intervals, together with information about durations, and about datetime information
- OWL encoding and a first-order logic axiomatization of the ontology
- It is an ontology to *talk* about time, but **not** to *represent and reason over* temporal knowledge, i.e., a 'workaround'

more info at http://www.w3.org/TR/owl-time/

Core: Topological Temporal Relations

- `TemporalEntity` with two subclasses `Instant` and `Interval`
- `hasBeginning` and `hasEnd` are relations between instants and temporal entities
- `inside` is a relation between an instant and an interval
- `before` relation on temporal entities, which gives directionality to time, but is not enforced in the language
- Interval relations, such as `intervalEquals`, `intervalBefore`, `intervalMeets` etc.

Core: Duration Description

- An interval can have multiple duration descriptions (e.g., 2 days, 48 hours), but can only have one duration
- Different sets of properties for `DateTimeDescription` and `DurationDescription`, because their ranges are different.
  - `year` (in `DateTimeDescription`) has a range of `xsd:gYear`, while `years` (in `DurationDescription`) has a range of`xsd:decimal` so that you can say duration of 2.5 years.
- `durationOf` that takes eight arguments, but split up into 8 binaries
- Other components: Time Zones, DateTime Description

Summary

Modelling challenges for OWL

Part-whole relations

- Parts, mereology, meronymy
- Taxonomy of types of part-whole relations
- Using the taxonomy of part-whole relations

The temporal dimension

- Identifying temporal aspects
- Time Ontology