Semantic Web Technologies

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

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Outline

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

Some questions and problems (not exhaustive...)[1]

- 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?

[1] The following slides are based on the tutorial given at Meraka [http://www.meteck.org/files/PartspresMOWS08.pdf], which does have the references to the related works.

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)

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

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

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

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

$$\forall x,y(part\_of(x,y) \rightarrow \neg part\_of(y,x)) \tag{6}$$

Irreflexivity (x is not part of itself)

$$\forall x \neg(part\_of(x,x)) \tag{7}$$

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)

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

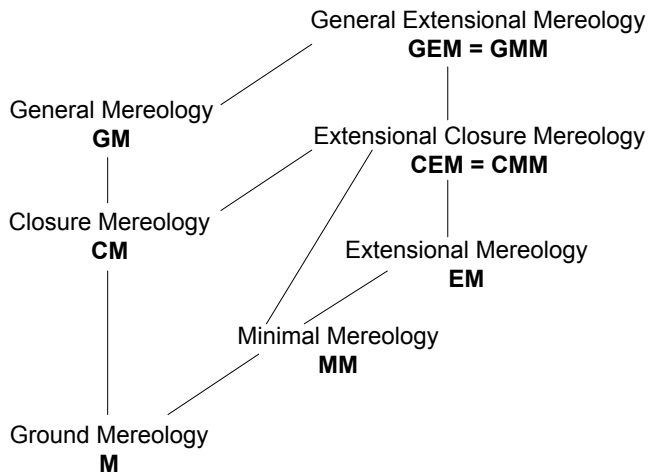

Fig. 1: Hasse diagram of mereological theories; from weaker to stronger, going uphill (after [44]).

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):

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

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

  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$_A$
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_1c_1t 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_1p_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_1c_1t 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 (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

Linguistic use of part-whole relations

- Part of?
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  - ⋆ Decimeter part of Meter
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- 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

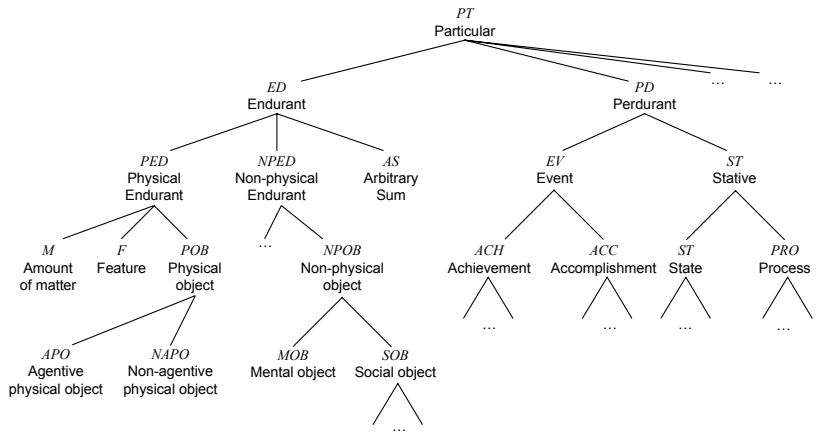
Addressing the issues

- Efforts to disambiguate this confusion; e.g. an informal taxonomy by WInston (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

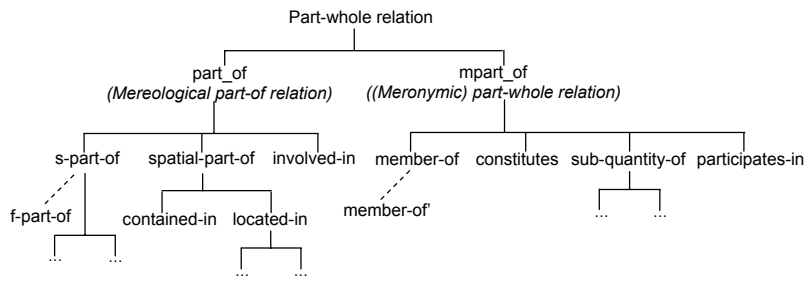
Overview

- 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, ...)

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)`

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

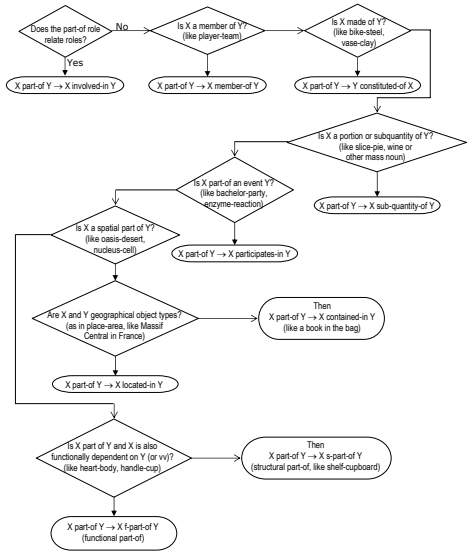
$$\forall x, y(located\_in(x, y) \triangleq part\_of(x, y) \wedge R(x) \wedge R(y) \wedge \exists z, w(has\_2D(z, x) \wedge has\_2D(w, y) \wedge ED(z) \wedge ED(w)))$$

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

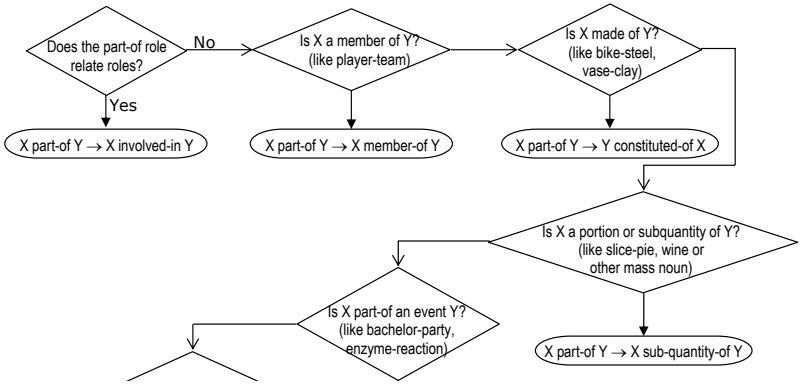
Using the taxonomy of part-whole relations

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

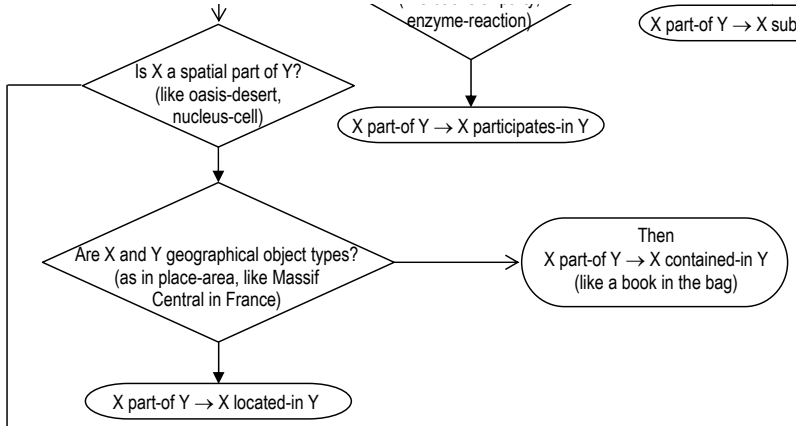
Decision diagram



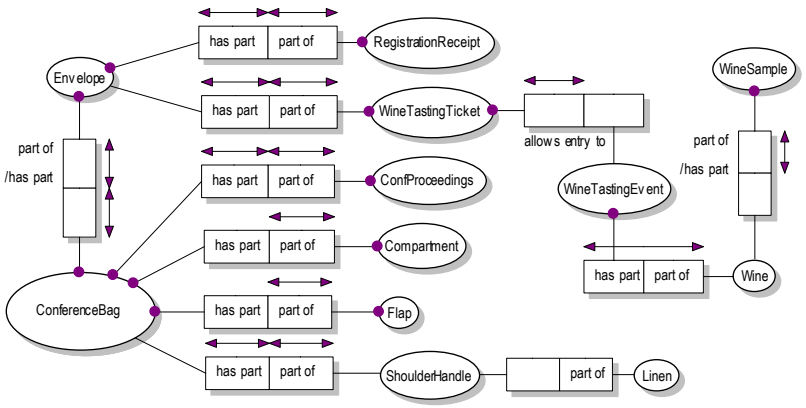
Decision diagram



Decision diagram



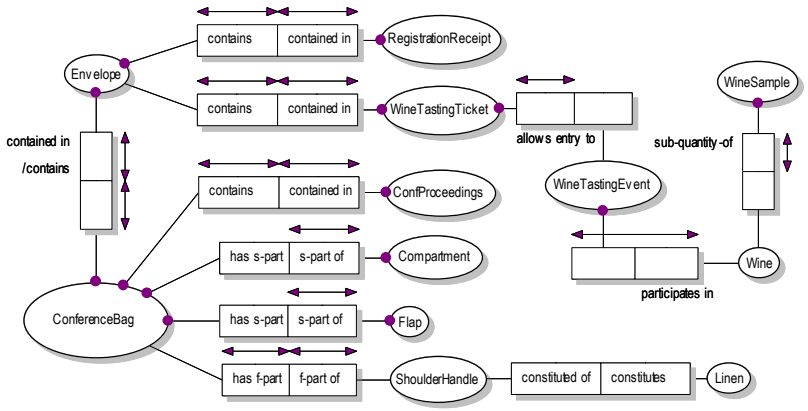
Example - before



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.

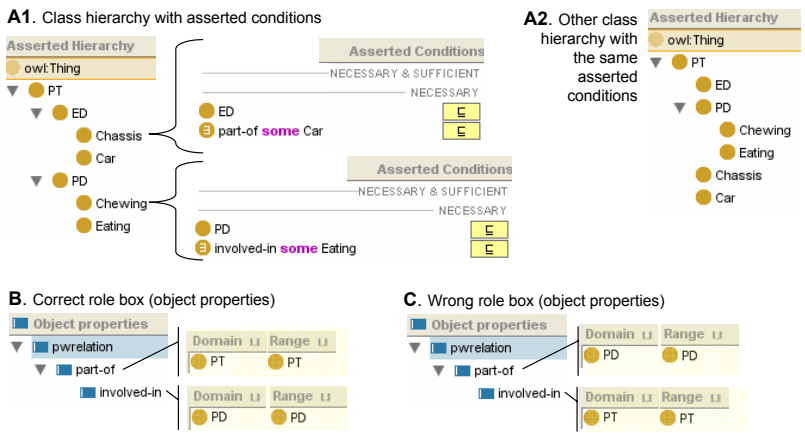
Example - after



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

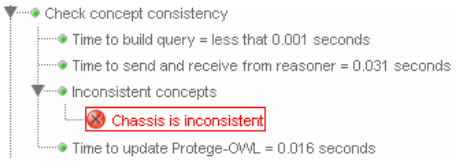


Current behaviour of reasoners

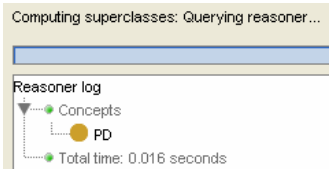
1. A1+B+racer: *ontology OK*

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).

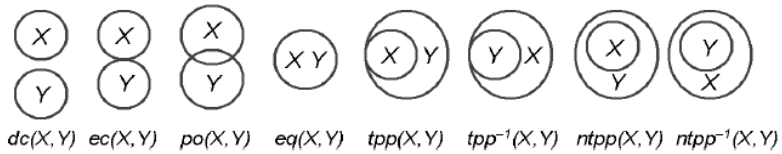
[3] The axiom $C_1 \equiv C_2$ is a shortcut for the axioms: $C_1 \sqsubseteq C_2$ and $C_2 \sqsubseteq C_1$.

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

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 p until q

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 for scheduling the lecture hours of a study programme

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