Representing and reasoning over relations in ontologies
– Tutorial –

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Outline

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Setting

- Representing hierarchies of classes [/concepts/universals/entity types/...] typically received first/most/only attention
- Things become interesting from the viewpoint of automated reasoning only if there are other axioms, or: properties of those classes

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⇒ How to model those? (and have good quality)

⇒ What effect does that have on the deductions? (preferably desired ones)

Some problematic examples with relationships

A. Trans($\texttt{partOf}$)

$\texttt{Hand} \sqsubseteq \exists\texttt{partOf}.\texttt{Musician}$

$\texttt{Musician} \sqsubseteq \exists\texttt{partOf}.\texttt{Orchestra}$

Deducing that each Hand is part of an Orchestra is *'wrong'*

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B. $\mathtt{hasMainTable} \circ \mathtt{hasFeature} \sqsubseteq \mathtt{hasFeature}$
$\mathtt{hasMainTable} \sqsubseteq \mathtt{DataSet} \times \mathtt{DataTable}$
$\mathtt{hasFeature} \sqsubseteq \mathtt{DataTable} \times \mathtt{Feature}$

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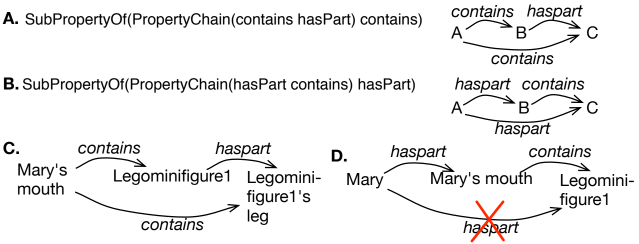
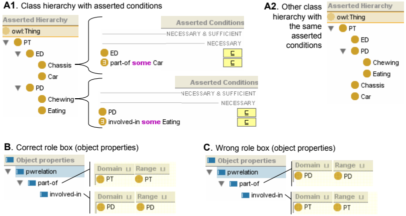
$\texttt{hasMainTable} \sqsubseteq \texttt{DataSet} \times \texttt{DataTable}$
$\texttt{hasFeature} \sqsubseteq \texttt{DataTable} \times \texttt{Feature}$

- Deduces $\texttt{DataSet} \sqsubseteq \texttt{DataTable}$, which is *'wrong'*



And old issue



- *(Live with Protégé)*

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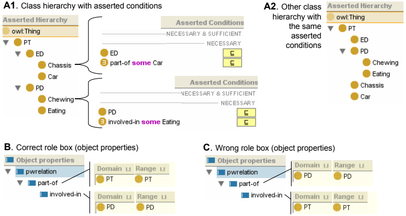

- *(Live with Protégé)*
- A1+B: OK; A2+B: OK
- A1+C: `Chassis` inconsistent; A2+C: `Chassis` (re)classified as a `PD`

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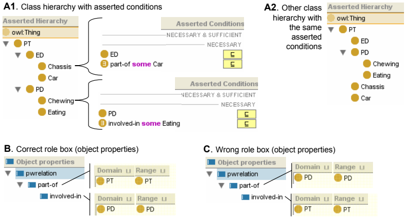

- *(Live with Protégé)*
- A1+B: OK; A2+B: OK
- A1+C: `Chassis` inconsistent; A2+C: `Chassis` (re)classified as a PD

C. But actually, the property hierarchy is *wrong* (mostly ignored by the DL/OWL reasoner, so can't find that mistake)

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Other modelling and implementation issues

- **Poll**: are `teaches` and `taught by` two relations?
  - ⇒ differentiate between *relation* between entities and *relational expression* describing that state
- **Poll**: How do you map UML's association ends (or ORM's roles) to an OWL object property (or vv.)?
  - ⇒ Bit tricky, you have to make a modelling decision...
- These two questions surface as a consequence of different ontological commitment as to what a relation really is (or what you're convinced of it is)

A few other modelling questions

- Should you introduce a minimum amount of properties in your ontology, or many?
- Always (try to) declare domain and range axioms?
- Use explicit inverses (extending the vocabulary) or not?
- What about ternaries?
- How to find and fix mistakes and pitfalls?
- What if solution X is better modelling than option Y but computationally more costly than Y?

Outline

Toward solving such issues

- Meaning of relations
  - Different modelling/representation languages have varying ‘ontological commitments’
  - When a relation(ship) is a specialisation of another
- Reuse relations that are already investigated widely cf. reinventing the wheel
- Methods and tools to avoid pitfalls

A note from philosophy

- Relations investigated in philosophy
  - Nature and properties of some specific relations (parthood, portions, participation, causation)
  - 'Categories' of relations (material, formal) (e.g., [Guizzardi and Wagner(2008)])
  - Nature of relation itself (standard, positionalist, anti-positionalist)
- Some results more useful for ontologies and conceptual modelling than others, some even for tool development

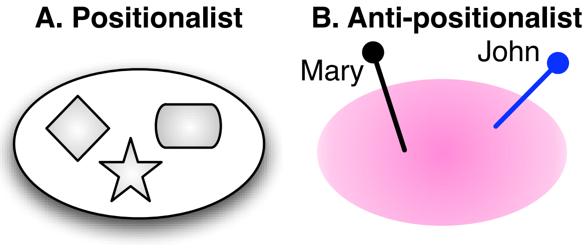
What relations are

- Three main options: standard, positionalist, anti-positionalist [Fine(2000), Leo(2008)]
- Applied to trying to resolve issues in ORM formalisations and tools [Keet(2009)]
- Not the arguments here, only present what they are

What relations are

- Three main options: standard, positionalist, anti-positionalist [Fine(2000), Leo(2008)]
- Applied to trying to resolve issues in ORM formalisations and tools [Keet(2009)]
- Not the arguments here, only present what they are
- Standard view relies on linguistics and the English language in particular
- Formalisation predicate-centred, order of entities important

Graphical depictions positionalist, anti-positionalist



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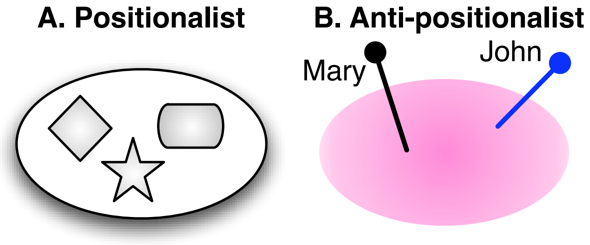

- Positionalist needs argument places in the "fundamental furniture of the universe", anti-positionalist does not
- UML Class Diagrams, ORM, ER all positionalist [Keet and Fillottrani(2013)], most of DL and FOL take standard view

Questions and Problems to address

- Modelling flaws in the RBox show up as unexpected or undesirable deductions regarding classes in the TBox, but current explanation algorithms (e.g., [Horridge et al.(2008), Parsia et al.(2005), Kalyanpur et al.(2006)]) mostly do not point to the actual flaw in the RBox
- What are the features of a ‘good’ RBox w.r.t. object property expressions?
- What type of flaws are being made?
- See [Keet(2014)]

Preliminaries (1/2)

- "basic form" for sub-properties, i.e., $S \sqsubseteq R$,
- "complex form" with property chains
- $R \sqsubseteq C_1 \times C_2$ as shortcut for domain and range axioms $\exists R \sqsubseteq C_1$ and $\exists R^- \sqsubseteq C_2$ where C_1 and C_2 are generic classes; `ObjectPropertyDomain(OPE CE)` and `ObjectPropertyRange(OPE CE)` in OWL.
- $R \sqsubseteq \top \times \top$ when no domain and range axiom has been declared

Definition (User-defined Domain and Range Classes)

Let R be an OWL object property and $R \sqsubseteq C_1 \times C_2$ its associated domain and range axiom. Then, with the symbol D_R we indicate the *User-defined Domain* of R—i.e., $D_R = C_1$—and with the symbol R_R we indicate the *User-defined Range* of R—i.e., $R_R = C_2$.

Definition ((Regular) Role Inclusion Axioms ([Horrocks et al.(2006)]))

Let $\prec$ be a regular order on roles. A **role inclusion axiom** (RIA for short) is an expression of the form $w \sqsubseteq R$, where w is a finite string of roles not including the universal role U, and $R \neq U$ is a role name. A **role hierarchy** $\mathcal{R}_h$ is a finite set of RIAs. An interpretation $\mathcal{I}$ **satisfies** a role inclusion axiom $w \sqsubseteq R$, written $\mathcal{I} \models w \sqsubseteq R$, if $w^{\mathcal{I}} \subseteq R^{\mathcal{I}}$. An interpretation is a **model** of a role hierarchy $\mathcal{R}_h$ if it satisfies all RIAs in $\mathcal{R}_h$, written $\mathcal{I} \models \mathcal{R}_h$. A RIA $w \sqsubseteq R$ is $\prec$**-regular** if R is a role name, and

$w = R \circ R$, or

$w = R^{-}$, or

$w = S_1 \circ \ldots \circ S_n$ and $S_i \prec R$, for all $1 \geq i \geq n$, or

$w = R \circ S_1 \circ \ldots \circ S_n$ and $S_i \prec R$, for all $1 \geq i \geq n$, or

$w = S_1 \circ \ldots \circ S_n \circ R$ and $S_i \prec R$, for all $1 \geq i \geq n$.

Finally, a role hierarchy $\mathcal{R}_h$ is **regular** if there exists a regular order $\prec$ such that each RIA in $\mathcal{R}_h$ is $\prec$-regular.

Object sub-properties

- Given $S \sqsubseteq R$, then all individuals in the property assertions involving property S must also be related to each other through property R (OWL 2 Spec.).
- Subsumption for OWL object properties (DL roles) holds if the subsumed property is more constrained such that in every model, the set of individual property assertions is a subset of those of its parent property

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- Given $S \sqsubseteq R$, then all individuals in the property assertions involving property S must also be related to each other through property R (OWL 2 Spec.).
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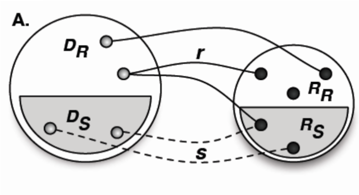
- Two ways to constrain a property, and either one suffices:
  - By specifying its domain or range
  - By declaring the property's characteristics

Constraining a property



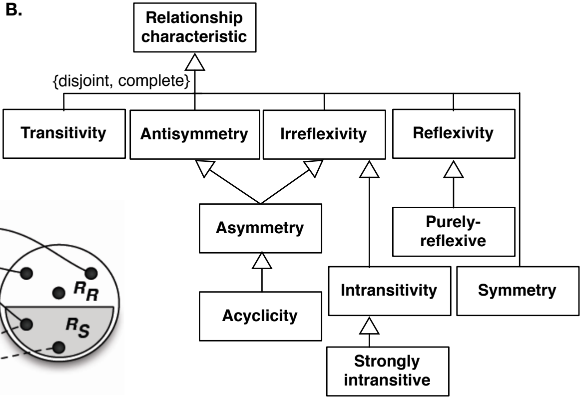


Figure: A: Example, alike the so-called 'subsetting' idea in UML; B: hierarchy of property characteristics (Based on Halpin 2001, 2011)

Constraining a property

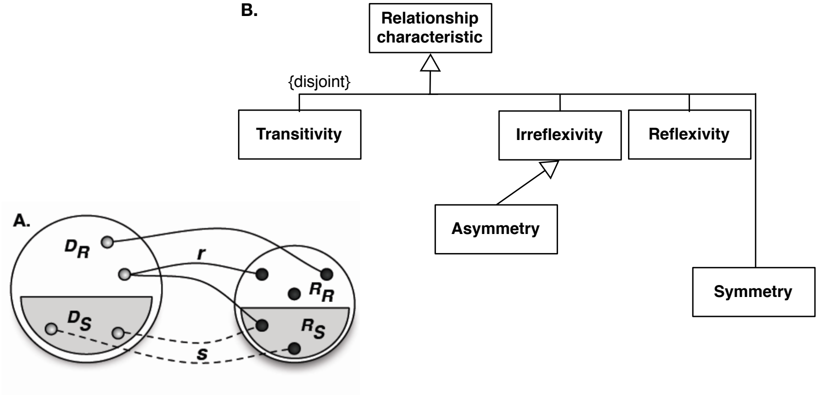


Figure: A: Example, alike the so-called 'subsetting' idea in UML; B: hierarchy of property characteristics relevant for OWL 2.

Outline Sub-Property compatibility Service (*SubProS*)

- First part extends the basic notions from the *RBox compatibility* [Keet and Artale(2008)] (defined for $\mathcal{ALCQI}$)
- Informally, it first checks the 'compatibility' of domain and range axioms w.r.t the object property hierarchy and the class hierarchy.

Outline Sub-Property compatibility Service (*SubProS*)

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- Informally, it first checks the 'compatibility' of domain and range axioms w.r.t the object property hierarchy and the class hierarchy.
- After that, *SubProS* checks whether the object property characteristic(s) conform to specification, provided there is such an expression in the ontology.
- It exhaustively checks each permutation of domain and range and then of the characteristic of the parent and child property in the object property hierarchy

Definition (Sub-Property compatibility Service (*SubProS*))

For each pair of object properties, $R, S \in \mathcal{O}$ such that $\mathcal{O} \models S \sqsubseteq R$, and $\mathcal{O}$ an OWL ontology adhering to the syntax and semantics as specified in OWL 2 Standard, check whether:

Test 1. $\mathcal{O} \models D_S \sqsubseteq D_R$ and $\mathcal{O} \models R_S \sqsubseteq R_R$;

Test 2. $\mathcal{O} \not\models D_R \sqsubseteq D_S$;

Test 3. $\mathcal{O} \not\models R_R \sqsubseteq R_S$;

Test 4. If $\mathcal{O} \models \mathrm{Asym}(R)$ then $\mathcal{O} \models \mathrm{Asym}(S)$;

Test 5. If $\mathcal{O} \models \mathrm{Sym}(R)$ then $\mathcal{O} \models \mathrm{Sym}(S)$ or $\mathcal{O} \models \mathrm{Asym}(S)$;

Test 6. If $\mathcal{O} \models \mathrm{Trans}(R)$ then $\mathcal{O} \models \mathrm{Trans}(S)$;

Test 7. If $\mathcal{O} \models \mathrm{Ref}(R)$ then $\mathcal{O} \models \mathrm{Ref}(S)$ or $\mathcal{O} \models \mathrm{Irr}(S)$;

Test 8. If $\mathcal{O} \models \mathrm{Irr}(R)$ then $\mathcal{O} \models \mathrm{Irr}(S)$ or $\mathcal{O} \models \mathrm{Asym}(S)$;

Test 9. If $\mathcal{O} \models \mathrm{Asym}(R)$ then $\mathcal{O} \not\models \mathrm{Sym}(S)$; *continues....*

Test 10. If $\mathcal{O} \models \mathrm{Irr}(R)$ then $\mathcal{O} \not\models \mathrm{Ref}(S)$;

Definition (Sub-Property compatibility Service (*SubProS*))

... *continued from previous page*

Test 10. If $\mathcal{O} \models \mathsf{Irr}(R)$ then $\mathcal{O} \not\models \mathsf{Ref}(S)$;

Test 11. If $\mathcal{O} \models \mathsf{Trans}(R)$ then $\mathcal{O} \not\models \mathsf{Irr}(R)$, $\mathcal{O} \not\models \mathsf{Asym}(R)$, $\mathcal{O} \not\models \mathsf{Irr}(S)$, and $\mathcal{O} \not\models \mathsf{Asym}(S)$;

An OWL object property hierarchy is said to be compatible iff

- *Test 1* and (*2* or *3*) hold for all pairs of property-subproperty in $\mathcal{O}$, and
- *Tests 4–11* hold for all pairs of property-subproperty in $\mathcal{O}$.

Property chains

- Recall the three cases for property chains, with $w \sqsubseteq R$:
  - Case S: $w = S_1 \circ \ldots \circ S_n$ and $S_i \prec R$, for all $1 \geq i \geq n$, or
  - Case RS: $w = R \circ S_1 \circ \ldots \circ S_n$ and $S_i \prec R$, for all $1 \geq i \geq n$, or
  - Case SR: $w = S_1 \circ \ldots \circ S_n \circ R$ and $S_i \prec R$, for all $1 \geq i \geq n$.

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  - Case SR: $w = S_1 \circ \ldots \circ S_n \circ R$ and $S_i \prec R$, for all $1 \geq i \geq n$.
- To ensure avoidance of undesirable classifications or inconsistencies, informally:
  - The domain/range class from left to right has to be equal or a superclass, on the lhs of the inclusion
  - Similarly for the outer domain and range on the lhs and domain and range of the object property on the rhs

Definition (Property Chain Compatibility Service (*ProChainS*))

For each set of object properties, $R, S_1, \ldots, S_n \in \mathcal{R}$, $\mathcal{R}$ the set of OWL object properties (V_{OP} in OWL 2) in OWL ontology $\mathcal{O}$, and $S_i \prec R$ with $1 \leq i \leq n$, $\mathcal{O}$ adheres to the constraints of Definition 2 (and, more generally, the OWL 2 specification), and user-defined domain and range axioms as defined in Definition 1, for each of the property chain expression, select either one of the three cases:

Case S. Property chain pattern as $S_1 \circ S_2 \circ \ldots \circ S_n \sqsubseteq R$. Test whether:

Test S-a. $\mathcal{O} \models R_{S1} \sqsubseteq D_{S2}, \ldots, R_{Sn-1} \sqsubseteq D_{Sn}$;
Test S-b. $\mathcal{O} \models D_{S1} \sqsubseteq D_R$;
Test S-c. $\mathcal{O} \models R_{Sn} \sqsubseteq R_R$;

Case RS. Property chain pattern as $R \circ S_1 \circ \ldots \circ S_n \sqsubseteq R$. Test whether:

Test RS-a. $\mathcal{O} \models R_{S1} \sqsubseteq D_{S2}, \ldots, R_{Sn-1} \sqsubseteq D_{Sn}$;
Test RS-b. $\mathcal{O} \models R_R \sqsubseteq D_{S1}$;
Test RS-c. $\mathcal{O} \models R_{Sn} \sqsubseteq R_R$;

continues...

Case SR. Property chain pattern as $S \circ \ldots \circ S \circ R \sqsubseteq R$. Test

Definition (Property Chain Compatibility Service (*ProChainS*))

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Case SR. Property chain pattern as $S_1 \circ \ldots \circ S_n \circ R \sqsubseteq R$. Test whether:

Test SR-a. $\mathcal{O} \models R_{S1} \sqsubseteq D_{S2}, \ldots, R_{Sn-1} \sqsubseteq D_{Sn}$;
Test SR-b. $\mathcal{O} \models D_{S1} \sqsubseteq D_R$;
Test SR-c. $\mathcal{O} \models R_{Sn} \sqsubseteq D_R$;

An OWL property chain expression is said to be compatible iff the OWL 2 syntactic constraints hold and either `Case S`, or `Case RS`, or `Case SR` holds.

Does it matter?

- or: How common are violations? which violations appear in ontologies ‘in the wild’?

Does it matter?

- or: How common are violations? which violations appear in ontologies 'in the wild'?
- Evaluated against 15 ontologies that have many OPs
- Two examples on next slide
- Then a summary of selection of TONES Repository ontologies (d.d. 12-3-2012) on next slide

BioTop's inconsistent 'has process role'

'has process role' in BioTop [Beisswanger et al.(2008)] (v. June 17, 2010) is inconsistent. Relevant axioms are:

$$\text{'has process role'} \sqsubseteq \text{'temporally related to'} \tag{E.1}$$

$$\text{'has process role'} \sqsubseteq \text{'processual entity'} \times \text{role} \tag{E.2}$$

$$\text{'temporally related to'} \sqsubseteq \text{'processual entity'} \sqcup \text{quality} \times \text{'processual entity'} \sqcup \text{quality} \tag{E.3}$$

$$\text{role} \sqsubseteq \neg \text{quality} \tag{E.4}$$

$$\text{role} \sqsubseteq \neg \text{'processual entity'} \tag{E.5}$$

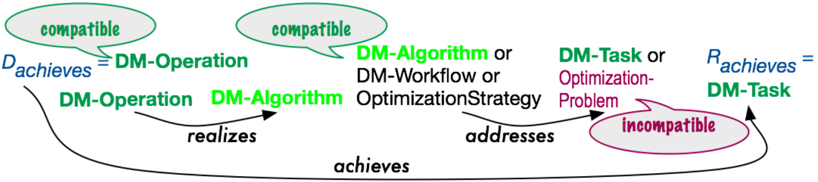
$$\text{Sym}(\text{'temporally related to'}) \tag{E.6}$$

BioTop's inconsistent 'has process role'

Use *SubProS* to isolate the flaw:

- `Test 1`: fail, because $R_{\text{hasprocessrole}} \sqsubseteq R_{\text{temporallyrelatedto}}$ is false, as the ranges (see E.2 cf. E.3) are disjoint (see E.4, E.5) and therewith 'has process role' is inconsistent;
- `Test 2` and 3: pass.
- `Test 4`: not applicable.
- `Test 5`: fail, because $\mathcal{O}$ does not contain Sym('has process role').
- `Test 6–11`: not applicable.

DMOP chain in v5.2



Of type *Case S*. `Test S-c` (for corrections) failed because $\mathcal{O} \not\models R_{\text{DM-Task}\sqcup\text{OptimizationProblem}} \sqsubseteq R_{\text{DM-Task}}$. Considering the suggestions for revision, step B's first option to revise the ontology was chosen, i.e., removing OptimizationProblem from the range axiom of addresses.

Ontology	No. of OPs	No. of SubOPs axioms	No. more constrained		Comments (partial)
			D or *R*	by char.	
DOLCE-lite	70	46	13	3	transitivity added
SAO 1.2	36	25	21	5	2 x transitivity; `Test 6` fails on has Vesicle Component
airsystem	111	56	43	2	imports DUL. *ProChainS* fails
family-tree	52	25	14	2	fails `Test 6` of *SubProS*
propreo	32	20	17	2	beyond OWL 2 DL (non-simple prop. in max card.)
heart	29	18	9	0	many inconsistencies
mygrid-unclassified	69	39	0	3	1 x transitive added
building Architecture	28	24	0	0	imports rcc, fails `Test 5` of *SubProS* (omission Asym on properPartOf)
biotop	89	84	45	9	with transitivity; 'has process role' is inconsistent (disjoint ranges), see *Evaluation 1*

Outline

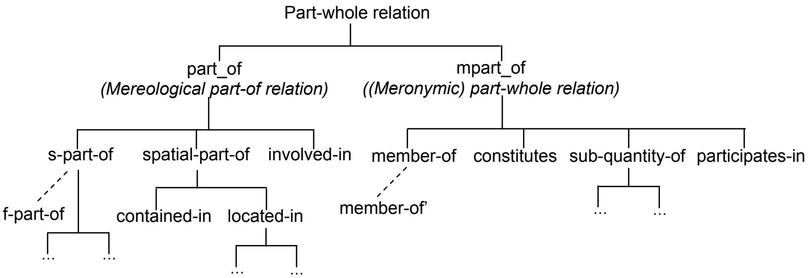
Don't reinvent the wheel

- Part-whole relations, probably received most attention in ontologies
- Spatial relations, and its interaction with parthood
- Participation, constitution, causation, ...
- Similarity: important for combination machine learning with ontologies

Taxonomy of part-whole relations

- Hierarchy of part-whole relations common in ontologies and conceptual data models
- Uses DOLCE foundational ontology [Masolo et al.(2003)] for domain and range of a relation
- Main distinction between transitive (parthood) vs non-transitive (just meronymic) part-whole relations
- Formally defined
- Details in [Keet and Artale(2008)]

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`)

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

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

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

Part-whole relations

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

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

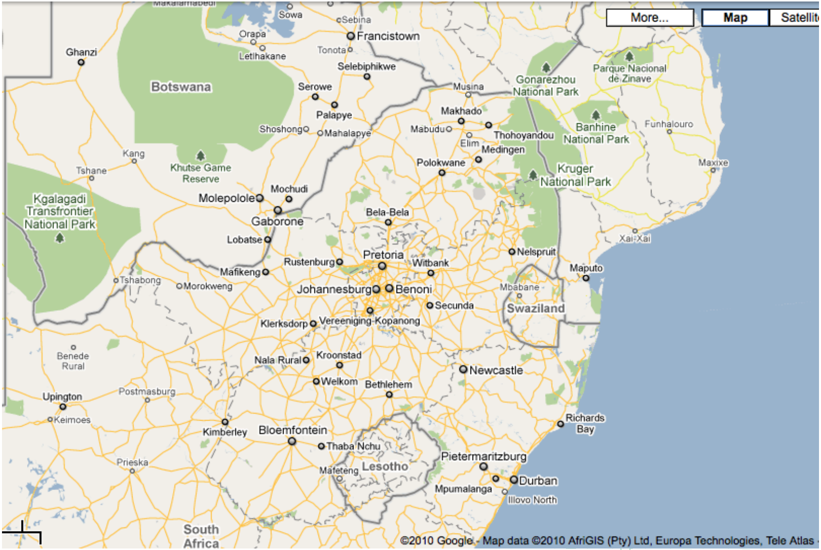
Object and its 2D or 3D region, such as `contained_in(John's address book, John's bag)` and `located_in(Pretoria, South Africa)`

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

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

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

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)?

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  - 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?

Parts and space

- Could not represent all of parthood in OWL or any DL, worse for mereotopology, but tried anyway [Keet et al.(2012)]
- Example:
  - Let `NTPLI` be a 'non-tangential proper located in' relation
  - $\texttt{EnclosedCountry} \equiv \texttt{Country} \sqcap \exists\texttt{NTPLI.Country}$
  - `NTPLI(Lesotho, South Africa)`, `Country(Lesotho)`, `Country(South Africa)`,
  - then it will correctly deduce `EnclosedCountry(Lesotho)`.
  - with merely 'part-of', one would not have been able to obtain this result

- 9-Intersection Method (9IM), based on point-set topology [Egenhofer and Herring(1990)]
- Region Connection Calculus (RCC), based on the reflexive and symmetric *connection* [Randell et al.(1992)]
- Neither one considers the combination of the space region with the object that occupies it
- This interaction is addressed by **mereotopology**, which focuses on spatial *entities*, not just regions.

Options to merging parts and locations

How to combine them? Concerning primitive relations [Cohn and Renz(2008), Varzi(2007)], one can

- define parthood, P, in terms of connection, C, (i.e., $P(x, y) =_{def} \forall z(C(z, x) \rightarrow C(z, y)))$ so that topology is principal and mereology a subtheory
- introduce topology as a sub-domain of mereology by introducing a sorted predicate to denote region (R) and define C in terms of overlapping regions ($C(x, y) =_{def} O(x, y) \wedge R(x) \wedge R(y))$ [Eschenbach and Heydrich(1995)]

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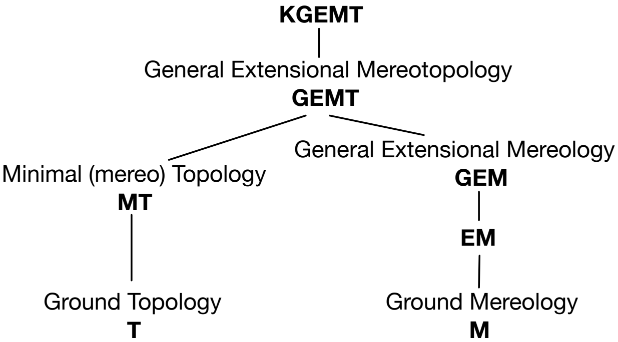
- consider both P and C as primitive
- introduce a ternary relation $CP(x, y, z)$, so that $P(x, y) =_{def} \exists z\ CP(x, z, y)$ and $C(x, y) =_{def} \exists z\ CP(x, y, z)$

Kuratowski extension of GEMT (KGEMT)



Kuratowski axioms for topological closure (inclusion, idempotence, and additivity), therewith a full account of intended interpretation of connection [Varzi(2007)].

Ground Topology

Core axioms and definitions			
$P(x,x)$	(t1)	$P(x,y) \wedge P(y,z) \rightarrow P(x,z)$	(t2)
$P(x,y) \wedge P(y,x) \rightarrow x = y$	(t3)	$\neg P(y,x) \rightarrow \exists z(P(z,y) \wedge \neg O(z,x))$	(t4)
$\exists w\phi(w) \rightarrow \exists z\forall w(O(w,z) \leftrightarrow \exists v(\phi(v) \wedge O(w,v)))$			(t5)
$C(x,x)$	(t6)	$C(x,y) \rightarrow C(y,x)$	(t7)
$P(x,y) \rightarrow E(x,y)$	(t8)	$E(x,y) =_{df} \forall z(C(z,x) \rightarrow C(z,y))$	(t9)
$E(x,y) \rightarrow P(x,y)$	(t10)	$SC(x) \leftrightarrow \forall y,z(x = y + z \rightarrow C(y,z))$	(t11)
$\exists z(SC(z) \wedge O(z,x) \wedge O(z,y) \wedge \forall w(P(w,z) \rightarrow (O(w,x) \vee O(w,y)))) \rightarrow C(x,y)$			(t12)
$z = \sum x\phi x \rightarrow \forall y(C(y,z) \rightarrow \exists x(\phi x \wedge C(y,x)))$			(t13)
$P(x, cx)$	(t14)	$c(cx) = cx$	(t15)
$c(x+y) = cx + cy$	(t16)	$cx =_{df} \sim(ex)$	(t17)
$ex =_{df} i(\sim x)$	(t18)	$ix =_{df} \sum z\forall y(C(z,y) \rightarrow O(x,y))$	(t19)
Additional axioms, definitions, and theorems			
$PP(x,y) =_{df} P(x,y) \wedge \neg P(y,x)$	(t20)	$O(x,y) =_{df} \exists z(P(z,x) \wedge P(z,y))$	(t21)
$EQ(x,y) =_{df} P(x,y) \wedge P(y,x)$	(t22)	$TPP(x,y) =_{df} PP(x,y) \wedge \neg IPP(x,y)$	(t23)
$IPP(x,y) =_{df} PP(x,y) \wedge \forall z(C(z,x) \rightarrow O(z,y))$			(t24)
$\neg PP(x,x)$	(t25)	$PP(x,y) \wedge PP(y,z) \rightarrow PP(x,z)$	(t26)
$PP(x,y) \rightarrow \neg PP(y,x)$	(t27)		

Minimal (mereo) Topology

Core axioms and definitions			
$P(x,x)$	(t1)	$P(x,y) \wedge P(y,z) \rightarrow P(x,z)$	(t2)
$P(x,y) \wedge P(y,x) \rightarrow x = y$	(t3)	$\neg P(y,x) \rightarrow \exists z(P(z,y) \wedge \neg O(z,x))$	(t4)
$\exists w \phi(w) \rightarrow \exists z \forall w(O(w,z) \leftrightarrow \exists v(\phi(v) \wedge O(w,v)))$			(t5)
$C(x,x)$	(t6)	$C(x,y) \rightarrow C(y,x)$	(t7)
$P(x,y) \rightarrow E(x,y)$	(t8)	$E(x,y) =_{df} \forall z(C(z,x) \rightarrow C(z,y))$	(t9)
$E(x,y) \rightarrow P(x,y)$	(t10)	$SC(x) \leftrightarrow \forall y,z(x = y + z \rightarrow C(y,z))$	(t11)
$\exists z(SC(z) \wedge O(z,x) \wedge O(z,y) \wedge \forall w(P(w,z) \rightarrow (O(w,x) \vee O(w,y)))) \rightarrow C(x,y)$			(t12)
$z = \sum x \phi x \rightarrow \forall y(C(y,z) \rightarrow \exists x(\phi x \wedge C(y,x)))$			(t13)
$P(x,cx)$	(t14)	$c(cx) = cx$	(t15)
$c(x+y) = cx + cy$	(t16)	$cx =_{df} \sim(ex)$	(t17)
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Additional axioms, definitions, and theorems			
$PP(x,y) =_{df} P(x,y) \wedge \neg P(y,x)$	(t20)	$O(x,y) =_{df} \exists z(P(z,x) \wedge P(z,y))$	(t21)
$EQ(x,y) =_{df} P(x,y) \wedge P(y,x)$	(t22)	$TPP(x,y) =_{df} PP(x,y) \wedge \neg IPP(x,y)$	(t23)
$IPP(x,y) =_{df} PP(x,y) \wedge \forall z(C(z,x) \rightarrow O(z,y))$			(t24)
$\neg PP(x,x)$	(t25)	$PP(x,y) \wedge PP(y,z) \rightarrow PP(x,z)$	(t26)
$PP(x,y) \rightarrow \neg PP(y,x)$	(t27)		

Minimal (mereo) Topology; Ground Mereology

Core axioms and definitions			
$P(x,x)$	(t1)	$P(x,y) \wedge P(y,z) \rightarrow P(x,z)$	(t2)
$P(x,y) \wedge P(y,x) \rightarrow x = y$	(t3)	$\neg P(y,x) \rightarrow \exists z(P(z,y) \wedge \neg O(z,x))$	(t4)
$\exists w \phi(w) \rightarrow \exists z \forall w(O(w,z) \leftrightarrow \exists v(\phi(v) \wedge O(w,v)))$			(t5)
$C(x,x)$	(t6)	$C(x,y) \rightarrow C(y,x)$	(t7)
$P(x,y) \rightarrow E(x,y)$	(t8)	$E(x,y) =_{df} \forall z(C(z,x) \rightarrow C(z,y))$	(t9)
$E(x,y) \rightarrow P(x,y)$	(t10)	$SC(x) \leftrightarrow \forall y,z(x = y + z \rightarrow C(y,z))$	(t11)
$\exists z(SC(z) \wedge O(z,x) \wedge O(z,y) \wedge \forall w(P(w,z) \rightarrow (O(w,x) \vee O(w,y)))) \rightarrow C(x,y)$			(t12)
$z = \sum x \phi x \rightarrow \forall y(C(y,z) \rightarrow \exists x(\phi x \wedge C(y,x)))$			(t13)
$P(x, cx)$	(t14)	$c(cx) = cx$	(t15)
$c(x+y) = cx + cy$	(t16)	$cx =_{df} \sim (ex)$	(t17)
$ex =_{df} i(\sim x)$	(t18)	$ix =_{df} \sum z \forall y(C(z,y) \rightarrow O(x,y))$	(t19)
Additional axioms, definitions, and theorems			
$PP(x,y) =_{df} P(x,y) \wedge \neg P(y,x)$	(t20)	$O(x,y) =_{df} \exists z(P(z,x) \wedge P(z,y))$	(t21)
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$\neg PP(x,x)$	(t25)	$PP(x,y) \wedge PP(y,z) \rightarrow PP(x,z)$	(t26)
$PP(x,y) \rightarrow \neg PP(y,x)$	(t27)		

Minimal (mereo) Topology; General Extensional Mereology

Core axioms and definitions			
$P(x,x)$	(t1)	$P(x,y) \wedge P(y,z) \rightarrow P(x,z)$	(t2)
$P(x,y) \wedge P(y,x) \rightarrow x = y$	(t3)	$\neg P(y,x) \rightarrow \exists z(P(z,y) \wedge \neg O(z,x))$	(t4)
$\exists w \phi(w) \rightarrow \exists z \forall w(O(w,z) \leftrightarrow \exists v(\phi(v) \wedge O(w,v)))$			(t5)
$C(x,x)$	(t6)	$C(x,y) \rightarrow C(y,x)$	(t7)
$P(x,y) \rightarrow E(x,y)$	(t8)	$E(x,y) =_{df} \forall z(C(z,x) \rightarrow C(z,y))$	(t9)
$E(x,y) \rightarrow P(x,y)$	(t10)	$SC(x) \leftrightarrow \forall y,z(x = y + z \rightarrow C(y,z))$	(t11)
$\exists z(SC(z) \wedge O(z,x) \wedge O(z,y) \wedge \forall w(P(w,z) \rightarrow (O(w,x) \vee O(w,y)))) \rightarrow C(x,y)$			(t12)
$z = \sum x \phi x \rightarrow \forall y(C(y,z) \rightarrow \exists x(\phi x \wedge C(y,x)))$			(t13)
$P(x,cx)$	(t14)	$c(cx) = cx$	(t15)
$c(x+y) = cx + cy$	(t16)	$cx =_{df} \sim(ex)$	(t17)
$ex =_{df} i(\sim x)$	(t18)	$ix =_{df} \sum z \forall y(C(z,y) \rightarrow O(x,y))$	(t19)
Additional axioms, definitions, and theorems			
$PP(x,y) =_{df} P(x,y) \wedge \neg P(y,x)$	(t20)	$O(x,y) =_{df} \exists z(P(z,x) \wedge P(z,y))$	(t21)
$EQ(x,y) =_{df} P(x,y) \wedge P(y,x)$	(t22)	$TPP(x,y) =_{df} PP(x,y) \wedge \neg IPP(x,y)$	(t23)
$IPP(x,y) =_{df} PP(x,y) \wedge \forall z(C(z,x) \rightarrow O(z,y))$			(t24)
$\neg PP(x,x)$	(t25)	$PP(x,y) \wedge PP(y,z) \rightarrow PP(x,z)$	(t26)
$PP(x,y) \rightarrow \neg PP(y,x)$	(t27)		

General Extensional MereoTopology

Core axioms and definitions			
$P(x,x)$	(t1)	$P(x,y) \wedge P(y,z) \rightarrow P(x,z)$	(t2)
$P(x,y) \wedge P(y,x) \rightarrow x = y$	(t3)	$\neg P(y,x) \rightarrow \exists z(P(z,y) \wedge \neg O(z,x))$	(t4)
$\exists w \phi(w) \rightarrow \exists z \forall w(O(w,z) \leftrightarrow \exists v(\phi(v) \wedge O(w,v)))$			(t5)
$C(x,x)$	(t6)	$C(x,y) \rightarrow C(y,x)$	(t7)
$P(x,y) \rightarrow E(x,y)$	(t8)	$E(x,y) =_{df} \forall z(C(z,x) \rightarrow C(z,y))$	(t9)
$E(x,y) \rightarrow P(x,y)$	(t10)	$SC(x) \leftrightarrow \forall y,z(x = y + z \rightarrow C(y,z))$	(t11)
$\exists z(SC(z) \wedge O(z,x) \wedge O(z,y) \wedge \forall w(P(w,z) \rightarrow (O(w,x) \vee O(w,y)))) \rightarrow C(x,y)$			(t12)
$z = \sum x \phi x \rightarrow \forall y(C(y,z) \rightarrow \exists x(\phi x \wedge C(y,x)))$			(t13)
$P(x,cx)$	(t14)	$c(cx) = cx$	(t15)
$c(x+y) = cx + cy$	(t16)	$cx =_{df} \sim (ex)$	(t17)
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Additional axioms, definitions, and theorems			
$PP(x,y) =_{df} P(x,y) \wedge \neg P(y,x)$	(t20)	$O(x,y) =_{df} \exists z(P(z,x) \wedge P(z,y))$	(t21)
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$\neg PP(x,x)$	(t25)	$PP(x,y) \wedge PP(y,z) \rightarrow PP(x,z)$	(t26)
$PP(x,y) \rightarrow \neg PP(y,x)$	(t27)		

Kuratowski General Extensional MereoTopology

Core axioms and definitions			
$P(x,x)$	(t1)	$P(x,y) \wedge P(y,z) \rightarrow P(x,z)$	(t2)
$P(x,y) \wedge P(y,x) \rightarrow x = y$	(t3)	$\neg P(y,x) \rightarrow \exists z(P(z,y) \wedge \neg O(z,x))$	(t4)
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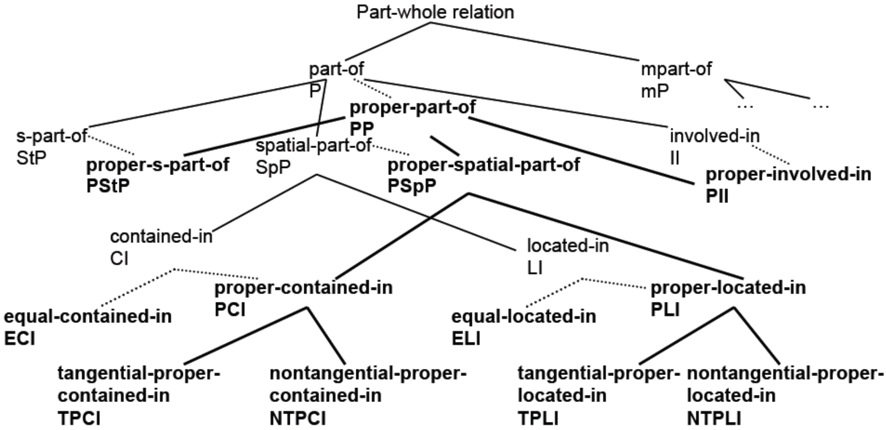
$PP(x,y) \rightarrow \neg PP(y,x)$	(t27)		

$$
\begin{array}{rcl}
\forall x, y(ECI(x,y) & \equiv & CI(x,y) \land P(y,x) \\
\forall x, y(PCI(x,y) & \equiv & PPO(x,y) \land R(x) \land R(y) \land \exists z, w(has\_3D(z,x) \land \\
 & & has\_3D(w,y) \land ED(z) \land ED(w))) \\
\forall x, y(NTPCI(x,y) & \equiv & PCI(x,y) \land \forall z(C(z,x) \rightarrow O(z,y))) \\
\forall x, y(TPCI(x,y) & \equiv & PCI(x,y) \land \neg NTPCI(x,y)) \\
\forall x, y(ELI(x,y) & \equiv & LI(x,y) \land P(y,x) \\
\forall x, y(PLI(x,y) & \equiv & PPO(x,y) \land R(x) \land R(y) \land \exists z, w(has\_2D(z,x) \land \\
 & & has\_2D(w,y) \land ED(z) \land ED(w))) \\
\forall x, y(NTPLI(x,y) & \equiv & PLI(x,y) \land \forall z(C(z,x) \rightarrow O(z,y))) \\
\forall x, y(TPLI(x,y) & \equiv & PLI(x,y) \land \neg NTPLI(x,y))
\end{array}
$$

$$
\begin{aligned}
\forall x, y(ECI(x,y) &\equiv CI(x,y) \wedge P(y,x) \\
\forall x, y(PCI(x,y) &\equiv PPO(x,y) \wedge R(x) \wedge R(y) \wedge \exists z, w(has\_3D(z,x) \wedge \\
&\quad has\_3D(w,y) \wedge ED(z) \wedge ED(w))) \\
\forall x, y(NTPCI(x,y) &\equiv PCI(x,y) \wedge \forall z(C(z,x) \rightarrow O(z,y))) \\
\forall x, y(TPCI(x,y) &\equiv PCI(x,y) \wedge \neg NTPCI(x,y)) \\
\forall x, y(ELI(x,y) &\equiv LI(x,y) \wedge P(y,x) \\
\forall x, y(PLI(x,y) &\equiv PPO(x,y) \wedge R(x) \wedge R(y) \wedge \exists z, w(has\_2D(z,x) \wedge \\
&\quad has\_2D(w,y) \wedge ED(z) \wedge ED(w))) \\
\forall x, y(NTPLI(x,y) &\equiv PLI(x,y) \wedge \forall z(C(z,x) \rightarrow O(z,y))) \\
\forall x, y(TPLI(x,y) &\equiv PLI(x,y) \wedge \neg NTPLI(x,y))
\end{aligned}
$$

$$
\begin{aligned}
\forall x, y(ECI(x,y) &\equiv CI(x,y) \wedge P(y,x) \\
\forall x, y(PCI(x,y) &\equiv PPO(x,y) \wedge R(x) \wedge R(y) \wedge \exists z, w(has\_3D(z,x) \wedge \\
&\quad has\_3D(w,y) \wedge ED(z) \wedge ED(w))) \\
\forall x, y(NTPCI(x,y) &\equiv PCI(x,y) \wedge \forall z(C(z,x) \rightarrow O(z,y))) \\
\forall x, y(TPCI(x,y) &\equiv PCI(x,y) \wedge \neg NTPCI(x,y)) \\
\forall x, y(ELI(x,y) &\equiv LI(x,y) \wedge P(y,x) \\
\forall x, y(PLI(x,y) &\equiv PPO(x,y) \wedge R(x) \wedge R(y) \wedge \exists z, w(has\_2D(z,x) \wedge \\
&\quad has\_2D(w,y) \wedge ED(z) \wedge ED(w))) \\
\forall x, y(NTPLI(x,y) &\equiv PLI(x,y) \wedge \forall z(C(z,x) \rightarrow O(z,y))) \\
\forall x, y(TPLI(x,y) &\equiv PLI(x,y) \wedge \neg NTPLI(x,y))
\end{aligned}
$$

Integrate the extension



Subsets of KGEMT that can be represented in OWL

- Reason of differences: the object property characteristics (e.g. t1/t6 = ref. of P/C, t25 = irr. of PP, t2= trans.).
- The six definitions (PP, O, TPP, etc.) can be simplified and added as primitives to each one.

OWL species	**Subsets of KGEMT axioms**
OWL 2 DL	(t1, t2, t6, t7, t8, t10, t26) or (t1, t2, t6, t7, t8, t10, t27) or (t1, t2, t6, t7, t8, t10, t25)
OWL DL	t2, t7, t8, t10, t26
OWL Lite	t2, t7, t8, t10, t26
OWL 2 RL	t2, t7, t8, t10, t26
OWL 2 EL	t1, t2, t6, t8, t10, t26
OWL 2 QL	t1, t6, t7, t8, t10

- Importance depends on the desired inference scenarios; thus far, Trans, Sym, Asym, and Irr seem to be more interesting, i.e., giving precedence to OWL 2 DL and OWL 2 RL (See [Keet et al.(2012)] for details on reasoning trade-offs)

Other relations in (foundational) ontologies

- Relation Ontology [Smith et al.(2005)]
- Relations that are sort-of temporal, but now not used as such; hence, one cannot reason 'fully' with them w.r.t. intended meaning
    - e.g.: `derived-from`, `transformation-of`
- dependence, inherence
- Attributes
- DOLCE's qualities

Some other aspects of relations (not covered now)

- constraints on participation (essential vs. immutable vs. mandatory)
- Modality, necessity, telic, atelic
- Temporal relations, relation migration
- *n*-ary relations and reifying (objectifying) them

Outline

Any suggestions for actual ontology development?

- Using the taxonomy of part-whole relations
- Reasoner-guided relation selection
- Performance tradeoffs with inverses

Using the taxonomy of part-whole relations

- Representing it correctly in ontologies and conceptual data models

- Reasoning with a taxonomy of relations

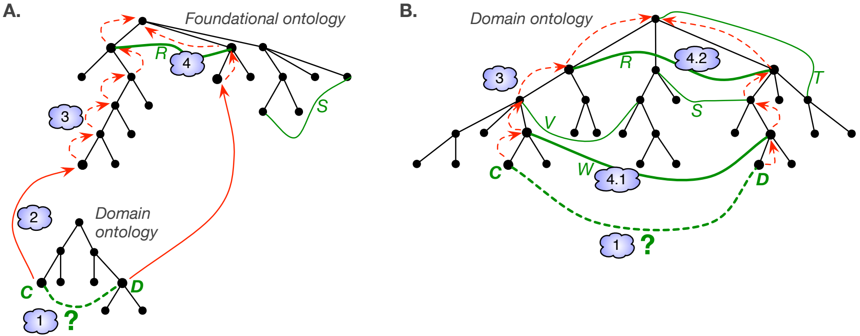
Using the taxonomy of part-whole relations

- 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: ONTOPARTS [Keet et al.(2012)] and OntoParts-2 [Keet et al.(2013b)]
- 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: OntoParts [Keet et al.(2012)] and OntoParts-2 [Keet et al.(2013b)]
- Reasoning with a taxonomy of relations
  - The *RBox reasoning service* [Keet and Artale(2008)] or *SubProS* [Keet(2014)] to pinpoint errors

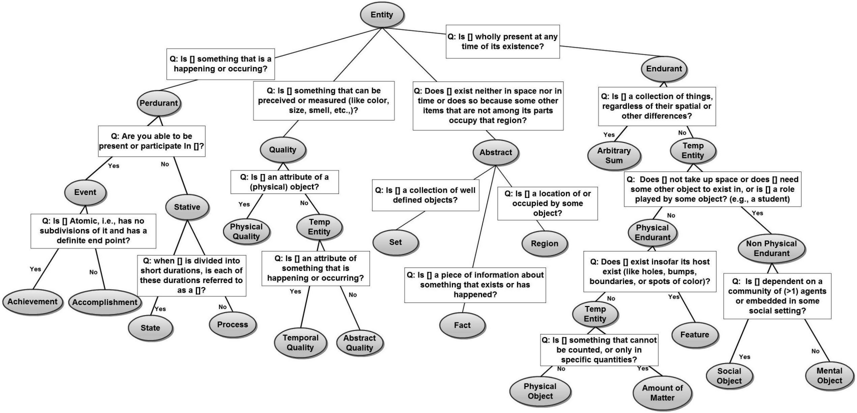
GENERATOR: Guided ENtity reuse and class Expression geneRATOR [Keet et al.(2013a)]



GENERATOR with FORZA

- FORZA: Foundational Ontology and Reasoner-enhanced axiomatiZAtion [Keet et al.(2013b)]
- Automated support for the linking with DOLCE categories
- Novel decision tree to categorise a subject domain class as a subclass of a DOLCE class (named D3)
- Novel algorithm that uses an automated reasoner to compute the applicable part-whole relation(s) between the selected classes (named OntoPartS-2)
- Avoids the common post-hoc checking, uses the reasoner to guide the 'trial' phase and reduce errors

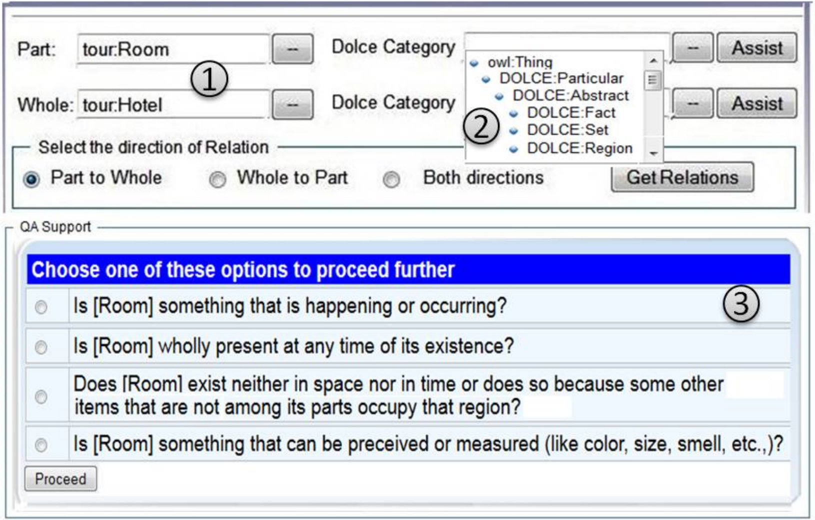
D3


Entity
Q: Is [] something that is a happening or occuring?
Q: Is [] something that can be preceived or measured (like color, size, smell, etc.,)?
Q: Does [] exist neither in space nor in time or does so because some other items that are not among its parts occupy that region?
Q: Is [] wholly present at any time of its existence?
Perdurant
Q: Are you able to be present or participate In []?
Yes
No
Event
Stative
Q: Is [] Atomic, i.e., has no subdivisions of it and has a definite end point?
Yes
No
Achievement
Accomplishment
Q: when [] is divided into short durations, is each of these durations referred to as a []?
Yes
No
State
Process
Quality
Q: Is [] an attribute of a (physical) object?
Yes
No
Physical Quality
Temp Entity
Q: Is [] an attribute of something that is happening or occurring?
Yes
No
Temporal Quality
Abstract Quality
Abstract
Q: Is [] a collection of well defined objects?
Set
Q: Is [] a location of or occupied by some object?
Region
Q: Is [] a piece of information about something that exists or has happened?
Fact
Endurant
Q: Is [] a collection of things, regardless of their spatial or other differences?
Yes
No
Arbitrary Sum
Temp Entity
Q: Does [] not take up space or does [] need some other object to exist in, or is [] a role played by some object? (e.g., a student)
No
Yes
Physical Endurant
Non Physical Endurant
Q: Does [] exist insofar its host exist (like holes, bumps, boundaries, or spots of color)?
No
Yes
Temp Entity
Feature
Q: Is [] something that cannot be counted, or only in specific quantities?
No
Yes
Physical Object
Amount of Matter
Q: Is [] dependent on a community of (>1) agents or embedded in some social setting?
Yes
No
Social Object
Mental Object

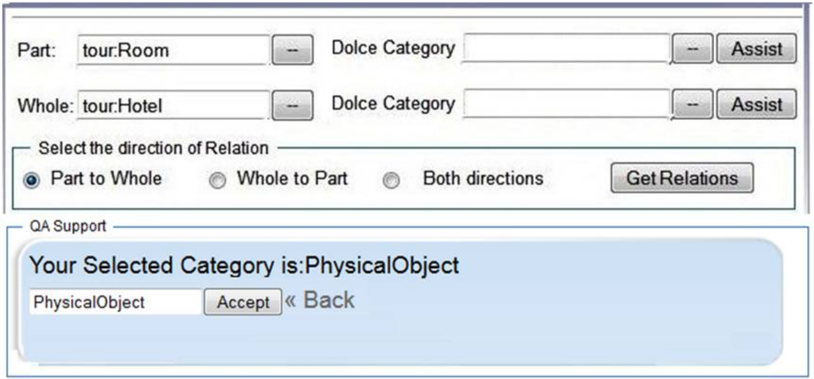
FORZA implementation

- OntoParts-2 (jar file)
- D3 as XML file
- Integrated in MoKI modelling wiki [Ghidini et al.(2009)]
- `sourceforge.net/projects/cikmontology/files/CIKM2013.zip/download`

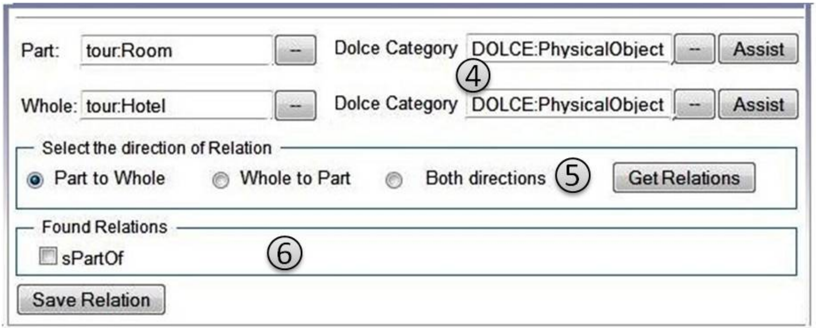
Example (1/3)


Part: tour:Room
Dolce Category
Assist
1
Whole: tour:Hotel
Dolce Category
Assist
owl:Thing
DOLCE:Particular
DOLCE:Abstract
DOLCE:Fact
DOLCE:Set
DOLCE:Region
2
Select the direction of Relation
Part to Whole
Whole to Part
Both directions
Get Relations
QA Support
Choose one of these options to proceed further
Is [Room] something that is happening or occurring?
3
Is [Room] wholly present at any time of its existence?
Does [Room] exist neither in space nor in time or does so because some other items that are not among its parts occupy that region?
Is [Room] something that can be preceived or measured (like color, size, smell, etc.,)?
Proceed

Example (2/3)


Part: tour:Room
Dolce Category
Assist
Whole: tour:Hotel
Dolce Category
Assist
Select the direction of Relation
Part to Whole
Whole to Part
Both directions
Get Relations
QA Support
Your Selected Category is:PhysicalObject
PhysicalObject
Accept
« Back

Example (3/3)


Part: tour:Room
--
Dolce Category DOLCE:PhysicalObject
--
Assist
4
Whole: tour:Hotel
--
Dolce Category DOLCE:PhysicalObject
--
Assist
Select the direction of Relation
Part to Whole
Whole to Part
Both directions
5
Get Relations
Found Relations
sPartOf
6
Save Relation

Effects of features on reasoning

- Disjoint OPs, reflexivity, and qualified cardinality only on *simple* OPs in OWL 2. with *non-simple* when:
  - if $\mathcal{O}$ contains an axiom $S \circ T \sqsubseteq R$
  - if R is non-simple, then so is its inverse R^-
  - if R is non-simple and $\mathcal{O}$ contains any of the axioms $R \sqsubseteq S$, $S \equiv R$ or $R \equiv S$, then S is also non-simple
- Domain and range axioms
- Role hierarchy with domain and range axioms vs. 'specialising' in class axioms (with existential) [Hammar(2014)]
- Inverses (next slide)
- 'understanding' the reasoner, predicting performance a hot topic; e.g. [Goncalves et al.(2012), Kang et al.(2012)]

Inverses

- Unsurprising (?) surprising reasoner performance with DMOP ontology [`www.dmo-foundry.org`]

Inverses

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- OWL 2 "new feature":
  - `ObjectInverseOf(OP)` instead of only `InverseObjectProperties(OPE1 OPE2)` in OWL 1 for two object properties in the ontology
  - E.g., `addresses` with as inverse `addressed by` vs. `addresses` and using (in Protégé notation) `inverse(addresses)` in an axiom
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Inverses

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- New feature slows down reasoner?
- DMOP v5.4 with all `InverseObjectProperties`; test now by replacing those ($n = 45$) with `ObjectInverseOf(OP)` and compare

Inverses: performance results

Table: Classification times (in minutes) of DMOP and DMOP with `ObjectInverseOf()`. [Keet et al.(2014)]

Component of classification	**DMOP v5.4**	**DMOP v5.4 inverses**
Class Hierarchy	6 mins	3 mins
Object Property Hierarchy	2 mins	1 min
Data Type Property Hierarchy	<1 min	few secs
Class instances	about 1 min	<1 min

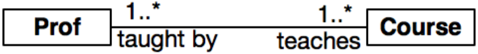
The `ObjectInverseOf()` feature of OWL 2 improves the reasoner performance in the ODE by at least a third.

Choose one involvement between Chewing and Eating

- Chewing involved-in some Eating
  $\texttt{Chewing} \sqsubseteq \exists \texttt{involved-in}.\texttt{Eating}$
- Chewing inverse(involves) some Eating
  $\texttt{Chewing} \sqsubseteq \exists \texttt{involves}^{-}.\texttt{Eating}$
- Eating involves some Chewing
  $\texttt{Eating} \sqsubseteq \exists \texttt{involves}.\texttt{Chewing}$
- Eating inverse(involved-in) some Chewing
  $\texttt{Eating} \sqsubseteq \exists \texttt{involved-in}^{-}.\texttt{Chewing}$

(simplified notation online)

How to formalise the UML diagram in OWL?



- teaches, taught-by, InverseObjectProperties(teaches taught-by)
  $\texttt{teaches} \sqsubseteq \top \times \top$
  $\texttt{taughtBy} \sqsubseteq \top \times \top$
  $\texttt{teaches} \equiv \texttt{taughtBy}^{-}$
- domain teaches: Prof, and range teaches: Course
  $\texttt{teaches} \sqsubseteq \texttt{Prof} \times \texttt{Course}$
- domain teaches: Prof, and range teaches: Course, domain taught-by: Course, range taught-by: Prof
  $\texttt{teaches} \sqsubseteq \texttt{Prof} \times \texttt{Course}$
  $\texttt{taughtBy} \sqsubseteq \texttt{Course} \times \texttt{Prof}$

(simplified notation online)

OWL files

- `http://www.meteck.org/teaching/ontologies/` has various versions of the African Wildlife Ontology (alone, linked to DOLCE, link to GFO)
- `http://www.meteck.org/files/ontologies/EvalComputer.owl` has no object properties at all. add both properties and axioms (details of exercise depends on number of participants)
- Pick one. Add missing object properties and/or axioms (details of exercise depends on number of participants)

The Wildlife Ontology and DOLCE

- Giraffes eat leaves and twigs. how do `Plant` and `Twig` relate?
    -
- The elephant's tusks (ivory) are made of apatite (calcium phosphate); which DOLCE relation can be reused?
    -
- How would you represent the `Size` (`Height`, `Weight`, etc.) of an average adult elephant?
    - with *quality* and *quale*
    - OWL data properties
        -
        -
        -

The Wildlife Ontology and DOLCE

- Giraffes eat leaves and twigs. how do `Plant` and `Twig` relate?
  - (some type of) parthood relation
- The elephant's tusks (ivory) are made of apatite (calcium phosphate); which DOLCE relation can be reused?
  - constitution
- How would you represent the `Size` (`Height`, `Weight`, etc.) of an average adult elephant?
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  - constitution
- How would you represent the `Size` (`Height`, `Weight`, etc.) of an average adult elephant?
  - with *quality* and *quale*
  - OWL data properties
    - What is the data type; integer, float, real, string?
    - Measure in meter, feet, kg, lb?
    - Introduce "`ElephantHeight`", and also "`LionHeight`", "`GiraffeHeight`', "`ImpalaHeight`", etc.?

A computer ontology

- CPU and Desktop?
- Who are members of an Agile team?

A computer ontology

- CPU and Desktop?
  - containment
- Who are members of an Agile team?
  - hasMember vs. memberOf

Outline

Recap

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