Modeling with Ontologies and Rules

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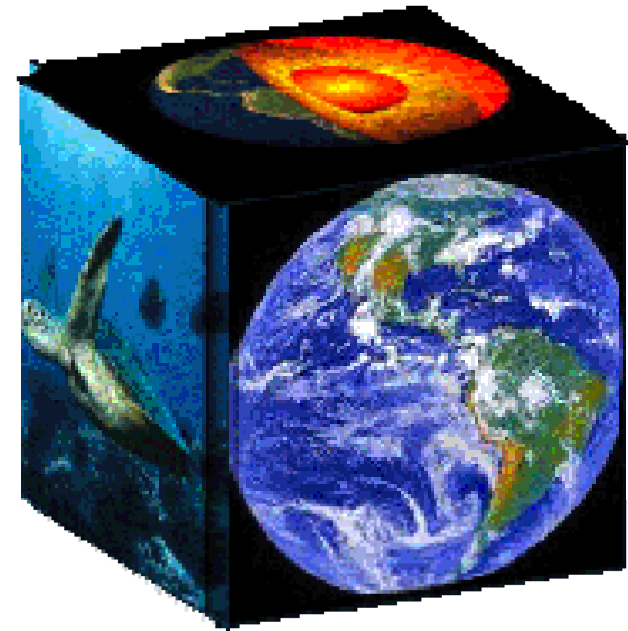
Part II
Ontology Design Patterns

NSF effort for the earth sciences

Goal:

To transform the conduct of research in the geosciences by developing IT solutions for the integration of information and data in the geosciences.

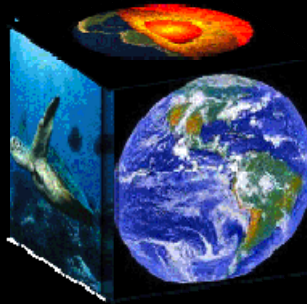**How this is going to be done is still in the making.**

Semantic Technologies have been part of the mix from the start.

[Berg-Cross, …, Hitzler et al., GIBDa 2012]

EarthCube requires

- information integration
- interoperability
- conceptual modeling
- intelligent search
- data-model intercomparison
- data publishing support

Semantic Web studies

- information integration
- interoperability
- conceptual modeling
- intelligent search
- data-model intercomparison
- data publishing support

Pascal Hitzler, WSU; Krzysztof Janowicz, UCSB

Vertical data integration
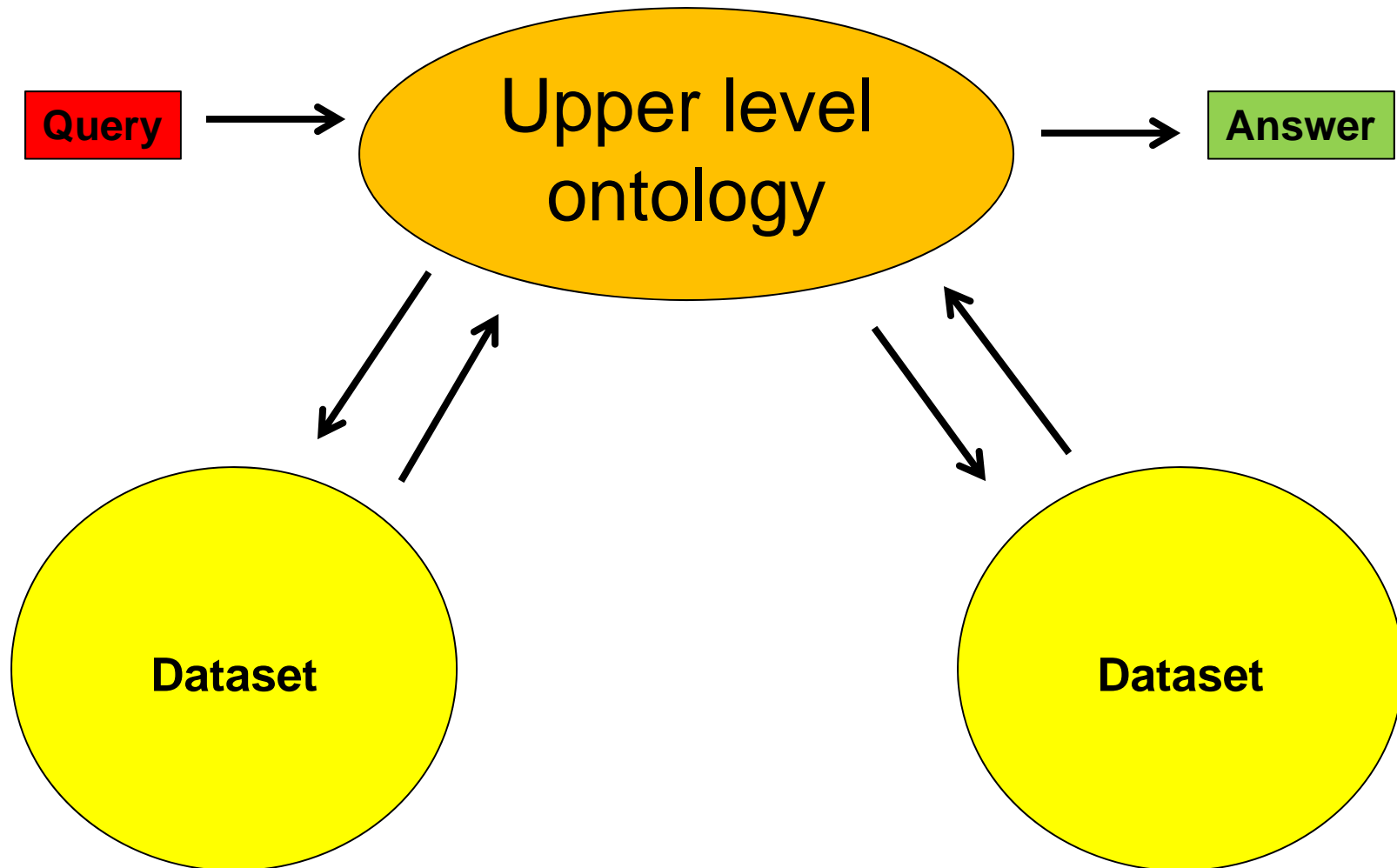
[Joshi, Jain, Hitzler et al. ODBASE 2012]

$$a{:}flowsInto \sqsubseteq a{:}IsConnected \quad (1)$$

$$a{:}IrrigationCanal \sqsubseteq a{:}Canal \quad (2)$$

$$\exists a{:}flowsInto.a{:}AgriculturalField \sqsubseteq a{:}IrrigationCanal \quad (3)$$

$$a{:}Waterbody \sqcap a{:}Land \sqsubseteq \bot \quad (4)$$

$$a{:}AgriculturalField \sqsubseteq a{:}Land \quad (5)$$

$$b{:}flowsInto \sqsubseteq b{:}IsConnected \quad (6)$$

$$b{:}Canal \sqsubseteq (\geq 2\ b{:}IsConnected.b{:}Waterbody) \quad (7)$$

$$b{:}IrrigationCanal \equiv (=1\ b{:}isConnected.b{:}Waterbody)$$

$$\sqcap (=1\ b{:}flowsInto.b{:}AgriculturalField) \quad (8)$$

Two ontologies.

Left: transportation domain

Right: agriculture domain

We cannot simply equate a:Canal and b:Canal !

"Nancy Pelosi voted in favor of the Health Care Bill."

Ontology Design Patterns
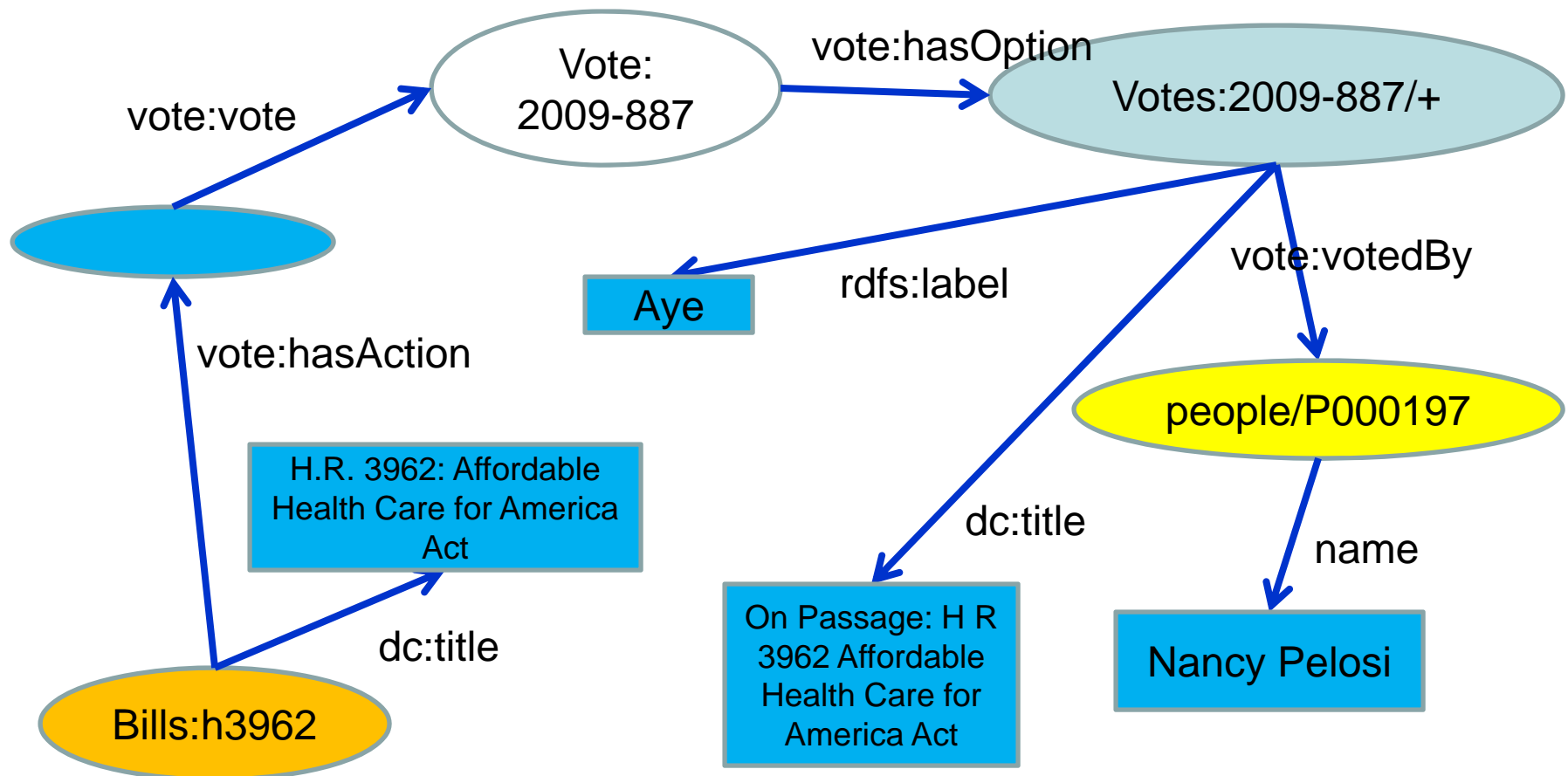
- **Bottom-up homogenization of data representation.**

- **Avoidance of strong ontological commitments.**

- **Avoidance of standardization.**

- **Well thought-out patterns can be very strong and versatile, thus serve many needs.**

We are currently establishing many geo-patterns in a series of hands-on workshops, the GeoVoCamps, see http://vocamp.org/

Ontology Design Patterns
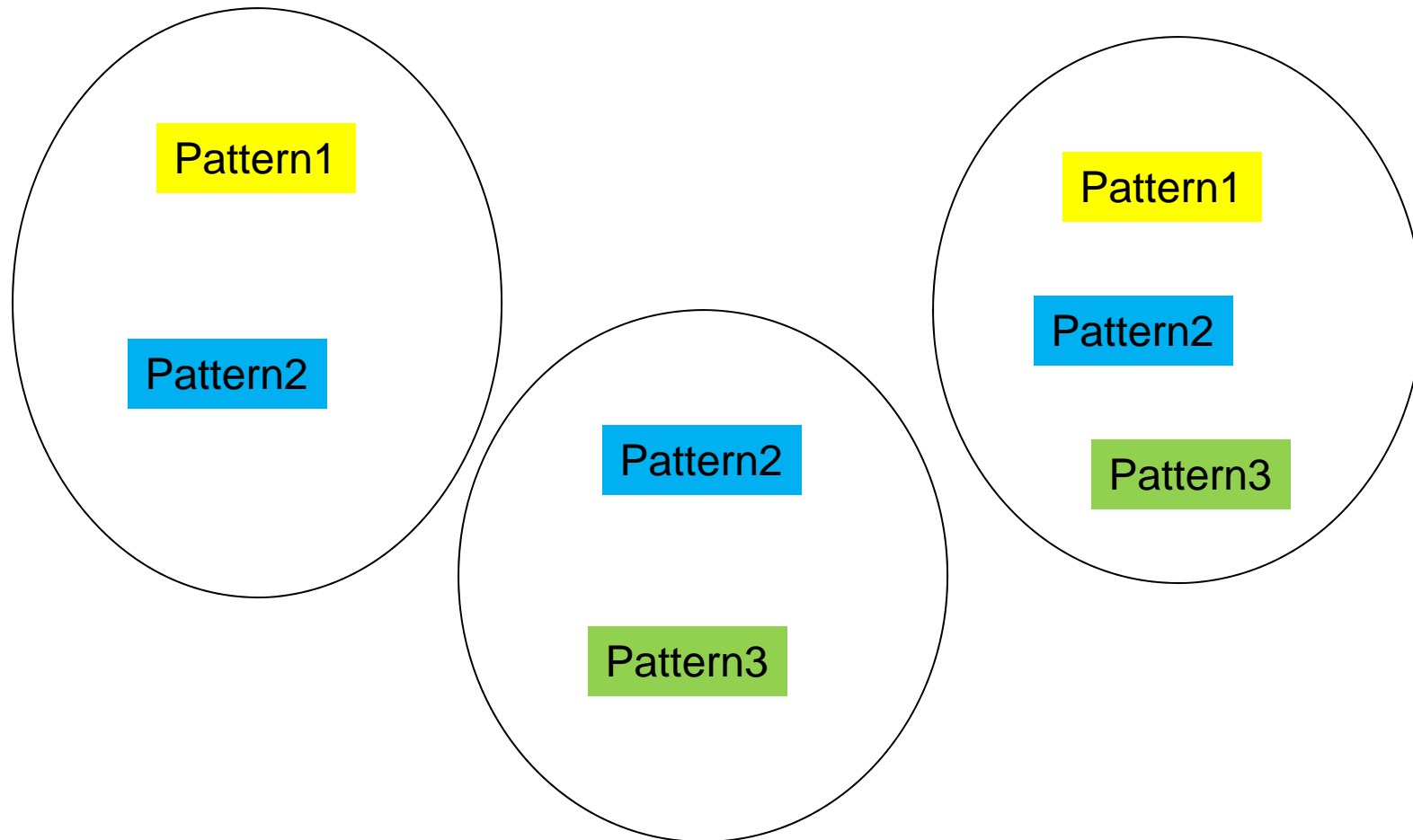
"Horizontal" alignment via patterns

Patterns TOC

- **Semantic Trajectories**
- **Biodiversity**
- **Map Scaling**
- **Part-of Relationships**

Semantic Trajectories

Raw trajectory data — Geographic information — Domain knowledge — Device information

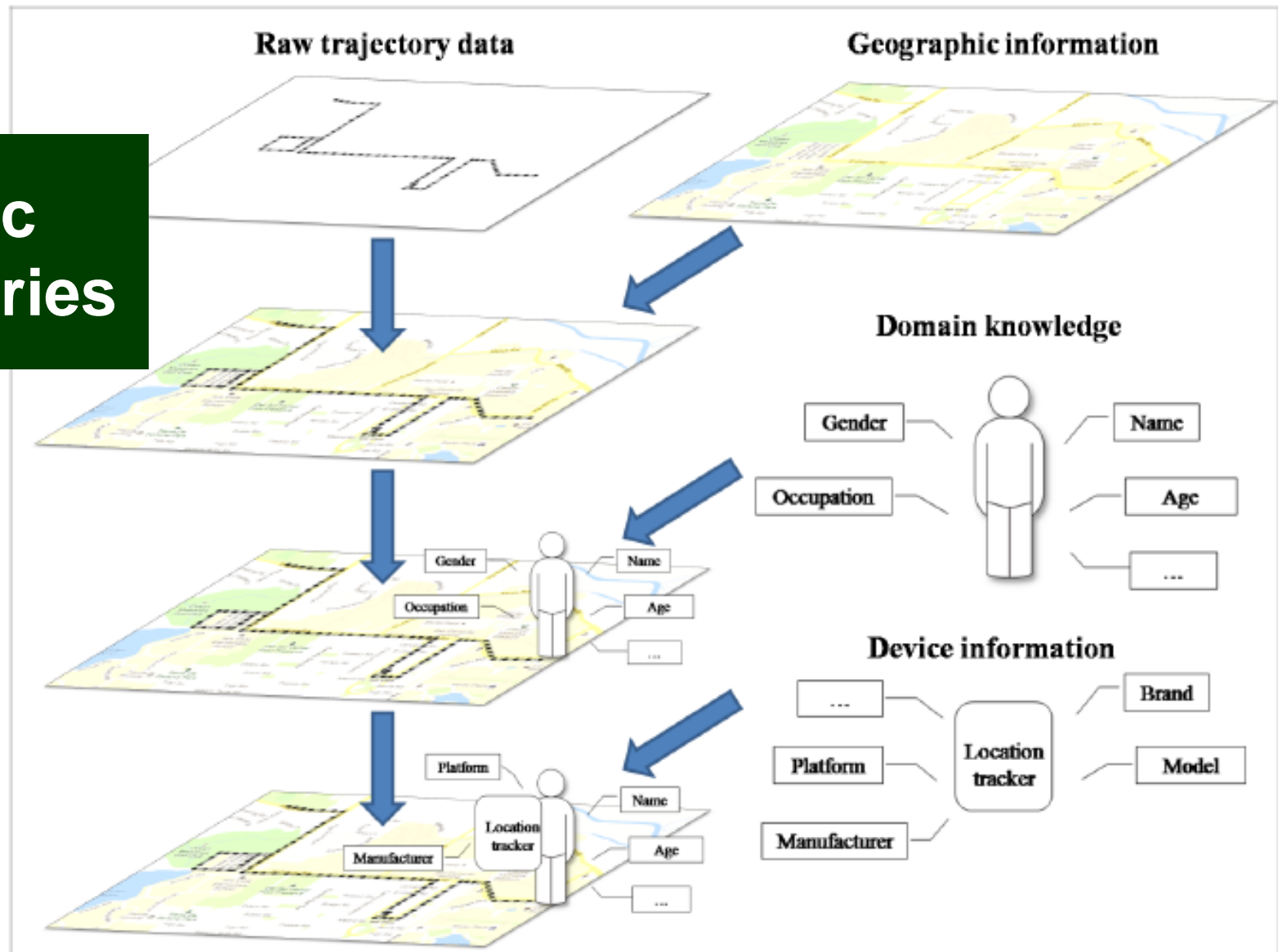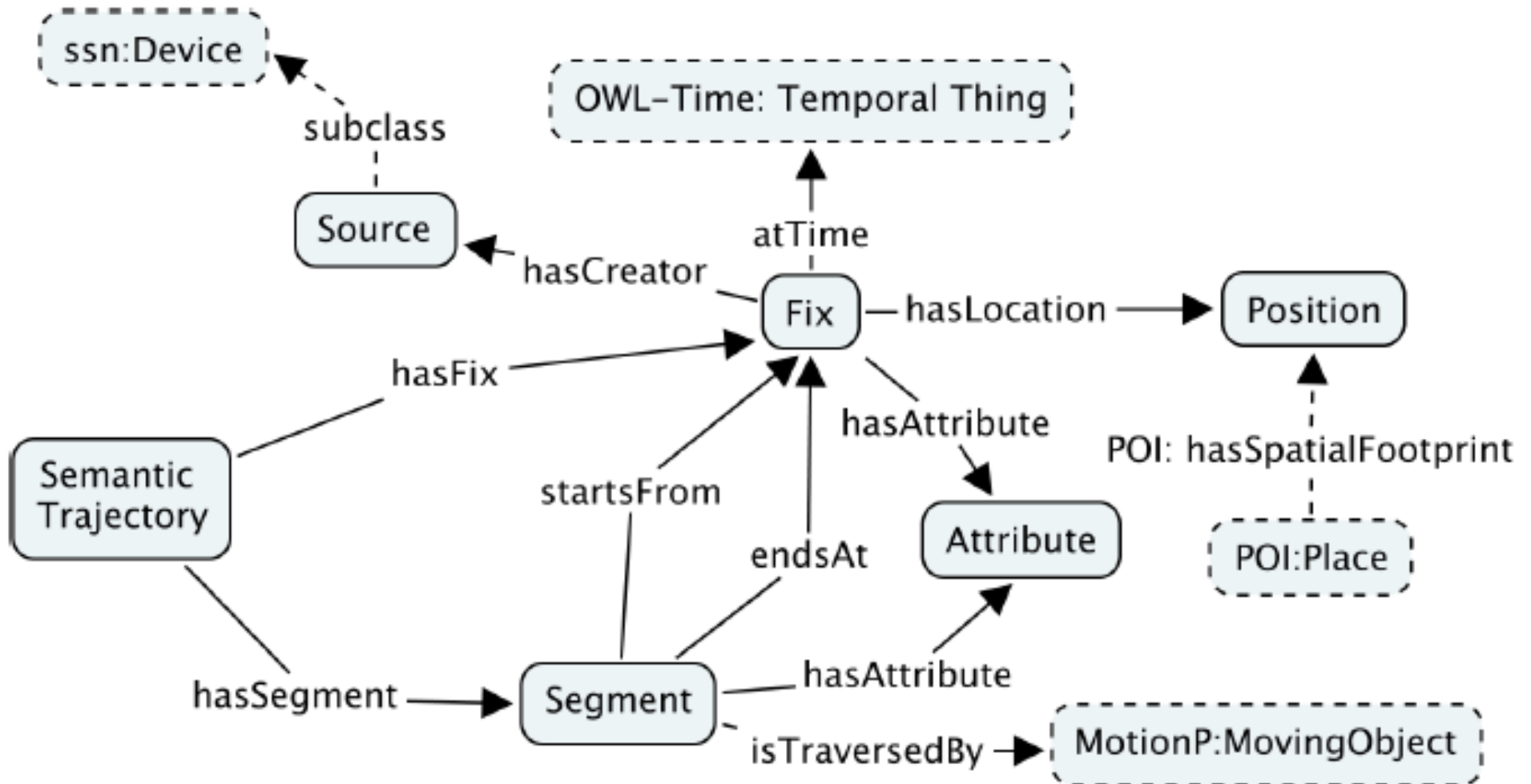**[Hu, Janowicz, Carral, Scheider, Kuhn, Berg-Cross, Hitzler, Dean, COSIT2013]**

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$$Fix \sqsubseteq \exists atTime.OWL\text{-}Time{:}Temporal\ Thing \sqcap \exists hasLocation.Position$$

$$\sqcap \exists hasFix^-.SemanticTrajectory \qquad (1)$$

$$Segment \sqsubseteq \exists startsFrom.Fix \sqcap \exists endsAt.Fix \qquad (2)$$

$$\top \sqsubseteq\ \leq 1startsFrom.\top \qquad (3)$$

$$\top \sqsubseteq\ \leq 1endsAt.\top \qquad (4)$$

$$Segment \sqsubseteq \exists hasSegment^-.SemanticTrajectory \qquad (5)$$

$$startsFrom^- \circ endsAt \sqsubseteq hasNext \qquad (6)$$

$$hasNext \sqsubseteq hasSuccessor \qquad (7)$$

$$hasSuccessor \circ hasSuccessor \sqsubseteq hasSuccessor \qquad (8)$$

$$hasNext^- \sqsubseteq hasPrevious \qquad (9)$$

$$hasSuccessor^- \sqsubseteq hasPredecesor \qquad (10)$$

$$Fix \sqcap \neg\exists endsAt.Segment \sqsubseteq StartingFix \quad (11)$$

$$Fix \sqcap \neg\exists startsFrom.Segment \sqsubseteq EndingFix \quad (12)$$

$$Segment \sqcap \exists startsFrom.StartingFix \sqsubseteq StartingSegment \quad (13)$$

$$Segment \sqcap \exists endsAt.EndingFix \sqsubseteq EndingSegment \quad (14)$$

$$SemanticTrajectory \sqsubseteq \exists hasSegment.Segment \quad (15)$$

$$hasSegment \circ startsFrom \sqsubseteq hasFix \quad (16)$$

$$hasSegment \circ endsAt \sqsubseteq hasFix \quad (17)$$

$$\exists hasSegment.Segment \sqsubseteq SemanticTrajectory \quad (18)$$

$$\exists hasSegment^{-}.SemanticTrajectory \sqsubseteq Segment \quad (19)$$

$$\exists hasFix.Segment \sqsubseteq SemanticTrajectory \quad (20)$$

$$\exists hasFix^{-}.SemanticTrajectory \sqsubseteq Fix \quad (21)$$

Patterns TOC

- **Semantic Trajectories**
- **Biodiversity**
- **Map Scaling**
- **Part-of Relationships**

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[ACM GIS 2012]

The pattern which we introduce is used for *type-count comparison* – we correspondingly call it the *type-count comparison pattern*. Syntactically, we write it as

$$R \equiv D \times D|_{C_1,\ldots,C_n},$$

where R is a role name, and D and the C_i are concepts.

Intuitively, the semantics of this pattern is as follows: Two individuals x and y shall be connected by the role R if and only if x is contained in strictly more different classes C_i than y. E.g., say x is contained in C_1 and C_5 (but not in any other C_i, while y is contained in C_2 (but not in any other C_j), then we would like to infer $R(x,y)$. The notation using a vertical bar is borrowed from a very common mathematical notation used for restricting functions to subsets of their domains.

Consider the knowledge base consisting of the following statements.

$$R \equiv \top \times \top|_{C_1,C_2}$$
$$C_1(a)$$
$$C_2(a)$$
$$C_1(b)$$

From this knowledge base we would like to infer $R(a, b)$, since a is known to be contained in the two classes C_1 and C_2, while b is only known to be contained in C_1.

However, now assume we add the axiom $C_2(b)$ to the knowledge base. Under this new knowledge base, we would no longer infer $R(a, b)$, since both a and b are contained in two of the classes. Note that the *addition* of the axiom $C_2(b)$ means that a previously drawn inference, namely $R(a, b)$, is no longer a valid inference. This observation shows that we are in fact considering a so-called *non-monotonic* semantics. Such non-monotonic semantics usually arise in the context of some kind of (local) world closure as discussed at the end of section 2.

In our formal semantics we will therefore have to reflect this, and introduce some non-monotonic semantic construct. We will discuss this further in section 3.3.

Semantics

$$\text{Close}(C_i) \tag{1}$$

for all $1 \leq i \leq n$.

$$R \sqsubseteq D \times D \tag{2}$$

$$D \sqsubseteq N_{0,0} \tag{3}$$

$$N_{m-1,k} \sqcap \neg C_m \sqsubseteq N_{m,k} \tag{4}$$

$$N_{m-1,k} \sqcap C_m \sqsubseteq N_{m,k+1} \tag{5}$$

where all $N_{i,j}$ are freshly introduced classes where $m = 1, \ldots, n$ and $k = 1, \ldots, m - 1$ for every m.

$$N_{n,i} \sqsubseteq \exists S_i.Self \tag{6}$$

where $i = 0, \ldots, n$.

$$S_i \circ R \circ S_j \sqsubseteq R_{\text{typeCountViolation}} \tag{7}$$

for all $i \leq j$ where $j = 0, \ldots, n$.

$$S_i \circ U \circ S_j \sqsubseteq R \tag{8}$$

for all $i > j$ where $i = 1, \ldots, n$.

Closure

- **Straightforward carrying over of circumscription to DLs:
  undecidable for expressive DLs
  [Bonatti, Lutz, Wolter, KR2006, JAIR 2009]**

  **Unintuitive modeling: extensions of minimized predicates may
  contain unknown individuals**

- **Fixing the unintuitive aspect: allow only named individuals in
  extensions of minimized predicates
  decidable even for very expressive DLs
  we also have a tableaux algorithm
  [Sengupta, Krisnadhi, Hitzler, ISWC2011]**

  called *Grounded Circumscription*

Circumscription

- **Use a knowledge base K as usual.**

- **Additionally, specify "circumscribed" (minimized) predicates.**

- **Among all models M of K, the circumscribed models (c-models) are those for which there is no model which is preferred over M.**

A model J is *preferred over* M if
a) they have the same domain of discourse
b) constants have the same extensions in both models
c) the J-extension of each minimized predicate is contained in its M-extension
d) the J-extension of some minimized predicate is strictly contained in its M-extension

- **Use a knowledge base K as usual.**

- **Additionally, specify "circumscribed" (minimized) predicates.**

- **Among all models M of K, the circumscribed models (gc-models) are those for which there is no model which is preferred over M and extensions of minimized predicates contain only named individuals.**

  A model J is *preferred over* M if
  a) they have the same domain of discourse
  b) constants have the same extensions in both models
  c) the J-extension of each minimized predicate is contained in its M-extension
  d) the J-extension of some minimized predicate is strictly contained in its M-extension

Circumscription vs. Grounded Circ.

- **Circumscription:**
  - minimization of roles leads to undecidability (for non-empty Tboxes

- **Grounded Circumscription:**
  - Decidable even under role grounding for very expressive decidable DLs.
  - Complexity upper bound for satisfiability or for finding a gc-model is EXP^C, where C is the complexity of the underlying DL.

We also have a tableaux algorithm for different reasoning tasks.

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$$\text{hasAuthor}(\text{paper1}, \text{author1}) \qquad \text{hasAuthor}(\text{paper1}, \text{author2})$$

$$\text{hasAuthor}(\text{paper2}, \text{author3}) \qquad \top \sqsubseteq \forall \text{hasAuthor}.\text{Author}$$

Both of

$$\neg \text{hasAuthor}(\text{paper1}, \text{author3})$$

$$(\leq 2\ \text{hasAuthor}.\text{Author})(\text{paper1})$$

are not logical consequences under classical DL semantics.

However, they are logical consequences when hasAuthor is minimized (using the UNA).

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Patterns TOC

- **Semantic Trajectories**
- **Biodiversity**
- **Map Scaling**
- **Part-of Relationships**

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sharesApplicationWith

isConstituentOf

ScaledRep

representsObject

Map

isScaled

GeographicThing

getMap

hasScale

ScaleLevel

isPresentedAs

hasUpperBound

isLargerThan

xsd:float

isCompatibleWith

hasLowerBound

GeometricRep

isMoreGeneralThan
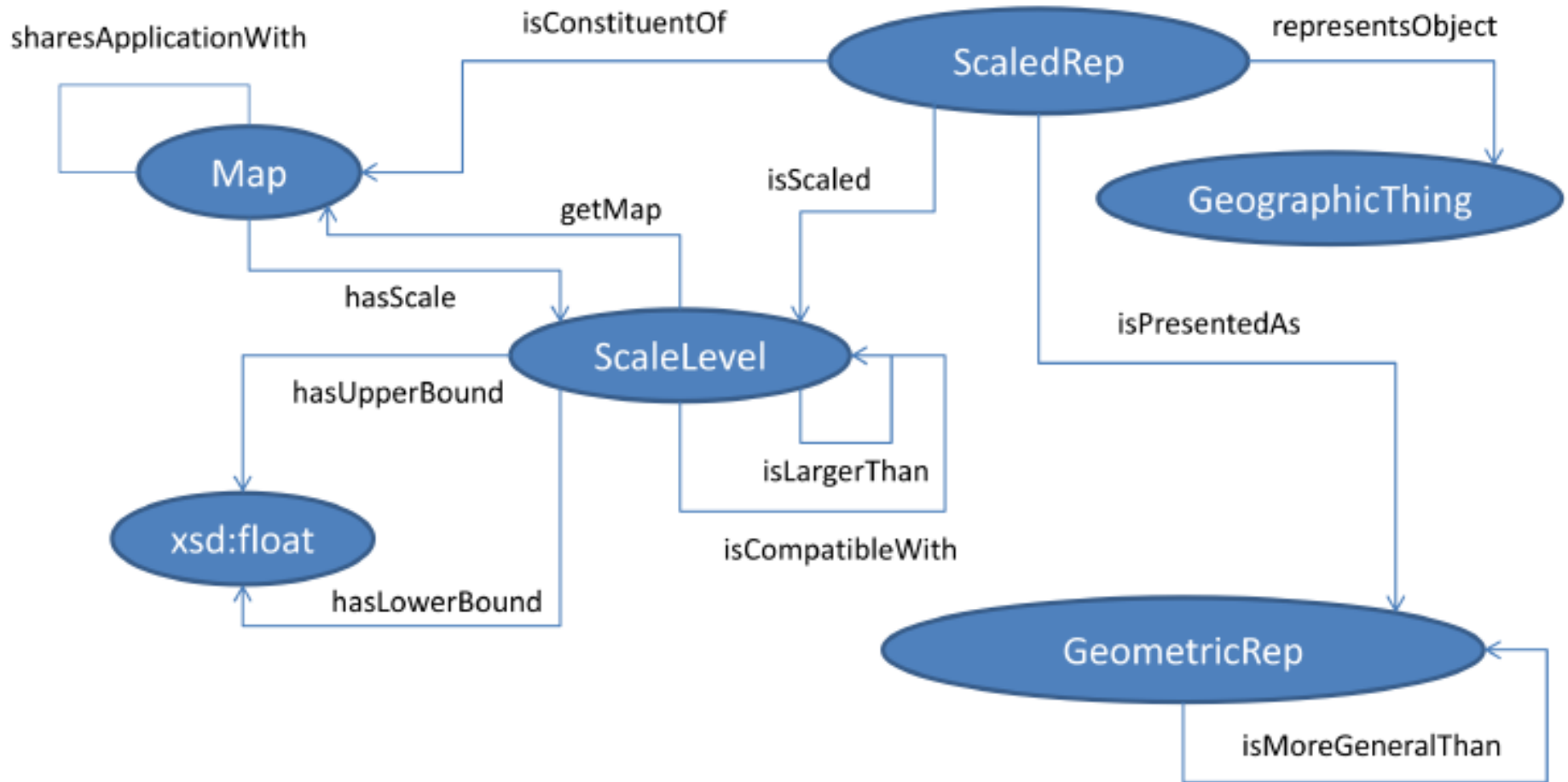
[Carral, Scheider, Janowicz, Vardeman, Krisnadhi, Hitzler, ESWC2013]

$$sharesApplicationWith \circ sharesApplicationWith \sqsubseteq sharesApplicationWith \quad (1)$$

$$sharesApplicationWith^- \sqsubseteq sharesApplicationWith \quad (2)$$

$$Map \sqsubseteq \exists sharesApplicationWith.Self \quad (3)$$

$$\top \sqsubseteq\ \leq 1hasScale.\top \quad (4)$$

$$hasScale^- \sqsubseteq getMap \quad (5)$$

$$\top \sqsubseteq\ \leq 1(getMap \circ sharesApplicationWith).\top \quad (6)$$

$$isConstituentOf \circ hasScale \sqsubseteq isScaled \quad (7)$$

$$isLargerThan \circ isLargerThan \sqsubseteq isLargerThan \quad (8)$$

$$\exists(isLargerThan \sqcap isLargerThan^-).\top \sqsubseteq \bot \quad (9)$$

$$isMoreGeneralThan \circ isMoreGeneralThan \sqsubseteq isMoreGeneralThan \quad (10)$$

$$\exists(isMoreGeneralThan \sqcap isMoreGeneralThan^-).\top \sqsubseteq \bot \quad (11)$$

$$isCompatibleWith^- \sqsubseteq isCompatibleWith \quad (12)$$

$$ScaleLevel \sqsubseteq \exists isCompatibleWith.Self \quad (13)$$

$$ScaleLevel \sqsubseteq \exists hasLowerBound.xsd\text{:}float \quad (14)$$

$$ScaleLevel \sqsubseteq \exists hasUpperBound.xsd\text{:}float \quad (15)$$

$$\top \sqsubseteq \leq 1hasLowerBound.\top \quad (16)$$

$$\top \sqsubseteq \leq 1hasUpperBound.\top \quad (17)$$

$$\top \sqsubseteq \leq 1isPresentedAs.\top \quad (18)$$

$$\top \sqsubseteq \leq 1isScaled.\top \quad (19)$$

$$\top \sqsubseteq \leq 1representsObject.\top \quad (20)$$

$$ScaledRep \sqsubseteq \exists isPresentedAs.GeometricRep \quad (21)$$

$$ScaledRep \sqsubseteq \exists isScaled.ScaleLevel \quad (22)$$

$$ScaledRep \sqsubseteq \exists representsObject.GeographicThing \quad (23)$$

$$isConstituentOf^- \circ representsObject \circ representsObject^- \sqsubseteq R_{aux} \quad (24)$$

$$\top \sqsubseteq \leq 1(R_{aux} \sqcap isConstituentOf^-).\top \quad (25)$$

$$sharesApplicationWith(m_x, m_y) \land hasScale(s_y, m_y) \land hasScale(s_x, m_x)$$
$$\land\, isLargerThan(s_x, s_y) \land$$
$$isConstituentOf(m_x, sr_x) \land isConstituentOf(m_y, sr_y) \land$$
$$representsObject(sr_x, g) \land representsObject(sr_y, g) \land$$
$$isPresentedAs(sr_x, grr_x) \land isPresentedAs(sr_y, grr_y) \land$$
$$isMoreGeneralThan(grr_x, grr_y) \rightarrow \bot(m_x)$$

This rule enforces that the ontology becomes inconsistent if

- there exist maps m_1 and m_2 belonging to the same application with scales s_1 and s_2,
- scale s_1 is larger than scale s_2,
- maps m_1 and m_2 contain scaled representations sr_1 and sr_2 that represent the same geographic thing g, and
- the geographic representation record grr_1 for sr_1 is more general than the one for sr_2, namely grr_2.

$$sharesApplicationWith(m_x, m_y) \land hasScale(s_y, m_y) \land hasScale(s_x, m_x)$$
$$\land\ isLargerThan(s_x, s_y) \land$$
$$isConstituentOf(m_x, sr_x) \land isConstituentOf(m_y, sr_y) \land$$
$$representsObject(sr_x, g) \land representsObject(sr_y, g) \land$$
$$isPresentedAs(sr_x, grr_x) \land isPresentedAs(sr_y, grr_y) \land$$
$$isMoreGeneralThan(grr_x, grr_y) \rightarrow \bot(m_x)$$

$$hasScale^- \circ sharesApplicationWith \circ hasScale \sqsubseteq R_1$$
$$R_1 \sqcap isLargerThan \sqsubseteq R_2$$
$$isScaled \circ R_2 \circ isScaled \sqsubseteq R_3$$
$$isPresentedAs \circ isMoreGeneralThan^- \circ isPresentedAs^- \sqsubseteq R_4$$
$$representsObject \circ representsObject^- \sqsubseteq R_5$$
$$R_3 \sqcap R_4 \sqcap R_5 \sqsubseteq R_\bot$$
$$\exists R_\bot.\top \sqsubseteq \bot$$

Patterns TOC

- **Semantic Trajectories**
- **Biodiversity**
- **Map Scaling**
- **Part-of Relationships**

Source

Content taken from

Morton E. Winston, Roger Chaffin, Douglas Herrmann, A Taxonomy of Part-Whole Relations, Cognitive Science 11, 417-444, 1987.

and the OWL modeling from

Prateek Jain, Pascal Hitzler, Kunal Verma, Peter Yeh, Amit Sheth, Moving beyond sameAs with PLATO: Partonomy detection for Linked Data. In: Ethan V. Munson, Markus Strohmaier (Eds.): 23rd ACM Conference on Hypertext and Social Media, HT '12, Milwaukee, WI, USA, June 25-28, 2012. ACM, 2012, pp. 33-42.

part-of relationships

- the X is part of the Y
- X is partly Y
- X's are part of Y's
- X is a part of Y
- The parts of a Y include the Xs, the Zs, …

- The head is part of the body
- Bicycles are partly aluminum
- Pistons are part of engines
- Dating is a part of adolescence
- The parts of a flower include the stamen, the petals, etc. …

- "meronymic" relations ("meros" is greek for "part")

One could think that part-of is a binary relation which is

- a strict partial ordering, i.e.
  - transitive
    If X part of Y, and Y part of Z. Then X part of Z.
  - irreflexive
    X is never part of X.
  - antisymmetric
    If X part of Y. Then Y is never part of X.

However, this view is problematic.

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Simpson's finger is part of Simpson's hand.

Simpson's hand is part of Simpson's body.

Simpson's finger is part of Simpson's body.

This works, but the following doesn't:

Simpson's arm is part of Simpson.

Simpson is part of the Philosophy Department.

Hence(?) Simpson's arm is part of the Philosophy Department.

So when do we have transitivity?

Winston's approach

Distinguish 6 different types of meronymic relations:

1. component – integral object   (pedal – bike)
2. member – collection   (ship – fleet)
3. portion – mass   (slice – pie)
4. stuff – object   (steel – car)
5. feature – activity   (paying – shopping)
6. place – area   (Everglades – Florida)

Dimensions of meronymic relations

A type of part-of relationships

- **functional**
  Functional parts are restricted, by their function, in their spatial or temporal location.
  handle – cup

- **homeomerous**
  Homeomerous parts are the same kind of thing as their wholes.
  slice – pie
  but not tree – forest

- **separable**
  Separable parts can in principle be separated from the whole.
  handle – cup
  but not steel – bike

Dimensions

Relation	Examples	Relation Elements		
		Functional	Homeomerous	Separable
Component/ Integral Object	handle-cup punchline-joke	+	−	+
Member/ Collection	tree-forest card-deck	−	−	+
Portion/Mass	slice-pie grain-salt	−	+	+
Stuff/Object	gin-martini steel-bike	−	−	−
Feature/Activity	paying-shopping dating-adolescence	+	−	−
Place/Area	Everglades-Florida oasis-desert	−	+	−

From Winston et al., A Taxonomy of Part-whole Relations,
Cognitive Science 11, 417-444, 1987.

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- A handle is part of a cup.
- Wheels are parts of cars.
- The refrigerator is part of the kitchen.
- Chapters are parts of books.
- A punchline is part of a joke.
- Belgium is part of NATO.
- Phonology is part of linguistics.
- The viola part in a symphony.

Member – Collection

- A tree is part of a forest.
- A juror is part of a jury.
- This ship is part of a fleet.

Do not confuse with class – member relationships, such as

- The Nile is a river.
- Fido is a dog.

which are not part-of relationships.

class membership: determined on the basis of similarity to other members.

member – collection: determined on the basis of spatial proximity or by social connection.

Portion – Mass

- **This slice is part of a pie.**
- **A yard is part of a mile.**
- **This hunk is part of my clay.**

Homeomerous: Every portion of a pie is "pie".

(while, e.g., a window is quite unlike the house of which it is part.)

Portion – Mass

Can be distinguished from component – integral object by substituting the phrase "some of":

- She asked me for part of my orange. (… for some of my orange)

However *not*: The engine is some of the car.

This test won't distinguish from member – collection:

- Some of the fraternity brothers are sophomores.
  (this is the "count" sense of "some", not the "mass" sense)

However, for member – collection we can phrase it as:

- One of the brothers is a sophomore.

Stuff – Object

- A martini is partly alcohol.
- The bike is partly steel.
- Water is partly hydrogen.

By asking for: "What is it made of?"

(For component – integral object we would ask: "What are its parts?")

Stuff cannot be separated from the object.

Feature – activity

- **Paying is part of shopping.**

- **Bidding is part of playing Bridge.**

- **Ovulation is part of the menstrual cycle.**

- **Dating is part of adolescence.**

Features or phases of activities and processes.

Unlike the other types, in this case we cannot say "X has Y", such as for others in

- **Sororities have members.**

- **Bicycles have pedals**

- **Plays have acts.**

E.g. we cannot say "Shopping has paying".

Place – Area

- **The Everglades are part of Florida.**
- **An oasis is a part of a desert.**
- **The baseline is part of a tennis court.**

- **Topological Inclusion**
  - The wine is in the cooler.
  - The meeting is in the morning.
  - Careful: "The Everglades are part of Florida" is meronymic. But "West Berlin is part of East Germany" is wrong. [Note paper was written 1987.]
- **Class Inclusion**
  - Cars are a type of vehicle.
  - Theft is a crime.
  - Careful: "Frying is a type of cooking" is meronymic, as is "Honesty is a type of virtue".

- **Attribution**
  - Towers are tall.
  - Coal burns.
  - The joke was funny.
- **Attachment**
  - Earrings are attached to ears.
  - Fingers are attached to hands.
    (note: they are also parts of hands)
- **Ownership**
  - A millionaire has money.
  - The author has the copyright.
  - Jenny has a bicycle.

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Simpson's hand is part of Simpson's body.

Simpson's finger is part of Simpson's body.

This works, but the following doesn't:

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Simpson is part of the Philosophy Department.

Hence(?) Simpson's arm is part of the Philosophy Department.

Winston argues: If we combine two sentences with the same type of meronymic relation, then we have transitivity.
Indeed, in all mixed cases, counterexamples to transitivity can be found (given in the paper).

Other properties – and some OWL modeling

Winston et al. list several properties of meronymic relations.

First some notation for the 6 types of part-of relations:

- po-component
- po-member
- po-portion
- po-stuff
- po-feature
- po-place

PO is the set containing these six binary relations.

- part-of: The "general" part-whole relation.
- spatially-located-in: topological located-in relationship

1. For all R $\in$ PO, R is transitive, asymmetric, and irreflexive (i.e., a strict partial order).
2. For all R $\in$ PO, R $\sqsubseteq$ part-of.
   Does not imply transitivity of part-of.
3. spatially-located-in is transitive and reflexive.
4. For all R $\in$ PO, we have
   - R $\circ$ spatially-located-in $\sqsubseteq$ spatially-located-in
   - spatially-located-in $\circ$ R $\sqsubseteq$ spatially-located-in
5. For all R $\in$ PO $\cup$ {spatially-located-in} and all classes C, we have $(\forall x)(\forall y)(R(x,y) \land C(y) \rightarrow (\exists z)(R(x,z) \land C(z)))$.
6. For all R $\in$ PO $\cup$ {spatially-located-in} and all classes C, we have $(\forall x)(\forall y)(C(y) \land (C(y) \rightarrow R(x,y)) \rightarrow R(x,y))$.

Note: 5+6 are tautologies, so need not be modeled in OWL.

Meronymic relations in OWL

1. For all R $\in$ PO, R is transitive, asymmetric, and irreflexive (i.e., a strict partial order).

2. For all R $\in$ PO, R $\sqsubseteq$ part-of.
   Does not imply transitivity of part-of.

3. spatially-located-in is transitive and reflexive.

4. For all R $\in$ PO, we have
   - R $\circ$ spatially-located-in $\sqsubseteq$ spatially-located-in
   - spatially-located-in $\circ$ R $\sqsubseteq$ spatially-located-in

This results in a total of 36+26+2+62 = 44 axioms, all expressible in OWL 2.

However, there is a catch!

A Catch

1. For all R $\in$ PO, R is transitive, asymmetric, and irreflexive (i.e., a strict partial order).

   Problem: A relation in OWL 2 DL cannot be transitive and reflexive at the same time:
   A transitive property is complex, and thus not simple. However only simple properties are allowed to be irreflexive.

   So: this ends up in OWL 2 Full.

   Straightforward fix:
   Drop irreflexivity. This will probably work in most cases.

   Better fixes are based on rules or nominal schemas (covered later in class).

All properties occuring in the above given part-of ontology are complex (i.e., non-simple).

OWL 2 has global restrictions on the use of such properties.

This hampers modeling, and may yield to OWL 2 Full ontologies after all desired relationships have been modeled.

Another problem: Regularity conditions may become violated if merging the part-of ontology with a domain ontology.

Fixes: as above (drop some axioms)

Better: rules or nominal schemas (covered later in class).

We have several issues with modeling the part-of ontology following Winston.

E.g., relations cannot be transitive, asymmetric, and irreflexive at the same time.

We can now approximate this as follows:

Characterize the relation (e.g., R) as transitive and asymmetric.

Furthermore, specify $\{x\} \sqcap \exists R.\{x\} \sqsubseteq \bot$.

More generally, if you run into a rule which you cannot model in OWL, simply approximate using nominal schemas.

References

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