

Usages de la méréologie en ontologie appliquée

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1 Mereology: from mathematics to metaphysics

- Lesniewski 1927-1931, On the Foundations of Mathematics
- Contemporary work in metaphysics: study of **the formal** parthood relation [Simons, 1987; Varzi, 2015], among others
- Basic assumptions on mereology in metaphysics:
 - (A) Applies to all that there is without restrictions (Husserl's sense of formal): a single parthood relation between entities of any kind
 - (B) Captures the structure of reality: a fundamental relation in formal ontology supplying existential and identity claims
- Assumption often (implicitly) adopted in Applied Ontology and in NL semantics, added to (B):
 - (C) Our commonsense concept of part and how it is expressed in NL reflects the structure of reality, and mereology directly and adequately models it

2 Purpose of this talk

- Show that mereology needs not be taken so “seriously”, especially in “applied” disciplines
- Dropping some or all of (A)-(C), mereology can be more simply taken as a family of theories which, when adequately chosen and supplemented by others, can account for a variety of phenomena

3 Outline

- Mereology in a nutshell
- Criticisms of general extensional mereology and some coping strategies
- A glance at part-whole relations in language
- Focus on “dot objects” and complex categories

Mereology in a nutshell

4 Basic Mereology

- parthood relation P : **partial ordering** axiomatized in FOL with identity

$$(M1) \quad \forall x P(x, x)$$

$$(M2) \quad \forall xyz ((P(x, y) \wedge P(y, z)) \rightarrow P(x, z))$$

$$(M3) \quad \forall xy ((P(x, y) \wedge P(y, x)) \rightarrow x = y)$$

$\mathbf{M} : M1, M2, M3$

- Definitions

$$PP(x, y) \equiv (P(x, y) \wedge \neg P(y, x))$$

$$O(x, y) \equiv \exists z (P(z, x) \wedge P(z, y))$$

$$PO(x, y) \equiv O(x, y) \wedge \neg P(x, y) \wedge \neg P(y, x)$$



5 Mereologies

- Obviously, a partial ordering can represent many relations (order between weights, numbers, times, preferences...)
- Need to specify further. Several ways to specify, several (families of) mereologies:
 - ▶ Supplementation, Extensionality
 - ▶ Sums, products, differences, complements
 - ▶ General fusion
 - ▶ Atomicity, divisibility
- Extensions: mereotopologies, mereogeometries
- [Varzi, 1996; Masolo and Vieu, 1999; Borgo and Masolo, 2010]

6 Extensional Mereology

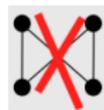
- Weak Supplementation ► minimum mereology $\mathbf{M} + (M4)$

$$(M4) \quad \forall xy (PP(x, y) \rightarrow \exists z(P(z, y) \wedge \neg O(z, x)))$$



- Strong Supplementation

$$(M5) \quad \forall xy (\neg P(x, y) \rightarrow \exists z(P(z, y) \wedge \neg O(z, x)))$$



- Extensionality

$$(E1) \quad \forall xy ((\exists z PP(z, x) \wedge \forall z(PP(z, x) \leftrightarrow PP(z, y))) \rightarrow x = y)$$

$$(E2) \quad \forall xy (\forall z(O(z, x) \leftrightarrow O(z, y)) \rightarrow x = y)$$

- Theorems

$$\mathbf{M}, (M4) \vdash (E1) ; \mathbf{M}, (M5) \vdash (M4) ; \mathbf{M}, (M5) \vdash (E2)$$

- $\mathbf{EM} = \mathbf{M} + (M5)$

7 Boolean operators: “closure mereology”

- Product

$$(M6) \quad \forall xy (O(x, y) \rightarrow \exists z \forall u (P(u, z) \leftrightarrow (P(u, x) \wedge P(u, y))))$$

- ▶ z is **the** product of x and y , noted $x \bullet y$



- Sum

$$(M7) \quad \forall xy \exists z \forall u (O(u, z) \leftrightarrow (O(u, x) \vee O(u, y)))$$

- ★ Unicity with extensionality (*E2*)

- ▶ z is **the** sum of x and y , noted $x + y$



- Similarly for difference and universe, complement is derived.

8 General Extensional or Classical Mereology

- General fusion

$$(M6') \exists x \phi(x) \rightarrow \exists z \forall y (\mathbf{O}(y, z) \leftrightarrow \exists x (\phi(x) \wedge \mathbf{O}(y, x)))$$

- ▶ axiom schema, useful only in infinite domains
- ▶ unicity guaranteed by (E2), z noted $\sigma x \phi(x)$
- Definitions for product, sum, complement, universe
- General extensional mereology

GEM : **M** + (M5) + (M6')

has for models Boolean algebras without null element [Tarski, 1935]

9 Main criticisms of GEM

- Extensionality questioned
 - ▶ gaining or losing parts across time, identity across time (Tibbles, ship of Theseus)
 - ▶ identity between a single object and the collection of its parts, e.g., *my body* and *the collection of my organs*, *the flock* and *the sheep*
 - ▶ more generally, co-located or coincident entities of different types: *the statue* and *the clay*, *me* and *my life*...
- Existence of sums questioned
 - ▶ scattered sums across space-time *my nose* and *Julius Caesar's left foot*
 - ▶ fusion: scattered infinite sums
 - ▶ sums between categories? *my nose* and *the outbreak of WWII*, *my nose* and *number 3*
- Even transitivity is questioned
 - ▶ *my arm*, *me*, *the committee* ; *the handle*, *the door*, *the building*

10 Some coping strategies-1

- Weaken the theory
 - ▶ Drop extensionality, and even drop the weak supplementation principle [Donnelly, 2011]
explicitly drops (A) as well
functionality of sums lost
 - ▶ Weakening the partial ordering is rarely proposed
- Distinguish parthood from other relations (solves some extensionality issues) [Rea, 1997; Masolo *et al.*, 2003]
 - ▶ Constitution: *the clay constitutes the statue*, it is not part of it
 - ▶ Participation: *I participate to my life*, I'm not part of it

11 Some coping strategies-2

- Go fully 4D (solves Tibbles's puzzle) Sider [2003]: against (A)
see also [Aurnague and Vieu, 1993b; Aurnague *et al.*, 1997]
- Temporalize parthood over objects, but not over events nor abstracts (solves Tibbles's puzzle) [Masolo *et al.*, 2003]: against (A)
 - ▶ $P(x, y)$
 - ▶ $P(x, y, t)$
- Restrict the application of general parthood to homogeneous categories. No object part of event, no amount of matter part of physical object, and vice-versa (partially solves the sums issue) [Masolo *et al.*, 2003]: against (A)
- Distinguish various parthood relations depending on the types of arguments [Mellor 2006]: against (A)
see also [Aurnague *et al.*, 1997; Vieu and Aurnague, 2007]

12 Some coping strategies-3

- Distinguish various parthood relations, to match various semantics of parthood expressions in language (partially solves the transitivity issue): against (C) and possibly (A)
 - ▶ Plurals and mass
Link's seminal account [1983] exploits *two* (related) partial orderings: one that may be seen as the general parthood, and an atomic one for plurals
 - ▶ Parthood expressions and ϕ -parts
 $\phi\text{-part}(x, y) \equiv P(x, y) \wedge \phi(x, y)$ [Simons, 1987; Varzi, 2006; Vieu, 2006]
see also [Winston *et al.*, 1987; Gerstl and Pribbenow, 1996; Vieu and Aurnague, 2007]
- Drop (B) to exploit mereology for NL semantics beyond parthood expressions, e.g., P as *spatio-temporal inclusion* with identity substituted for co-location in (M2) [Aurnague and Vieu, 1993b; Aurnague *et al.*, 1997]

A glance at part-whole relations in language

13 Multiple part-whole relations

- Winston *et al.* [1987] distinguish several parthood relations
 - ▶ component-integral object (*handle-door, engine-car*)
 - ▶ member-collection (*ship-fleet, tree-forest*)
 - ▶ portion-mass (*slice-pie*)
 - ▶ stuff-object (*steel-bike, sugar-bottle of syrup*)
 - ▶ feature-activity (*paying-shopping*)
 - ▶ phase-process (*adolescence-growing up*)
 - ▶ place-area (*oasis-desert*)
- Hypotheses that each relation is transitive, and that transitivity is blocked across relations: actually both are **false**

14 Ontological grounds for Part-whole relations variety - 1

Vieu and Aurnague [2007]

basis: P as a spatio-temporal inclusion + added constraints

- Number (plurals and collections): additional mereological order + Constitution cf. [Link, 1983]
 - ▶ Member-Collection (*tree-forest, cow-herd*)
 - ▶ Subcollection-Collection (*Benelux-EU*)
- Categories (Substance, Amount of matter, Physical object) + Constitution
 - ▶ Portion-Whole (*slice-pie*)
 - ▶ Substance-Whole (*steel-bike, sugar-bottle of syrup*)
 - ▶ Event parthood? Location parthood? → Component-IntegralWhole
- Mereotopology: Connectedness (spatio-temporal sense)
 - ▶ Piece-Whole (*south hemisphere-earth, bottom-wardrobe*)

15 Ontological grounds for Part-whole relations variety - 2

- Generic functional dependence between **lexical terms**
 - ▶ Component-IntegralWhole (*tête-lit*, ??*tête-meuble*)
- A Part-of B: at least two possible meanings
 - ▶ A Part-of-1 B iff $\forall x (A(x) \rightarrow \exists y (B(y) \wedge P(x, y)))$
nucleus-cell, hand-arm, roof-building
 - ▶ A Part-of-2 B iff $\forall y (B(y) \rightarrow \exists x (A(x) \wedge P(x, y)))$
membrane-cell, hand-arm, wall-building, roof-building, wheel-car
 - ▶ *handle-door*: indirect dependence *handle*-“something movable by hand” (for instance, a door)
- Added notion of “being in use” (function)

Mereology for complex categories and dot objects?

[Arapinis and Vieu, 2014]

16 Inherent polysemy, a linguistic phenomenon

- **inherent nominal polysemy**³ \subset **logical polysemy**² \subset **systematic polysemy**¹
(Pustejovsky's terminology)

¹ Systematic patterns of conceptual relations (e.g. metonymy)

CLIENT/ORDER: the ham-sandwich left without paying

² Lexicalized complementary senses with overlapping, dependent, or shared meanings (e.g. selectional polysemy)

PHYSICAL OBJECT/SUBSTANCE: I bought an apple vs. You have apple on your shirt

³ Inherent senses constitutive of the complex word-meaning, definitional of the kind of entity denoted

TOME/TEXT: the book is on the table vs. the book is complex

17 Linguistic tests for inherent polysemy

- **Copredication** tests show that there is a single referent or ontological correlate despite the predicates' contradictory selectional restrictions

*This thick **book** is incomprehensible:* physical object and information object

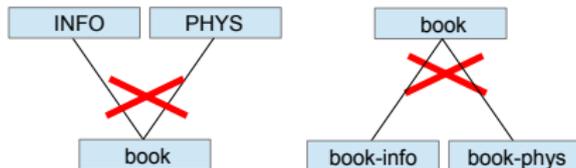
*The **inflammation** is acute and visible to the naked eye:* process and physical object

*The **university** in the city center specializes in humanities:* building and institution (and staff)

*Brazil is a large two-century-old portuguese-speaking **country**:* land, institution, people

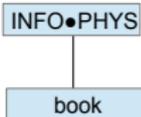
18 What inherent polysemy isn't

- It is **not conjunction**: categories of “aspects” are most often disjoint, conjunction would yield inconsistency
In a taxonomy of classes representing nouns, multiple inheritance cannot do
- It is **not disjunction**, not a simple polysemy: aspects are present “together” and selecting one aspect with a predication doesn't rule out the other aspect
In a taxonomy of classes representing nouns, subsumption cannot do



- [Pustejovsky, 1995] and [Asher, 2011] argue that “dual-aspect” nouns denote entities having **complex types** (or dot types) called **dot objects**

book is of type $INFO \bullet PHYS$



19 Polysemy beyond the linguistic phenomenon

- Concepts are often accessed through language: polysemy is known to affect ontology construction, even when the ontology is not built from texts.
- Ill-defined classes associated to nouns presenting standard inherent polysemy found in many ontologies and lexicons
 - ▶ *sawm%1:09:00* in WordNet: ambiguous between the activity of fasting that is prescribed by Islam and the principle which dictates when to practice it
- Inconsiderate use of multiple inheritance from disjoint categories.

20 Need for complex categories-1

- Can we eliminate all such incoherences by a careful identification of well-defined “simple” categories?
- Difficult in many cases, the tight dependence between “aspects” is lost
 - ▶ *letter%1:10:00* in WordNet: inherits from both *text%1:10:00* (abstract) and *document%1:06:00* (physical object)
 - ▶ Libraries in DBpedia: both buildings (place) and educational institutions (agent)
 - ▶ Diabetic Cataract in UMLS: both a “disease or syndrome” (process) and an “anatomical abnormality” (physical object)

21 Need for complex categories-2

- What to do with individuals?
 - ▶ 0 “*Brazil*” and 3 *Brazil-territory*, *Brazil-state*, and *Brazil-nation* or 1 “*Brazil*” arbitrarily picked among these?
 - ▶ in WordNet, *country%1:15:00* as location and *country%1:14:01* as people, but individual countries are unique, instances of *country%1:15:00*. Makes membership between citizens and their countries (e.g., Ethiopian member of Ethiopia) meaningless [Verdezoto and Vieu, 2011]
- What to do with properties that apply to several aspects at once?
 - ▶ What do you *read*: the information or the physical artifact?
 - ▶ What do you *diagnose* and *treat*: the physical symptom or the disease?

22 Clean ontologies need complex categories

- The question is not how to avoid stumbling on the linguistic phenomenon of inherent polysemy by properly identifying classes of homogeneous individuals belonging to a single top-level category
- The question rather is how to deal with the conceptual and ontological issues underlying this linguistic phenomena and inevitably appearing within our ontologies
 - ▶ We need to accommodate complex categories in ontologies
 - ▶ We need to accommodate complex individuals, i.e., dot objects, in ontologies
- How to do so?

23 Ontological grounds for dot objects and complex categories

- Language is often arbitrary. But no arbitrariness for inherent polysemy like for homonymy (*bank* – financial institution / *bank* – river side).
No two senses can be glued up to refer to dot-objects at will
- [Arapinis, 2013] argues that inherent polysemy arises only when there are **dependence** relations [Fine, 1995; Correia, 2008] involved, and that the dot-object is related to its aspect components through a kind of **constitution** relation [Rea, 1997; Baker, 1999]
 - ▶ Rigid Existential Dependence
 $x \text{ RED } y =_{df}$ Necessarily, x exists only if y exists
This book RED its information content
 - ▶ Generic Existential Dependence
 $x \text{ GED } A =_{df}$ Necessarily, x exists only if some A exists
The University of Toulouse GED professors, students, etc.
The information content of this book GED its copies

24 Beyond material constitution

- Traditionally, constitution requires vertical material coincidence between the constituting and constituted entity
- The constitution of a dot entity places a horizontal requirement of coincidence between aspects (the vertical is derivatively obtained)
Concrete categories glued only when spatio-temporal **coincidence** occur
 - ▶ *country*: people (usually) located on land
 - ▶ *university, newspaper*: staff (usually) working in building
 - ▶ *newspaper*: institutional building and paper copy **cannot** be glued together
- Concrete coincidence can be extended to cover abstract categories as well
 - ▶ *book, newspaper*: text physically realized on paper
 - ▶ *university*: staff acting on behalf of the institution

25 Dot objects

- Two formal approaches to dot objects
- Asher's proposal [Asher, 2011]:
 - ▶ dot objects are **primary entities**, aspects are derived through a kind of *qua*-construction
- Mereological account (suggested but not developed by [Cooper, 2006]):
 - ▶ dot objects are **mereological sums** of their aspect components
 - ▶ dot-objects (of complex categories) and their aspect components (of simple categories) are citizens of the ontology on an equal footing, linked by a kind of mereological composition

26 Asher's objections to a mereological account

- Aspects are not parts, i.e., no parthood expression is able to pick them up
 - ▶ “Normal parts of objects have names and can be referred to. This isn't true of the inhabitants of ●-types like lunches. This should lead us to be suspicious of this view.”
 - ▶ Not all parts have names, some aspects do have names
- Mereology gets identity criteria wrong
 - ▶ More precisely, it gets counting books wrong, as it posits objects (sums) that we never count when we count books
 - ▶ Misses the coincidence constraint between entities joined in a dot

27 Does mereology get identity criteria wrong?

- Two many sums, classical argument against fusion in **GEM**
 - ▶ A problem for the ontologist assuming Mereology strictly captures the structure of reality (B), not a problem for those who take it as a formal tool
 - ▶ No need to assume that “all that there is” is part of the domain of discourse and can be named in language (against strong version of (C))
 - ▶ Even without (B) (and (C)), no need to assume the dot operator *just* is the general mereological sum
- Not all sums of *book-PHYS* and *book-INFO* are instances of *book-PHYS•INFO*
 - ▶ **Restriction** to those entities that have been glued together by the printing process, the physical realization of the text on paper
 - ▶ With this “glue” constraint made explicit, right sums

28 Towards a mereological account of ●

- The general mereological **sum operator**: +
 - ▶ to be clarified if **GEM** is adequate
- The general **coincidence** relation C
 - ▶ various sorts of coincidence depending on the categories of entities involved (strict spatio-temporal colocation or some looser variant)
 - ▶ coincidence implies a sort of dependence between (at least) one aspect component and the other(s)
lunch: participation (both ways dependence), *book*: dependence of the phys-book on the info-book
- Let A and B be two categories. The complex category $A \bullet B$ is so constrained:
$$\forall x (A \bullet B(x) \leftrightarrow \exists yz (A(y) \wedge B(z) \wedge x = y + z \wedge (C(y, z) \vee C(z, y))))$$
- $\forall xyz (x = y + z \wedge C(y, z)) \rightarrow (C(x, y) \wedge C(x, z))$

29 Concluding regarding complex categories

- Inherent polysemy is a linguistic phenomenon emerging from conceptual and ontological grounds
- Issues related to inherent polysemy is pervasive in existing ontologies, linguistically oriented or not, and even appears in those relying on foundational ontologies
- To build clean, coherent, ontologies as well as well-founded lexicons, we need to recognize the phenomenon and introduce complex categories and dot-objects in ontologies
- Mereological sum together with coincidence are “standard” formal ontology tools that appear adequate to do this. Renouncing though to principle (B).
- Future work
 - ▶ Which mereology, which general coincidence relation
 - ▶ Predicting complex categories
 - ▶ Subsumption relations between dot categories

30 General conclusions

- Mereology proves useful in many areas of applied ontology including NL semantics, provided we take distance with standard ontological assumptions in metaphysics, as well as, the too often taken for granted assumption that the various manifestations of parthood in language directly denote the mereological relation, without restrictions nor calling for other ontological relations.
- When mereology is supplemented by varieties of dependence relations (functional dependence; constitution, participation, and other “coincidence” relations), it can adequately model puzzling linguistic phenomena.

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