The Meaning of Part

Stefan Schulz
Department of Medical Informatics
University Hospital Freiburg (Germany)
# Relations in Biomedical Terminologies / Ontologies

## Part-Of

<table>
<thead>
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<th>Purpose-Specific Relations in Clinical Terminologies</th>
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<td>Foundational Relations in Formal Ontologies</td>
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- **Algebraic Properties:**
  - *Part-of*: Transitive, Reflexive, Antisymmetric
  - *Proper-Part-Of*: Transitive, Irreflexive, Asymmetric
- **Mereological Principles:**
  - Sum, Product, Supplementation, Extensionality, Proper Part Principle...
  
  P. Simons, Casati & Varzi

- **Subrelations:**
  - *direct-part-of*, *functional-part-of*, *component-of*, *subdivision-of*, *boundary-of*, ...

  Galen, FMA
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P. Simons, Casati & Varzi

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                • Mereological Principles:  
                                Sum, Product, Supplementation, Extensionality, Proper Part Principle...  
                • Subrelations:  
                                direct-part-of, functional-part-of, component-of, subdivision-of, boundary-of, ...  
                P.Simons, Casati & Varzi |                                                                                       |
<p>| Classes,      |                                                                                   |                                                                                       |
|               |                                                                                   |                                                                                       |</p>
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<td>Parts and Processes</td>
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Example I

Parts and Time
Example II

Parts and Time
Two views

1. The tooth is no longer considered part of the dental arcade after extraction: $d = d'$
   
   Problem: it has still some kind of relation with the dental arcade. Which one?

2. The tooth continues being considered a (now disconnected) part of the dental arcade even after extraction: $d = d' + t \rightarrow d \neq d'$
   
   Problem: what is then the spatial extension of the dentition? Is the dental arcade no longer the same?
Historic Parthood

Don’t take historic parthood for parthood
“bone (in an archeologic site) forming part of a skeleton...”
“transplanting part of a liver...”
“sample of gastric mucosa of patient X was examined”

Time-indexed parthood:
\( \text{part-of} \ (a, b, t) \)

Historic parthood:
\( \text{hist-part-of} \ (a, b) = \text{def } \exists t, u: \text{part-of} \ (a, b, t) \land \neg \text{part-of} \ (a, b, u) \land \text{earlier} (t, u) \)
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Regions

- At every moment in time a spatial object is located in a single region of space.
- At different moments spatial objects may be located in different regions.
At every moment in time a spatial object is located in a single region of space.

At different moments spatial objects may be located in different regions.
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Regions

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Regions

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- At different moments spatial objects may be located in different regions.
Parthood and Spatial Inclusion

- $R(z)$  
  $z$ is a region in space

- $z = r(x, t)$  
  $z$ is the region where $x$ is located at $t$

- $part-of(x, y, t) \rightarrow part-of(r(x,t), r(y,t))$

  (Donnelly, IJCAI 03)

- Spatial inclusion (coverage, (partly) location,...)

- $spatially-included(x, y, t) =_{def} part-of(r(x, t), r(y,t))$

  $x$ is spatially included by $y$ at $t$
Phagocytosis / Digestion

Objects: Cell, Virus
Phagocytosis / Digestion

Regions: Space occupied by Cell, space occupied by Virus

\[
\text{part-of} \ (r \ (v, \ t_3), \ r \ (c, \ t_3))
\]
General Problem

- Parthood always implies spatial inclusion, but spatial inclusion does not always imply parthood:
  \[ \text{part-of} \ (x, y, t) \rightarrow \text{spatially-included} \ (x, y, t) \]

- Under which circumstances \( \phi \) can we infer parthood from spatial inclusion? When does inclusion without parthood obtain?
  \[ \text{spatially-included} \ (x, y, t) \wedge \phi \rightarrow \text{part-of} \ (x, y, t) \]
  \[ \text{spatially-included} \ (x, y, t) \wedge \phi' \rightarrow \neg \text{part-of} \ (x, y, t) \]
Inferring part from spatial inclusion: 1. Sortality

Rules out objects of certain sort as parts:

- **x is material, y is immaterial:**
  \[
  \text{Solid} \ (x) \land \text{Hole} \rightarrow (y) \land \text{spatially-included} \ (x, y) \rightarrow \neg \text{part-of} \ (x, y)
  \]
  \[
  \text{spatially-included} \ (\text{myBrain}, \text{myCranialCavity}) \rightarrow
  \neg \text{part-of} \ (\text{myBrain}, \text{myCranialCavity})
  \]

- **x is an non-biological artifact:**
  \[
  \text{spatially-included} \ (\text{myPacemaker}, \text{myBody}) \rightarrow
  \neg \text{part-of} \ (\text{myPacemaker}, \text{myBody})
  \]
  \[
  \text{spatially-included} \ (\text{myInlay}, \text{myTooth}) \rightarrow
  \neg \text{part-of} \ (\text{myInlay}, \text{myTooth})
  \]
Inferring part from spatial inclusion: 2. Genetic Identity

Rules out objects of different genetic origin:

- **Symbionts:**
  \[\text{spatially-included} \ (\text{anEcoliBacterium}, \ \text{myIntestine}) \rightarrow \neg \text{part-of} \ (\text{anEcoliBacterium}, \ \text{myIntestine})\]

- **Parasites:**
  \[\text{spatially-included} \ (\text{anEchinococcus}, \ \text{myLiver}) \rightarrow \neg \text{part-of} \ (\text{anEchinococcus}, \ \text{myLiver})\]

- **Preys:**
  \[\text{spatially-included} \ (\text{anElephant}, \ \text{aSnake}) \rightarrow \neg \text{part-of} \ (\text{anElephant}, \ \text{aSnake})\]

- **Embryos, Fetuses:**
  \[\text{spatially-included} \ (\text{Leonardo}, \ \text{Caterina}) \rightarrow \neg p \ (\text{Leonardo}, \ \text{Caterina})\]
3. Life Cycle patterns which allow to assert parthood:

- aGlycinMolecule, aCollagenFiber
- aCytoplasm, aCell
- aGlioblastoma, aBrain

Parts and Regions
3. Life Cycle patterns which allow to rule out parthood:

- *aWaterMolecule, aCell*

- *aBrainMetastasis, aBrain*

  but: part-of what?
4. Essential for function

- **Transplants**

\[
\text{functionally\_related (aTransplant, anOrganism)} \\
\land \text{spatially\_included (aTransplant, anOrganism) } \rightarrow \\
\text{part-of (aTransplant, anOrganism)}
\]

- **Body Substances:**

\[
\text{functionally\_related (myCSF, myCNS)} \\
\land \text{spatially\_included (myCSF, myCNS) } \rightarrow \\
\text{part-of (myCSF, myCNS)}
\]

... but not: \text{part-of (thisVolumeOfUrine, myBladder)}, because not essential for function
Inferring part from spatial inclusion: Decision algorithm

If located_in (c, d, t)
  If Artifact(c) then
    contained_in(c, d, t)
  Else
    If functionally_related (c, d, t) then
      part_of (c, d, t)
    Else
      If not same_genetic_origin (c, d) or
      (material (c) and immaterial (d)) then
        contained_in (c, d, t)
      Else
        If originates_in (c, d) or
        originates_in (c, m) and part_of (m, d, t) then
          part_of (c, d, t)
        Else
          contained_in (c, d, t)
      End If
  End If
End If
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Part-of between individuals and universals (classes)

- myThumb part-of myHand
- Italy part-of Europe
- Thumb part-of Hand

Individuals

Classes
### Do Classes or Concepts Have Parts?

#### UMLS Metathesaurus: MRREL table

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Do Classes Have Parts?

“Axon part-of Cell” (Gene Ontology)
- Do cells without axons exist?
- Do axons without cells exist?

“Axon part-of Neuron” (FMA)
- Does every neuron has an axon?

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Do Classes Have Parts?

“Axon part-of cell” (Gene Ontology)
- Do cells without axons exist?
- Do axons without cells exist?

“Axon part-of Neuron” (FMA)
- Does every neuron have an axon?

“Keep in mind that part_of means can be a part of, not is always a part of “

“The part_of relationship (...) is usually necessarily is_part””
GO Editorial Style Guide, May 2005

“A part_of B if and only if: for any instance x of A there is some instance y of B which is such that x stands to y in the instance-level part relation, and vice versa”
Rosse & Smith MEDINFO 2004
# Class-level Part-Of: Different Interpretations

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<th>One-sided Dependency</th>
<th>Examples</th>
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<td>Prostate Tumor – Prostate</td>
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<td>Tooth – Human</td>
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Class-level Part-Of: Different Interpretations

- **One-sided Dependency**
  - Part on Whole
  - Examples:
    - Cell Nucleus – Cell
    - Uterus – Human Body
    - Prostate Tumor – Prostate

- **One-sided Dependency**
  - Whole on Part
  - Examples:
    - Sulfur – Methionin
    - Cell – Human Body
    - Connective Tissue – Liver

- **Mutual Mereological Dependency**
  - Examples:
    - Cell Membrane – Cell
    - Vertebra – Vertebrate
    - Brain - Head

- **Mereological Independency**
  - Examples:
    - Uterus – Mammal
    - Sulfur – Amino Acid
    - Tooth – Human
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Example

Surgical Procedure

Removal of foreign body from stomach

Removal of foreign body from stomach
by endoscopy

Removal of foreign body from stomach
by incision

Preparation for Endoscopy

Introduction of Endoscope

Exploration

Extraction of Endoscope

Removal of foreign body

Preparation for Surgery

Incision

Exploration

Removal of foreign body

Closure
Example

**Taxonomy of Processes**

**Surgical Procedure**

Removal of foreign body from stomach

- Removal of foreign body from stomach by endoscopy
  - Preparation for Endoscopy
    - Introduction of Endoscope
    - Exploration
  - Extraction of Endoscope
    - Removal of foreign body
- Removal of foreign body from stomach by incision
  - Preparation for Surgery
    - Incision
  - Exploration
  - Removal of foreign body
  - Closure
Example

Surgical Procedure

Removal of foreign body from stomach

Removal of foreign body from stomach by endoscopy

- Preparation for Endoscopy
- Introduction of Endoscope
- Exploration
- Extraction of Endoscope
- Removal of foreign body

Removal of foreign body from stomach by incision

- Preparation for Surgery
- Incision
- Exploration
- Removal of foreign body
- Closure

Mereology of Processes
What are the instances of processes? Concurrent views

1. A process is (sequentially) instantiated by its subprocesses:
   - Subprocesses do not exist simultaneously
   - You are doing something even if you have not done it (completely)

2. A process is instantiated by its temporal parts:
   - Before having performed the complete process it is open whether the process will really be completed
   - An aborted (token) process does not fulfill the necessary conditions which define the (type) process
Theory 1: Process is instantiated by its subprocesses

Boris Hennig, unpublished
Theory 2: Subprocesses are parts of their parent processes
Conflicting views in Medical Terminologies

Most procedure classifications (roughly Theory 1)

\[ \text{Process is subsumed by its subprocesses} \]

SNOMED CT (Theory 2)

\[ \text{Subprocesses are parts of their parent processes} \]

Removal of foreign body from stomach

- Incision of Stomach
  - Removal of foreign body from stomach by incision

Removal of foreign body from stomach by incision

- Incision of Stomach
  - Removal of foreign body from stomach
Rg (relation group) can be re-interpreted as has-part

\[
\text{RemovalOfForeignBodyFromTheStomachByIncision} \equiv \\
\exists \text{rg.}( \exists \text{hasProcedureSite.StomachStructure} \sqcap \\
\quad \exists \text{hasMethod.IncisionAction}) \sqcap \\
\exists \text{rg.}( \exists \text{hasProcedureSite.DigestiveStructure} \sqcap \\
\quad \exists \text{hasDirectMorphology.ForeignBody} \sqcap \\
\quad \exists \text{hasMethod.RemovalAction})
\]
Conclusions

- Parthood has multiple meanings
- Interoperability between ontologies and ontology based systems requires normative measures to avoid conflict between different meanings
- Spatial inclusion may be a “better” foundational relation for describing biological continuants
- Parthood between occurrents still requires thorough ontological enquiry
Thanks
Meaning of Part in Biomedical Ontologies

Mereological relations are fundamental for any formal ontological description of entities of the biomedical domain. A formal account of what part is and isn’t is an indispensable requirement for interoperability between human and software agents.
Basics


- part-of: transitive, reflexive, antisymmetric relation between individuals:
  - part-of (myThumb, myHand) & part-of (myHand, myBody) => part-of (myThumb, myHand)
  - part-of (myThumb, myHand) => NOT part-of (myHand, myThumb)
  - part-of (myThumb, myThumb)
Part-Of: derived relations

- **proper-part-of:**
  - proper-part-of (myThumb, myHand)
  - NOT proper-part-of (myThumb, myThumb)

more suitable for the biomedical domain, e.g.:
“partial resection of stomach” ≠ “total resection of stomach”

- **proper overlap**
  - sharing of proper parts
    overlap (myThorax, myVagusNerve)
    (“exclusive part-of”, cf. R. Schubert 1999)

unorthodox understanding of parthood-
not to be taken for parthood
Part-Of Subrelations (1)

- Partitions / Subdivisions:
  disjoint parts which jointly sum up to a whole
  (Bittner 2004)
  decomposition of the entire body or any anatomical
  structure in a given context (Mejino 2004)

- $p_1 = \{\text{my Body}\}$
- $p_2 = \{\text{my head, my neck, my torso, my limbs}\}$
- $p_3 = \{\text{my head, my neck, my torso, my left leg, my right leg, my left arm, my right arm}\}$
- $p_4 = \{\text{my head, my neck, my thorax, my abdomen, my left leg, my right leg, my left upper arm, my left lower arm, my right upper arm, my right lower arm}\}$
Part-Of Subrelations (2)

- (Functional) Components of integral compounds:
  - The part contributes to the whole not just as a structural unit but as essential to the purposeful activity of the whole (Pat Lambrix)
- How to define function?
Part-Of Variations (3)

- Collections, Partonomic Inclusion
  Uniform elements, e.g. blood, water, urine
  (Gerstl 1995, Bittner 2004)
- homomerous = parts are of the same sort
Part-of: Dimensionality

- part-of (a, b) requires $\dim(a) \leq \dim(a)$:
  - $\Rightarrow$ e.g. 2D boundaries can be part of 3D objects
- in Medicine: different conceptualizations, e.g. in the FMA boundaries cannot be part of 3D objects