

# **Parthood as Spatial Inclusion Evidence from Biomedical Conceptualizations**

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# Bio-Ontologies

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## Occurrents:

(Changes of) states of affairs of the physical world:

*Examples: disease process, procedure, action*

depend on

## Continuants:

Entities of the physical world

*("Biomedical Structure"):*

*Examples: body, organ, tissue, molecule,..*

# Domain ontologies of biomedical structure

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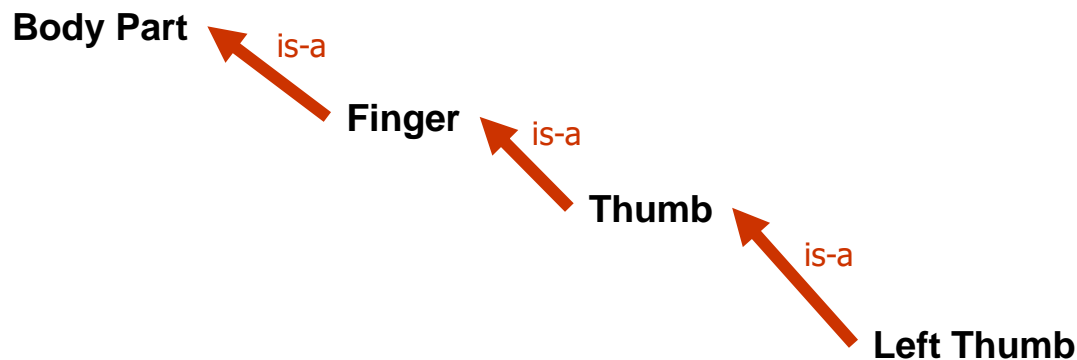
- **Gene Ontology: Cellular Component branch**  
(species independent) [www.geneontology.org/](http://www.geneontology.org/)
- **Foundational Model of Anatomy (FMA)**  
(canonic adult human) [sig.biostr.washington.edu/projects/fm/](http://sig.biostr.washington.edu/projects/fm/)
- **Open Biological Ontologies (OBO):**  
(drosophila, zebrafish, mouse [adult and embryonic stages]...) [obo.sourceforge.net](http://obo.sourceforge.net)
- **GALEN CORE anatomy**  
(clinical medicine) [www.opengalen.org](http://www.opengalen.org)
- **SNOMED anatomy branch**  
(human and vet medicine) [www.snomed.org](http://www.snomed.org)
- **UMLS Semantic Net (upper model)**  
(human and vet medicine) [www.nlm.nih.gov/pubs/factsheets/umlssemn.html](http://www.nlm.nih.gov/pubs/factsheets/umlssemn.html)

**Size: 14 (UMLS SN) –  $10^3$  (Adult Mouse) –  $10^5$  (FMA)**

# Common Denominator of different "anatomies"

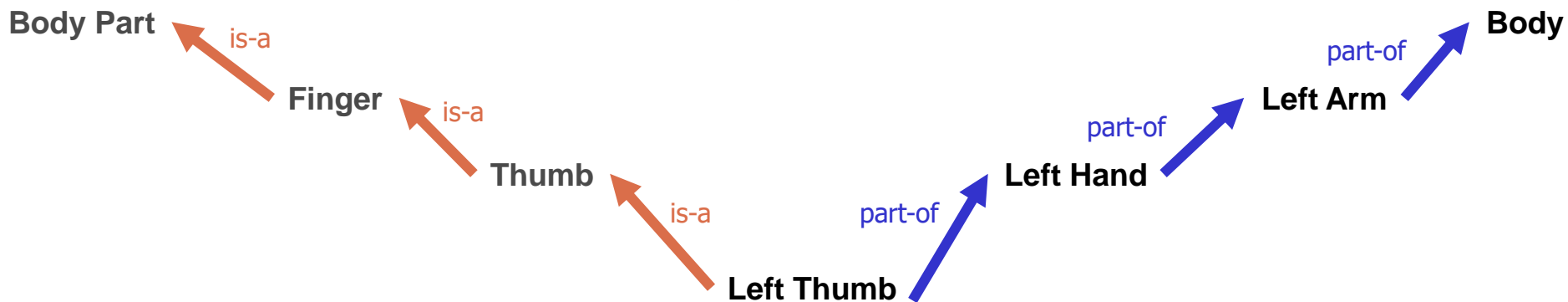
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- Concept - Oriented (make assertions about **classes** of individual objects)
- Binary Relations:  $Rel (C_1, C_2)$
- Two main hierarchy-building relations
  - Taxonomy:  $Is-A (C_1, C_2)$



# Common Denominator of different "anatomies"

- Concept - Oriented (make assertions about **classes** of individual objects)
- Binary Relations:  $Rel (C_1, C_2)$
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  - Taxonomy:  $Is-A (C_1, C_2)$
  - Partonomy:  $Part-Of (C_1, C_2)$



# Typical part-of related reasoning problem:

## ■ “Property inheritance” across mereologic hierarchies

*has-location (InsulinProduction, BetaCells)*  
*part-of (BetaCells, Pancreas)*

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*has-location (InsulinProduction, Pancreas)*



*has-location (Mitosis, EukaryoticCells)*

*part-of (EukaryoticCells, Pancreas)*

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*has-location (Mitosis, Pancreas)*



*amputation-of (ToeAmputation, Toe)*

*part-of (Toe, Foot)*

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*amputation-of (ToeAmputation, Foot)*



*inflammation-of (Glomerulonephritis, Glomerulum)*

*part-of (Glomerulum, Kidney)*

*inflammation-of (Nephritis, Kidney)*

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*is-A (Glomerulonephritis, Nephritis)*



*inflammation-of (Appendicitis, Appendix)*

*part-of (Appendix, Intestine)*

*inflammation-of (Enteritis, Intestine)*

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*is-A (Appendicitis, Enteritis)*



# Part-of in Biomedical structure models: Two Major Deficits

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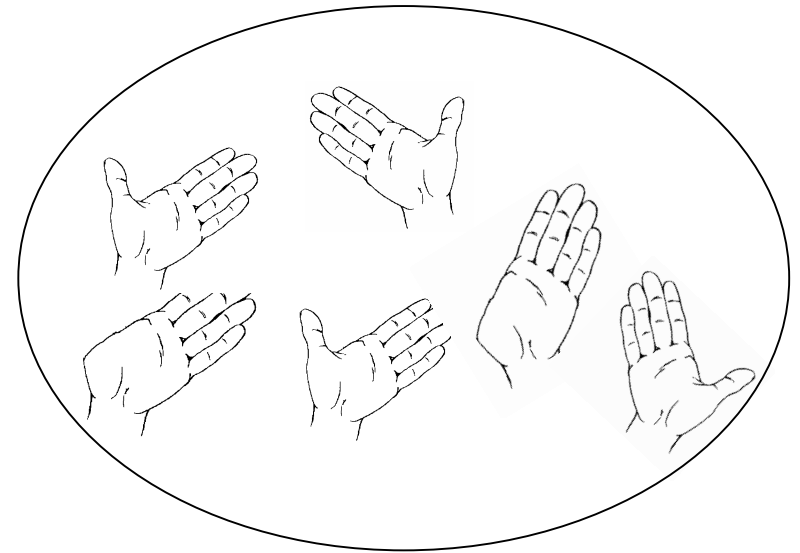
- Part-of originally relates individuals, but here it relates universals (classes of individuals, concepts)

# Part-of between individuals and universals

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*British Columbia* **part-of** *Canada*



*Thumb* **Part-Of** *Hand*



# Part-of in Biomedical structure models: Two Major Deficits

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- Unclear Semantics: part-of has locative, functional, temporal aspects

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- Unclear Semantics: part-of has locative, functional, temporal aspects

**Further Specification Needed !**

# Class-level Part-Of : Different Interpretations

	Class A (part)	Class B (whole)	Examples
<ul style="list-style-type: none"> <li>One-sided Mereological Dependency</li> </ul>		<ul style="list-style-type: none"> <li>Cell Nucleus – Cell</li> <li>Chlorophyll – Organism</li> <li>Prostate Tumor – Prostate</li> </ul>	
<ul style="list-style-type: none"> <li>Mutual Mereological Dependency</li> </ul>		<ul style="list-style-type: none"> <li>Sulfur – Methionin</li> <li>Wing – Chicken</li> <li>Heart – Drosophila</li> </ul>	
<ul style="list-style-type: none"> <li>Mereological Independency</li> </ul>		<ul style="list-style-type: none"> <li>Uterus – Mammal</li> <li>Sulfur – AMino Acid</li> <li>Tooth – Human</li> </ul>	
<ul style="list-style-type: none"> <li>Mereological Disjointness</li> </ul>		<ul style="list-style-type: none"> <li>Wing – Mouse</li> <li>Sulfur – Alanin</li> <li>Lung – Hand</li> </ul>	

# Part-Of between Classes: Different Interpretations

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# Definition: *Part-Of* / *Has-Part* vs. *part-of* / *has-part* (*proper-part*)

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## ■ Instance level :

$part-of(a, b), part-of(b, c) \rightarrow part-of(a, c)$

$part-of(a, b) \rightarrow \neg part-of(b, a)$

$part-of(a, b) \rightarrow a \neq b$

$part-of(a, b) \rightarrow has-part(b, a)$

## ■ Class level:

$Part-Of(A, B) =_{def}$

$\forall x: inst-of(x, A) \rightarrow \exists y: inst-of(y, B) \wedge part-of(x, y)$

$Has-Part(B, A) =_{def}$

$\forall y: inst-of(y, B) \rightarrow \exists x: inst-of(x, A) \wedge part-of(x, y)$

$Has-Part(B, A)$  does not necessarily imply  $Part-Of(A, B)$

# Part-of in Biomedical structure models: Two Major Deficits

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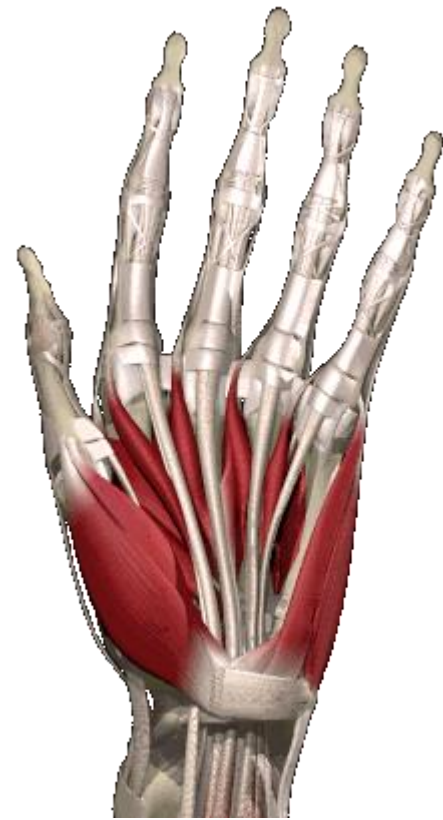
- Part-of originally relates individuals, but here it relates universals (classes of individuals, concepts)
- Unclear Semantics: part-of has locative, functional, time-dependent aspects

**Examples**

# Parthood or Location?

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*Part-Of (Finger, Hand)*

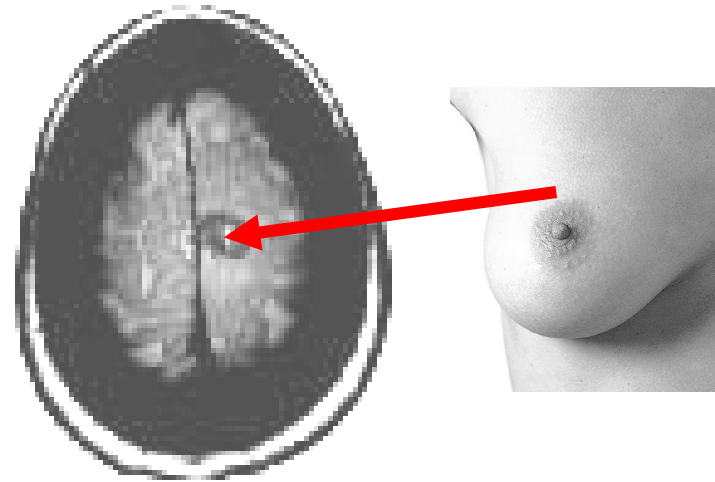


# Parthood or Location?

---

*Part-Of (Finger, Hand)*

*Part-Of (Brain Metastasis, Brain)*





# Parthood or Location?

---

*Part-Of (Finger, Hand)*

*Part-Of (Brain Metastasis, Brain)*

*Part-Of (Meningioma, Brain)*



# Parthood or Location?

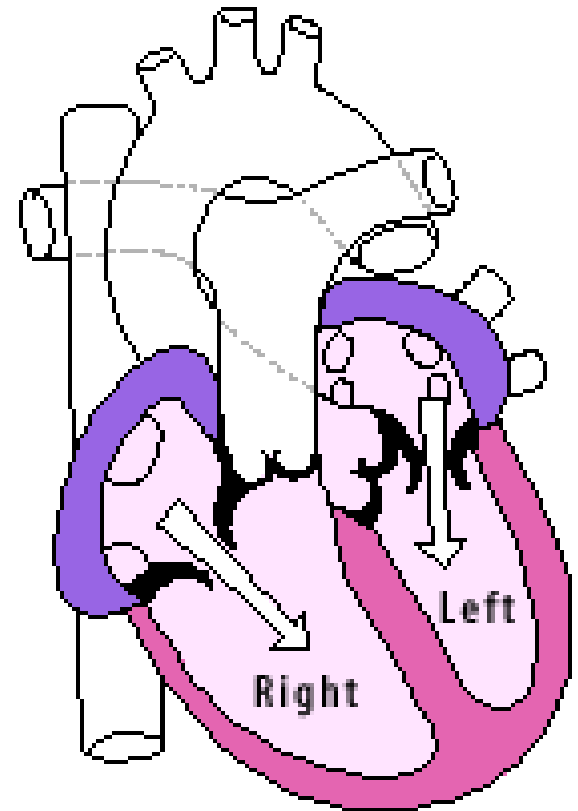
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*Part-Of (Finger, Hand)*

*Part-Of (Brain Metastasis, Brain)*

*Part-Of (Meningioma, Brain)*

*Part-Of (Right Ventricle, Heart)*



# Parthood or Location?

---

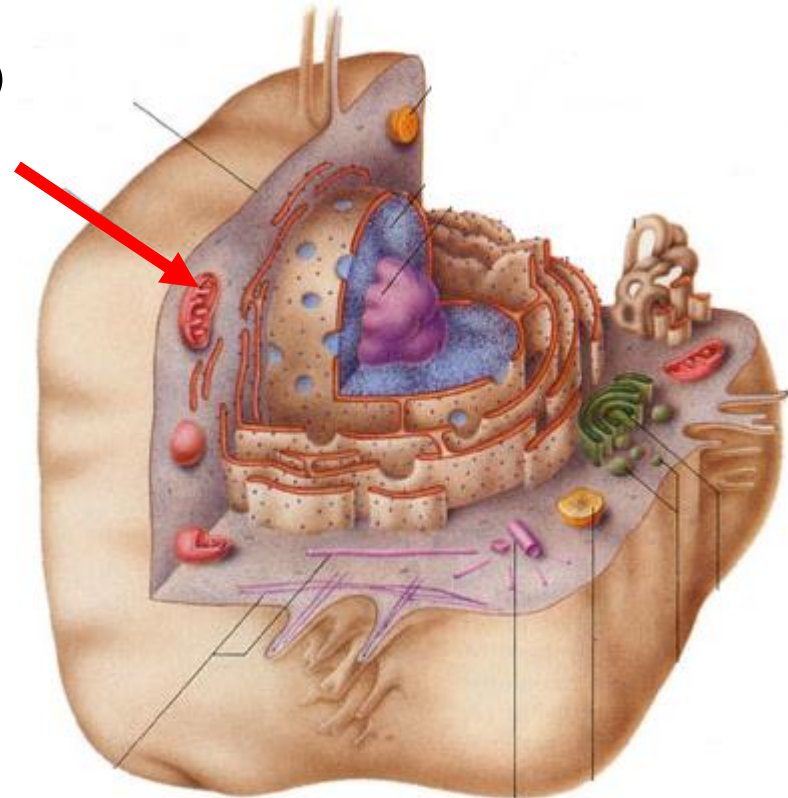
*Part-Of (Finger, Hand)*

*Part-Of (Brain Metastasis, Brain)*

*Part-Of (Meningioma, Brain)*

*Part-Of (Right Ventricle, Heart)*

*Part-Of (Mitochondria, Cell)*



# Parthood or Location?

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*Part-Of (Finger, Hand)*

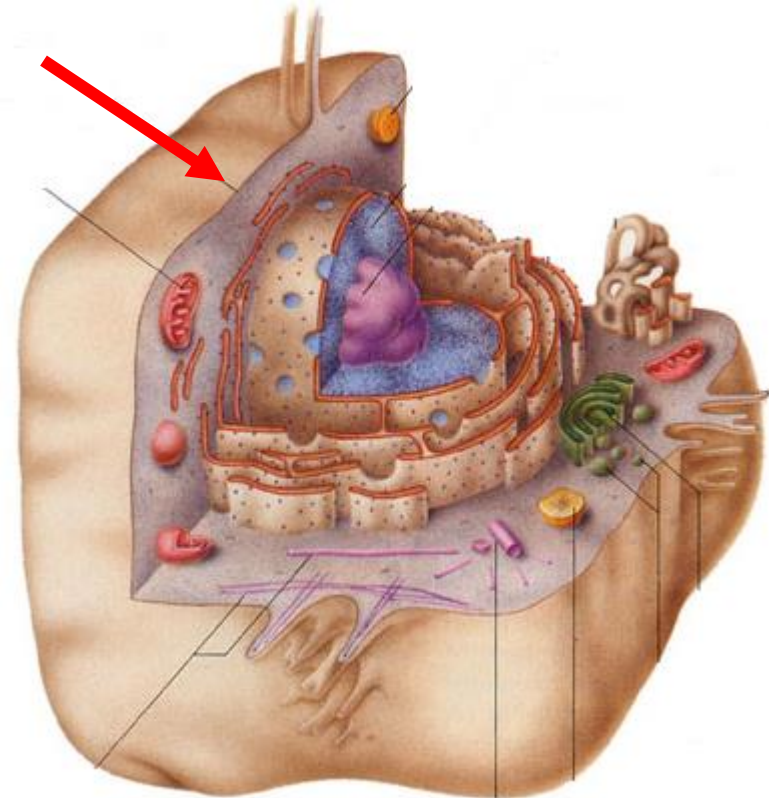
*Part-Of (Brain Metastasis, Brain)*

*Part-Of (Meningioma, Brain)*

*Part-Of (Right Ventricle, Heart)*

*Part-Of (Mitochondria, Cell)*

*Part-Of (Cell Membrane, Cell)*



# Parthood or Location?

*Part-Of (Finger, Hand)*

*Part-Of (Brain Metastasis, Brain)*

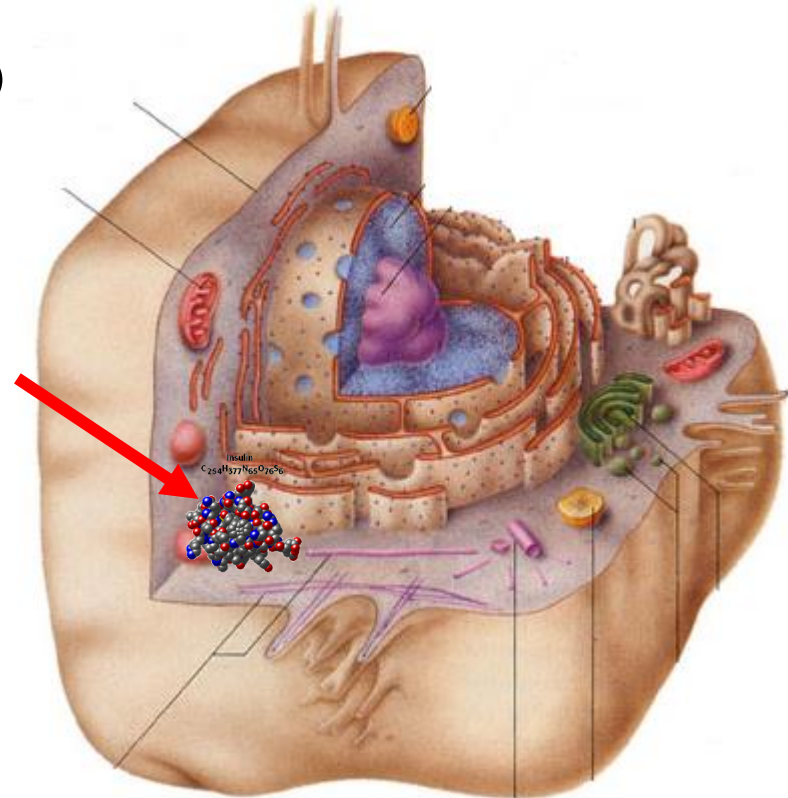
*Part-Of (Meningioma, Brain)*

*Part-Of (Right Ventricle, Heart)*

*Part-Of (Mitochondria, Cell)*

*Part-Of (Cell Membrane, Cell)*

*Part-Of (Insulin, Beta Cell)*



# Parthood or Location?

*Part-Of (Finger, Hand)*

*Part-Of (Brain Metastasis, Brain)*

*Part-Of (Meningioma, Brain)*

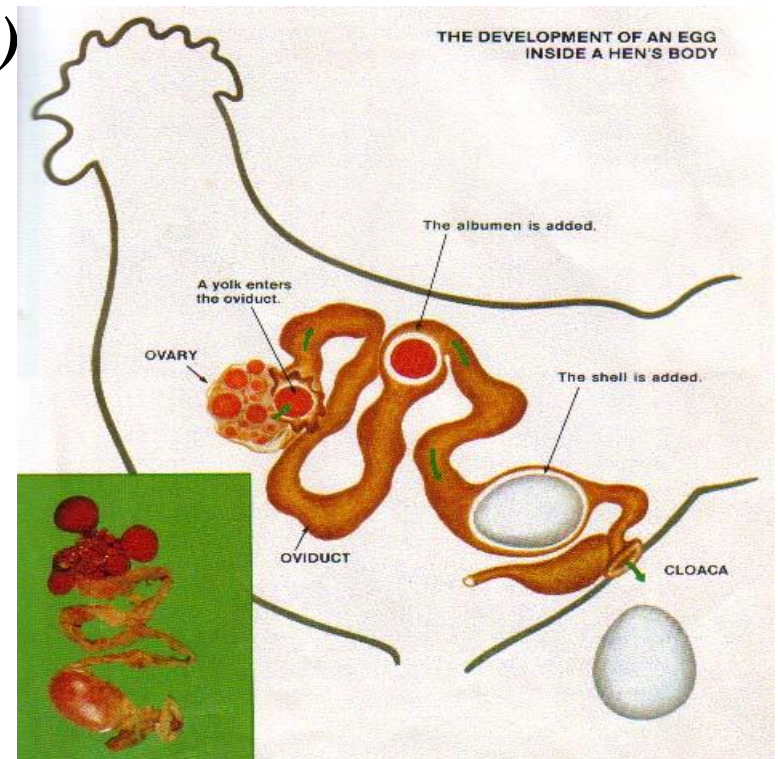
*Part-Of (Right Ventricle, Heart)*

*Part-Of (Mitochondria, Cell)*

*Part-Of (Cell Membrane, Cell)*

*Part-Of (Insulin, Beta Cell)*

*Part-Of (Egg, Chicken)*



# Parthood or Location?

---

*Part-Of (Finger, Hand)*

*Part-Of (Brain Metastasis, Brain)*

*Part-Of (Meningioma, Brain)*

*Part-Of (Right Ventricle, Heart)*

*Part-Of (Mitochondria, Cell)*

*Part-Of (Cell Membrane, Cell)*

*Part-Of (Insulin, Beta Cell)*

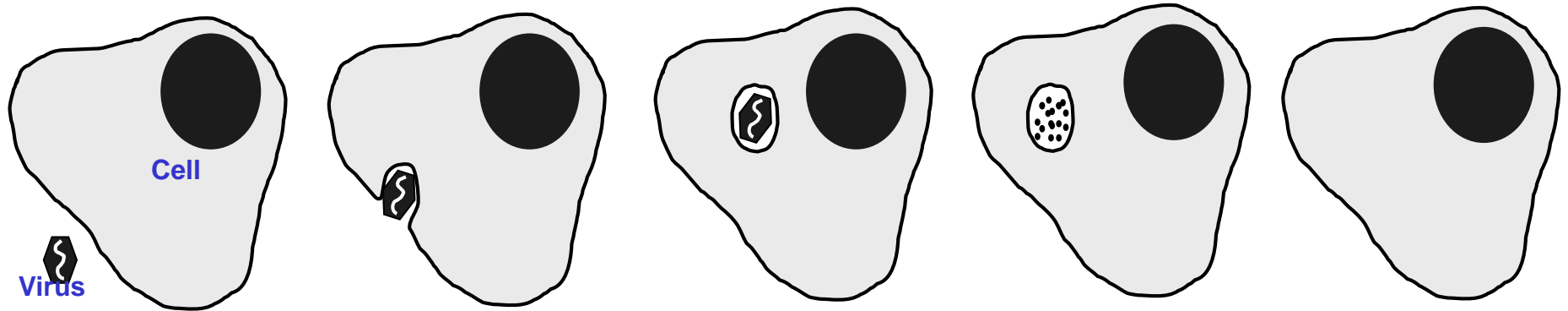
*Part-Of (Egg, Chicken)*

*Part-Of (Leaf, Tree)*



# Phagocytosis / Digestion

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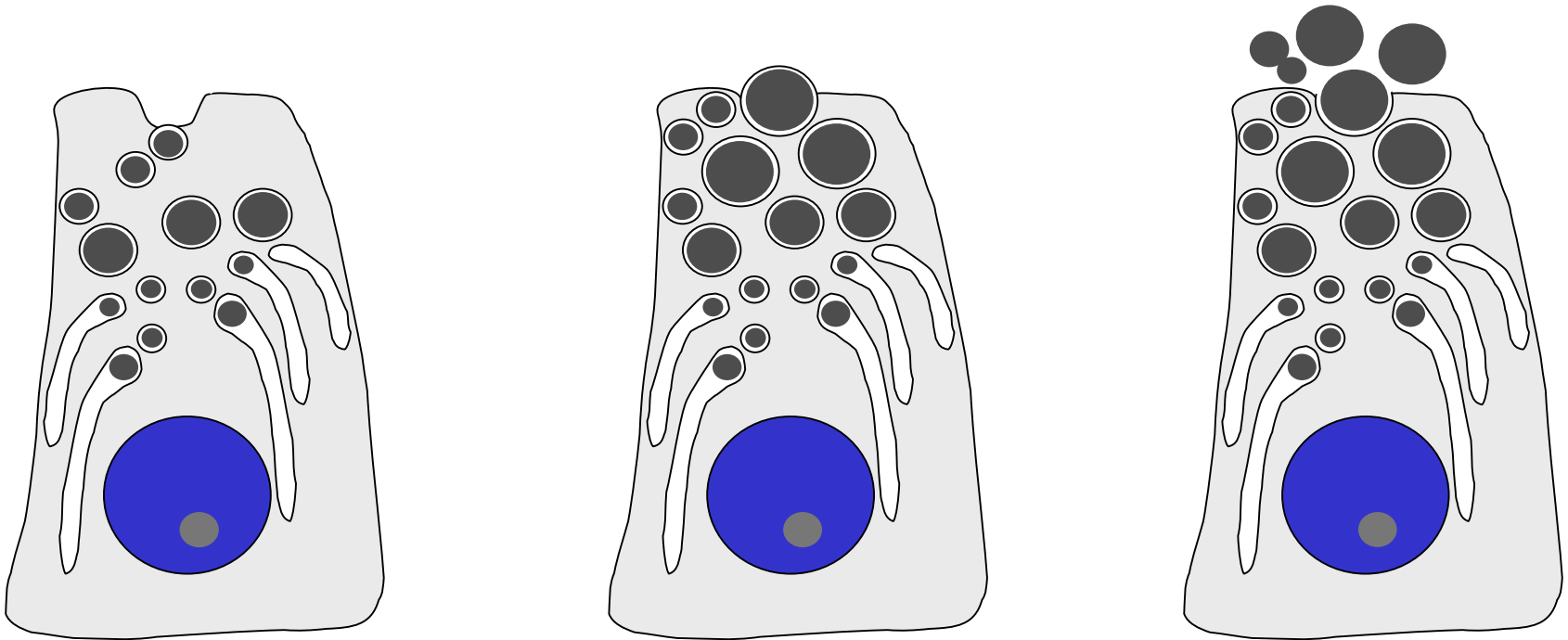


Parthood or Location ?



# Excretion / Secretion

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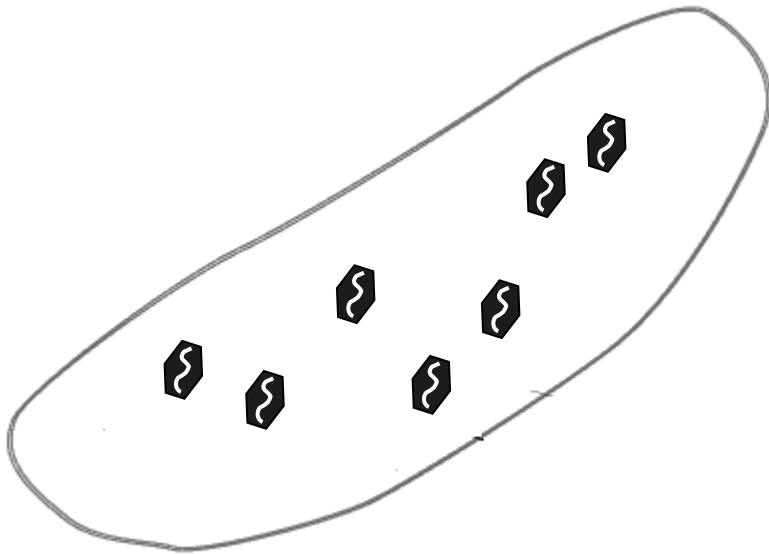


Parthood or Location ?  
Inside or Outside

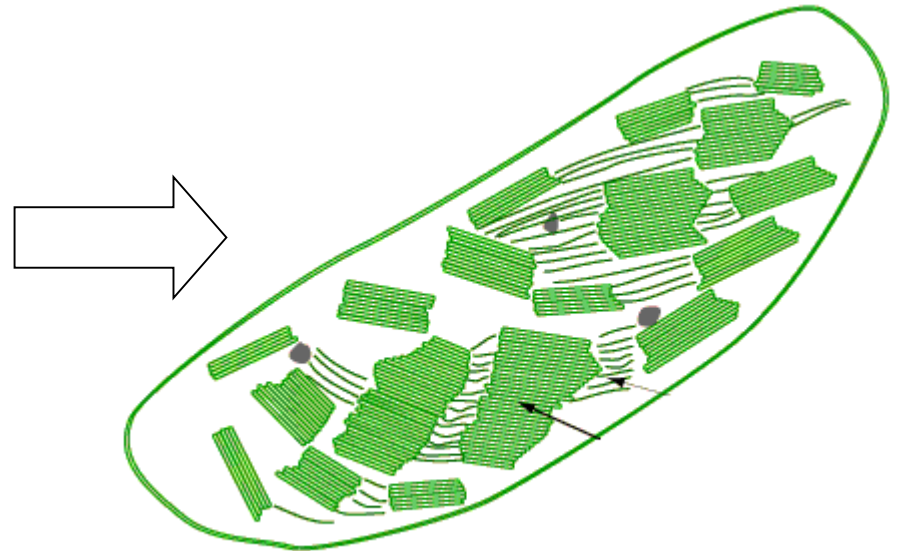
# Endosymbiont Hypothesis

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2.5 billion years ago:  
Primitive cell with  
bacterium-like symbionts



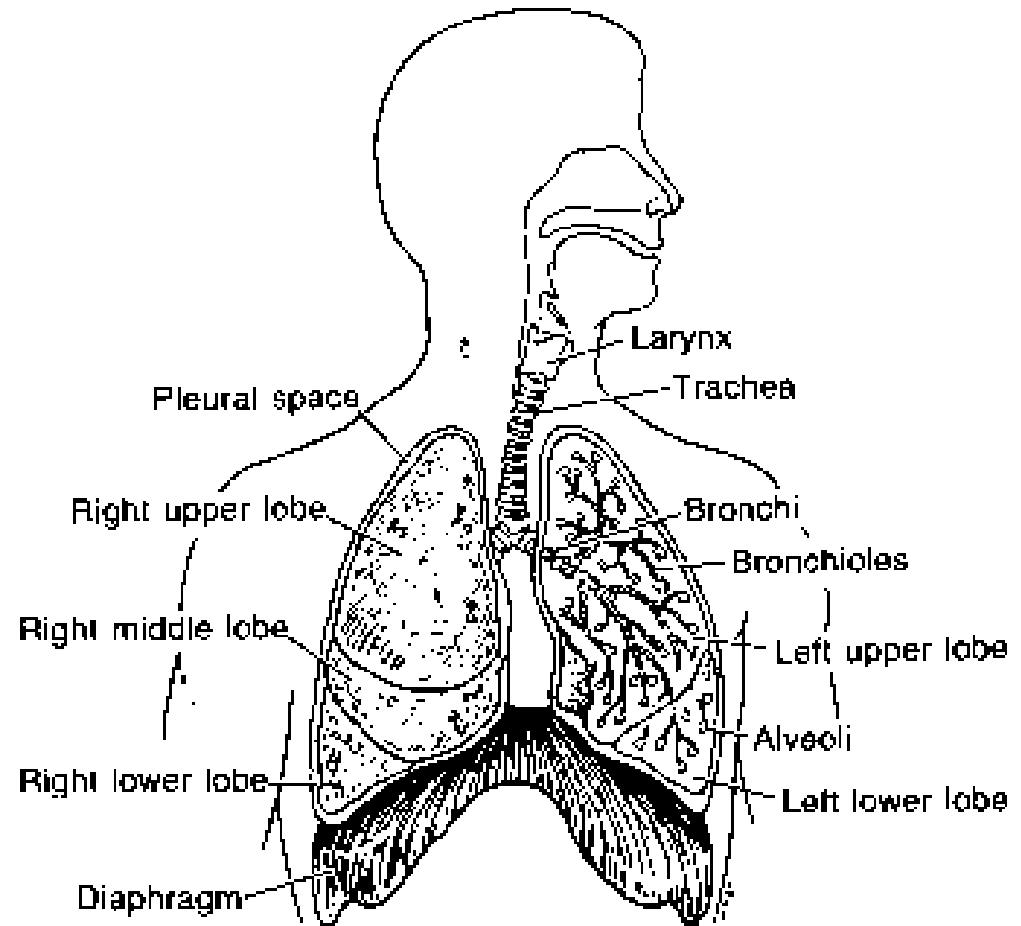
Today:  
Plant cell with chloroplasts



Parthood or Location ?

# Hollow Spaces (I)

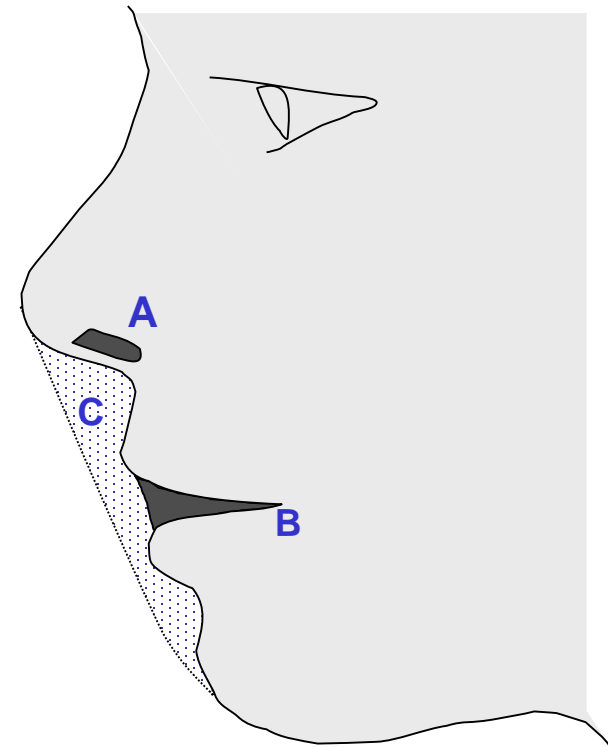
- Inside or outside ?
- Example: Bronchi  
A foreign body  
in a bronchus  
is in the lung
- Topological view  
vs.  
Shared medical  
conceptualization



# Hollow Spaces (II)

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- Convex hull operator ?  
 $C$  would be “inside”
- Pragmatic solution:  
“Inside” a biological structure =  
located in the solid parts or in those hollow spaces which are defined ***included into*** structure (here  $A$  and  $B$ )



# Proposal:

## generalize *part-of* to *has-location*

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- Domain: solids, hollows, occurrents
- Range: solids, hollows

Examples:

*Has-Location (Brain, Cranial Cavity)*

*Has-Location (Pharyngitis, Pharynx)*

*Has-Location (Finger, Hand)*

*Has-Location (Embryo, Uterus)*

- Advantage: clear semantics, easier consensus
- Disadvantage: functional aspects hidden

# Definition: *Loc / Inc vs. loc / inc*

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## ■ Instance level:

*loc* = *has-location* is transitive, reflexive, antisymmetric

*inc* = *includes* is the inverse of *loc*

## ■ Class level:

*Loc*(*A*, *B*) = <sub>def</sub>

$\forall x: \text{inst-of}(x, A) \rightarrow \exists y: \text{inst-of}(y, B) \wedge \text{loc}(x, y)$

*Inc*(*B*, *A*) = <sub>def</sub>

$\forall y: \text{inst-of}(y, B) \rightarrow \exists x: \text{inst-of}(x, A) \wedge \text{inc}(x, y)$

*Inc*(*B*, *A*) does not necessarily imply *Loc*(*A*, *B*)

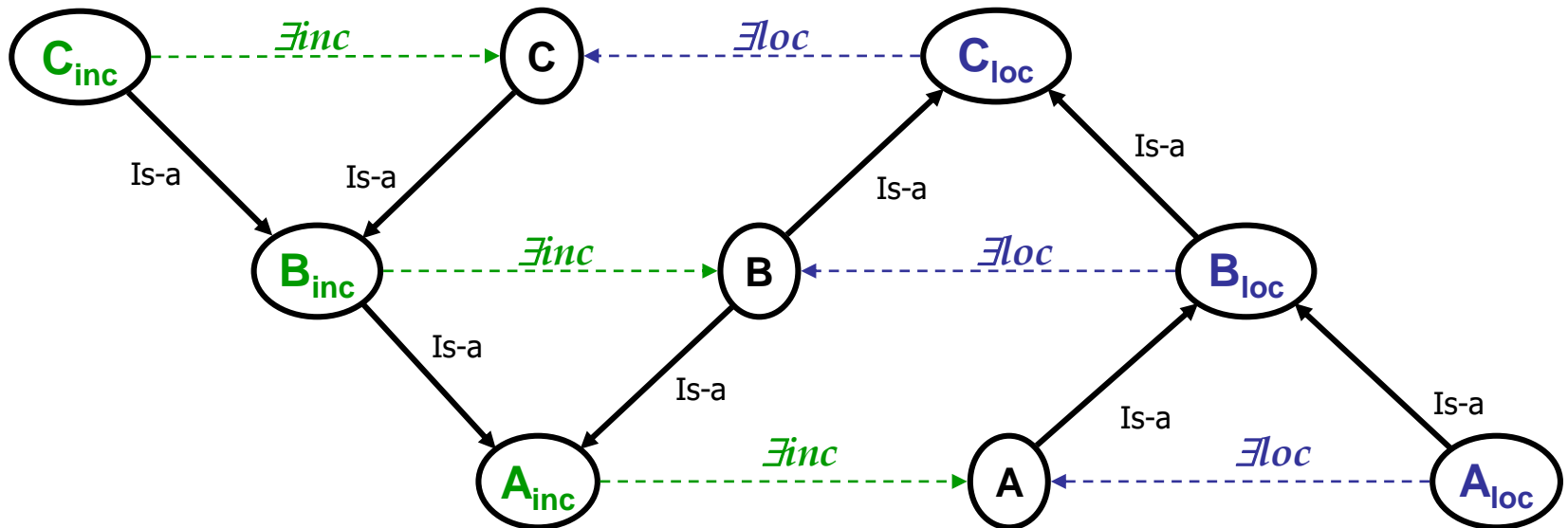
# Class-level Loc / Inc :

## Different Interpretations

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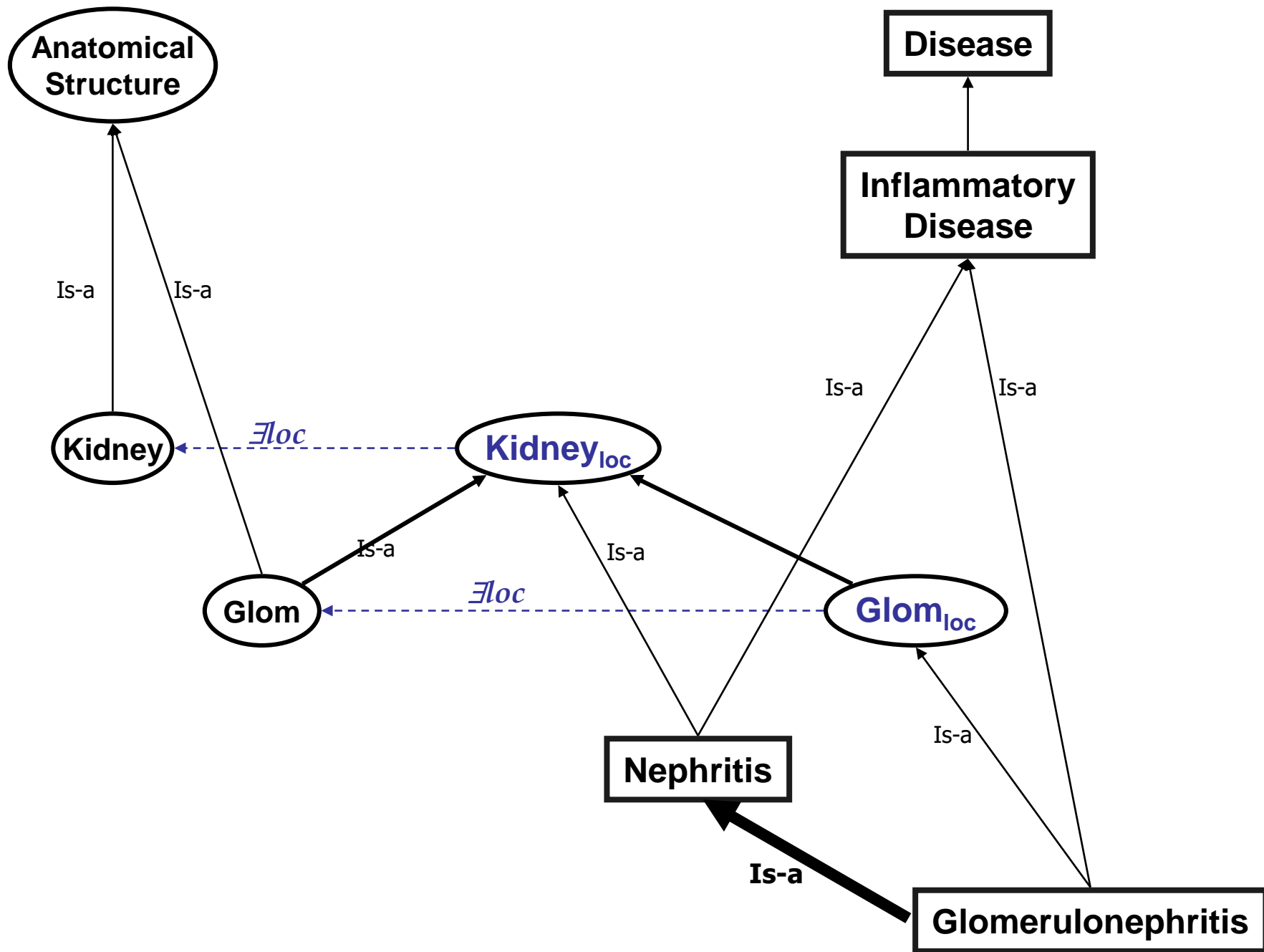
# Reification of *inc* and *loc*

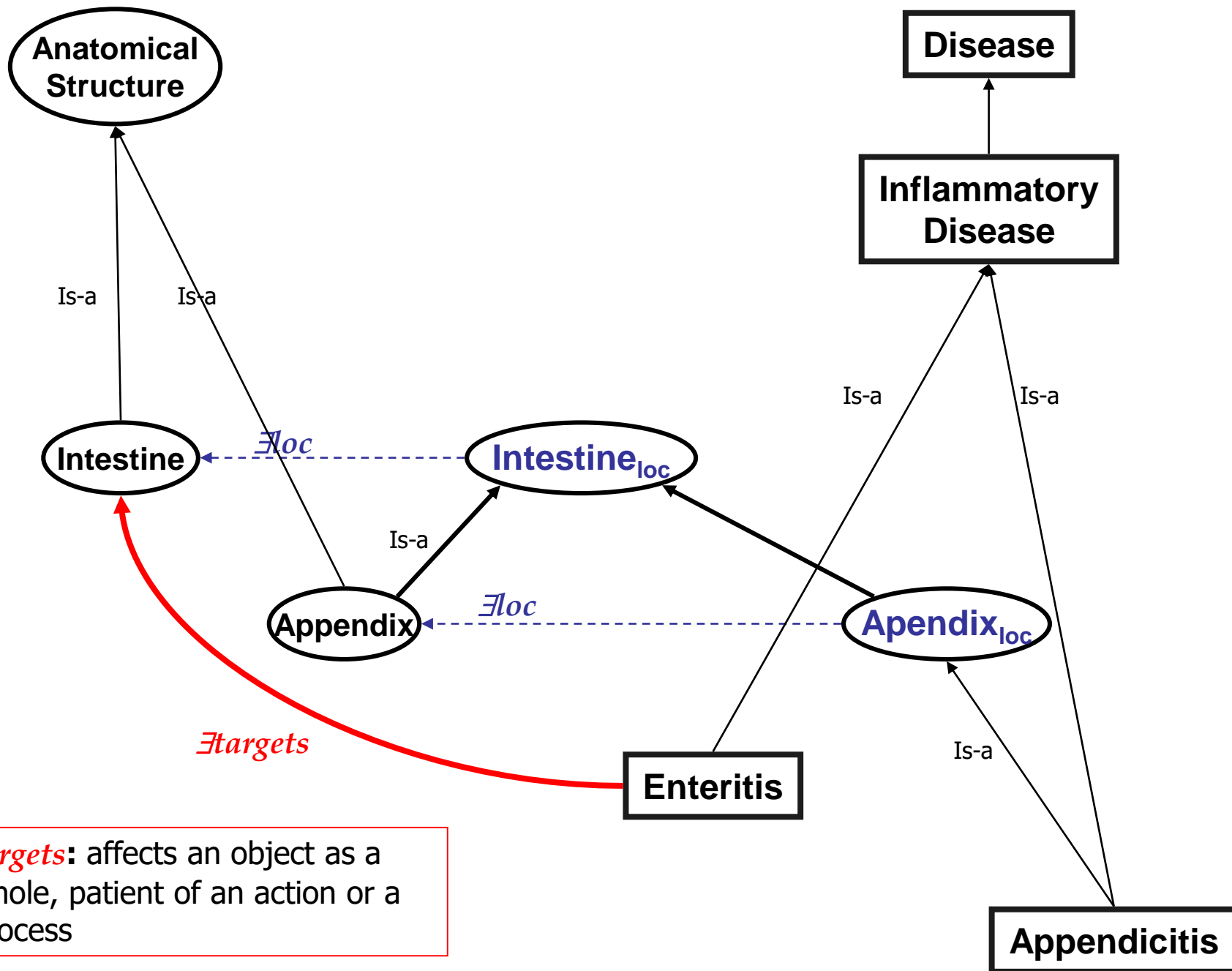
$\forall x: \text{inst-of}(x, A_{loc}) \rightarrow \exists y: \text{inst-of}(y, A) \wedge \text{loc}(x, y)$   
 $\forall x: \text{inst-of}(x, A_{inc}) \rightarrow \exists y: \text{inst-of}(y, A) \wedge \text{inc}(x, y)$



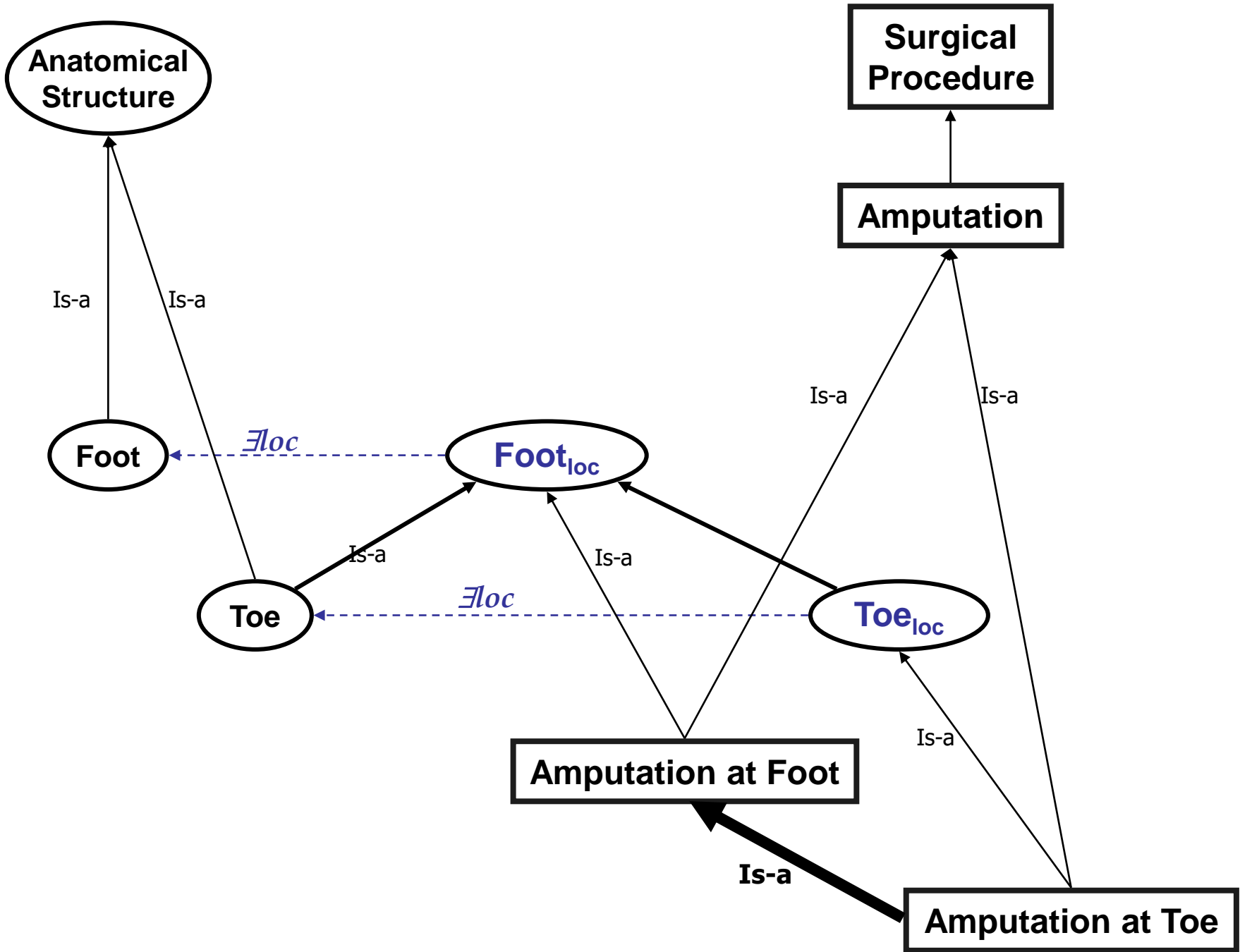
Extended Taxonomy

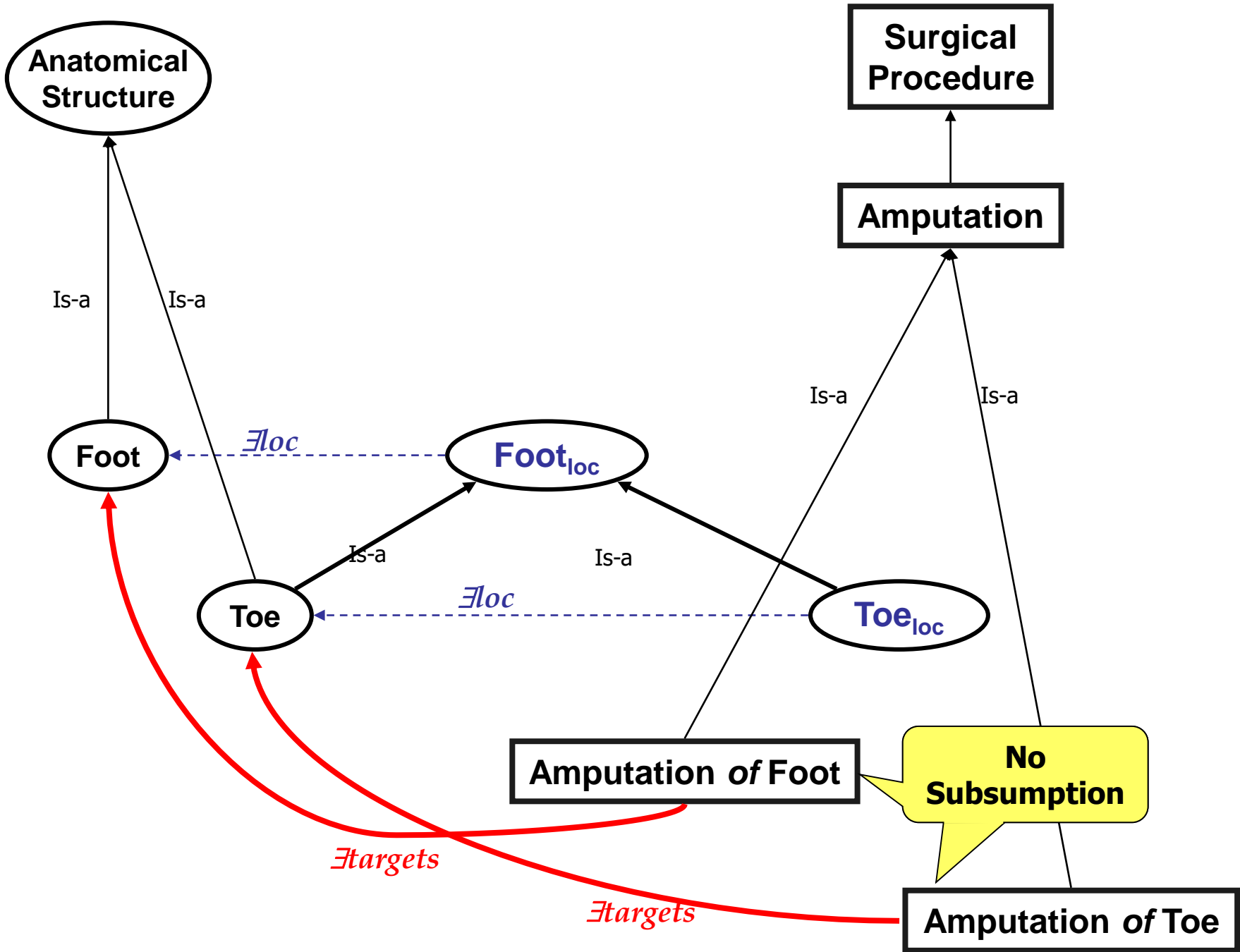






**targets:** affects an object as a whole, patient of an action or a process





# Conclusion

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- Domain idiosyncrasies:
  - Unclear distinction between parthood and location
  - Hollow spaces are considered “part-of” their host
  - No obvious need of a distinction between an object and the region it occupies
- Use strict topological inclusion for biological domain models
- Facilitates consensus between knowledge engineers
- Facilitates “role propagation” in compositional hierarchies
- Ontological inquiry of the consequences of the fusion of parthood with location still due



# Plausible inferences by taxonomic subsumtion

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“*Amputation of a foot is an amputation which targets a foot and is located at a foot.*”

$$\begin{aligned} \forall x : \text{instance-of}(x, \text{AmputationOfFoot}) \rightarrow \\ (\text{instance-of}(x, \text{Amputation}) \wedge \text{instance-of}(x, \text{Foot}_{loc}) \wedge \\ \exists y : \text{instance-of}(y, \text{Foot}) \wedge \text{targets}(x, y)) \end{aligned}$$

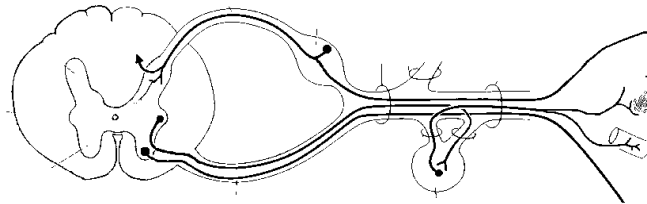
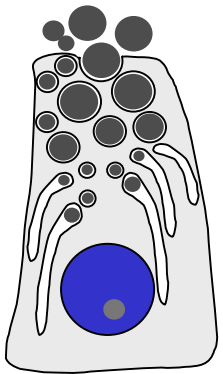
“*Amputation at a foot is an amputation which is located at a foot.*”

$$\begin{aligned} \forall x : \text{instance-of}(x, \text{AmputationAtFoot}) \rightarrow \\ (\text{instance-of}(x, \text{Amputation}) \wedge \text{instance-of}(x, \text{Foot}_{loc})) \end{aligned}$$

- Given  $\text{Is-A}(\text{Toe}_{loc}, \text{Foot}_{loc})$ , “amputation of a toe” can be classified as “amputation at a foot”, but not as an “amputation of a foot”

# Part-of: Locative flavor

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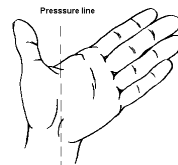
# Part-of in Biomedical structure models: Deficits

- Commitment to algebraic foundations (transitivity, reflexivity, symmetry)
- Semantics: locative, functional, time-dependent
- Open or Closed World
- Part-of between Classes



BC  
part-of Canada

Individuals



Thumb  
Part-Of Hand

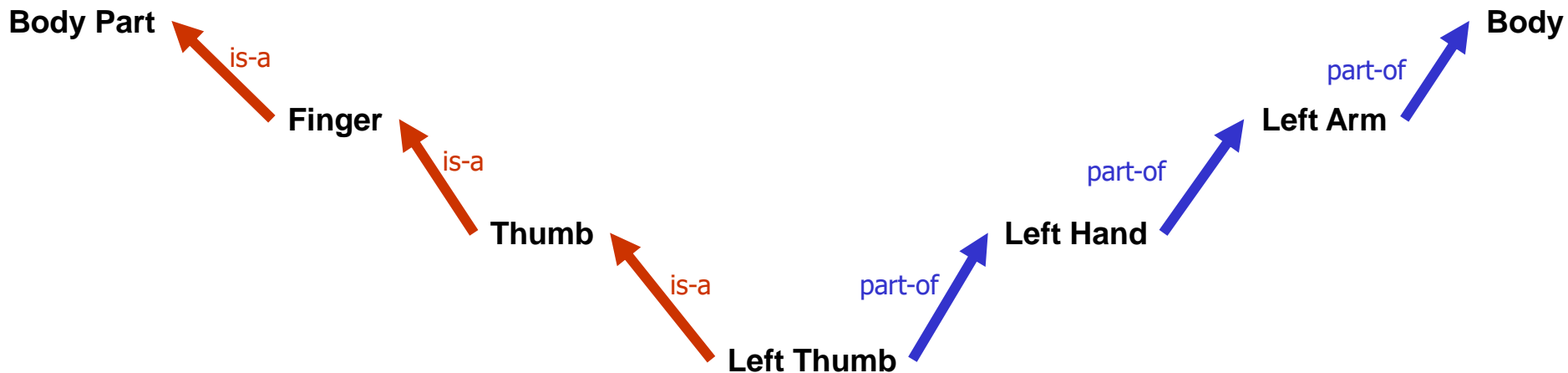
Classes of Individuals

# Common Denominator of different "anatomies"

- Concepts (classes of individuals) with Semantic Links

<i>Concept 1</i>	<i>relation</i>	<i>Concept 2</i>
HEART	part_of	ORGANISM
HEART	is_a	ORGAN
HEART	has_part	HEART-ATRIUM
HEART	has_part	MYOCARDIUM
HEART	has_part	MITRAL-VALVE
MITRAL-VALVE	is_a	VALVE

- Double hierarchy (taxonomic / partonomic)



# Part-of in Biomedical structure models: Deficits

---

- Commitment to algebraic foundations (transitivity, reflexivity, symmetry)
- Semantics: locative, functional, time-dependent
- Open or Closed World

*Part-Of*( $A, B$ ) =<sub>def</sub>

$\forall x : \text{instance-of}(x, A) \rightarrow \exists y : (\text{instance-of}(y, B) \wedge \text{part-of}(x, y))$

*Has-Part*( $A, B$ ) =<sub>def</sub>

$\forall x : \text{instance-of}(x, A) \rightarrow \exists y : (\text{instance-of}(y, B) \wedge \text{has-part}(x, y))$

---

$Loc(A, B) =_{def}$

$\forall x : instance-of(x, A) \rightarrow \exists y : (instance-of(y, B) \wedge loc(x, y))$

$Inc(A, B) =_{def}$

$\forall x : instance-of(x, A) \rightarrow \exists y : (instance-of(y, B) \wedge inc(x, y))$

---

$$\textit{Real-Part-Of} (A, B) =_{def} \textit{Loc}(A, B) \wedge \textit{Inc}(B, A)$$

---

$$\forall x : \text{instance-of}(x, A_{loc}) \rightarrow \exists y : (\text{instance-of}(y, A) \wedge \text{loc}(x, y))$$
$$\forall x : \text{instance-of}(x, A_{inc}) \rightarrow \exists y : (\text{instance-of}(y, A) \wedge \text{inc}(x, y))$$

$\forall x : \text{instance-of}(x, \text{Glomerulonephritis}) \rightarrow$   
 $(\text{instance-of}(x, \text{Inflammation}) \wedge \text{instance-of}(x, \text{Glomerulum}_{loc}))$

$\text{Is-A}(\text{Glomerulum}_{loc}, \text{Kidney}_{loc})$

$\forall x : \text{instance-of}(x, \text{Nephritis}) \rightarrow$   
 $(\text{instance-of}(x, \text{Inflammation}) \wedge \text{instance-of}(x, \text{Kidney}_{loc}))$



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$$\text{Is-A}(\text{Toe}_{loc}, \text{Foot}_{loc})$$

