Ninth International Conference on Principles of Knowledge Representation and Reasoning (KR2004), June 2 - 5, 2004, Whistler (Canada)

Parthood as Spatial Inclusion Evidence from Biomedical Conceptualizations

Stefan Schulz
Department of Medical Informatics
University Hospital Freiburg (Germany)

Udo Hahn
Text Knowledge Engineering Lab
University of Jena (Germany)

Bio-Ontologies

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,..

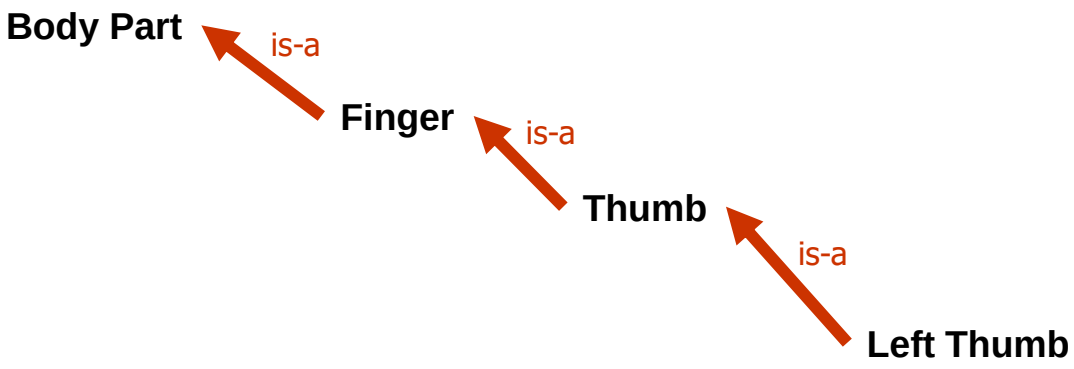
Domain ontologies of biomedical structure

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

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

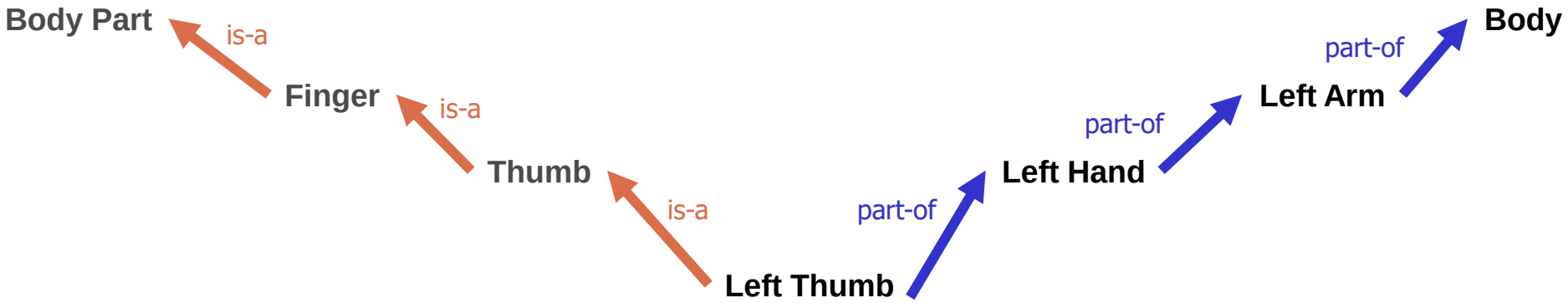
Common Denominator of different "anatomies"

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



Common Denominator of different "anatomies"

- Concept - Oriented (make assertions about classes of individual objects)
- Binary Relations: $Rel\ (C_1, C_2)$
- Two main hierarchy-building relations
  - Taxonomy: $Is\text{-}A\ (C_1, C_2)$
  - Partonomy: $Part\text{-}Of\ (C_1, C_2)$



Typical part-of related reasoning problem:

- "Property inheritance" across mereologic hierarchies

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

has-location (Mitosis, EukaryoticCells)
part-of (EukaryoticCells, Pancreas)
---
has-location (Mitosis, Pancreas) ✗

amputation-of (ToeAmputation, Toe)
part-of (Toe, Foot)
---
amputation-of (ToeAmputation, Foot) ✗

inflammation-of (Glomerulonephritis, Glomerulum)
part-of (Glomerulum, Kidney)
inflammation-of (Nephritis, Kidney)
---
is-A (Glomerulonephritis, Nephritis) ✓

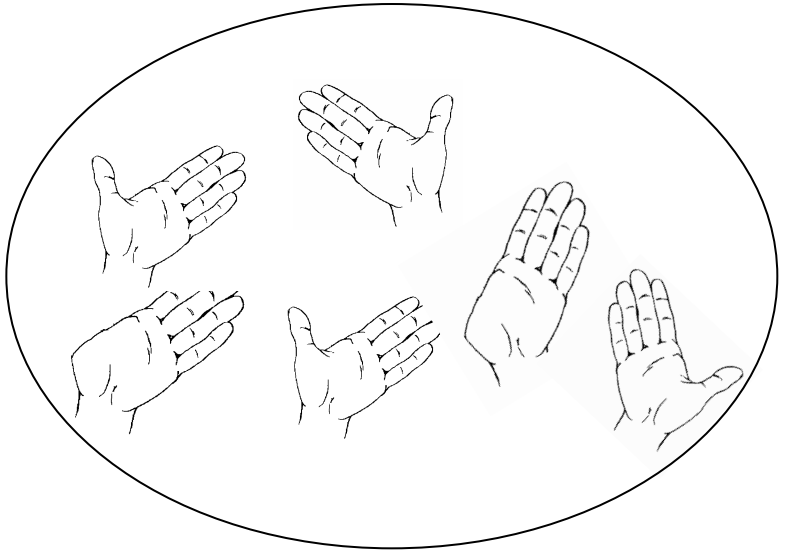
inflammation-of (Appendicitis, Appendix)
part-of (Appendix, Intestine)
inflammation-of (Enteritis, Intestine)
---
is-A (Appendicitis, Enteritis) ✗

Part-of in Biomedical structure models: Two Major Deficits

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

Part-of between individuals and universals

British Columbia part-of Canada



Thumb Part-Of Hand

Part-of in Biomedical structure models: Two Major Deficits

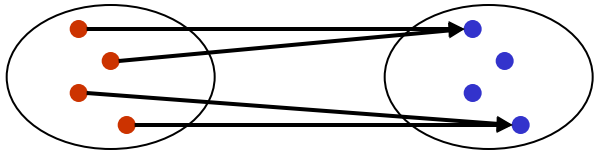
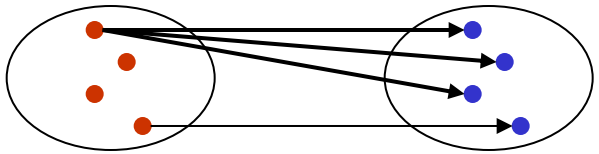
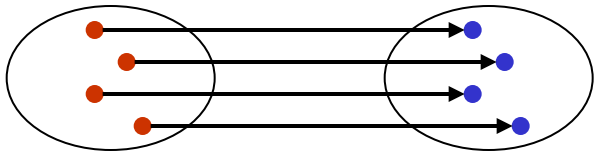
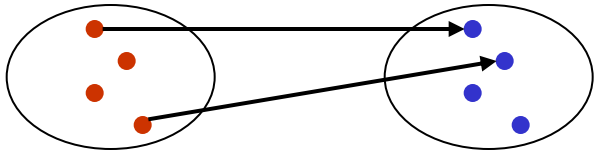
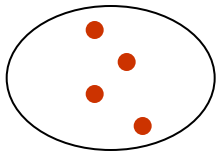
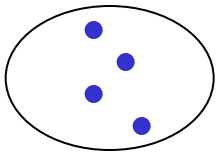
- Part-of originally relates individuals, but here it relates universals (classes of individuals, concepts)
- Unclear Semantics: part-of has locative, functional, temporal aspects

Part-of in Biomedical structure models: Two Major Deficits

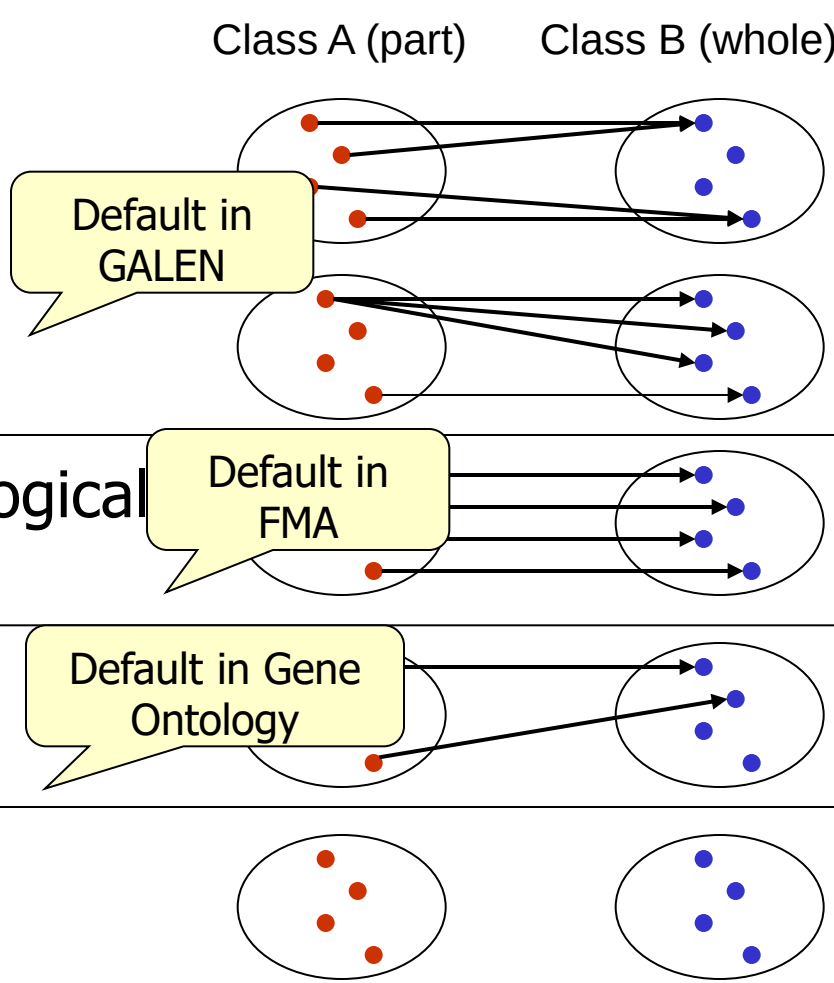
- Part-of originally relates individuals, but here it relates universals (classes of individuals, concepts)
- Unclear Semantics: part-of has locative, functional, temporal aspects

Further Specification Needed !

Class-level Part-Of : Different Interpretations

	Class A (part)	Class B (whole)	Examples
■ One-sided Mereological Dependency			Cell Nucleus – Cell Chlorophyll – Organism Prostate Tumor – Prostate
			Sulfur – Methionin Wing – Chicken Heart – Drosophila
■ Mutual Mereological Dependency			Cell Membrane – Cell Vertebra – Vertebrate Body Surface – Body
■ Mereological Independency			Uterus – Mammal Sulfur – AMino Acid Tooth – Human
■ Mereological Disjointness			Wing – Mouse Sulfur – Alanin Lung – Hand

Part-Of between Classes: Different Interpretations



- One-sided Mereological Dependency
- Mutual Mereological Dependency
- Mereological Independency
- Mereological Disjointness

Examples
Cell Nucleus – Cell Chlorophyll – Organism Prostate Tumor – Prostate
Sulfur – Methionin Wing – Chicken Heart – Drosophila
Cell Membrane – Cell Vertebra – Vertebrate Body Surface – Body
Uterus – Mammal Sulfur – AMino Acid Tooth – Human
Wing – Mouse Sulfur – Alanin Lung – Hand

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

- Instance level :

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

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

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

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

- Class level:

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

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

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

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

  $Has\text{-}Part\ (B, A)$ does not necessarily imply $Part\text{-}Of\ (A, B)$

Part-of in Biomedical structure models: Two Major Deficits

- 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

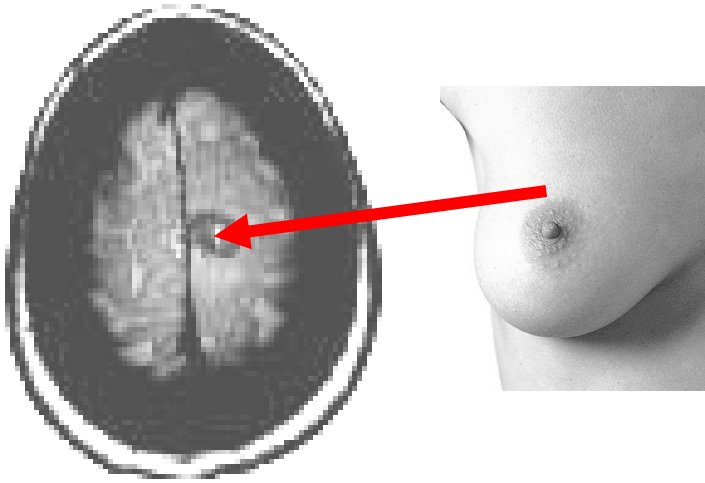
Parthood or Location?

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)

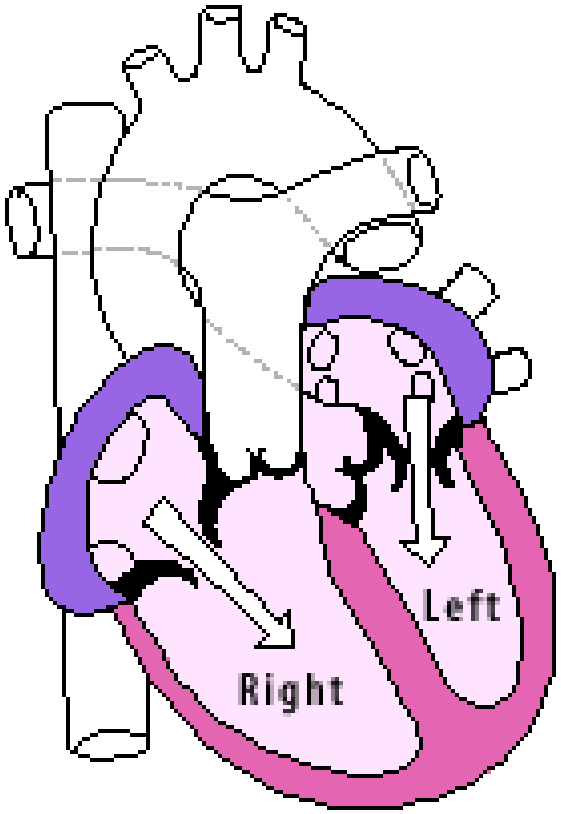
Parthood or Location?

Part-Of (Finger, Hand)

Part-Of (Brain Metastasis, Brain)

Part-Of (Meningioma, Brain)

Part-Of (Right Ventricle, Heart)



Parthood or Location?

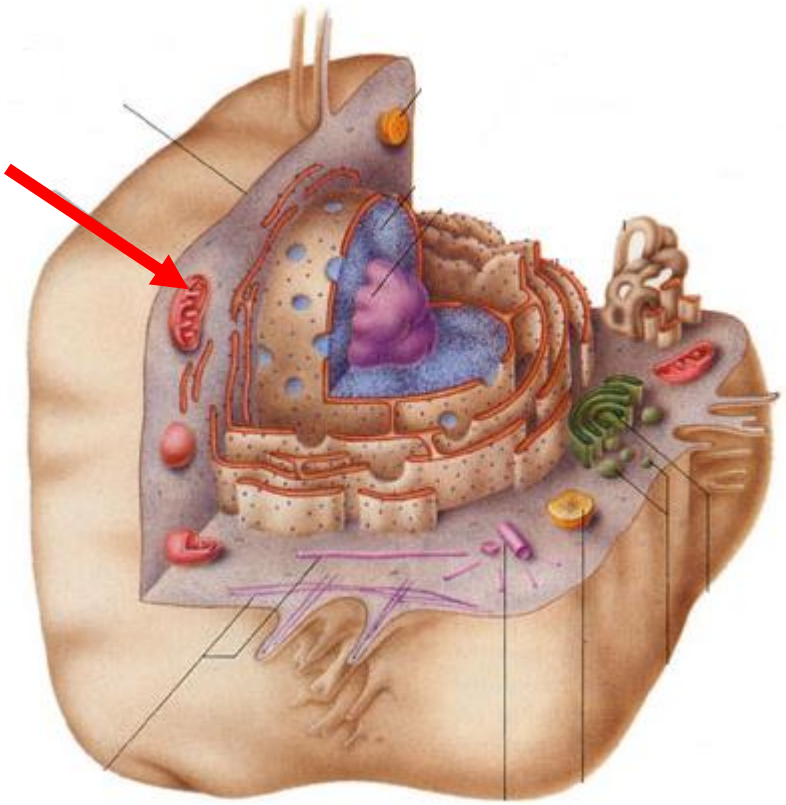
Part-Of (Finger, Hand)

Part-Of (Brain Metastasis, Brain)

Part-Of (Meningioma, Brain)

Part-Of (Right Ventricle, Heart)

Part-Of (Mitochondria, Cell)



Parthood or Location?

Part-Of (Finger, Hand)

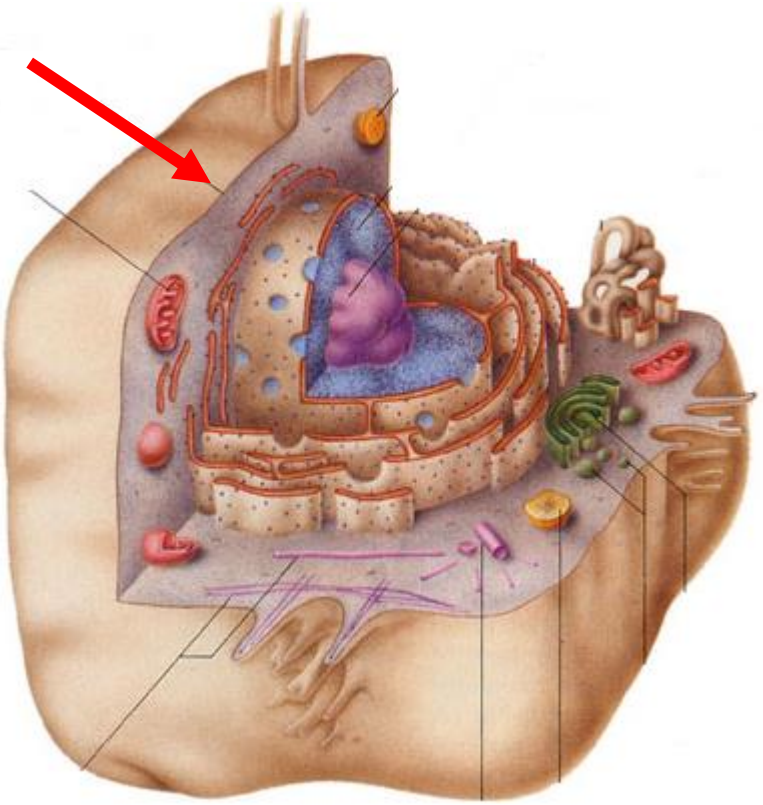
Part-Of (Brain Metastasis, Brain)

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)

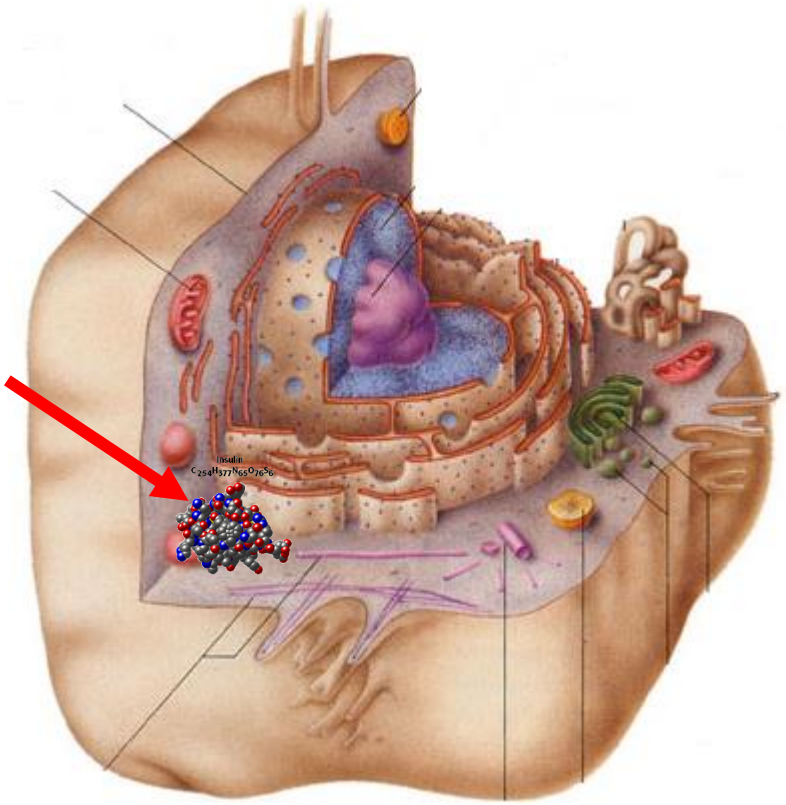
Part-Of (Meningioma, Brain)

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)

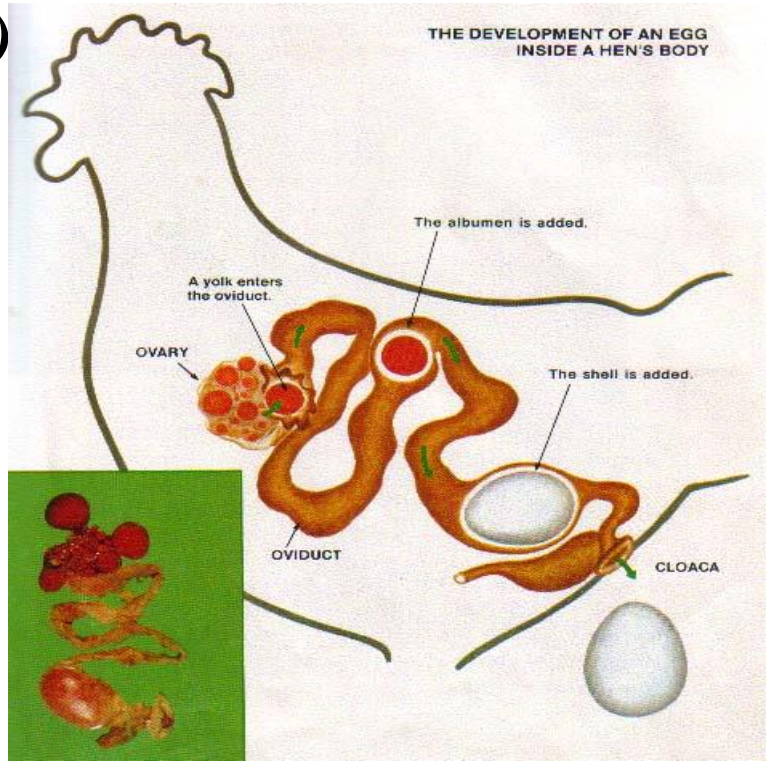
Part-Of (Right Ventricle, Heart)

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)

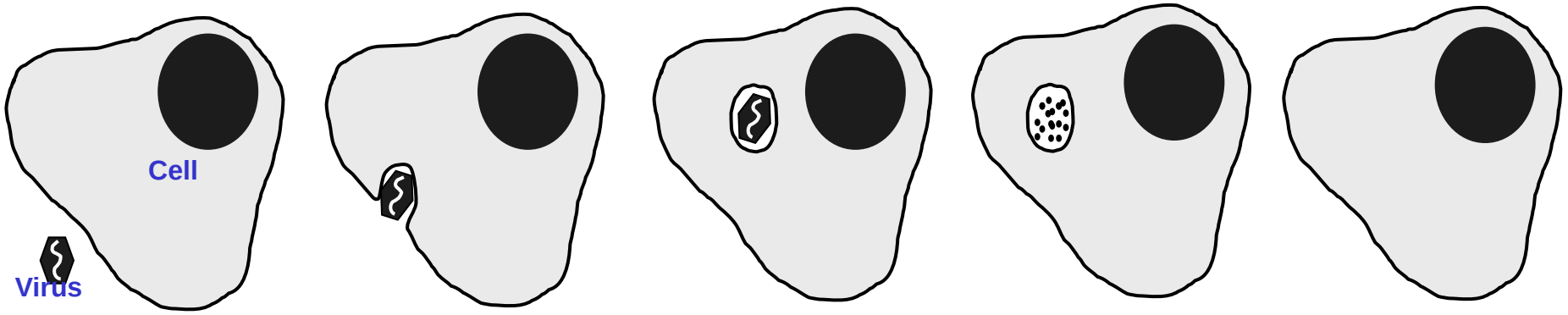
Part-Of (Cell Membrane, Cell)

Part-Of (Insulin, Beta Cell)

Part-Of (Egg, Chicken)

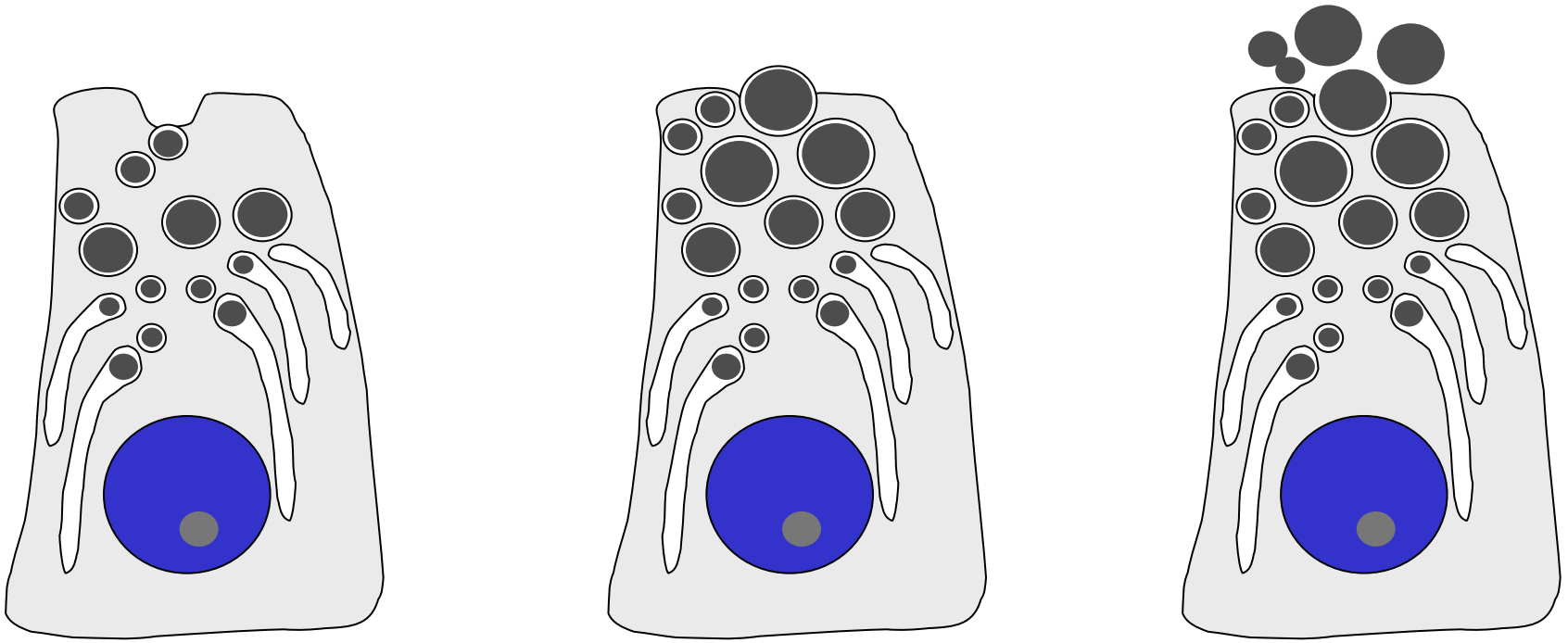
Part-Of (Leaf, Tree)

Phagoctosis / Digestion



Parthood or Location ?

Excretion / Secretion

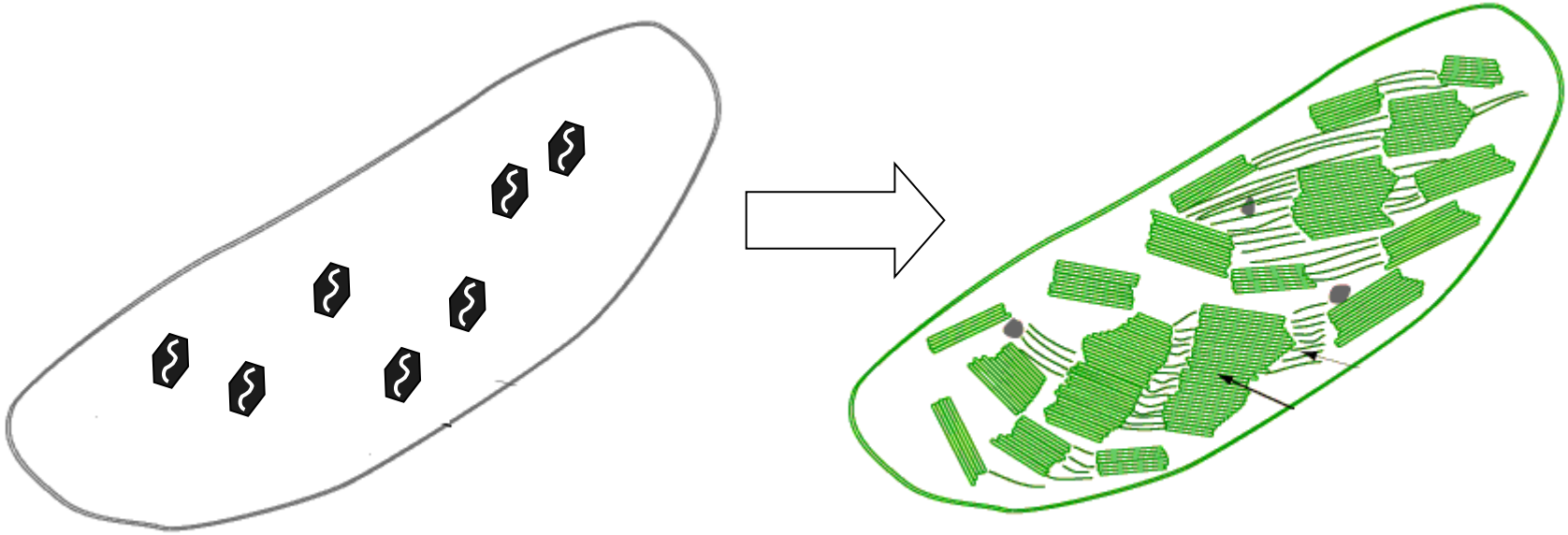


Parthood or Location ?
Inside or Outside

Endosymbiont Hypothesis

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

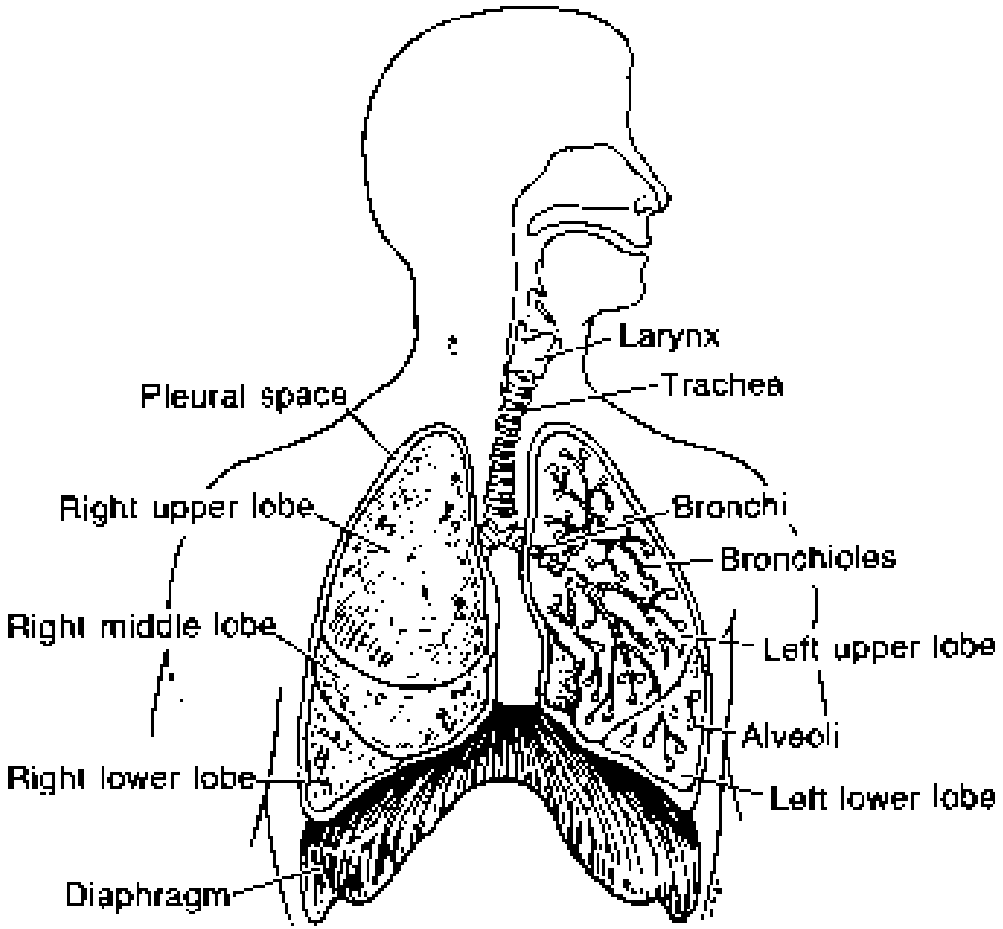
Today:
Plant cell with chloroplasts



Parthood or Location ?

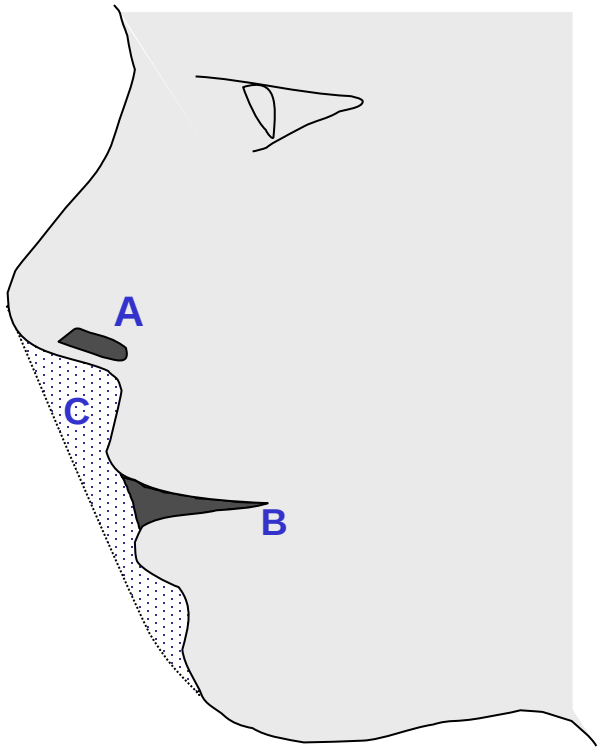
Hollow Spaces (I)

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



Hollow Spaces (II)

- 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*

- 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*

- Instance level:

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

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

- Class level:

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

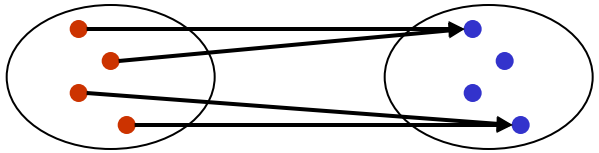
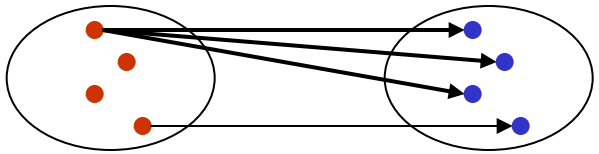
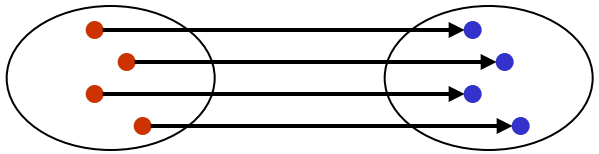
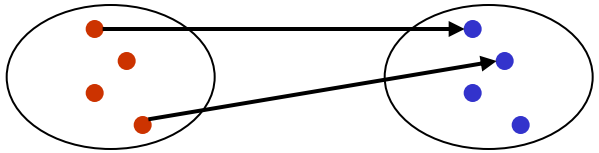
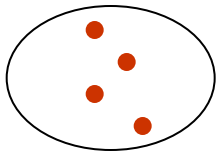
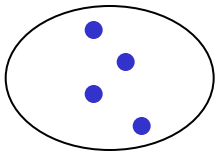
  $\forall x: inst\text{-}of\ (x, A) \rightarrow \exists y: inst\text{-}of\ (y, B) \wedge loc\ (x, y)$

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

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

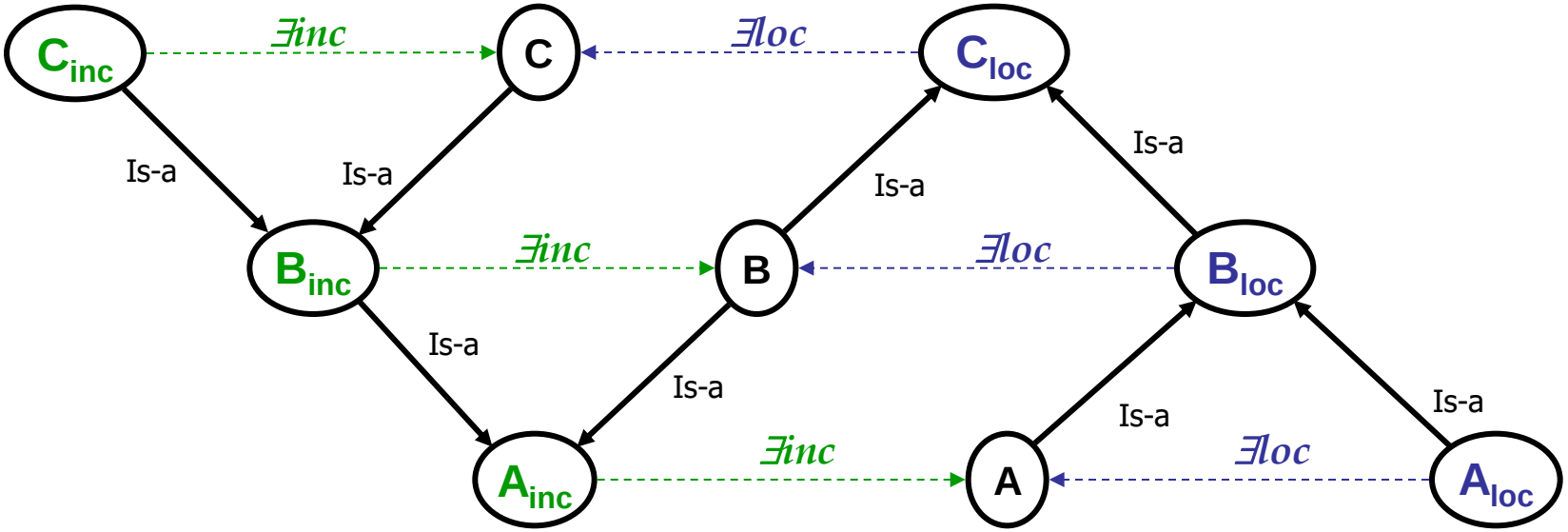
  Inc (*B, A*) does not necessarily imply *Loc* (*A, B*)

Class-level Loc / Inc : Different Interpretations

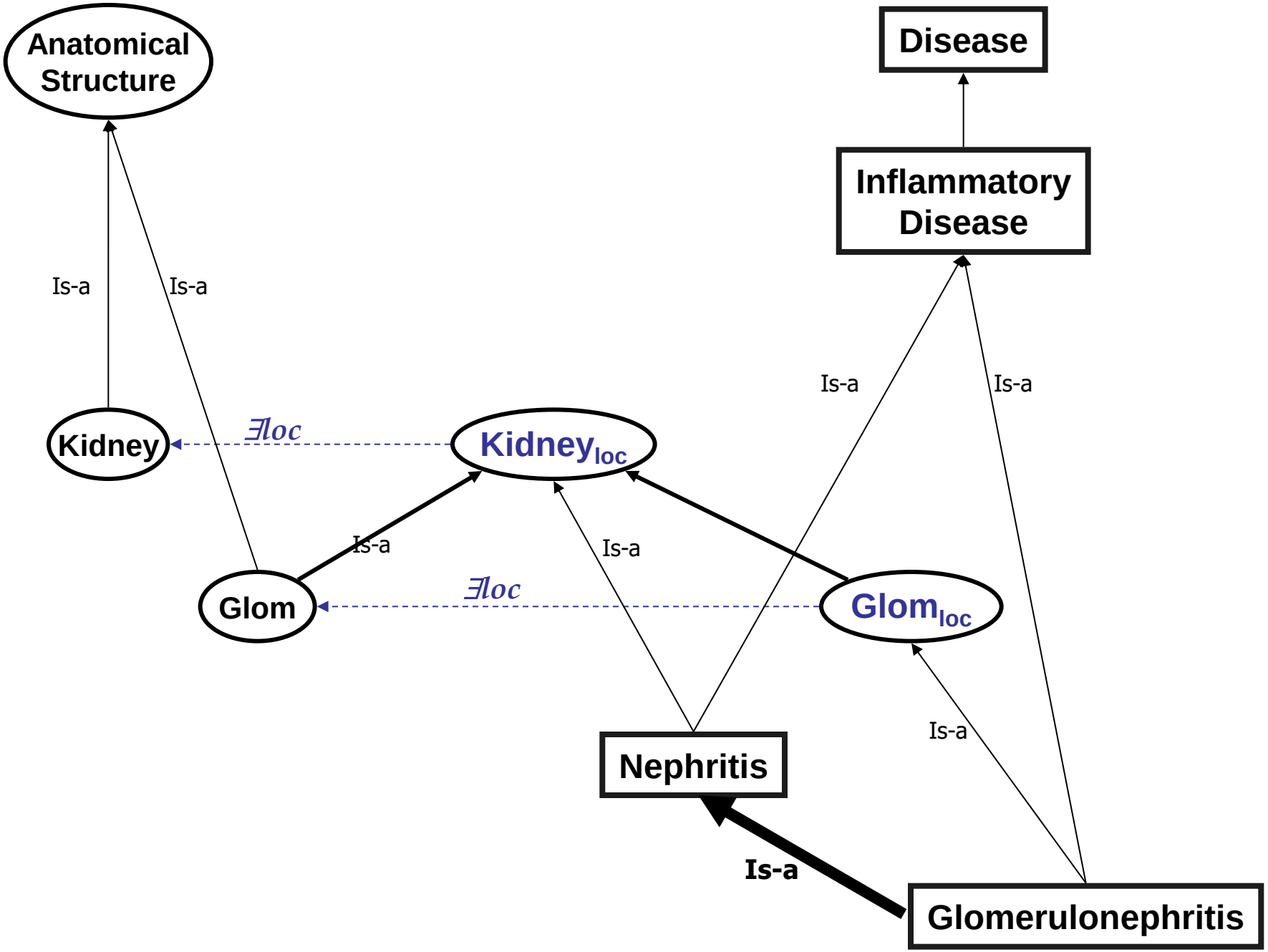
	Class A (includee)	Class B (includer)	Examples
■ One-sided Mereotopological Dependency			Cell Nucleus – Cell Chlorophyll – Organism Prostate Tumor – Prostate
			Sulfur – Methionin Wing – Chicken Heart – Drosophila
■ Mutual Mereotopo-logical Dependency			Cell Membrane – Cell Vertebra – Vertebrate Body Surface – Body
■ Mereotopological Independency			Uterus – Mammal Sulfur – AMino Acid Tooth – Human
■ Mereotopological Disjointness			Wing – Mouse Sulfur – Alanin Lung – Hand

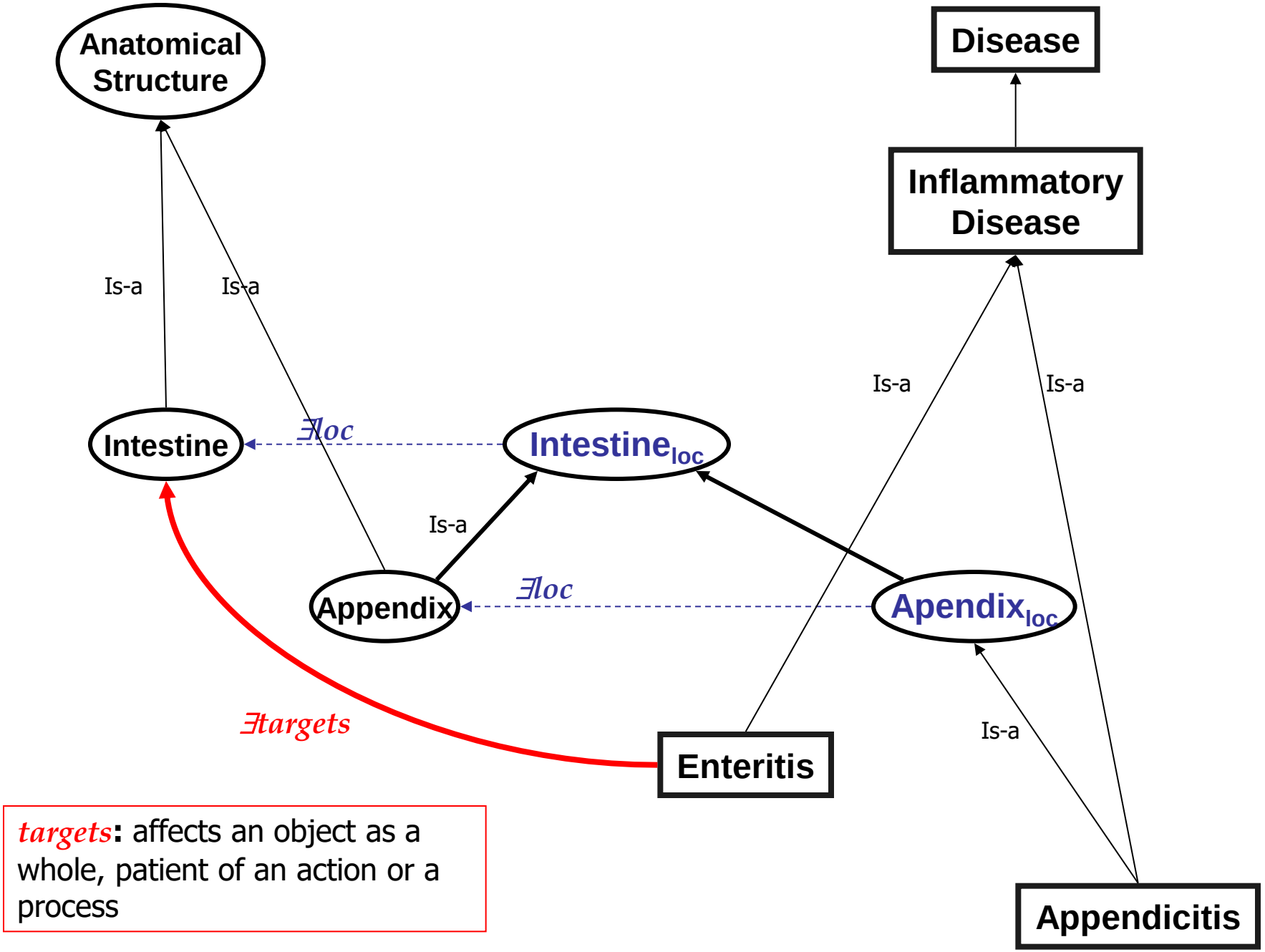
Reification of *inc* and *loc*

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

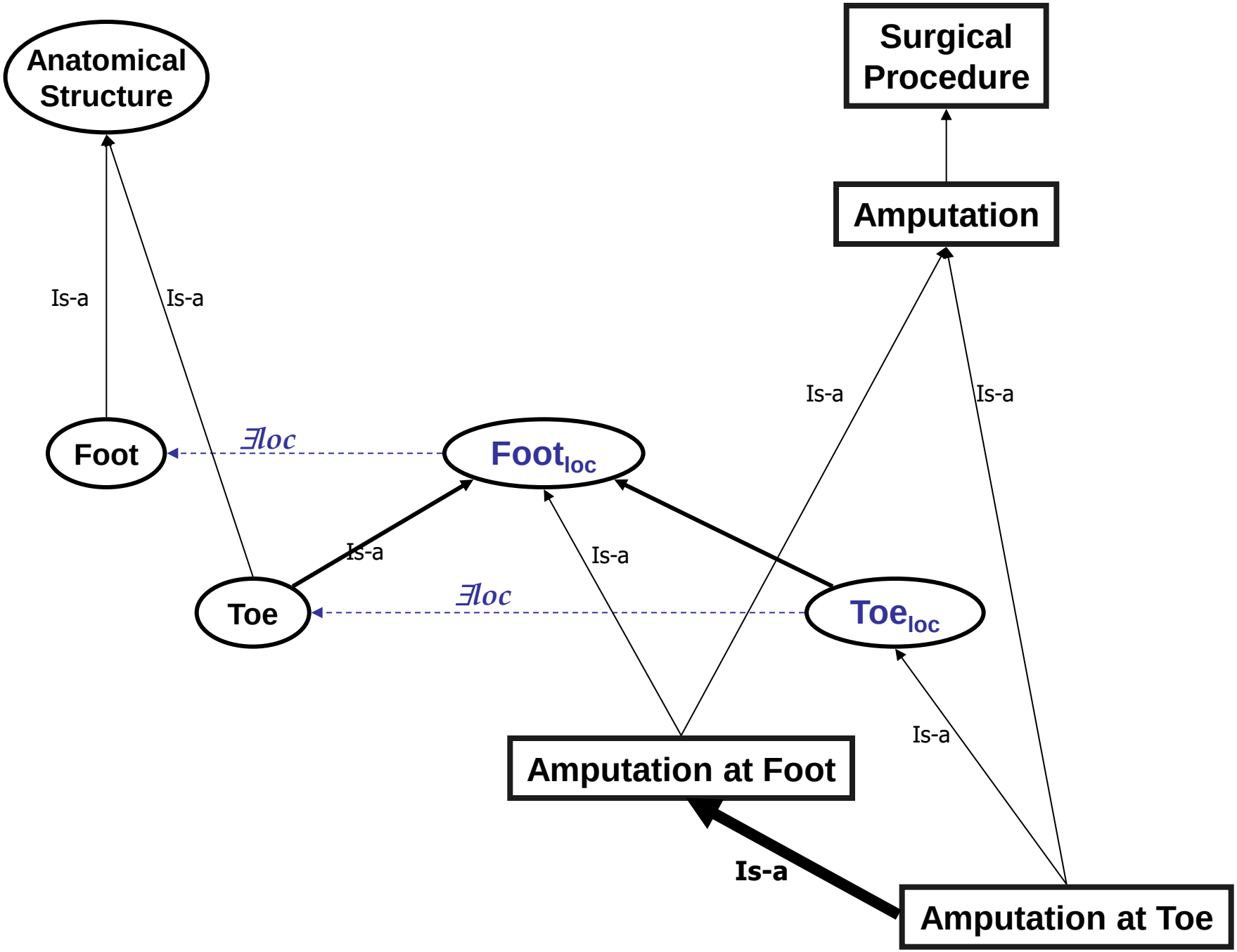


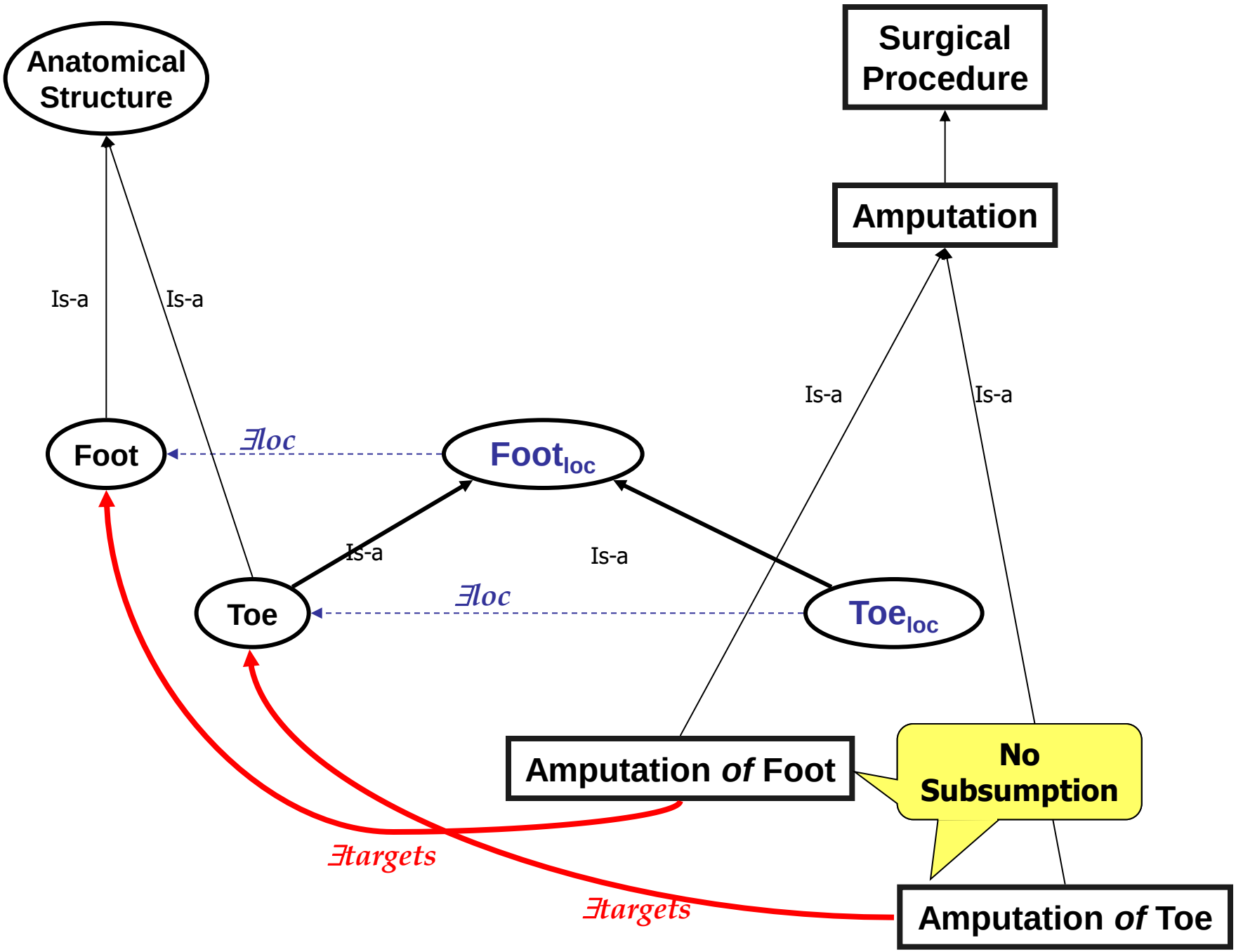
Extended Taxonomy


Anatomical Structure
Disease
Inflammatory Disease
Is-a
Is-a
Is-a
Is-a
Kidney
∃loc
Kidney$_{loc}$
Is-a
Is-a
Glom
∃loc
Glom$_{loc}$
Is-a
Nephritis
Is-a
Glomerulonephritis



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


Anatomical Structure
Surgical Procedure
Amputation
Is-a
Is-a
Is-a
Is-a
Foot
∃loc
Foot$_{loc}$
Is-a
Is-a
Toe
∃loc
Toe$_{loc}$
Is-a
Amputation at Foot
Is-a
Amputation at Toe


Anatomical Structure
Surgical Procedure
Amputation
Is-a
Is-a
Is-a
Is-a
Foot
∃loc
Foot$_{loc}$
Is-a
Is-a
Toe
∃loc
Toe$_{loc}$
Amputation *of* Foot
No Subsumption
∃targets
∃targets
Amputation *of* Toe

Conclusion

- 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

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

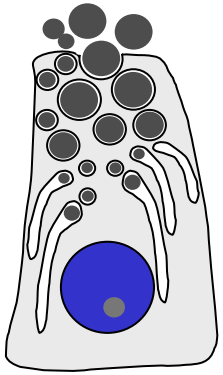
$$\forall x : instance\text{-}of(x, AmputationOfFoot) \rightarrow$$
$$(instance\text{-}of(x, Amputation) \wedge instance\text{-}of(x, Foot_{loc}) \wedge$$
$$\exists y : instance\text{-}of(y, Foot) \wedge targets(x, y))$$

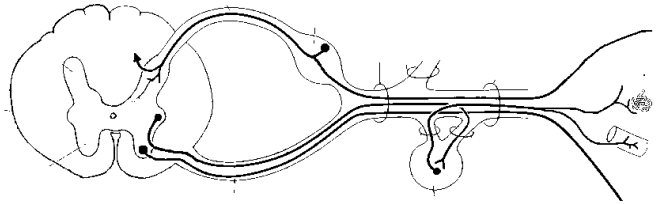
"Amputation **at** *a foot is an amputation which is located at a foot."*

$$\forall x : instance\text{-}of(x, AmputationAtFoot) \rightarrow$$
$$(instance\text{-}of(x, Amputation) \wedge instance\text{-}of(x, Foot_{loc}))$$

- Given $Is\text{-}A(Toe_{loc}, Foot_{loc})$, "amputation of a toe" can be classified as "amputation at a foot", but not as an "amputation of a foot"

Part-of: Locative flavor





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

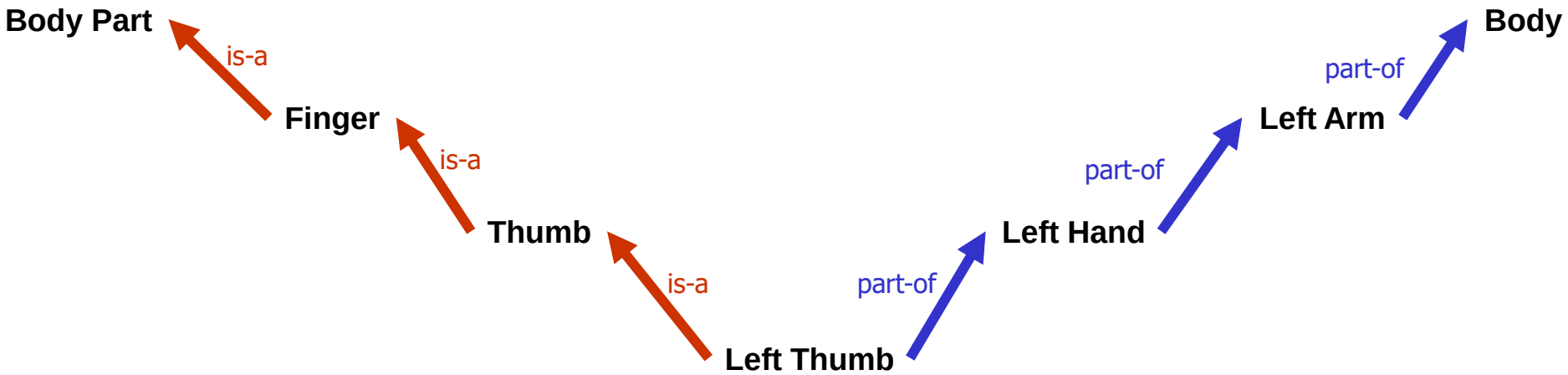
Classes of Individuals

Common Denominator of different "anatomies"

- Concepts (classes of individuals) with Semantic Links

Concept 1	*relation*	*Concept 2*
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

$$Part\text{-}Of(A, B) =_{def}$$
$$\forall x : instance\text{-}of(x, A) \rightarrow \exists y : (instance\text{-}of(y, B) \wedge part\text{-}of(x, y))$$
$$Has\text{-}Part(A, B) =_{def}$$
$$\forall x : instance\text{-}of(x, A) \rightarrow \exists y : (instance\text{-}of(y, B) \wedge has\text{-}part(x, y))$$

$$Loc(A, B) =_{def}$$
$$\forall x : instance\text{-}of(x, A) \rightarrow \exists y : (instance\text{-}of(y, B) \wedge loc(x, y))$$
$$Inc(A, B) =_{def}$$
$$\forall x : instance\text{-}of(x, A) \rightarrow \exists y : (instance\text{-}of(y, B) \wedge inc(x, y))$$

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

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

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

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

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

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

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

"Amputation **at** *a foot is an amputation which is located at a foot."*

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

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