Criteria for distinguishing parthood from spatial inclusion in biological objects

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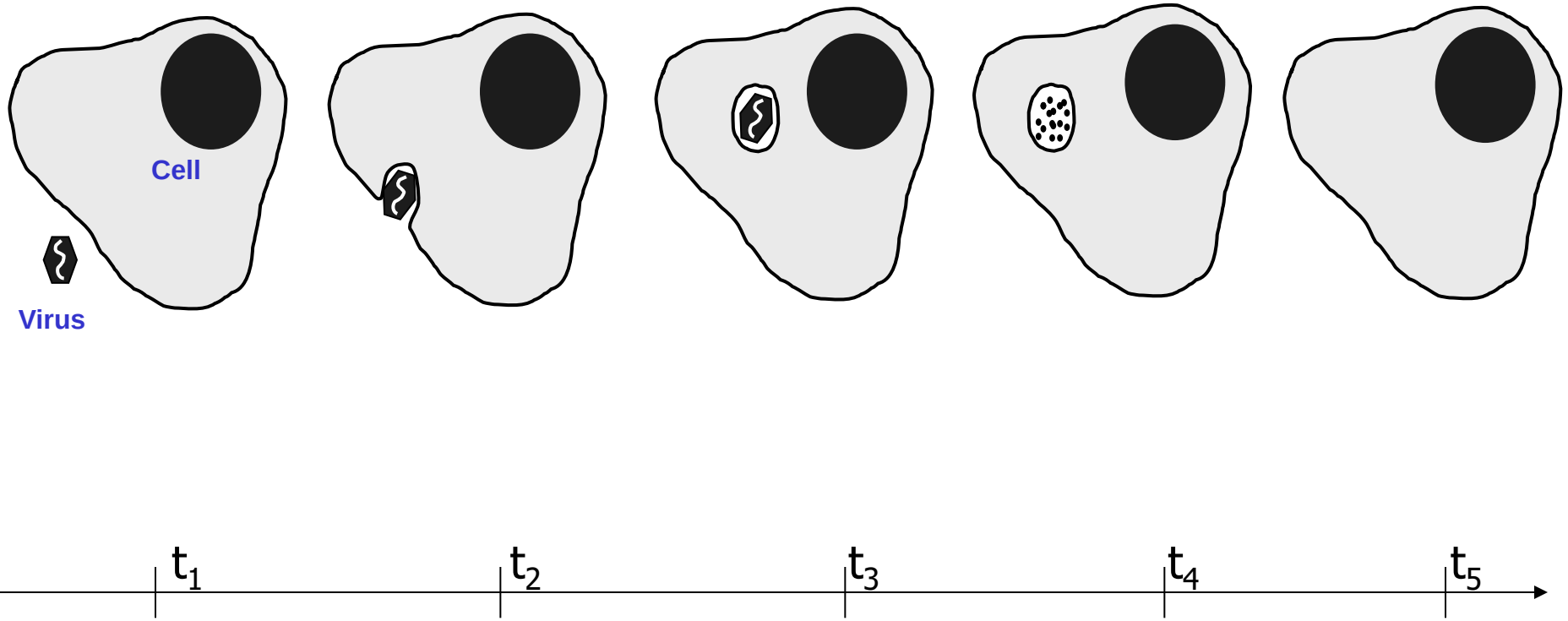
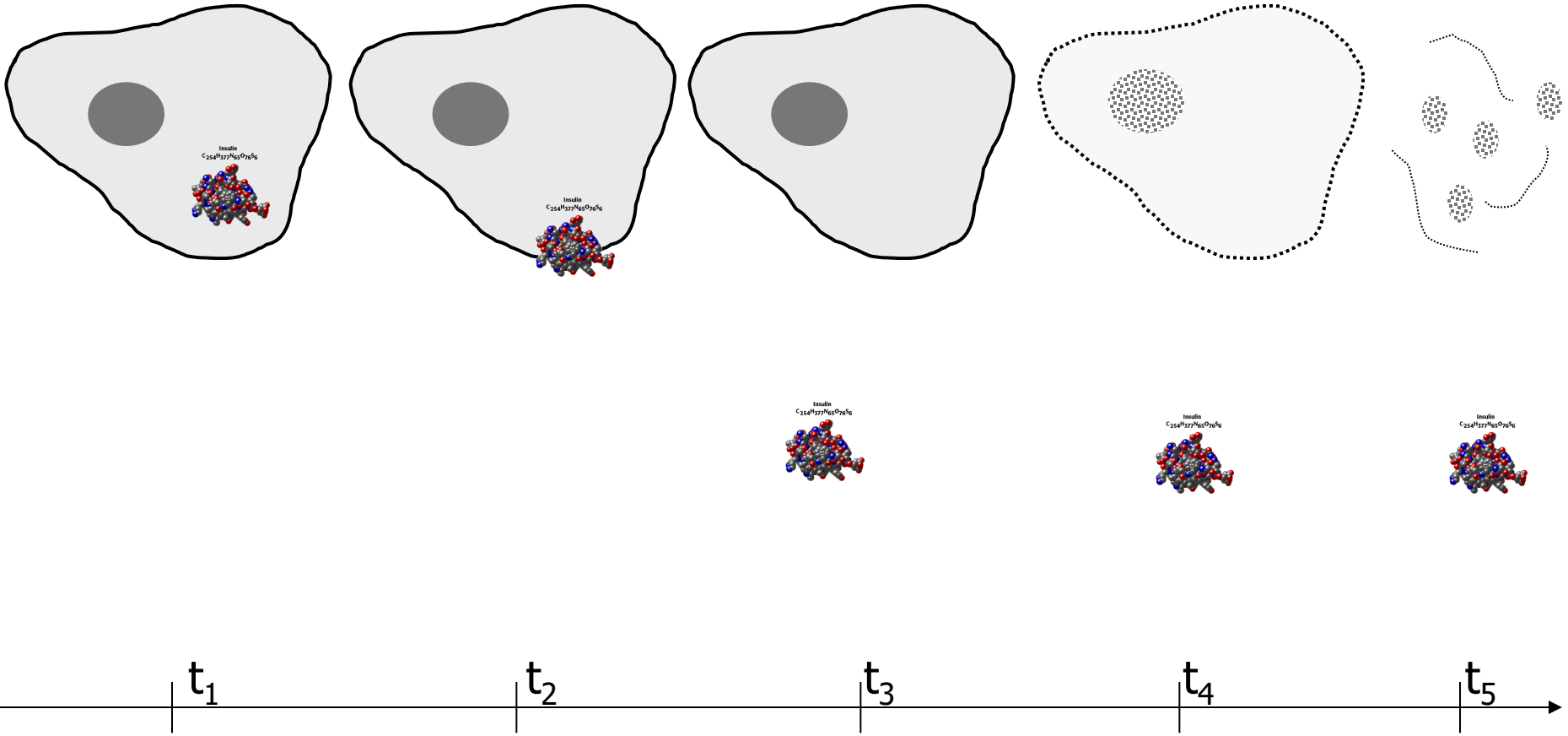
Beyond Part-Of

- Part-of / has-part: Generally accepted foundational relation to describe the spatial composition of biological organisms
- Can the generic part-of be clearly distinguished from other relations by non-discretionary criteria ?
- Is the part-of relation suitable for an ontology of biological systems ?

Phagocytosis / Digestion



Secretion



Parthood and Spatial Inclusion

part-of :	$p\ (x, y, t)$	generic parthood relation between objects
Region:	$R(z)$	z is a region in (Euklidean) space
	$z = r\ (x, t)$	z is the region where x is located at t

$p\ (x, y, t) \rightarrow p\ (r\ (x\ ,t),\ r\ (y,\ t))$

(Donnelly, IJCAI 03)

Spatial inclusion (coverage, (partly) location,…)

si spatially included by:

$si\ (x, y, t) =_{def}\ p\ (r\ (x,\ t),\ r\ (y\ ,t))$

When does inclusion imply parthood ?

- Under which circumstances ϕ can we infer parthood from spatial inclusion ?

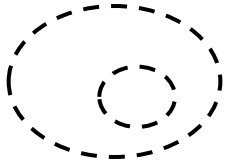
$$si\,(x, y, t) \wedge \phi \rightarrow p\,(x, y, t)$$

  - Sortal constraints
  - Life cycle
  - Ontological Dependence
  - Function

1. Sortal Constraints

- x and y are regions: +

  $R(x) \wedge R(y) \wedge si(x, y) \rightarrow p(x, y)$



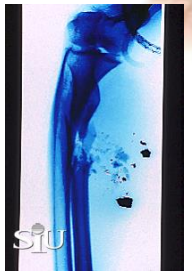
- x is material, y is immaterial: –

  $Solid(x) \wedge Hole \rightarrow (y) \wedge si(x, y) \rightarrow \neg p(x, y)$

  - $si(myBrain, myCranialCavity) \rightarrow \neg p(myBrain, myCranialCavity)$

- x is an non-biological artifact: –

  - $si(myPacemaker, myBody) \rightarrow \neg p(myPacemaker, myBody)$
  - $si(myInlay, myTooth) \rightarrow \neg p(myInlay, myTooth)$
  - $si(aBullet, myArm) \rightarrow \neg p(aBullet, myArm)$

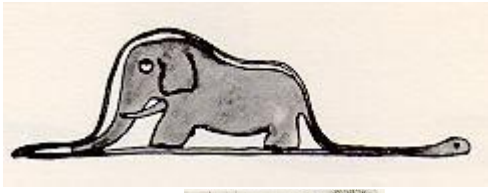


1. Sortal Constraints

- Alien organisms (and what they spatially include)
  - Symbionts:
  - *si (anEcoliBacterium , myIntestine) → ¬ p (anEcoliBacterium , myIntestine)*

  - Parasites:
  - *si (anEchinococcus, myLiver) → ¬ p (anEchinococcus, myLiver)*

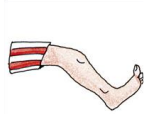
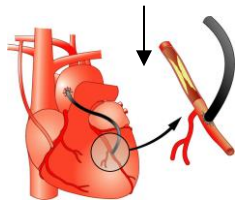
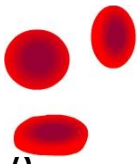
  - Preys:
  - *si (anElephant, aSnake) → ¬ p (anElephant, aSnake)*



  - Embryos, Fetuses:
  - *si (Leonardo, Caterina) → ¬ p (Leonardo, Caterina)*

1. Sortal Constraints Borderline cases (I)

- Grafts, transplants, transfusions
  - autologous:
    - *si (mySaphenousVein, myHeart)* $\overset{?}{\rightarrow} \neg$ *p (mySaphenousVein, myHeart)*
  - homologous:
    - *si (thisTransfusedRBC, myBlood)* $\overset{?}{\rightarrow} \neg$ *p (thisTransfusedRBC, myBlood)*
  - heterologous:
    - *si (thisPigValve, myHeart)* $\overset{?}{\rightarrow} \neg$ *p (thisPigValve, myHeart)*

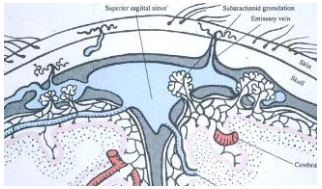


1. Sortal Constraints Borderline cases (II)

- Masses and Collections
  - Body Fluids (constant exchange but few discharge)

    … as a whole (endure over time)

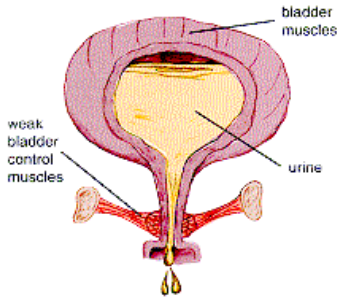
    ?
  - *si (myCSF, myCNS) → p (myCSF, myCNS)*



    … ad hoc (momentaneous existence)

    –
  - *si (thisAmountOfCSF, myFourthVentricle) → ¬ p (thisAmountOfCSF, myFourthVentricle)*
  - Body Secretions (periodic discharge):

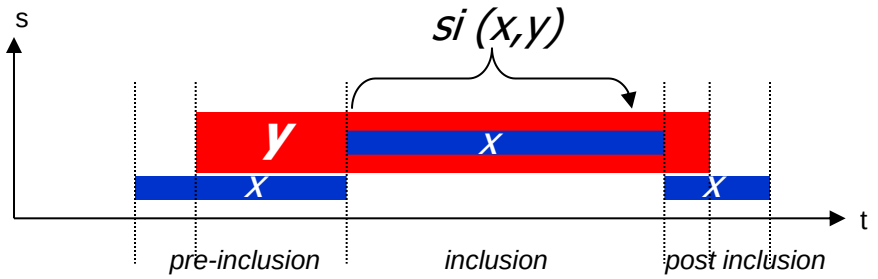
    –
  - *si (thisAmountOfUrine, myBladder) → ¬ p (thisAmountOfUrine, myBladder)*



  - Other cases:
  - *si (myLung, thisVolumeOfAir)*

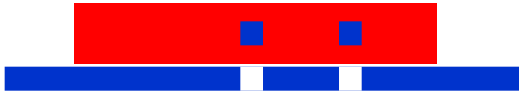
    –
  - *si (thisCOllectionOfLeukozytes, myGastricMucosa)*

2. Life Cycle




+ *p (aFingertip, aFinger)*


+ *p (myHead, myBody)*


— *p (aK⁺Ion, aHeartMuscleCell)*


+ *p (a CaHA crystal, aBone)*


? *p (anInsuline Molecule, aPancreaticBetaCell)*

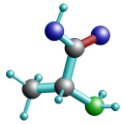

— *p (aLung, anN_2Molecule)*

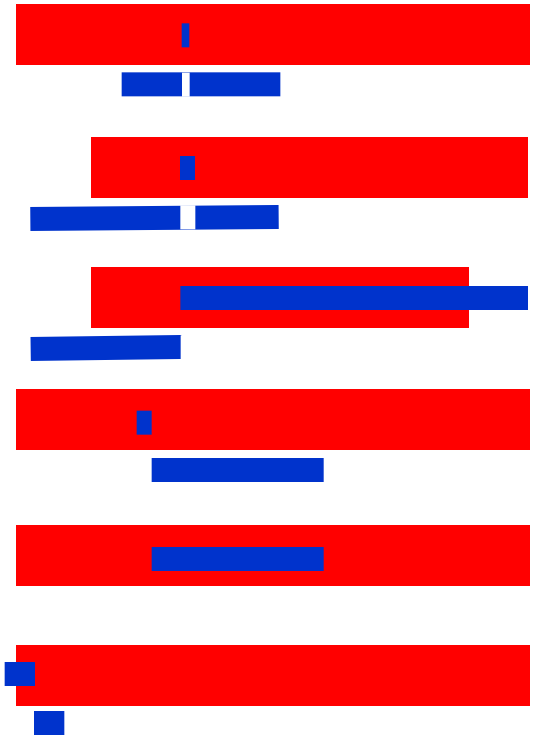

? *p (anAlaninMolecule, myBody)*

Which patterns allow the inference from inclusion to part ?

2. Life Cycle: Case study

si (anAlaninMolecule, anAnimalBody)





Ingested contained as ingredient of vegetal fibers, excreted by feces without digestion

Ingested contained as ingredient of a bone, digested and used for albumin synthesis. Albumin excreted by urine

Ingested, metabolized and used for collagen synthesis. Integrated in the structure of a bone

Synthesized in the liver, built in a hemoglobin molecule, leaves body by bleeding

Synthesized in the liver, built into a globulin molecule, then catabolized in a cell

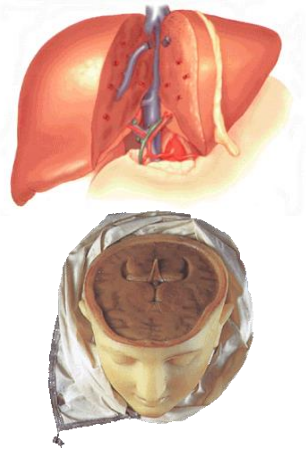
Included in the zygote and the early embryo. Then catabolized in the maternal organism

3. Ontological Dependency

- Individual level

  x can only exist when y exists:

  - Boundaries, non-detachable objects:
  - *si (myLiverSurface , myLiver) → p (myLiverSurface , myLiver)*
  - *si (mySkull, MyHead) → p (myLiverSurface , myLiver)*
  - Identity-bearing Objects
  - *si (myBrain, MyHead) → p (myBrain , myHead)*



- Class level

  x can only exist if an instance of the class Y exists

  - $\forall x$: *is-a (x, Cell)* $\rightarrow \exists y$: *is-a (y,* H_2O*)* $\wedge$ *si*$^{-1}$*(x, y)*

    Does not allow the inference from inclusion to part!

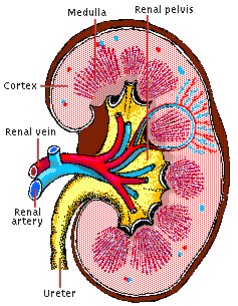
4. Function

- Preliminary sketch:
- If x is missing, then a function of y cannot be realized:

  Example:

  If a kidney is missing, then the filtration function of the body cannot be realized.

  Hence, a transplanted kidney, which has this function, can be considered *part-of* the receptor organism.



Microsoft Illustration

Conclusion

- Parthood implies Spatial inclusion
- What differentiates Parthood in biological organisms ?
- Workflow of analyses needed:
  1. Check sortal constraints
  2. Analyze life cycle
  3. Analyse ontological dependency
  4. Analyse function (?)
- Unclear cases remain !
- Implication for biological ontologies:
  - Use Spatial inclusion as primitive instead of Parthood
  - Automatic Refinement to Parthood where the above workflow yields unambiguous results

Anatomical boundaries and immaterial objects

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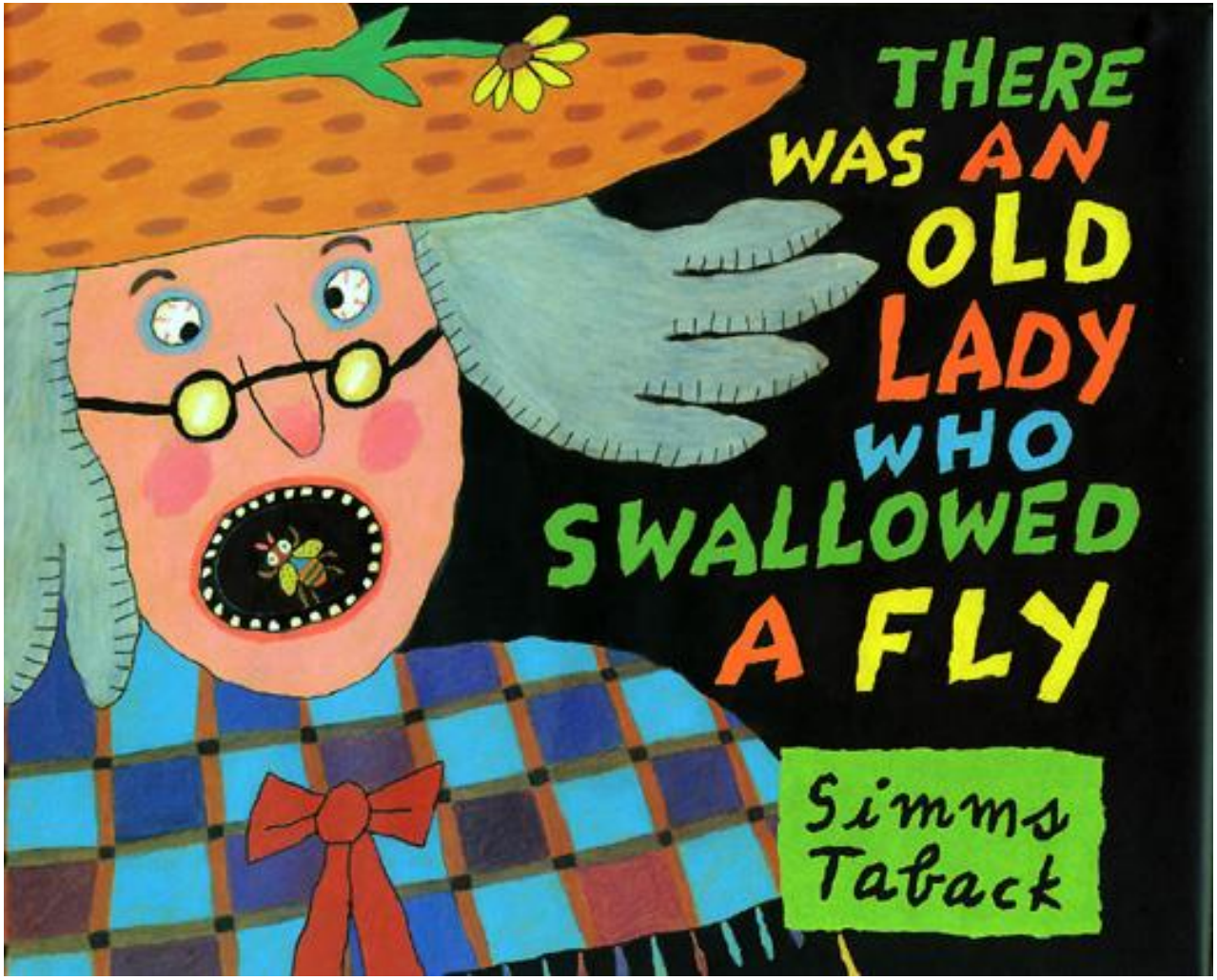
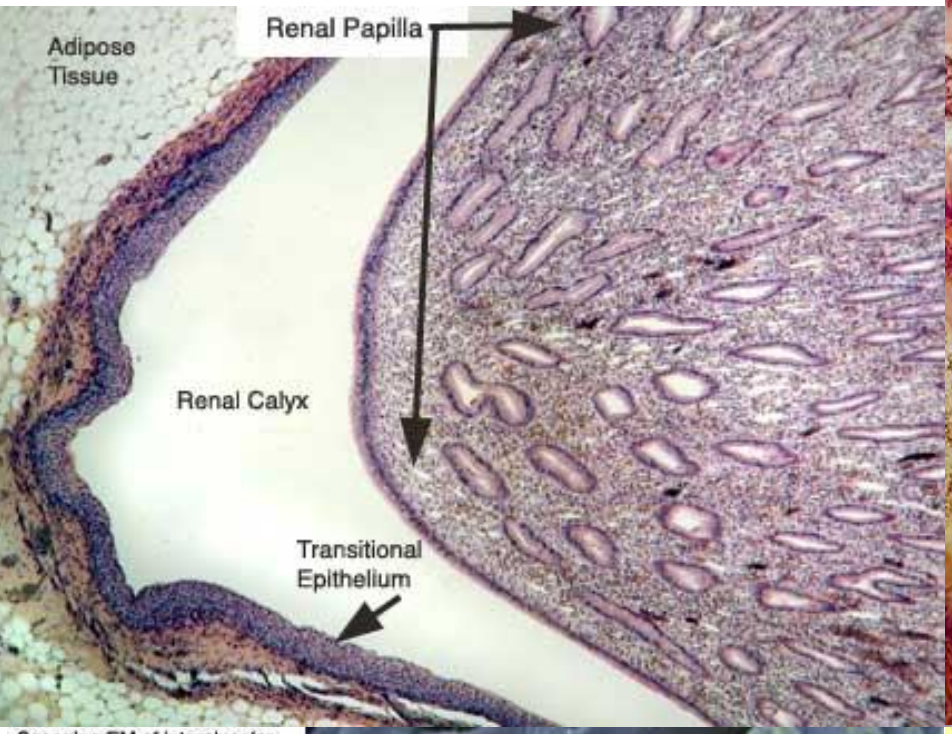


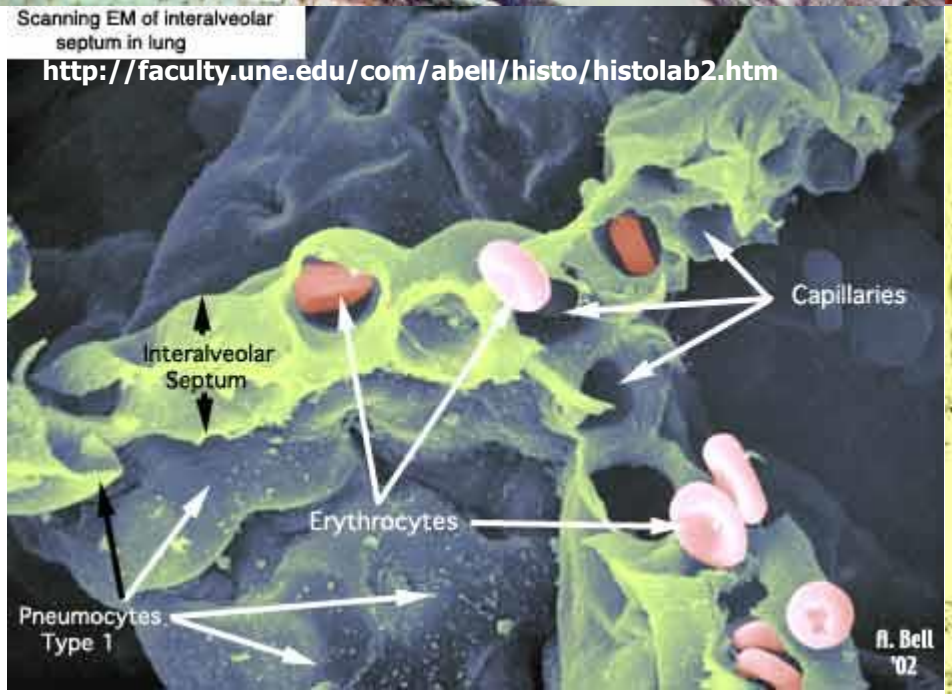
Is the fly inside or outside her body ?

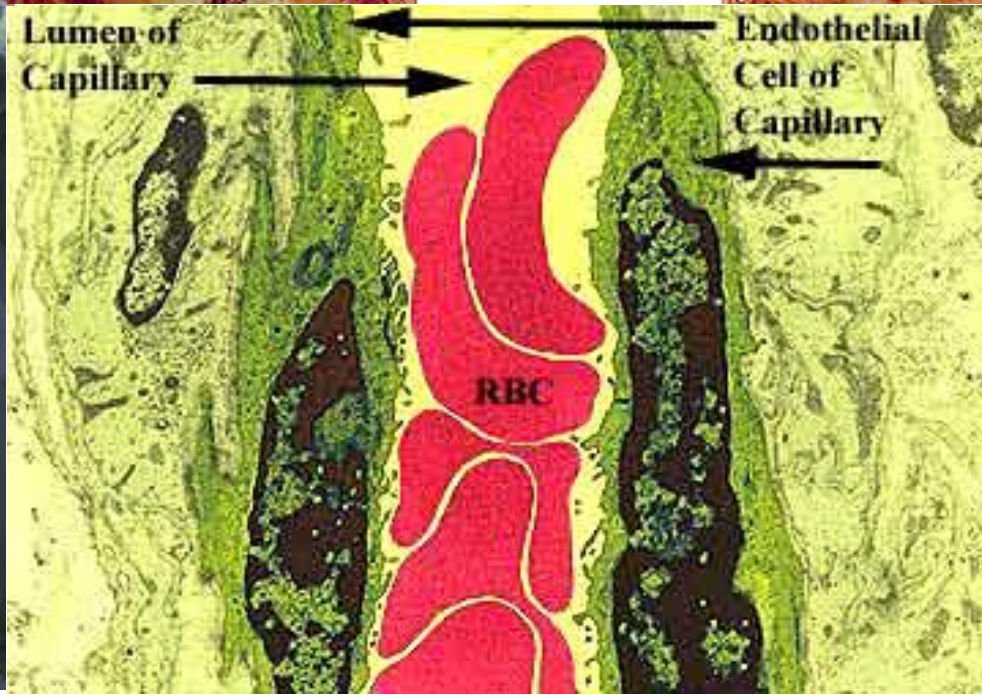
Problem (I)

- Biological objects need clearly defined boundaries to enable assertions parthood and location
- Most Biological objects are sponge-like (full of vessels, capillaries, cavities, holes and other hollow spaces)


Adipose Tissue
Renal Papilla
Renal Calyx
Transitional Epithelium


Stereocila in head of Epididymis

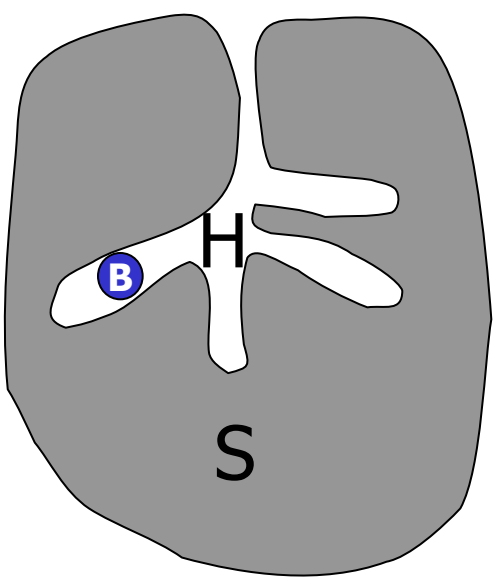

Scanning EM of interalveolar septum in lung
http://faculty.une.edu/com/abell/histo/histolab2.htm
Capillaries
Interalveolar Septum
Erythrocytes
Pneumocytes Type 1
A. Bell '02


Lumen of Capillary
Endothelial Cell of Capillary
RBC

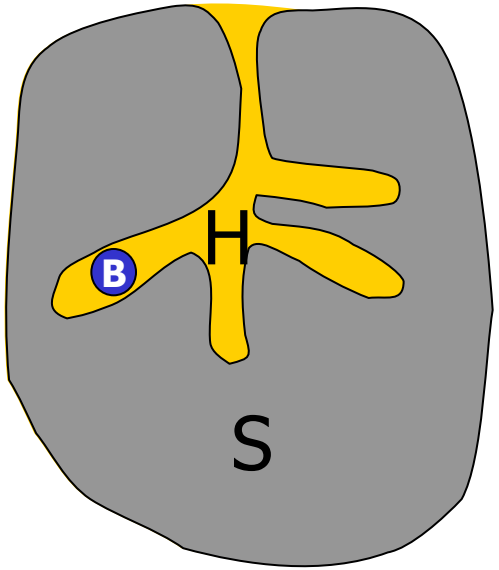
Problem (II)

- Many cavities communicate with the exterior space (e.g. respiratory system)
- Common conceptualization (cf. biomedical terminologies): biological objects have immaterial parts, eg. Lumen of esophagus, alveolar lumen, many cavities and holes in bones, …

How to deal with hollow spaces ?



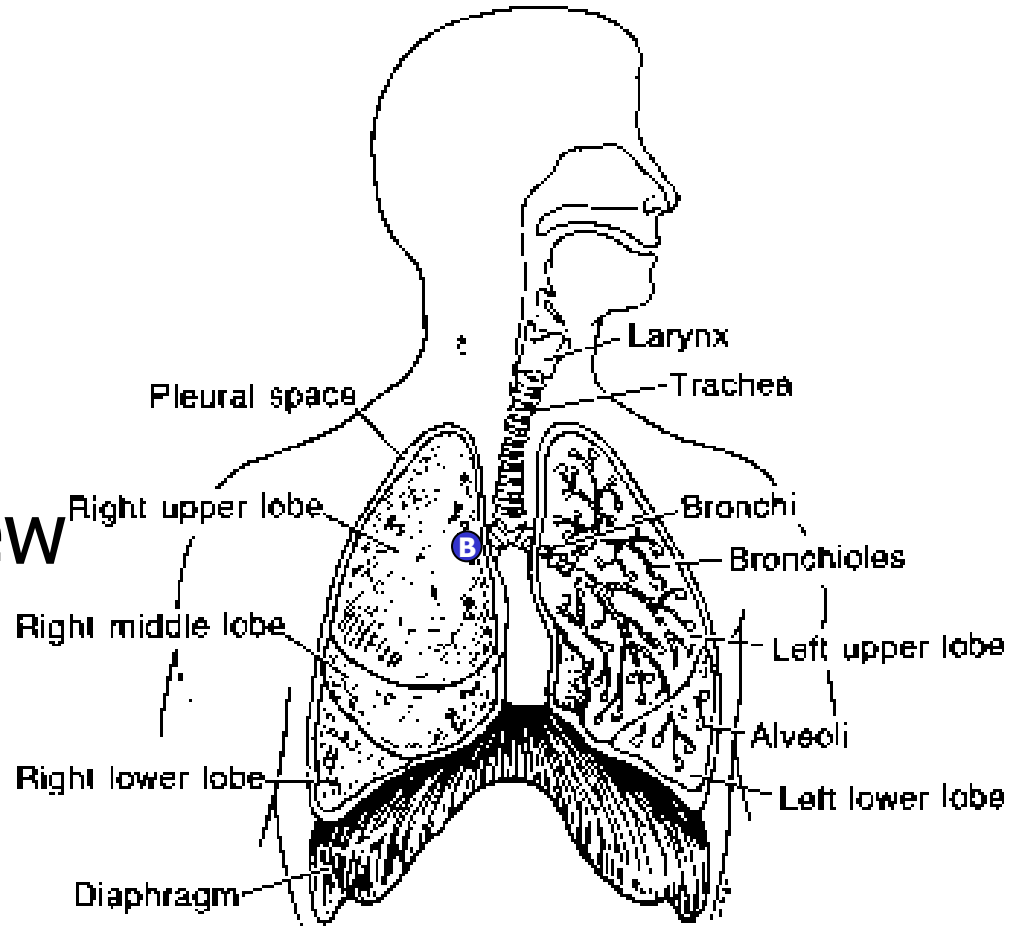
H is part of E, hence B is located outside of S



H is part of S, hence B is located inside of S

Problem

- Inside or outside ?
- Example: Bronchi
  A foreign body
  in a bronchus
  is in the lung
- Strict topological view
  conflicts with
  shared
  conceptualization



Where to delimit ?

1. All hollow spaces are part of the exterior…

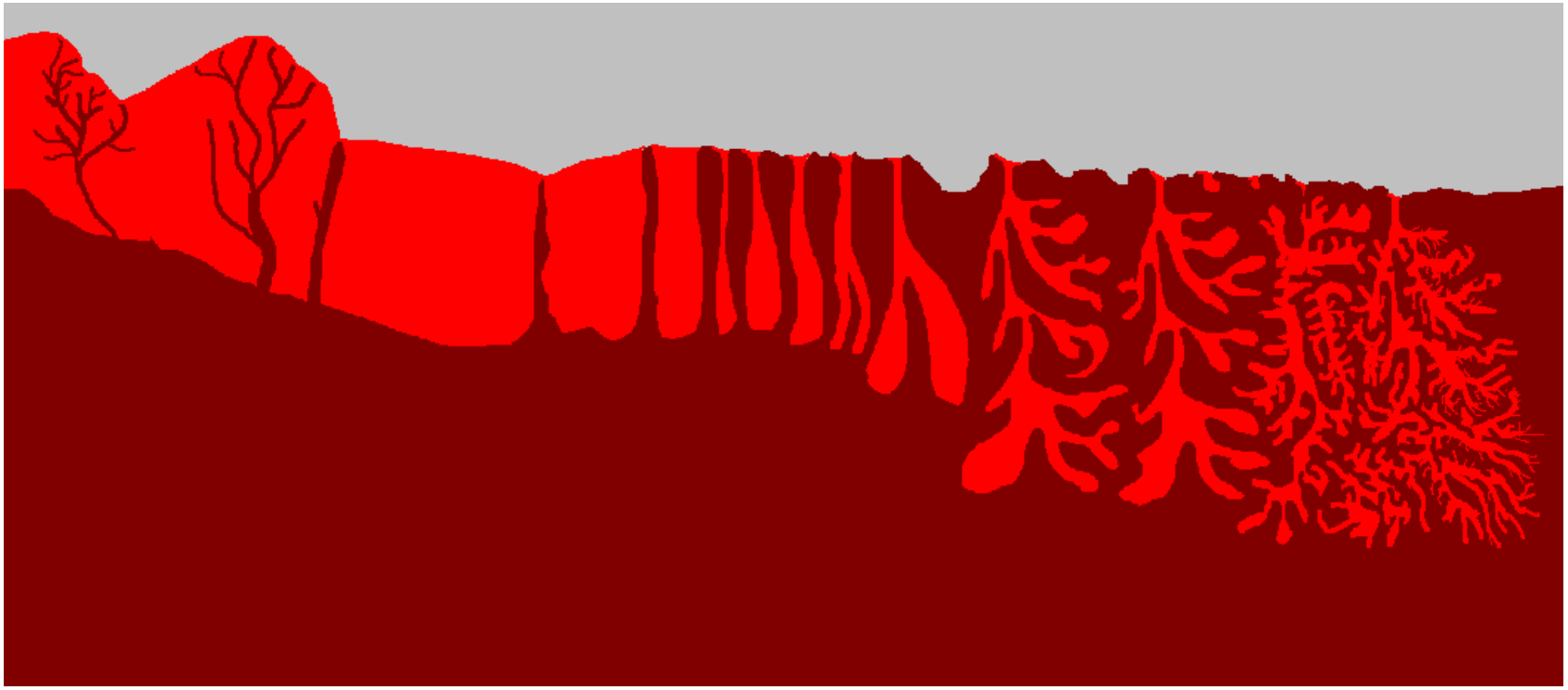
… but nothing can be located inside…

2. Those hollow spaces which communicate with the exterior are part of the exterior space…

… what if some spaces only temporarily communicate ?

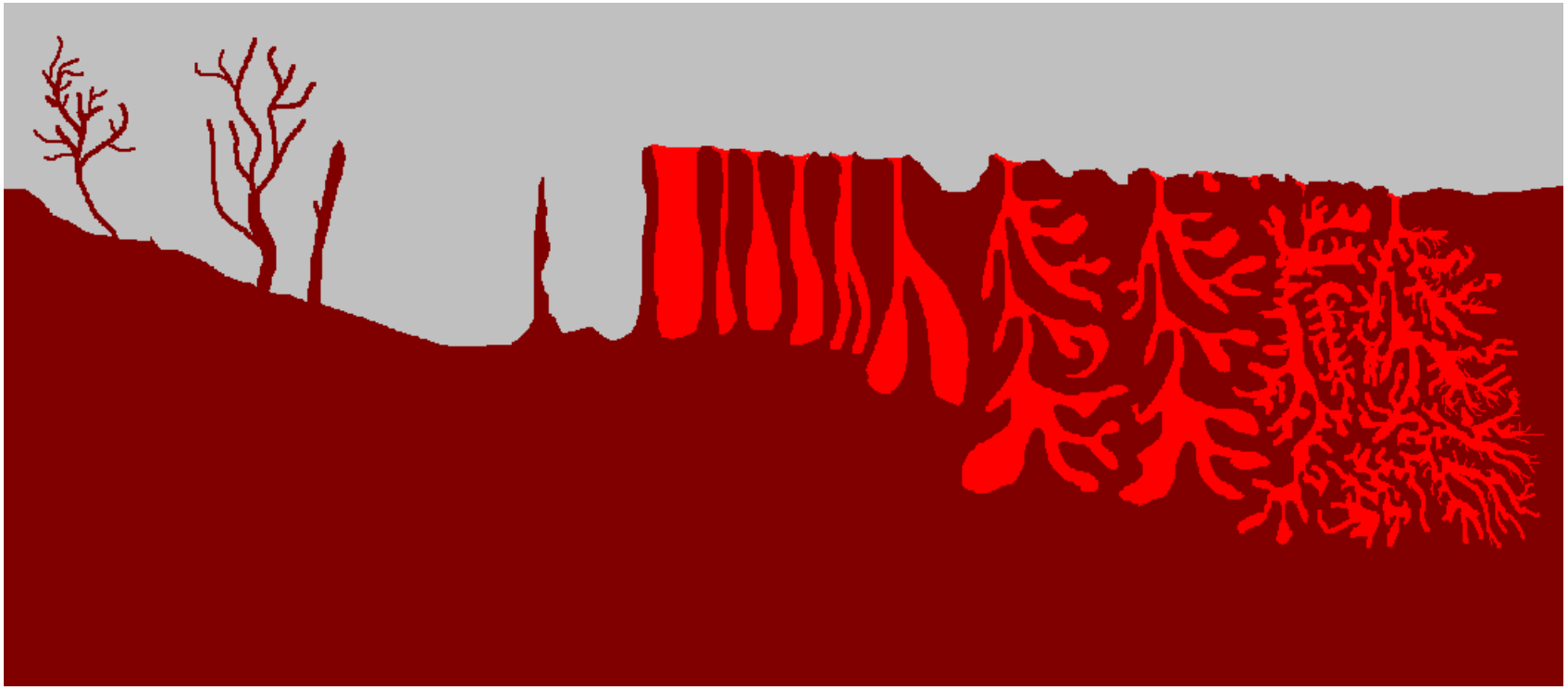
4. The complete convex hull is part of the object…

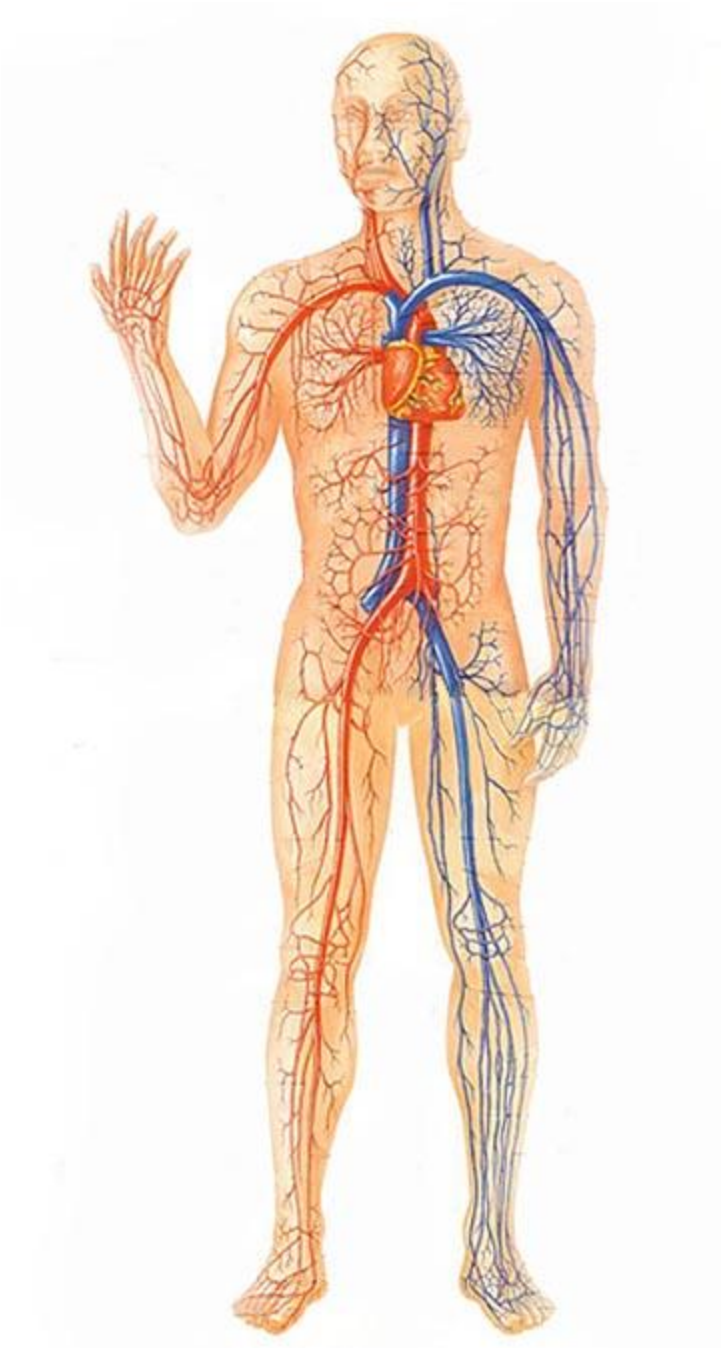
… then the body would practically spatially coincide with the vascular system !



3. Only those hollow spaces which are containers something are part of the exterior space…

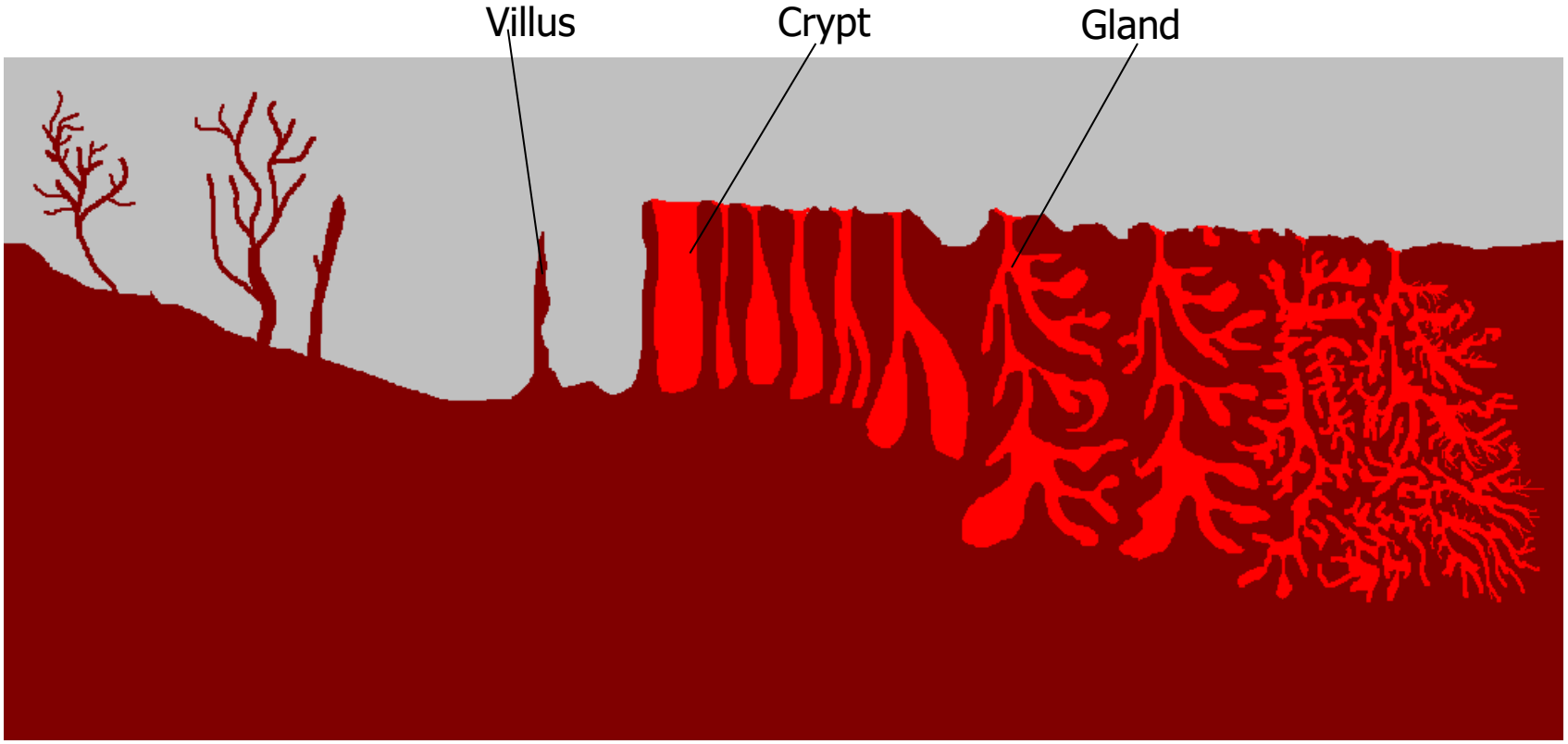
… how to ascertain whether they are containers ?





Solution

… how to ascertain whether they are containers ?



Algebraic Properties: *Part-Of | Has-Part vs. part-of | has-part*

- Instance level :

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

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

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

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

- Class level*:

  $Part\text{-}For\ (A, B),\ Part\text{-}For\ (B, C) \rightarrow Part\text{-}For\ (A, C)$

  $Part\text{-}For\ (A, B) \rightarrow \neg\, Part\text{-}For\ (B, A)$

  $Part\text{-}For\ (A, B) \rightarrow \neg\, Is\text{-}A\ (A, B)$ ***?***

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

  $Possible\text{-}Part\ (B, A)$ implies $Has\text{-}Possible\text{-}Part\ (A, B)$

  $(\ldots)$

Part-Of in Anatomies: Consensus required about

- Domain and range of part-of relations
- Algebraic properties of part-of relations
- Intended meaning of part-of relations in the domain of biology and medicine

instance level

Different notions of part-of

- Time-independent:
  - Compositional
  - Functional
  - Topological
- Time-dependent:
  - *a part-of b* at any point of time → *a part-of b* at every point of time
  - *a part-of b* at one point of time, *a NOT part-of b* at another point of time

instance level

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- Time-independent:
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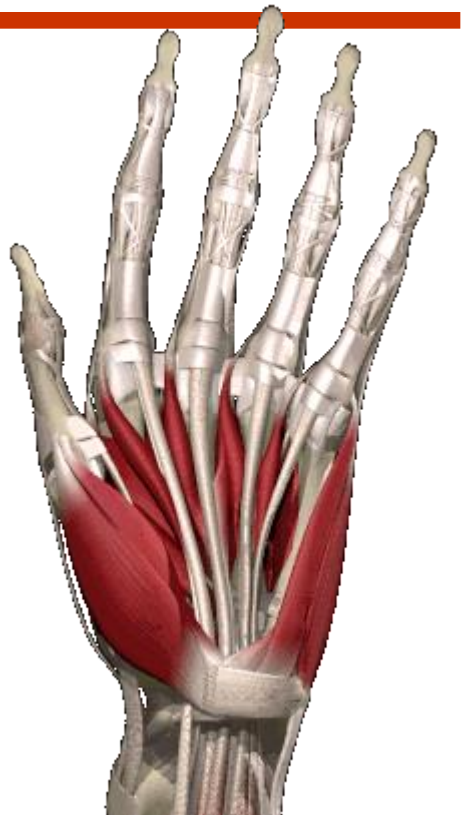
Parts as Components

Parts "build"
the whole



part-of (Finger, Hand)

part-of (Bone Marrow, Bone)

part-of (Sodium Ion, Cytoplasm) ?

part-of (Sarcomer, Muscle)

part-of (Heart, Human Body)

"Intuitive" notion of part. Controversial

instance level

Different notions of part-of

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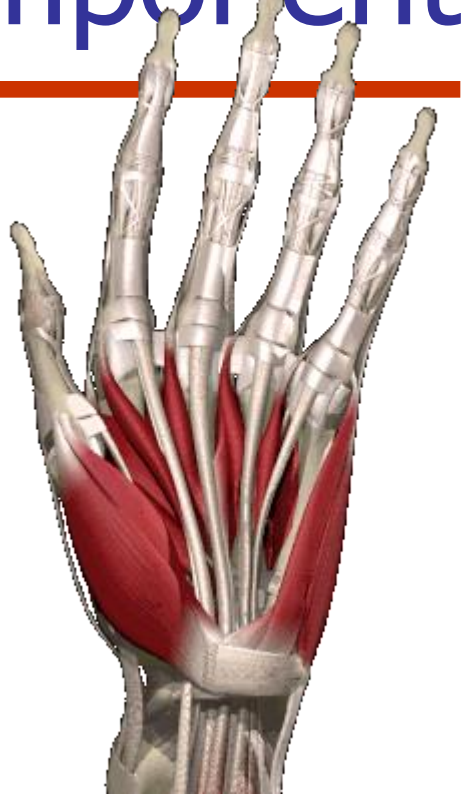
Parts as Functional Components

Part contributes to the function of the whole



part-of (Finger, Hand)

part-of (Lymph Node, Lymphatic System)

part-of (Cell Nucleus, Cell)

part-of (Tendon, Muscle)

part-of (Tooth, Jaw)

More restricted, may conflict with notions of connection

instance level

Different notions of part-of

- Time-independent:
  - Compositional
  - Functional
  - Topological
- Time-dependent:
  - *a part-of b* at any point of time → *a part-of b* at every point of time
  - *a part-of b* at one point of time, *a NOT part-of b* at another point of time

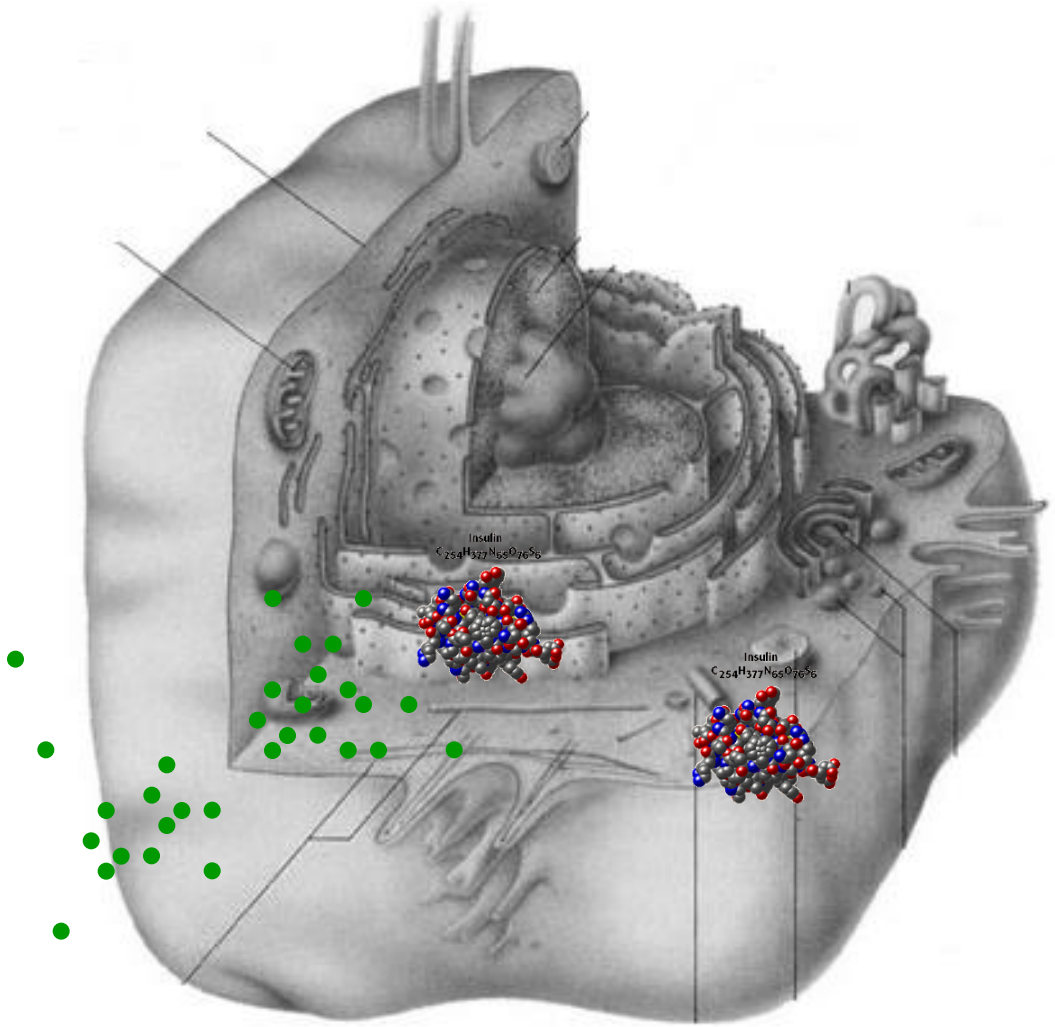
no clear distinction !

instance level

Different notions of part-of

- Time-independent:
  - Compositional
  - Functional
  - Topological
- Time-dependent:
  - *a part-of b* at any point of time → *a part-of b* at every point of time
  - *a part-of b* at one point of time, *a NOT part-of b* at another point of time

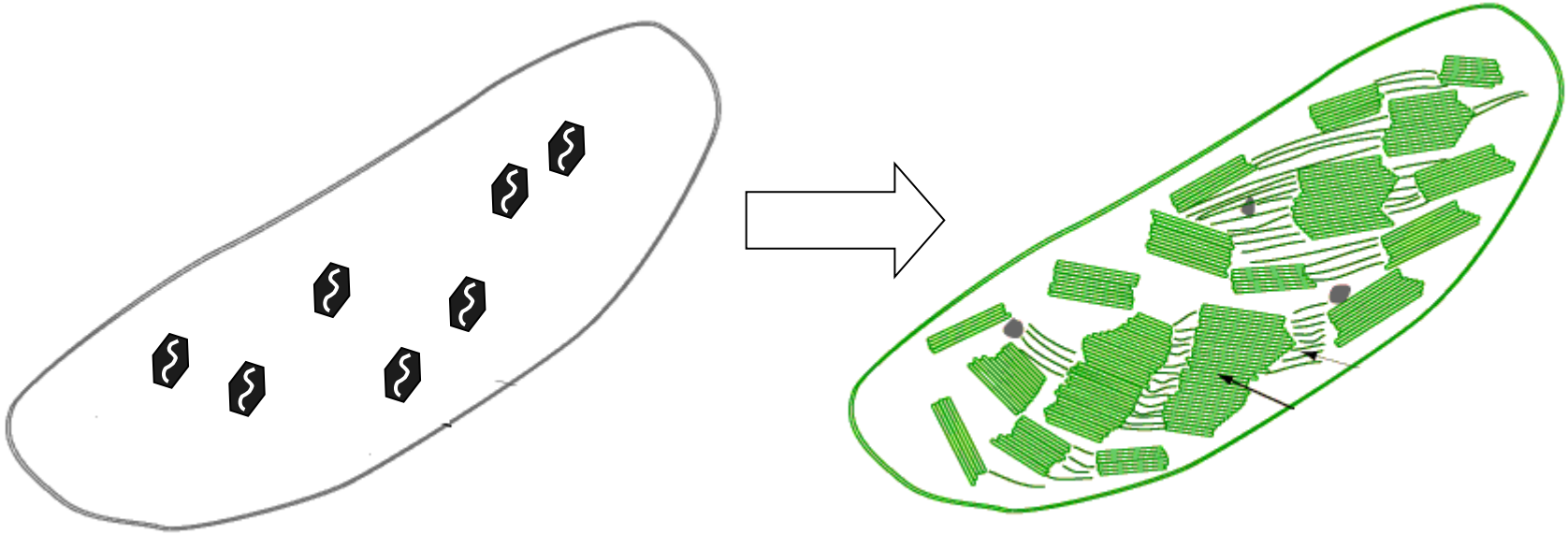
Continuous exchange of matter



Endosymbiont Hypothesis

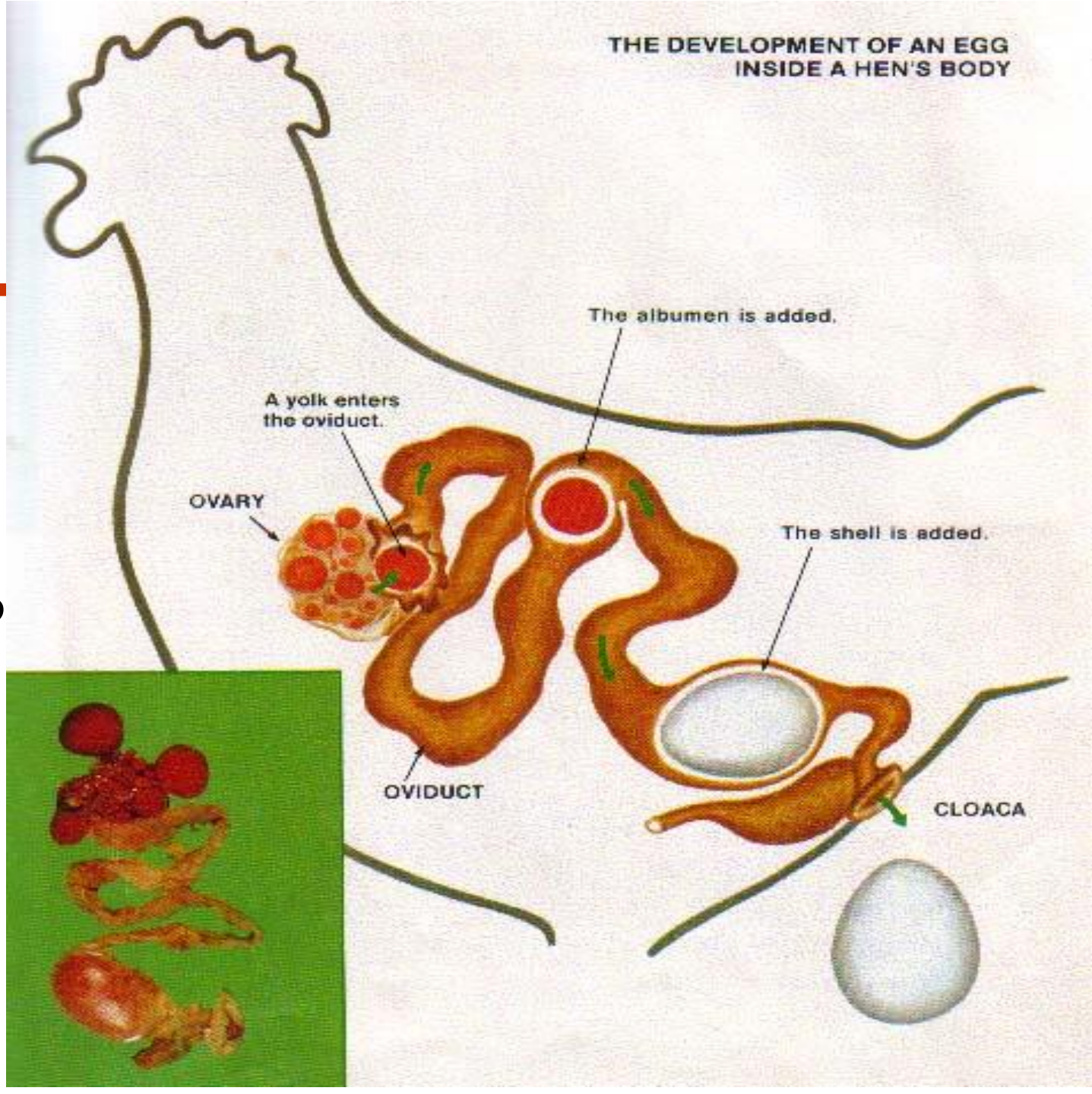
2.5 billion years ago:
Primitive cell with
bacterium-like symbionts

Today:
Chloroplasts (Plants)
Mitochondria



Are the organells part of the cell

- Which eggs are part of the body ?



Topological parts

Located within the boundaries of an object

part-of (Mitochondrium, Cell)
part-of (Brain, Head)

part-of (Brain, Cranial Cavity) ?

part-of (Ovum, Oviduct) ?

part-of (Finger, Hand)

part-of (Amount of Blood, Right Ventricle) ?

has-location instead of *part-of* ?

Topological parts

Located within the boundaries of an object

has-location (Mitochondrium, Cell)
has-location (Brain, Head)

has-location (Brain, Cranial Cavity)

has-location (Ovum, Oviduct)

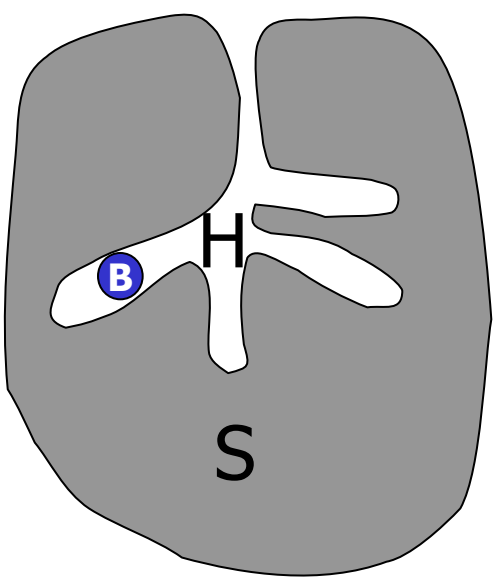
has-location (Finger, Hand)

has-location (amount of Blood, Right Ventricle)

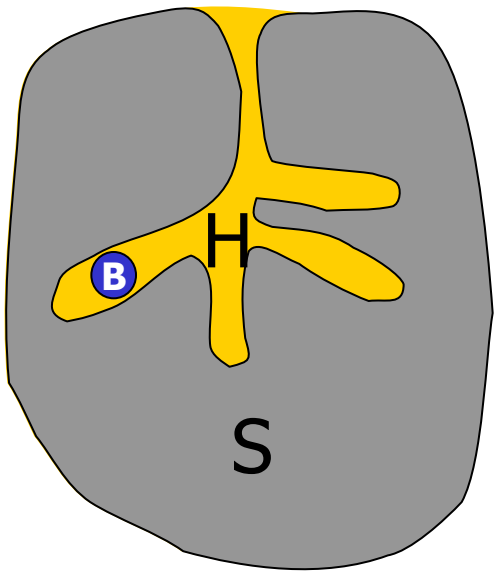
has-location as a mereotopological primitive ?

Topological parts

How to deal with hollow spaces ?



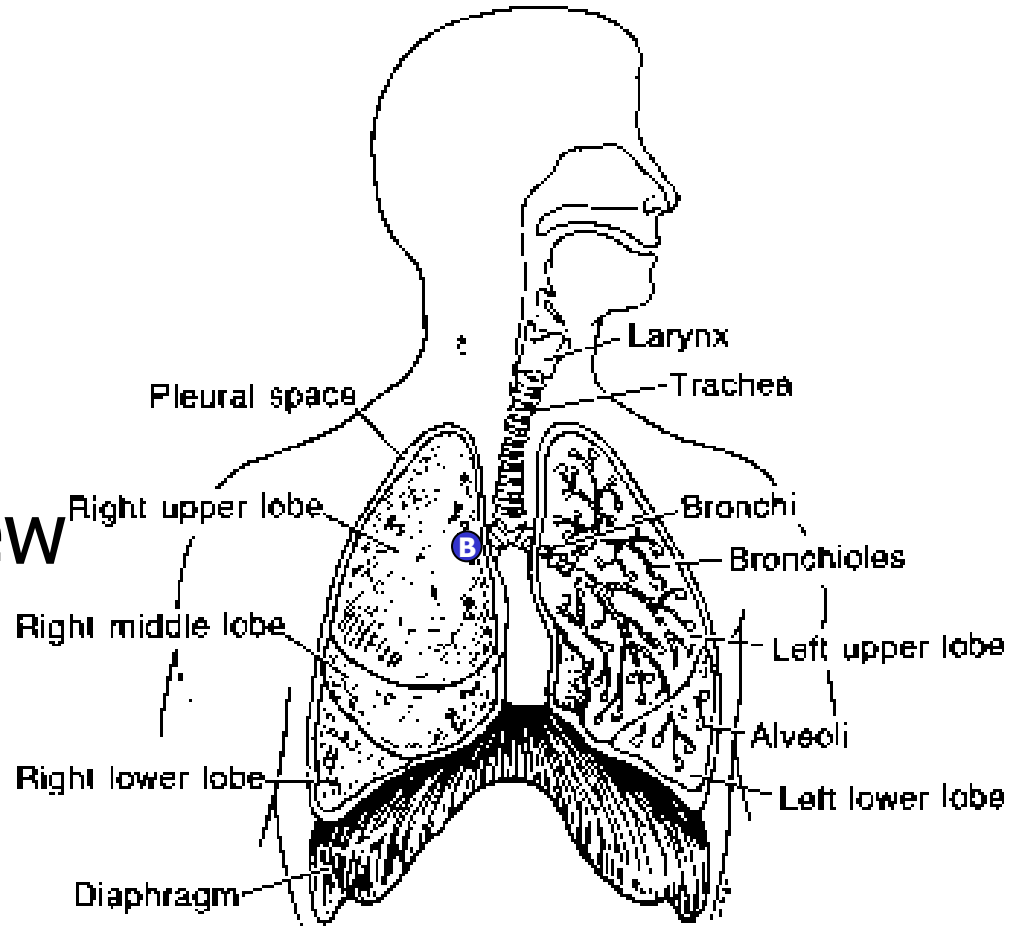
H is part of E, hence B is located outside of S



H is part of S, hence B is located inside of S

Example

- Inside or outside ?
- Example: Bronchi
  A foreign body
  in a bronchus
  is in the lung
- Strict topological view
  conflicts with
  shared
  conceptualization

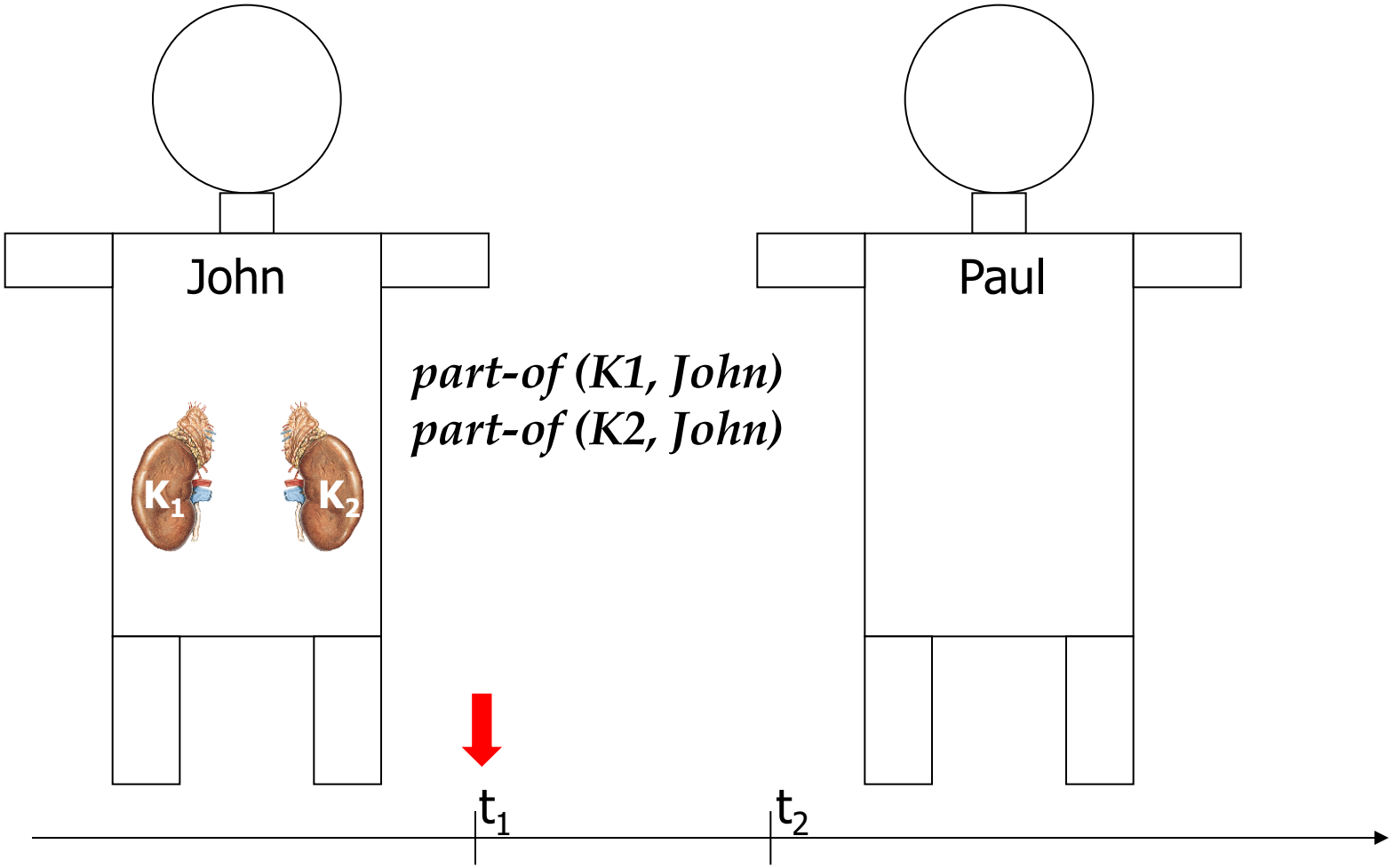


instance level

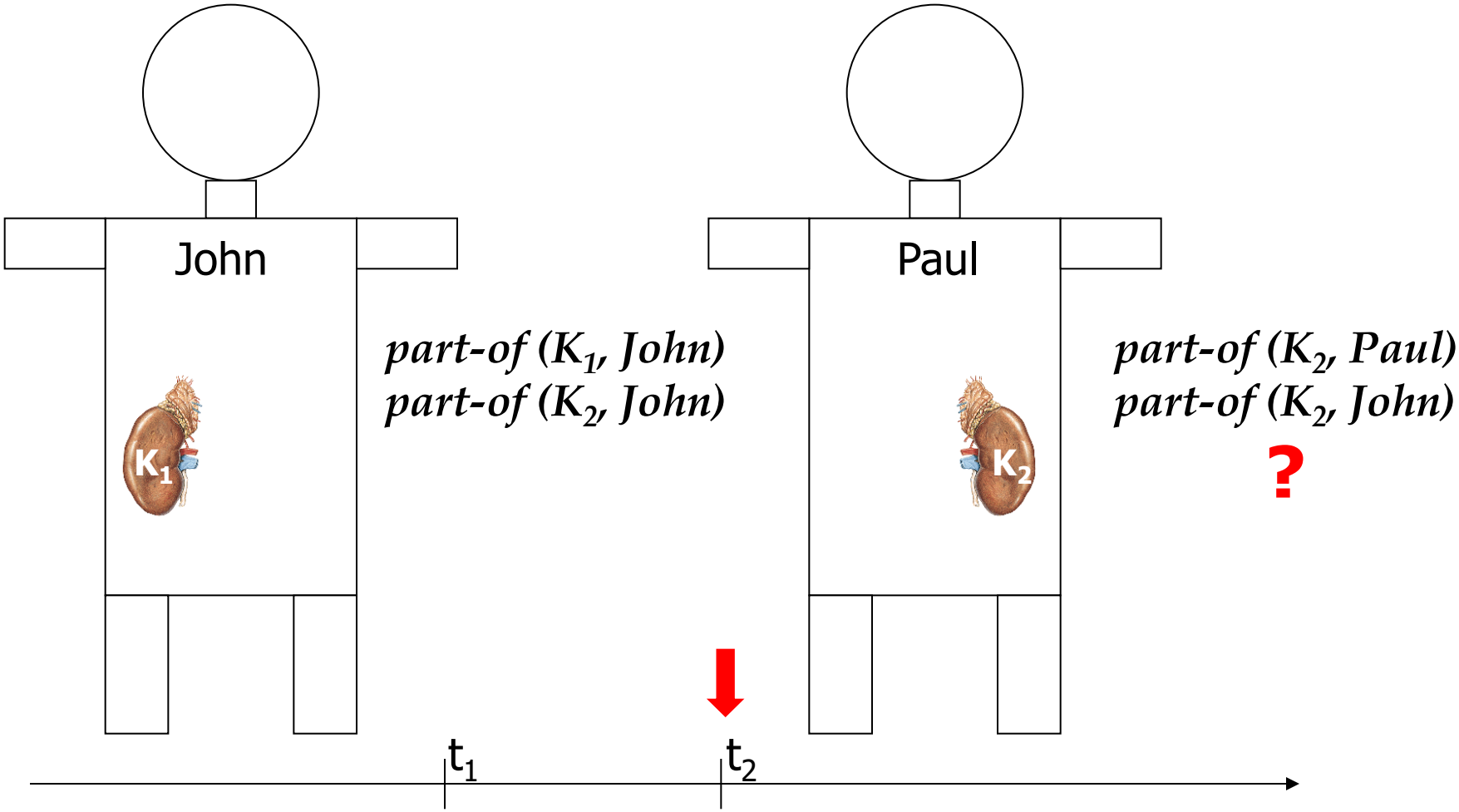
Different notions of part-of

- Time-independent:
  - Compositional
  - Functional
  - Topological
- Time-dependent:
  - *a part-of b* at any point of time → *a part-of b* at every point of time
  - *a part-of b* at one point of time, *a NOT part-of b* at another point of time

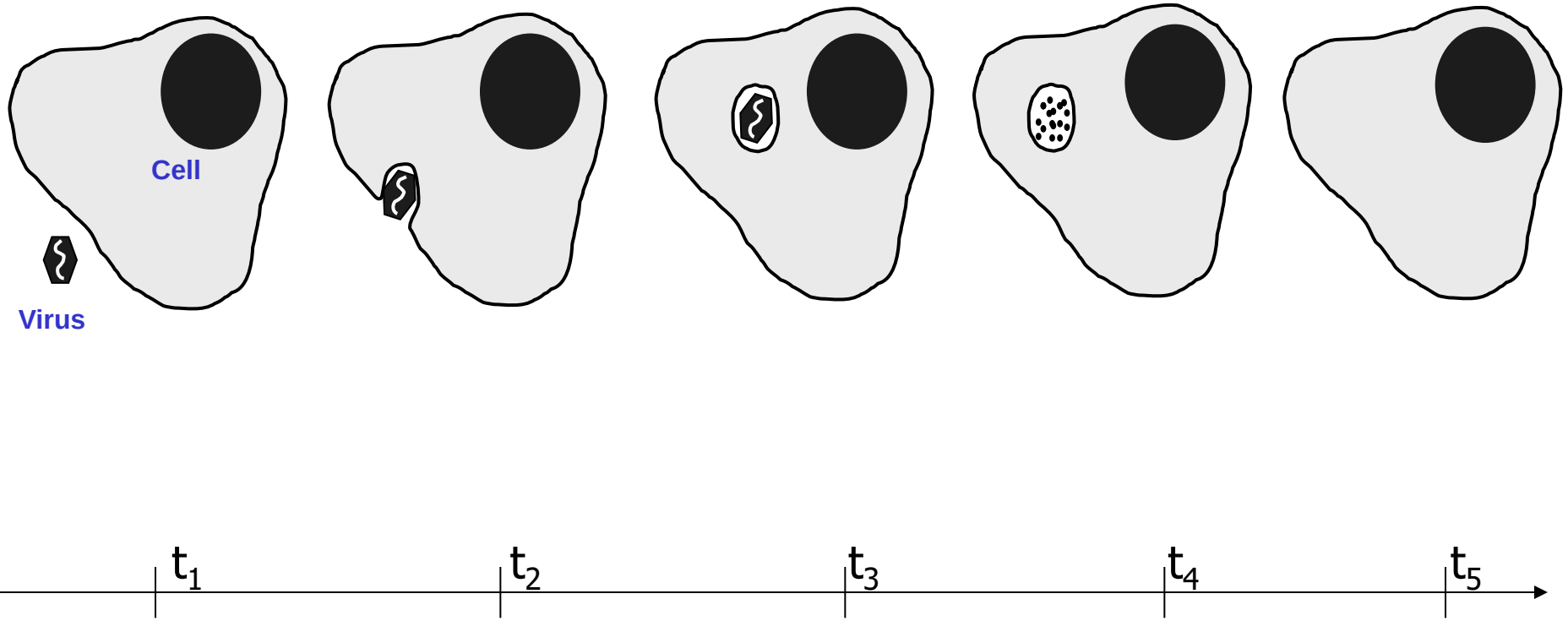
Example: Transplantation



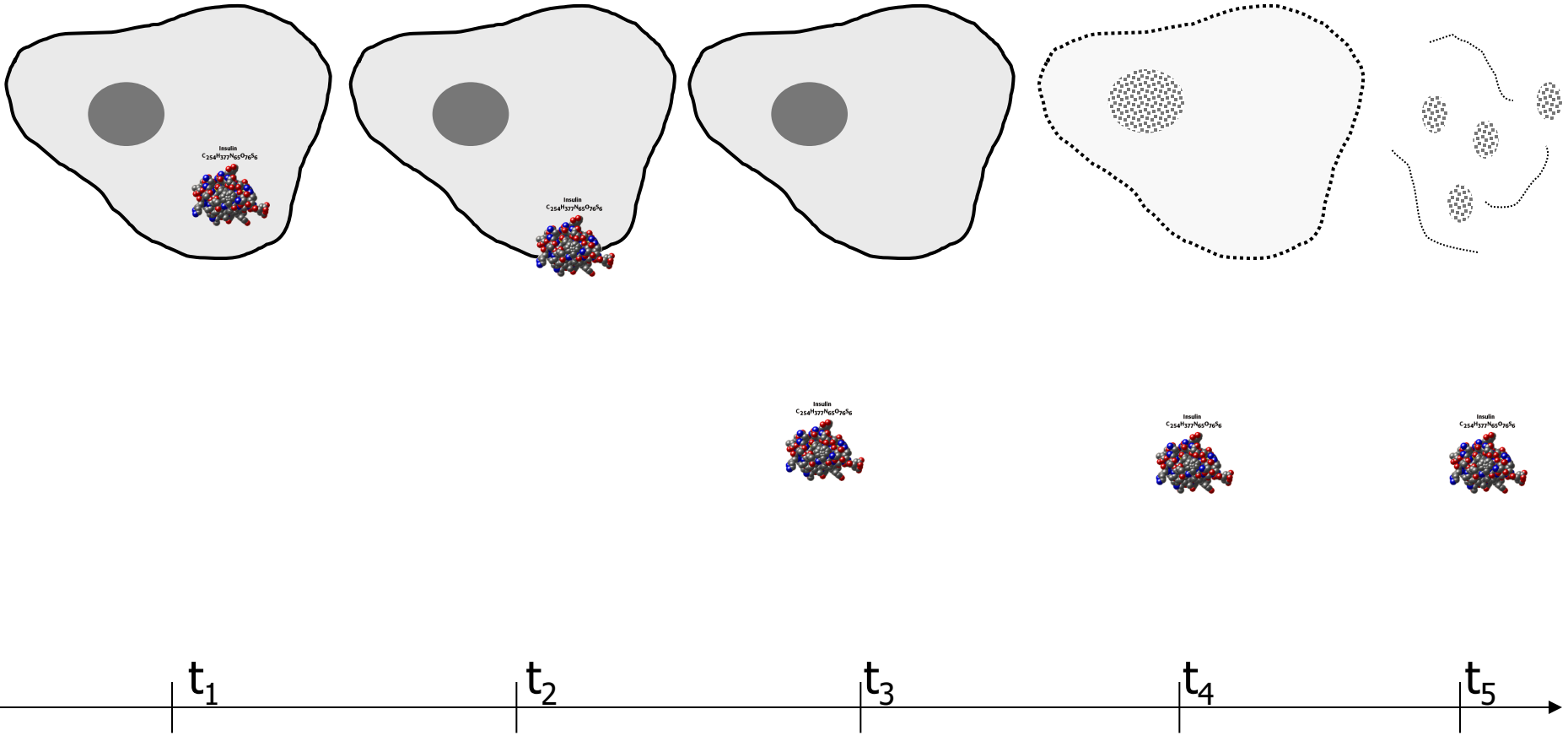
Example: Transplantation



Phagocytosis / Digestion



Secretion



Conclusion

- Part-of: example, how many different interpretations co-exist
- Standardization: need to eliminate ambiguity by precise characterization of foundational primitives (properties, relations)
- Solid theoretical basis is needed, e.g. mereotopology: Simons, Casati, Smith, Varzi,…