

How to compare FMA – GALEN

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Overview

- Ontologies and their representation
- Methodology and related work
- Basic formal ontology as reference framework
- Top-level design of GALEN (Anatomy) and FMA
- Parthood and containment in GALEN and FMA
- Problems with reification
- Summary

Ontologies and their representation

Ontologies

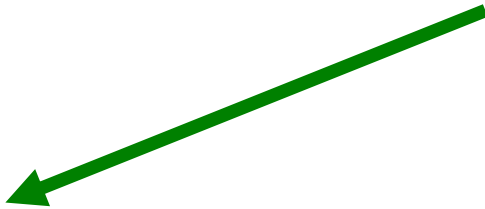
- Definition (Guarino 1998):
 - A shared vocabulary plus a specification (characterization) of its intended meaning

Kinds of Ontologies

A shared vocabulary plus a set of formal rules for reasoning

Different **degrees of expressive power** for the specification of the intended meaning

Two extremes



*Meaning
specified
implicitly and
informally in
natural language*

Kinds of Ontologies

A shared vocabulary plus a specification of its intended meaning

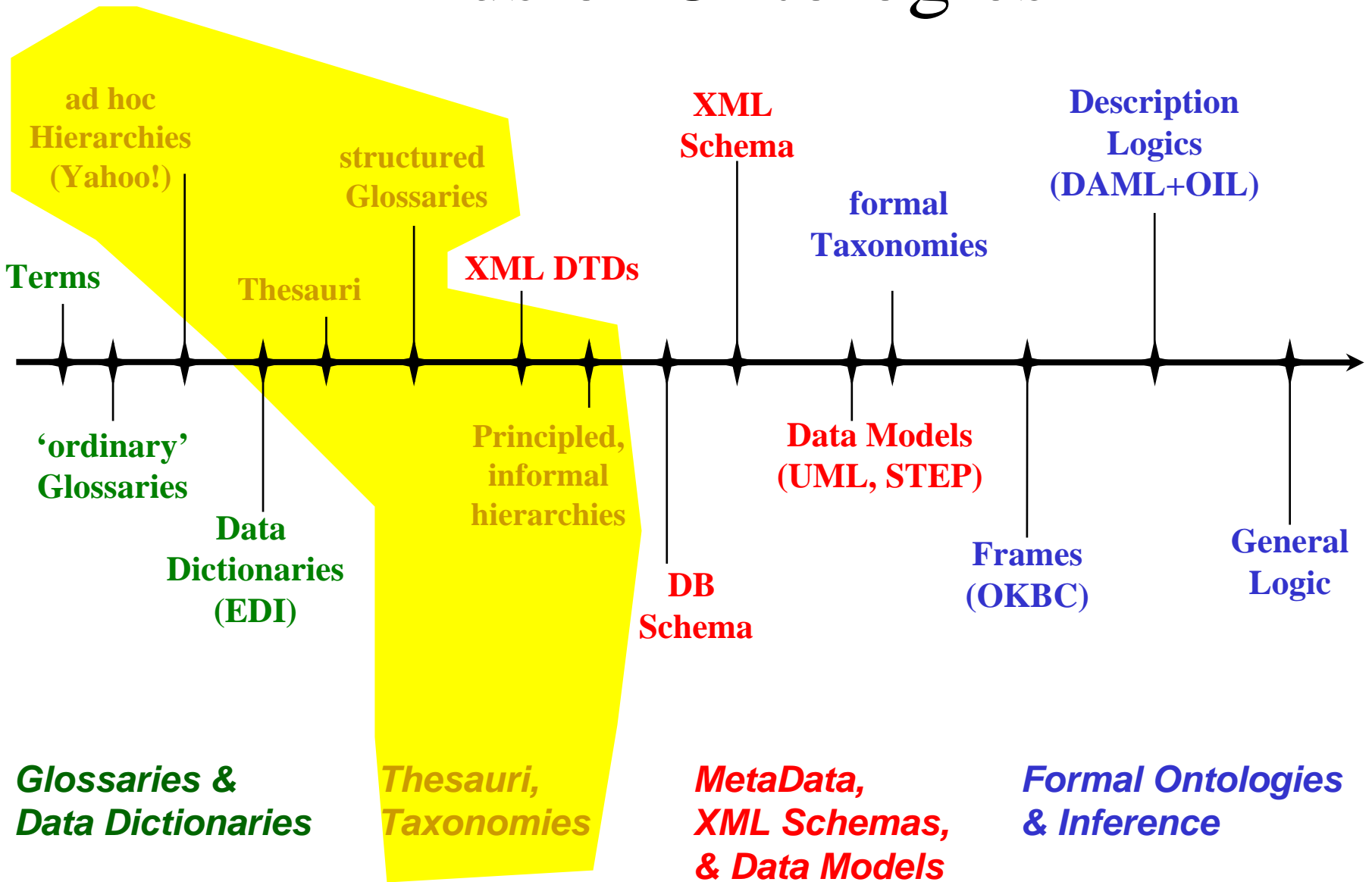
Different degrees of rigor of the specification of the intended meaning

Two extremes

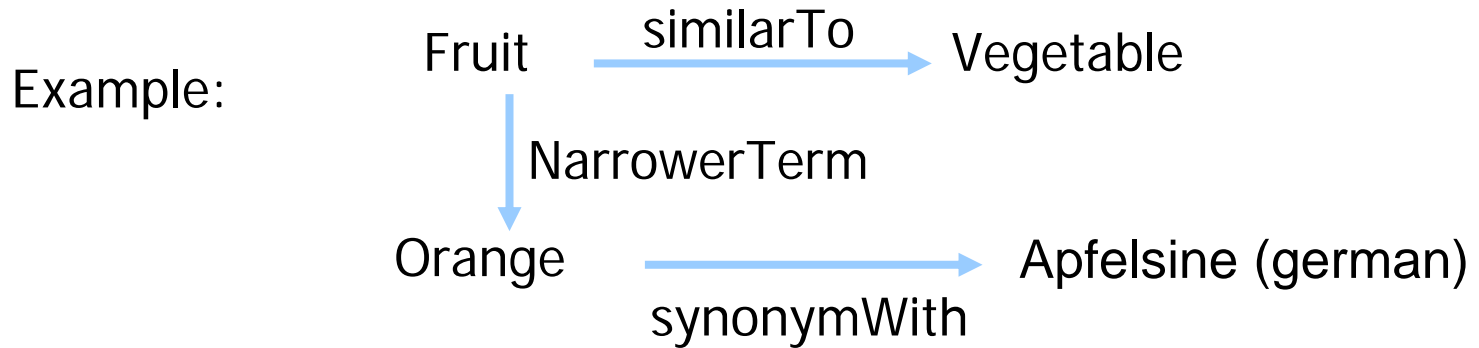
*Meaning
specified
implicitly and
informally in
natural language*

*meaning specified
explicitly as a
logical theory*

Kinds of Ontologies



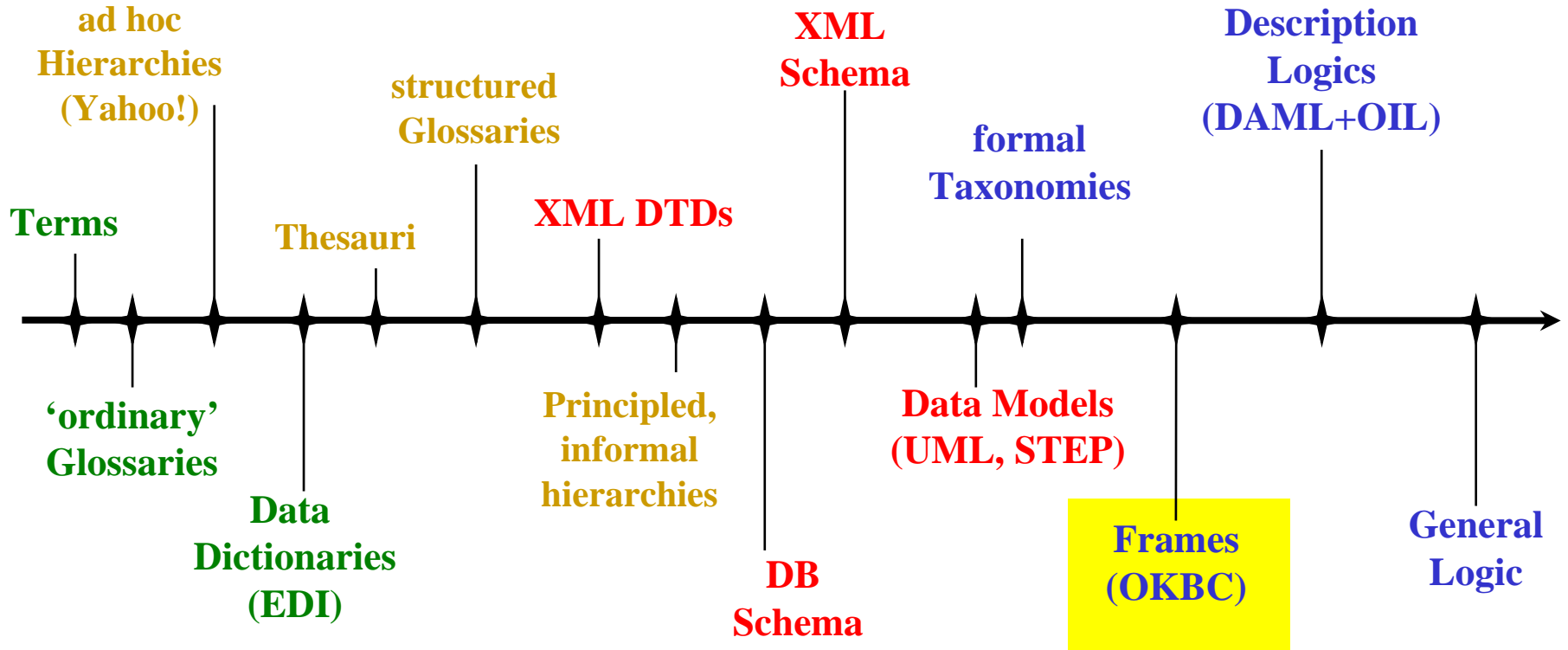
Thesauri



- Graph with labels edges (similar, nt, bt, synonym)
- Fixed set of edge labels (aka relations)
- no instances

- Well known in library science
- cf. terminologies / classifications (Dewey)

Kinds of Ontologies



Glossaries & Data Dictionaries

Thesauri, Taxonomies

MetaData, XML Schemas, & Data Models

Formal Ontologies & Inference

Frames

- Rich set of language constructs: frames, slots, defaults, ...
- Impose restrictive constraints on how they are combined or used to define a class.
- All frames asserted into taxonomy by hand.
- All concepts are primitive.
- Octet/GKB, Protégé, OCML, ...



- THING A
- SYSTEM-CLASS A
- Dimensional entity
- Physical state
- Anatomical entity
- Physical anatomical entity M
- Material physical anatomical entity
 - Anatomical structure
 - Body
 - Organ
 - Organ part
 - Tissue
 - Tissue subdivision
 - Cell
 - Cell part
 - Body part
 - Body part subdivision
 - Organ system
 - Organ system subdivision
 - Acellular anatomical structure
 - Biological macromolecule
 - Gestational structure
 - Vestigial embryonic structure
 - Variant anatomical structure
 - Anatomical junction
 - Anatomical cluster
 - Body substance
- Non-material physical anatomical entity

Name	Documentation	Constraints
Body		
Role		
Concrete		

Template Slots

Name	Type	Cardinality	Other Facets
inherent 3-D shape	Class	single	parents={Volume}
attributed part	Instance	multiple	classes={Body part part_of relati...
adjacency	Instance	multiple	classes={Anatomical coordinate ε...
orientation	Instance	multiple	classes={Anatomical orientation}
has inherent 3-D shape	Boolean	single	value={true}
regional part	Class	multiple	parents={Anatomical structure,Ar...
regional part of	Class	multiple	parents={Anatomical structure,Ar...
constitutional part	Class	multiple	parents={Physical anatomical ent...
constitutional part of	Class	multiple	parents={Physical anatomical ent...
segmental supply	Class	multiple	parents={Segmental innervation}
bounded by	Class	multiple	parents={Body surface} value={B...
systemic part	Class	multiple	parents={Anatomical structure,Ar...
custom partonomy	Class	multiple	parents={Physical anatomical ent...

Definition

Examples: There is only one human body.

UWDAID

20394

Preferred Name Body

Synonyms

THING A

- SYSTEM-CLASS A
- OpenGALEN_Model
 - Anatomical_Concept
 - Anatomy_By_Body_Sy
 - Anatomy_Specific_to
 - Anatomy_Of_Major_B
 - Major_Division_Of_Bo
 - Trunk
 - HeadAndNeck
 - Extremity M
 - Anatomical_Space
 - Foramina
 - Anatomical_Subpart
 - Anatomy_By_Body_Ca
 - Anatomy_with_Latera
 - Body_System
 - BodyAsAWhole
 - VisceralPeritoneum
 - GRAILExteriorOfBody
 - Diverticulum
 - SurfaceBodyStructure
 - Placenta
 - InternalOrgan
 - Conceptus
 - Cell
 - Process

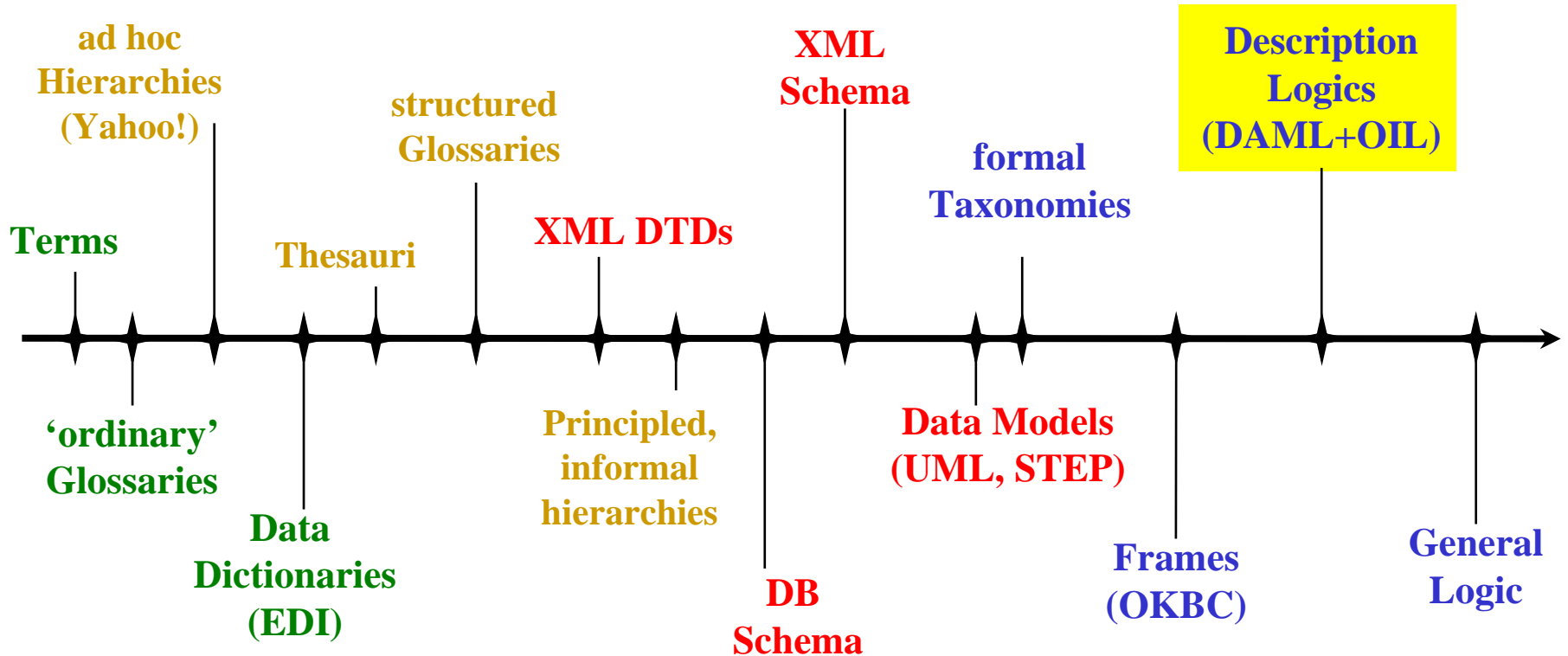
Trunk (type=Major_Body_Division)

Name	Trunk	Pairing	unpaired	HasFunction	
GenEnglish	trunk				
HasPart	<ul style="list-style-type: none"> Abdomen Back PelvicPartOfTrunk Precordium Thorax 	HasCompo		HasSurfaceSt	<ul style="list-style-type: none"> Abdomen Back PelvicPartOfTrunk Precordium Thorax
IsPartOf	<ul style="list-style-type: none"> BodyAsAWhole 	IsCompone		IsSurfaceDivi:	<ul style="list-style-type: none"> BodyAsAWhole
HasIrregularS		HasLayer		HasPouch	
IsIrregularPie		IsLayerOf		IsPouchOf	
				HasFunction	
				HasSelecto	
				Connects	
				HasBranch	
				IsBranchOf	
				ServedBy	
				Serves	

erclasses + -

Major_Division_Of_Body

Kinds of Ontologies



**Glossaries &
Data Dictionaries**

**Thesauri,
Taxonomies**

**MetaData,
XML Schemas,
& Data Models**

**Formal Ontologies
& Inference**

What's in a "DL based ontology"?

- Primitive concepts - in a hierarchy
 - Described but not defined
- Properties - relations between concepts, also in a hierarchy
- Constructors – on concepts and properties
 - “some”, “only”, “at least”, “at most”, and, or, not.
- Defined concepts
 - Made from primitive concepts, constructors and descriptors
 - Enzyme \equiv protein and catalyses reaction.
 - Reason that enzyme is a kind of protein.
- “is-kind-of” = “implies”
 - “Dog is a kind of wolf” mean “All dogs are wolves”
- Axioms
 - disjointness, further description of defined concepts
- A Reasoner
 - to organise it for you. Consistency & Taxonomy for defined concepts established though logical reasoning.

DAML+OIL Class Constructors

Constructor	DL Syntax	Example
intersectionOf	$C_1 \sqcap \dots \sqcap C_n$	Human \sqcap Male
unionOf	$C_1 \sqcup \dots \sqcup C_n$	Doctor \sqcup Lawyer
complementOf	$\neg C$	\neg Male
oneOf	$\{x_1 \dots x_n\}$	{john, mary}
toClass	$\forall P.C$	\forall hasChild.Doctor
hasClass	$\exists P.C$	\exists hasChild.Lawyer
hasValue	$\exists P.\{x\}$	\exists citizenOf.{USA}
minCardinalityQ	$\geq n P.C$	≥ 2 hasChild.Lawyer
maxCardinalityQ	$\leq n P.C$	≤ 1 hasChild.Male
cardinalityQ	$= n P.C$	$= 1$ hasParent.Female

- ☞ XMLS **datatypes** as well as classes
- ☞ Arbitrarily complex **nesting** of constructors
 - E.g., Person $\sqcap \forall$ hasChild.(Doctor $\sqcup \exists$ hasChild.Doctor)

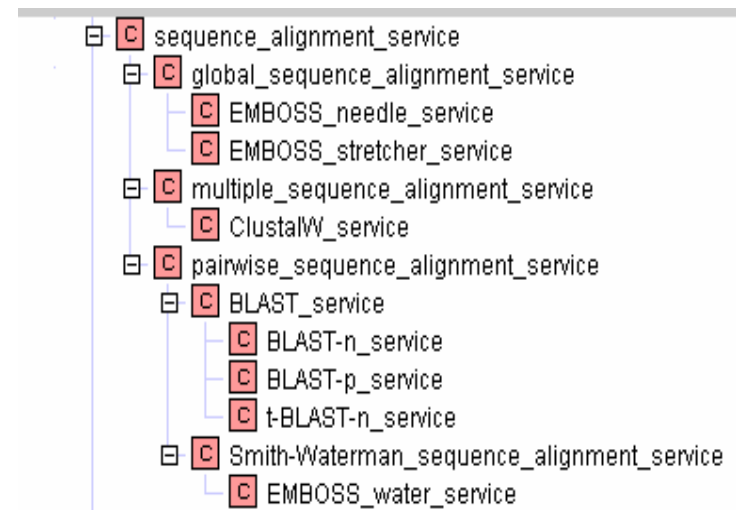
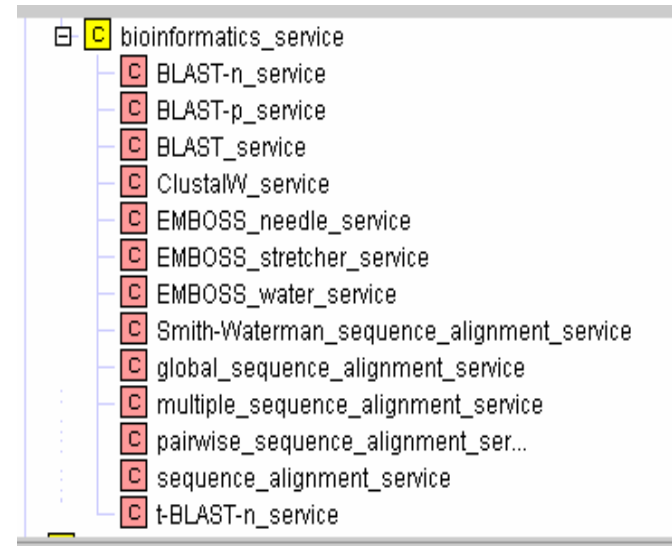
DAML+OIL Axioms

Axiom	DL Syntax	Example
subClassOf	$C_1 \sqsubseteq C_2$	Human \sqsubseteq Animal \sqcap Biped
sameClassAs	$C_1 \equiv C_2$	Man \equiv Human \sqcap Male
subPropertyOf	$P_1 \sqsubseteq P_2$	hasDaughter \sqsubseteq hasChild
samePropertyAs	$P_1 \equiv P_2$	cost \equiv price
sameIndividualAs	$\{x_1\} \equiv \{x_2\}$	{President_Bush} \equiv {G_W_Bush}
disjointWith	$C_1 \sqsubseteq \neg C_2$	Male $\sqsubseteq \neg$ Female
differentIndividualFrom	$\{x_1\} \sqsubseteq \neg\{x_2\}$	{john} $\sqsubseteq \neg$ {peter}
inverseOf	$P_1 \equiv P_2^-$	hasChild \equiv hasParent ⁻
transitiveProperty	$P^+ \sqsubseteq P$	ancestor ⁺ \sqsubseteq ancestor
uniqueProperty	$\top \sqsubseteq \leq 1P$	$\top \sqsubseteq \leq 1$ hasMother
unambiguousProperty	$\top \sqsubseteq \leq 1P^-$	$\top \sqsubseteq \leq 1$ isMotherOf ⁻

☞ Axioms (mostly) **reducible to subClass/PropertyOf**

Reasoning support

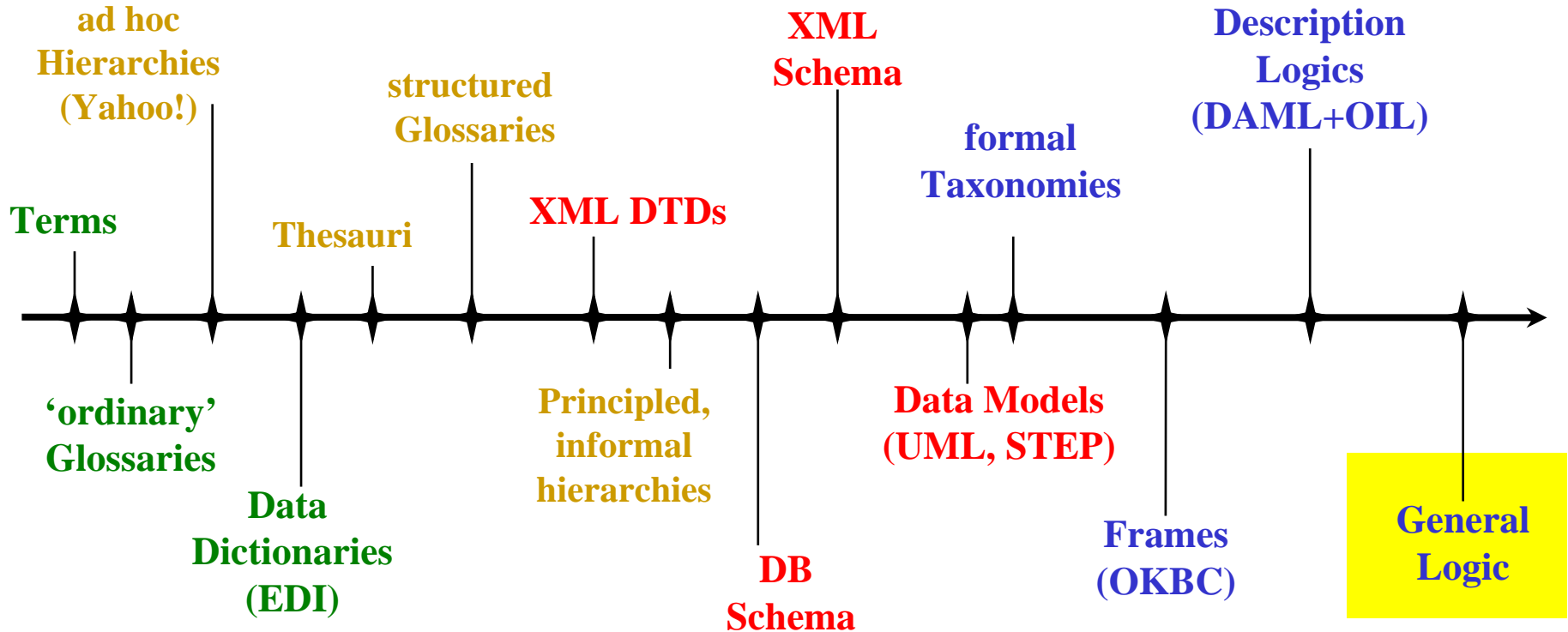
- **Consistency** — check if knowledge is meaningful
- **Subsumption** — structure knowledge, compute taxonomy
- **Equivalence** — check if two classes denote same set of instances
- **Instantiation** — check if individual is instance of class C
- **Retrieval** — retrieve set of individuals that instantiate C



Why Reasoning Services ?

- **Ontology design**
 - Check class consistency and (unexpected) implied relationships
 - Particularly important with large ontologies/multiple authors
- **Ontology integration**
 - Assert inter-ontology relationships
 - Reasoner computes integrated class hierarchy/consistency
- **Ontology deployment**
 - Determine if set of facts are consistent w. r. t. ontology
 - Determine if individuals are instances of ontology classes
 - Query Inclusion
 - Service description matchmaking
 - Classification-based querying.

Kinds of Ontologies



Glossaries & Data Dictionaries

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Formal Ontologies & Inference

First order logic

- High expressive power
- High complexity
- Limited automatic reasoning support



3.2 Definitions

Mereological Definitions

- (D14) $PP(x, y) =_{df} P(x, y) \wedge \neg P(y, x)$ *(Proper Part)*
- (D15) $O(x, y) =_{df} \exists z(P(z, x) \wedge P(z, y))$ *(Overlap)*
- (D16) $At(x) =_{df} \neg \exists y(PP(y, x))$ *(Atom)*
- (D17) $AtP(x, y) =_{df} P(x, y) \wedge At(x)$ *(Atomic Part)*
- (D18) $x + y =_{df} \iota z \forall w(O(w, z) \leftrightarrow (O(w, x) \vee O(w, y)))$ *(Binary Sum)*
- (D19) $\sigma x \phi(x) =_{df} \iota z \forall y(O(y, z) \leftrightarrow \exists w(\phi(w) \wedge O(y, w)))^1$ *(Sum of ϕ 's)*

- (D20) $PP(x, y, t) =_{df} P(x, y, t) \wedge \neg P(y, x, t)$ *(Temporary Proper Part)*
- (D21) $O(x, y, t) =_{df} \exists z(P(z, x, t) \wedge P(z, y, t))$ *(Temporary Overlap)*
- (D22) $At(x, t) =_{df} \neg \exists y(PP(y, x, t))$ *(Temporary Atom)*
- (D23) $AtP(x, y, t) =_{df} P(x, y, t) \wedge At(x, t)$ *(Temporary Atomic Part)*
- (D24) $x \equiv_t y =_{df} P(x, y, t) \wedge P(y, x, t)$ *(Coincidence)*
- (D25) $CP(x, y) =_{df} \exists t(PR(y, t)) \wedge \forall t(PR(y, t) \rightarrow P(x, y, t))$ *(Constant Part)*
- (D26) $x +' y =_{df} \iota z \forall w, t(O(w, z, t) \leftrightarrow (O(w, x, t) \vee O(w, y, t)))$
- (D27) $\sigma' x \phi(x) =_{df} \iota z \forall y, t(O(y, z, t) \leftrightarrow \exists w(\phi(w) \wedge O(y, w, t)))^2$

Quality

- (D28) $dqt(x, y) =_{df} qt(x, y) \wedge \neg \exists z(qt(x, z) \wedge qt(z, y))$ *(Direct Quality)*
- (D29) $qt(\phi, x, y) =_{df} qt(x, y) \wedge \phi(x) \wedge SBL_x(Q, \phi)$ *(Quality of type ϕ)*

Temporal and Spatial Quale

(D30) $qt(x, y) =_{df} \exists t(PP(x, y, t) \wedge \neg \exists z(PP(z, x, t) \wedge PP(z, y, t)))$

First order logic (FOL)

- High expressive power
- High complexity
- Limited automatic reasoning support



**However if you want to build bio-medical ontologies
you will need to represent PARTS of it in FOL**

On Comparing FMA and GALEN

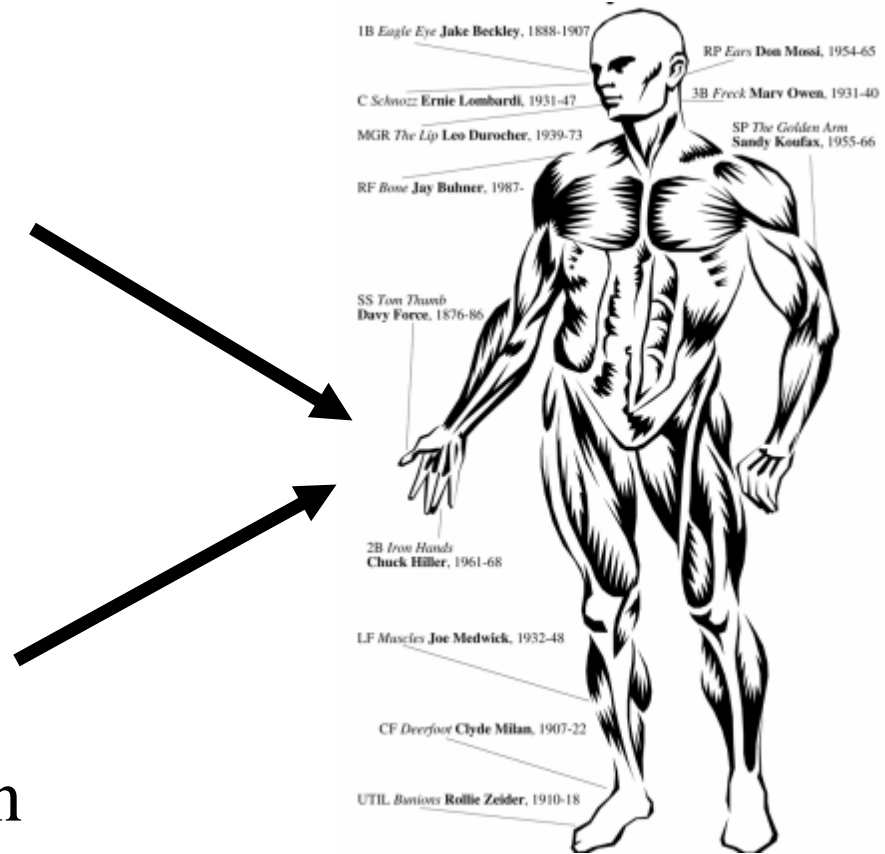
Comparing FMA and GALEN

FMA

- Uni-Washington
- Protégé – frame system

GALEN

- Uni-Manchester
- GRAIL – description logic

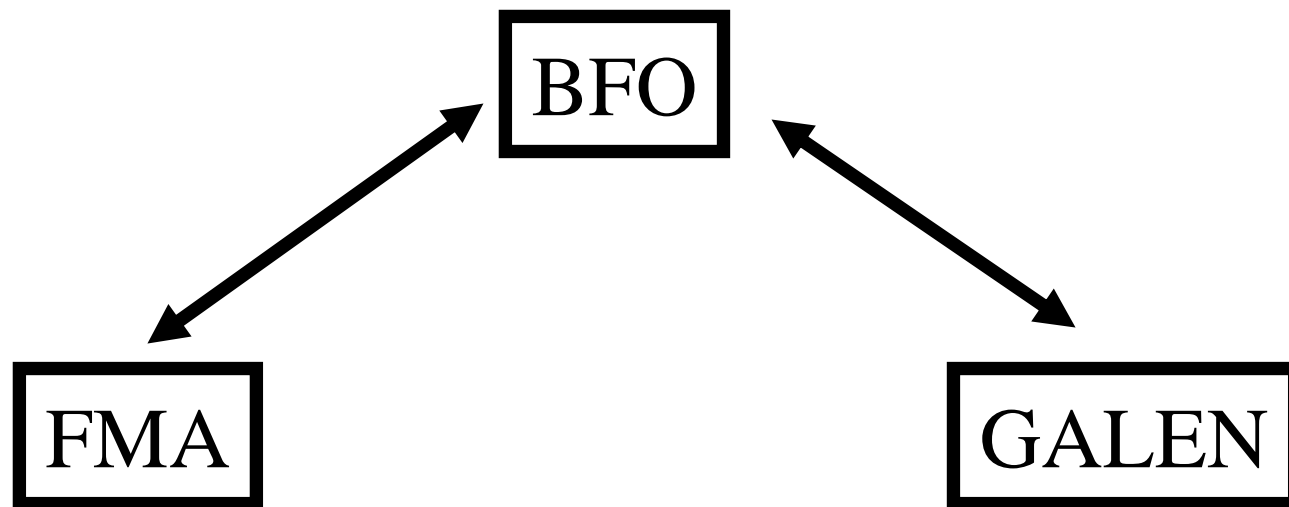


Human anatomy

Reference framework

Basic Formal Ontology (BFO)

Full first order logic

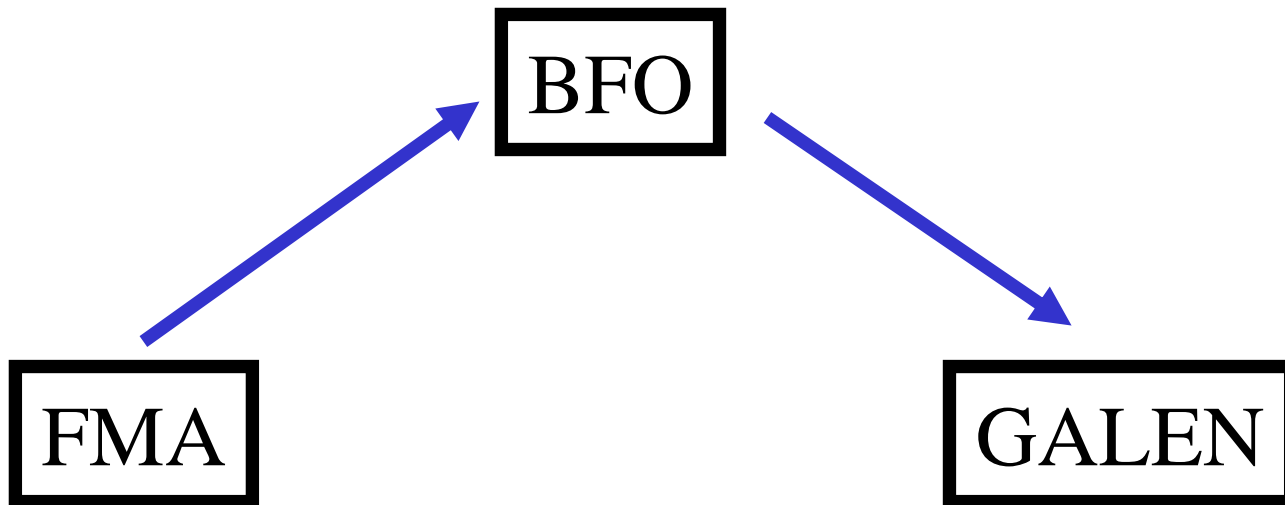


Protégé,
Frame system

GRAIL
Description logic

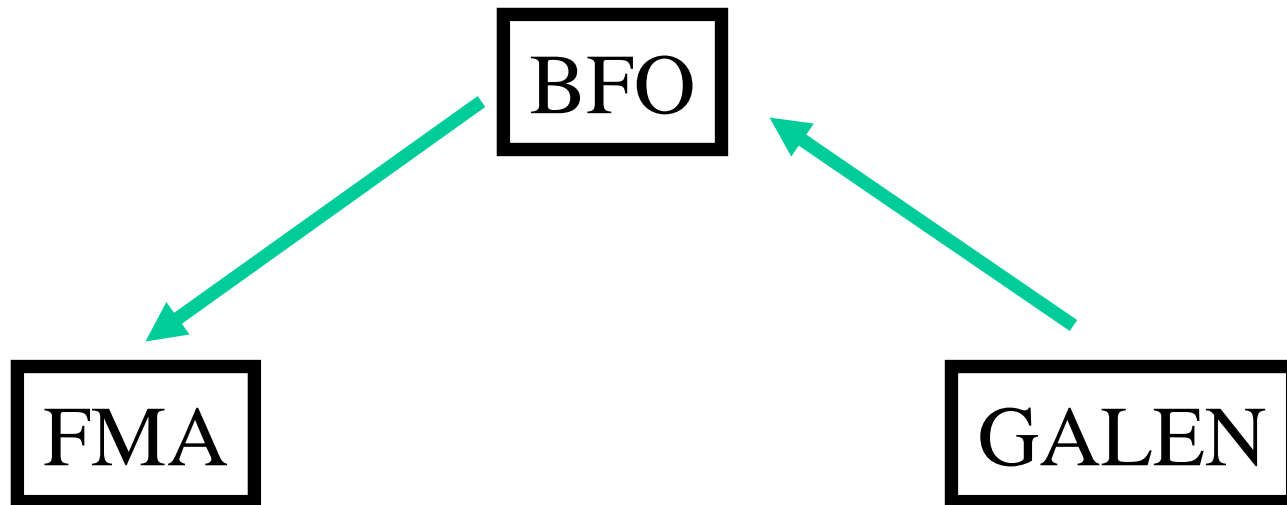
Reference framework

Basic Formal Ontology (BFO)

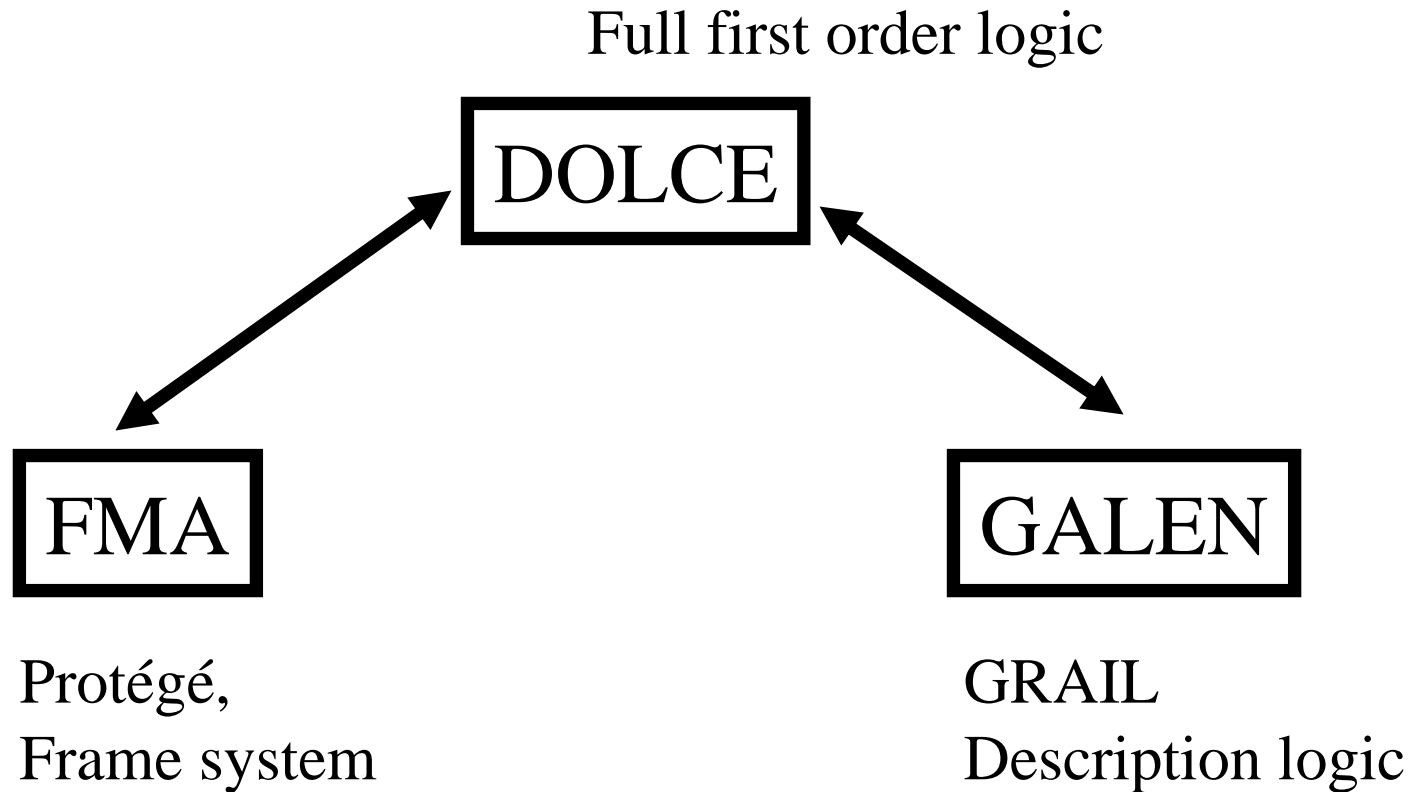


Reference framework

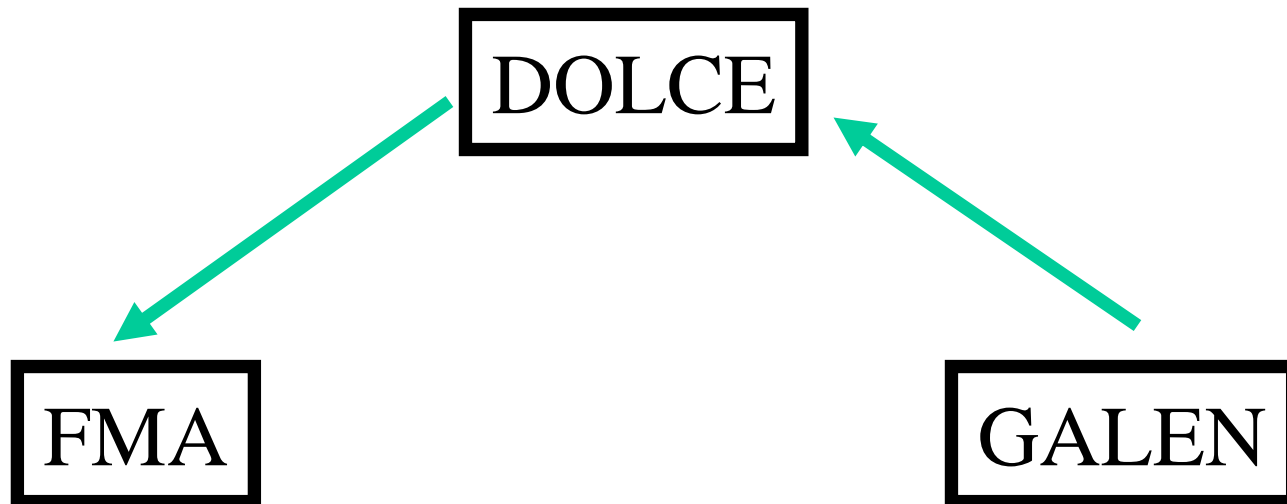
Basic Formal Ontology (BFO)



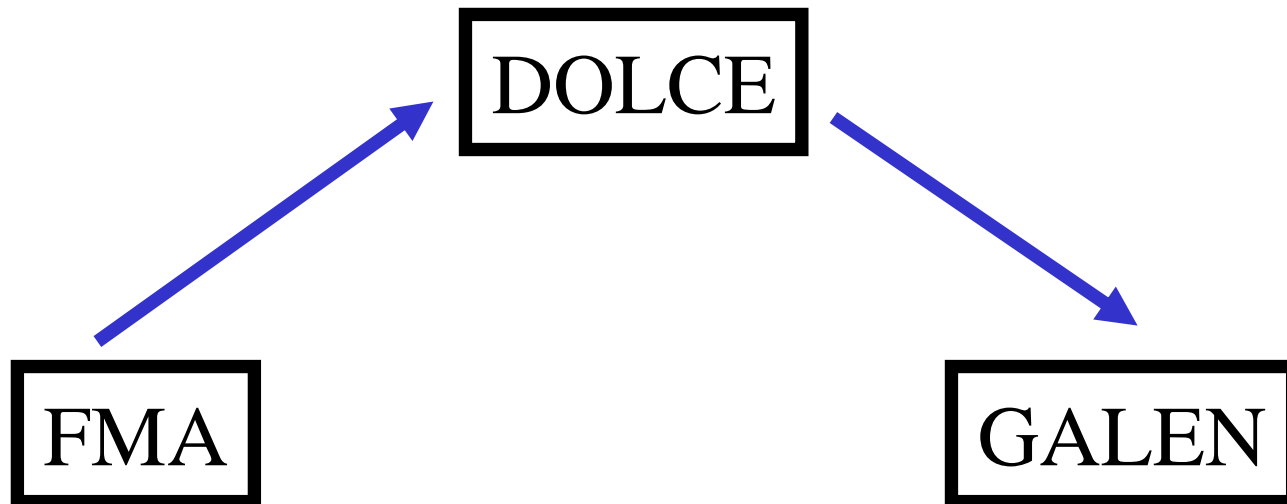
Alternative possibility:
use DOLCE (Guarino at al.) as
reference ontology



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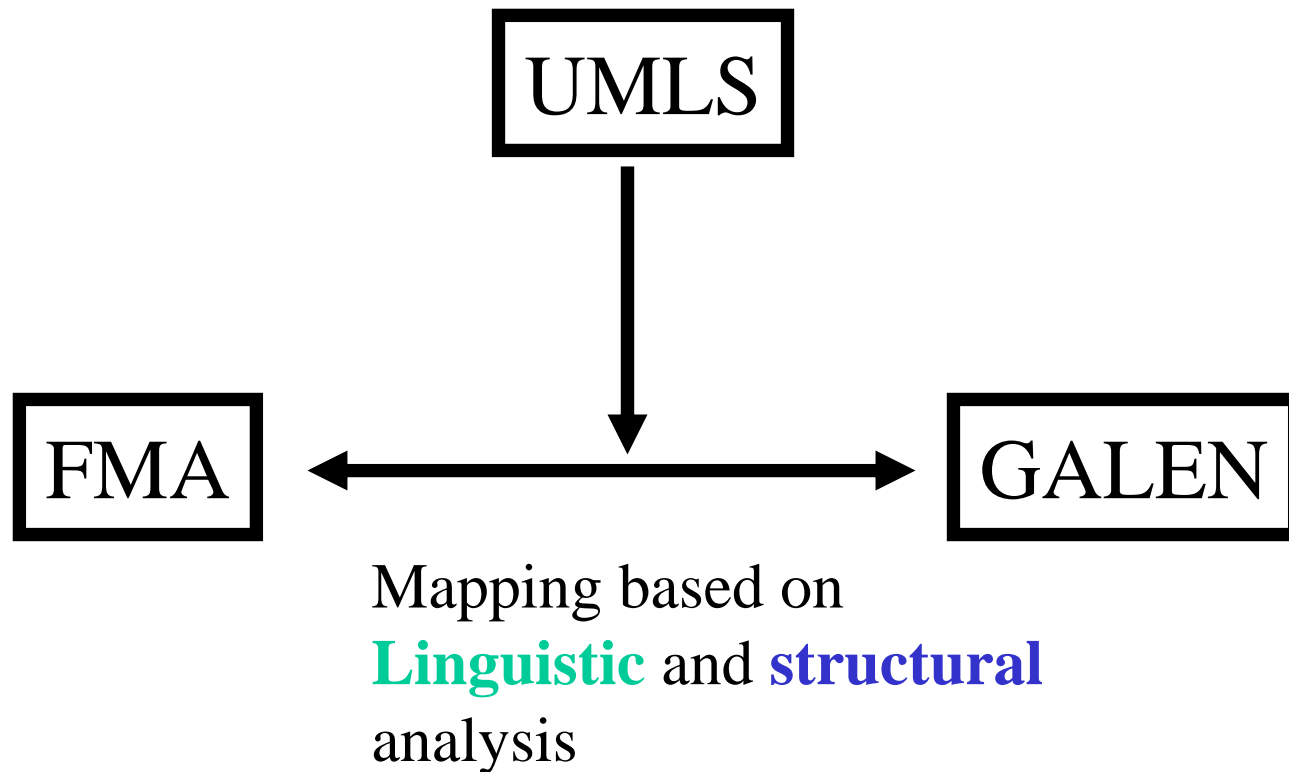


Alternative possibility:
use DOLCE (Guarino at al.) as
reference ontology



Alternative approaches

Bodenreider at. al



Alternative approaches

Bodenreider at. al



Mapping based on
Linguistic and **structural**
analysis

Alternative approaches

Bodenreider at. al

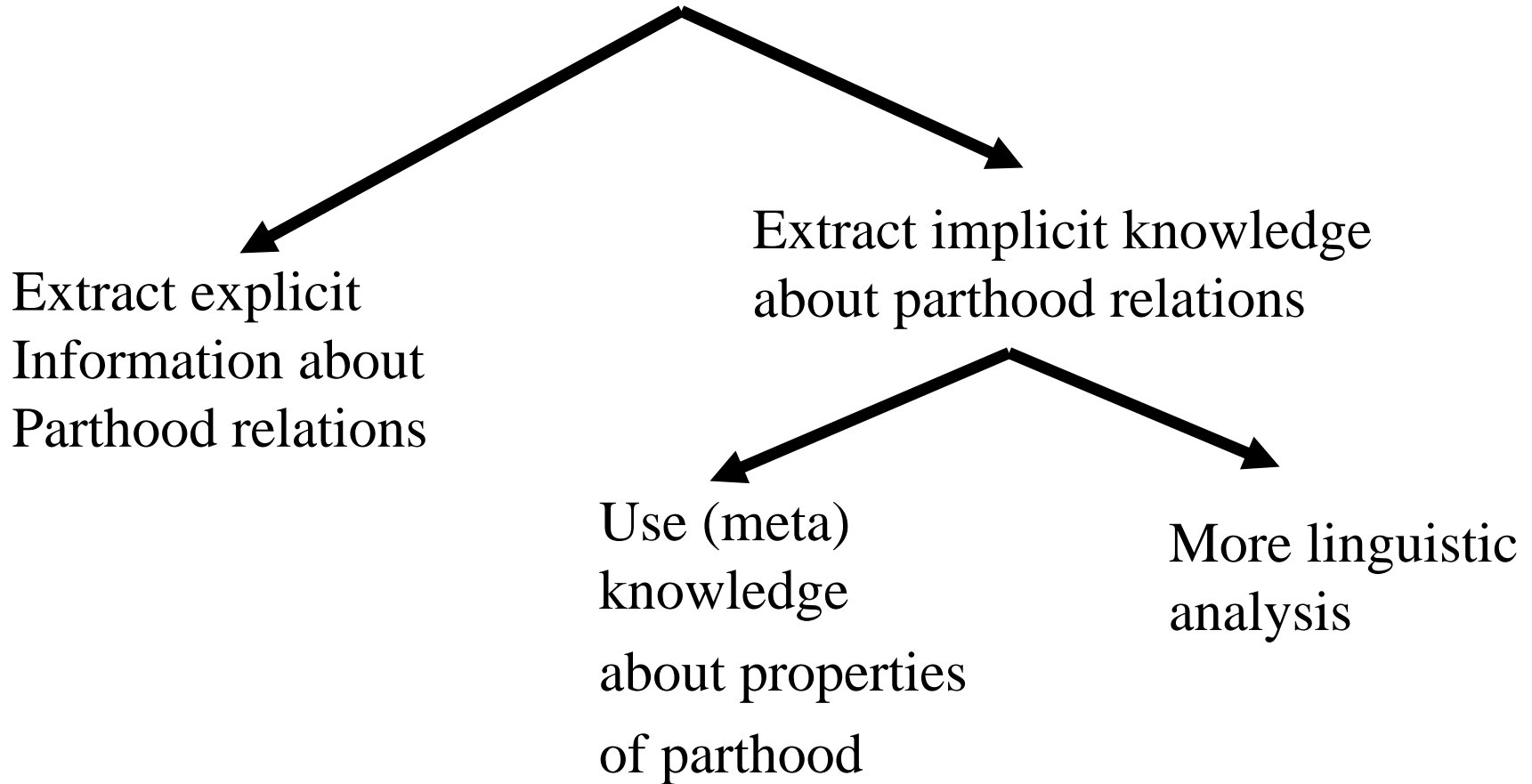
- **Identify** anchor concepts by means of **linguistic analysis**
 - matching index: 0
GALEN[912]=polyhedral
FMA[69751]=Polyhedral
 - matching index: 9
GALEN[1204]=TemperatureValue
FMA[69888]=Temperature value
 - matching index: 13
GALEN[7242]=ReticuloendothelialSystem
FMA[57800]=Mononuclear phagocyte system

Alternative approaches

Bodenreider at. al

- **Verify** anchor concepts by means of **structural** analysis
 - Structural analysis: compare information about **parthood** relations that hold between the anchor concepts in FMA and in GALEN
 - Structural information provides **positive or negative** evidence for anchor concepts
 - Positive evidence: compatible *part-of* relations
 - Negative evidence: incompatible *part-of* relations

How to compare information about parthood relations?



How to extract implicit knowledge about parthood relations?

Use (meta) knowledge about properties of parthood

- *part-of* and *has-part* are converse relations
IF *part-of* xy THEN
has-part yx
- *subdivision-of* is a specific *part-of* relation
- *Part-of* is transitive
- ...

How to extract implicit knowledge about parthood relations?

More linguistic analysis

- infer relations from class names
- IF P *isA* PartOfW THEN P *part-of* W
- IF
 CardiacChamber *isA* SubdivisionOfHeart
THEN
 CardiacChamber *part-of* Heart

Alternative approaches

Bodenreider at. al

Results:

Anchors identified by lexical alignment

2,353 matching anchor concepts were identified lexically, accounting for about 4% of FMA concepts and 9% of GALEN concepts.

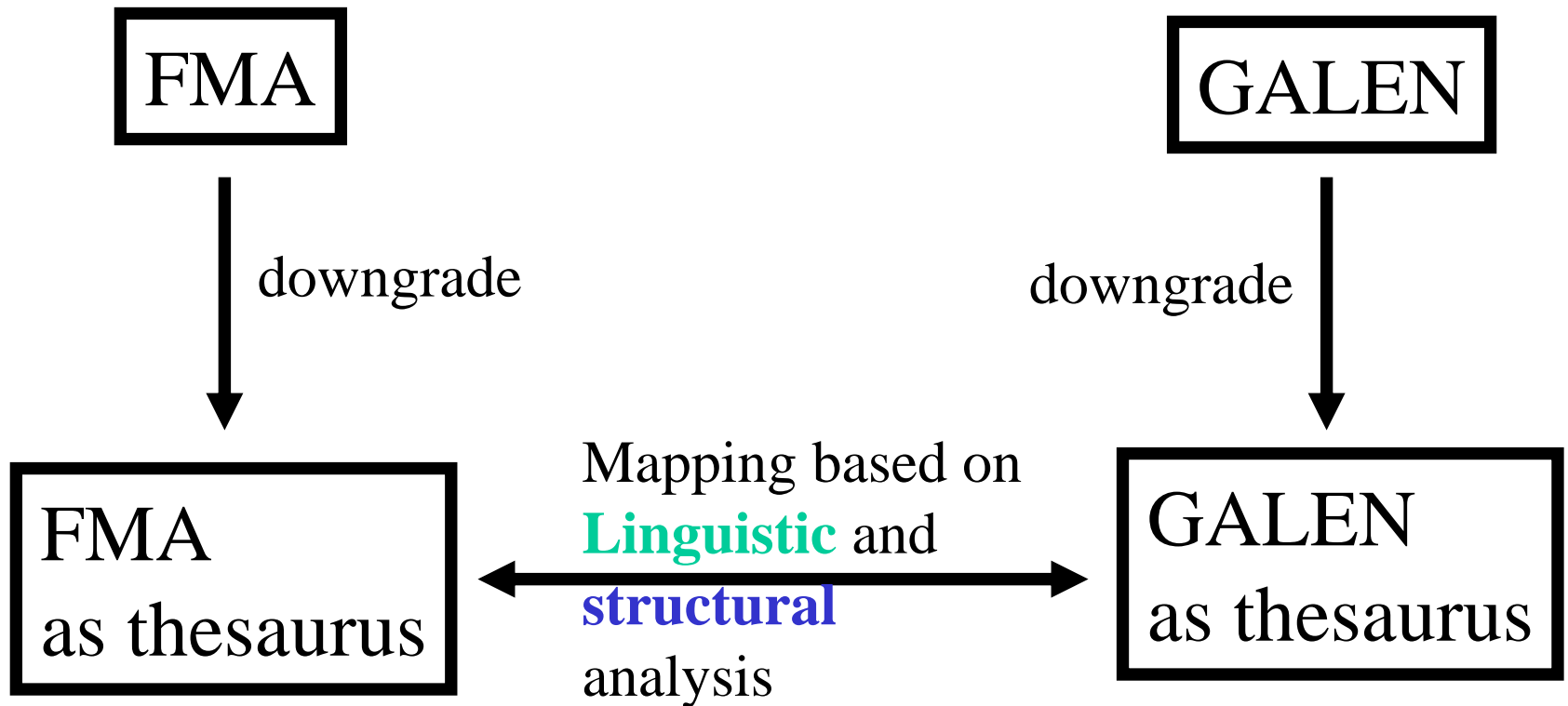
Zhang at al. 2003

Why are there only so few matches?

Discussion (O. Bodenreider)

- Are working on improving the results: currently, about 7% of FMA concepts and 33% of GALEN concepts are anchors
- not all GALEN concepts are anatomical entities; among anatomical concepts, not all are canonical (normal) anatomy.
- FMA concepts are generally finer-grained than GALEN's. E.g., some 20,000 concepts in FMA exhibit a laterality marker (left/right) while virtually no GALEN concept does.

The fundamental problem of linguistic approaches:



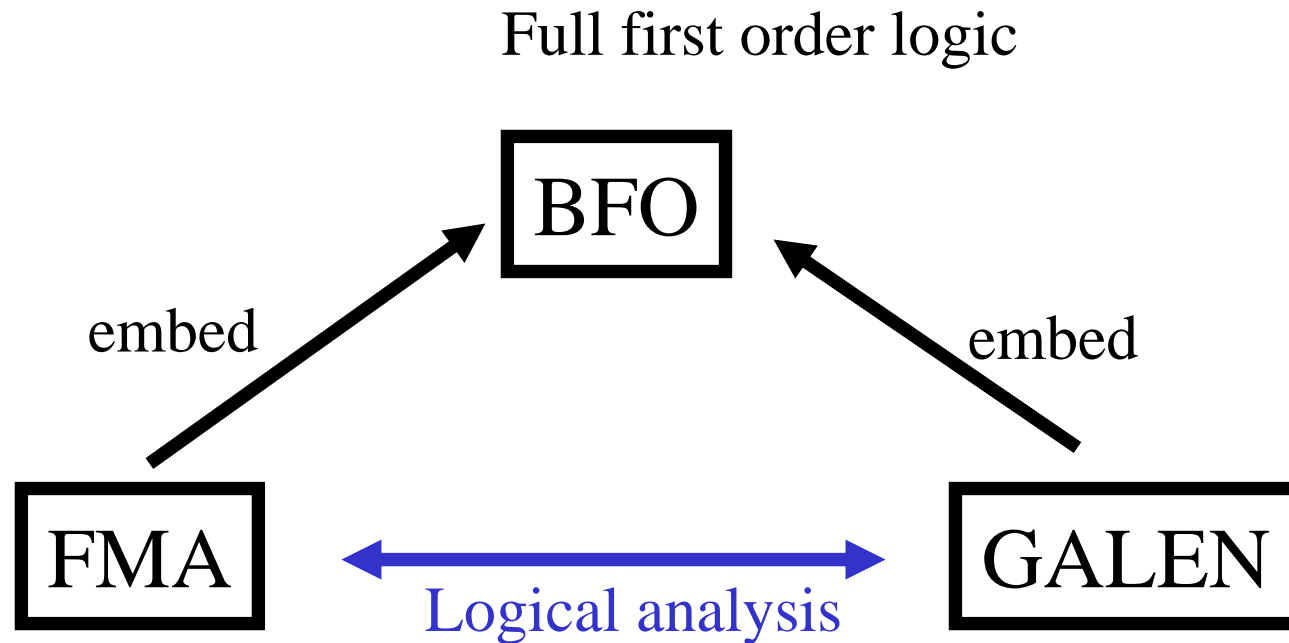
A logic-based analysis
is needed!!!

Will OWL-implementations of FMA and GALEN help?

- There is C-OWL an extension of OWL
- **User provides mappings** between concepts in different ontologies
 - C_{01} subsumes C_{02}
 - C_{01} and C_{02} are equivalent
 - C_{01} and C_{02} are disjoint
- DL-reasoner checks consistency, derives additional consequences, ...

Where do the mappings come from ?

FOL Reference framework, e.g., Basic Formal Ontology (BFO)



Reference framework BFO

- Basic ontological distinctions manifested in
 - Theory of individuals and universals ✓
 - Theory of endurants and perdurants ✓
 - Theory of material and non-material entities in progress
- Theories of formal relations
 - Mereology ✓
 - Topology ✓
 - Location ✓
 - Containment in progress
 - Dependence ???

Reference framework BFO

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Two distinct realms of being

universals

general

types

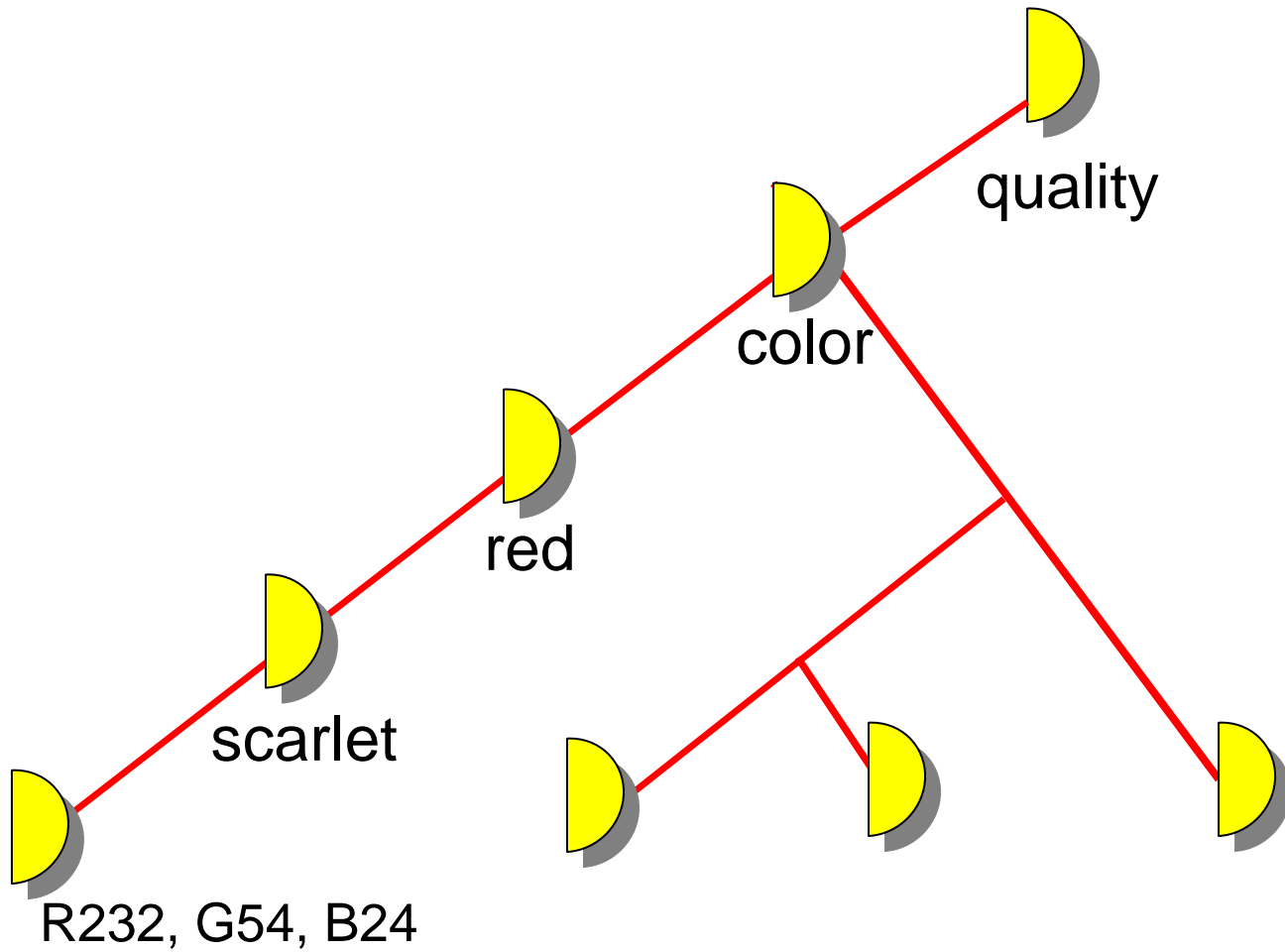
species

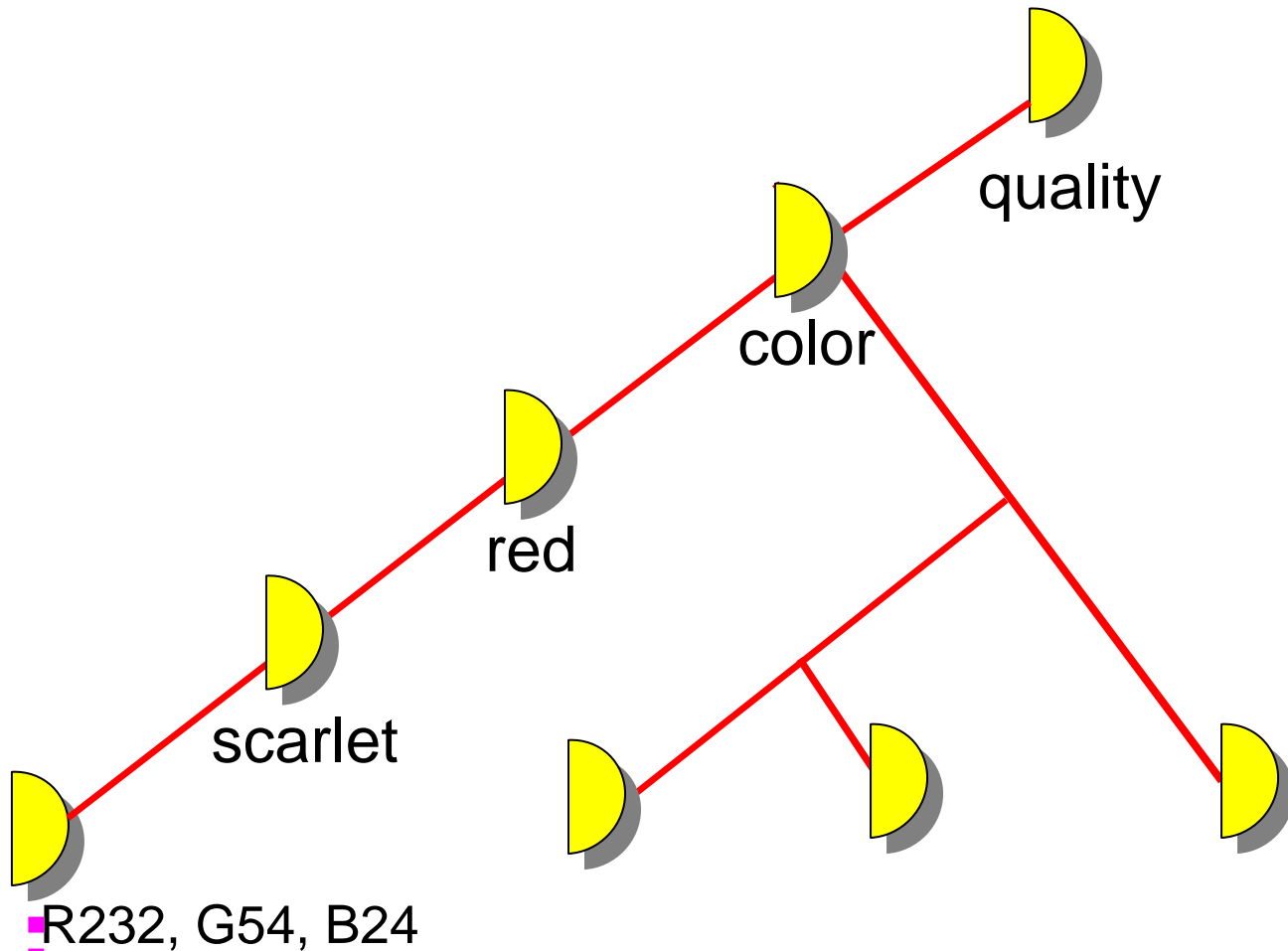
particulars

individual

tokens

instances





↓ this individual token of redness
● (this token redness – here, now)

Reference framework BFO

- Basic categorial distinctions manifested in
 - Theory of individuals and universals
 - **Theory of endurants and perdurants**
 - Theory of material and non-material entities
- Theories of formal relations
 - Mereology
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Entities

that exist in space and time

```
graph TD; A[Entities that exist in space and time] --> B[Endurants:]; A --> C[Perdurants:];
```

Endurants:

- substances (things)
- you, me, your heart
- your chest cavity
- John's pneumonia

Perdurants:

- processes
- your life
- the course of John's pneumonia

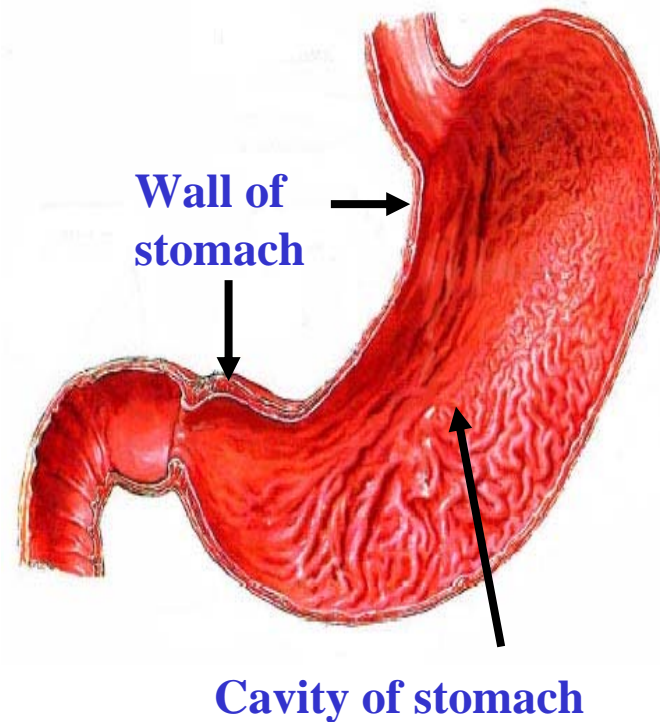
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Material vs. non-material entities

Endurants

- Material: stomach, wall of stomach
- Non-material: cavity of stomach
- Can material entities have non-material parts?



- CavityOfStomach *PartOf* Stomach?

Reference framework BFO

- Basic categorial distinctions manifested in
 - Theory of individuals and universals
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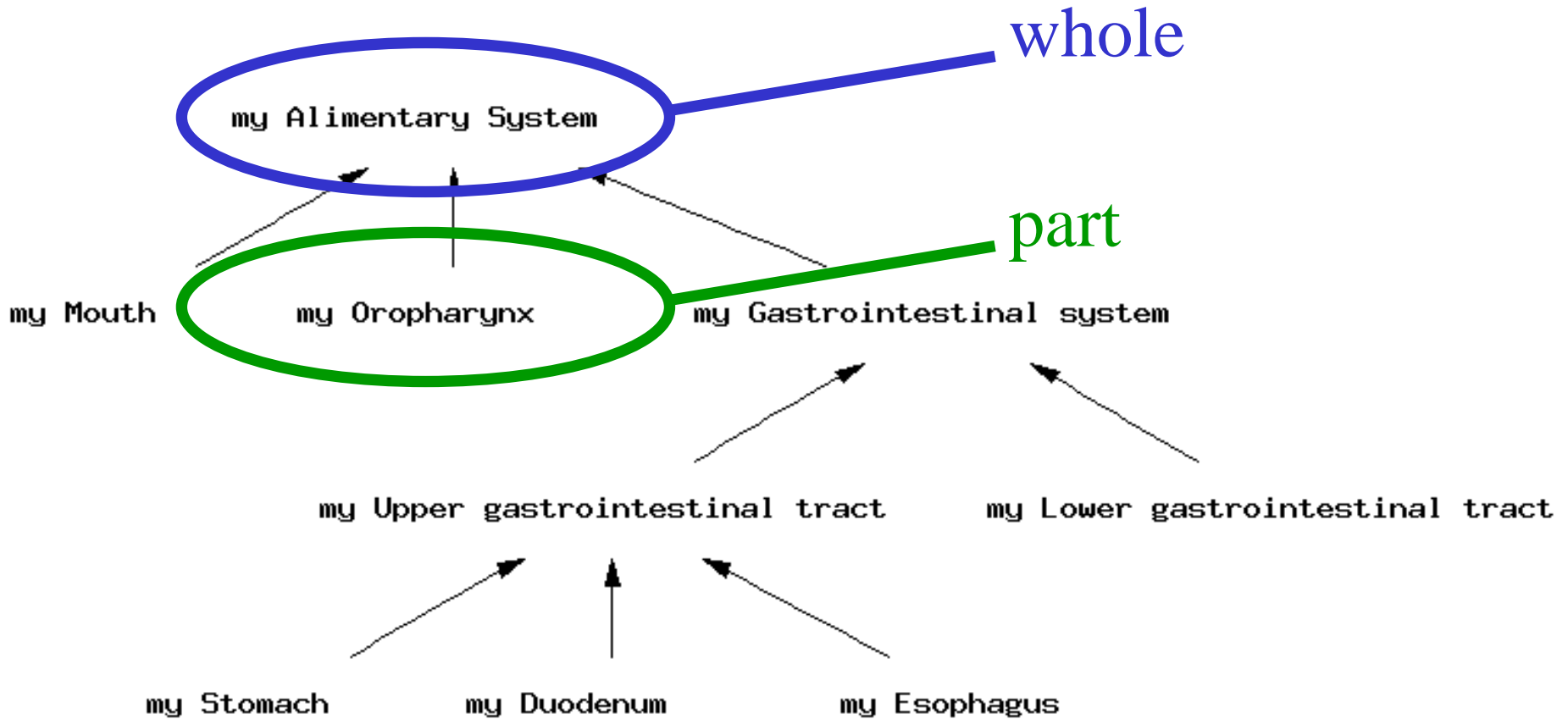
Partial orderings

- Binary relation
 - $x < y$
 - between x and y the relation of proper partial ordering holds
- Properties of ' $<$ ' :
 - Asymmetry:
 - IF $x < y$ THEN NOT $y < x$
 - We cannot switch the arguments
 - Transitivity
 - If $x < y$ AND $y < z$ THEN $x < z$
 - We can form chains of partially ordered entities

Two distinct kinds of partial ordering relations

1. Theory of the **part-of** relation
 - x **is-part-of** y
 - **is-part-of** is reflexive and transitive
2. Theory of **containment**
 - x **is-contained-in** y
 - **is-contained-in** is reflexive and transitive

part-of



The containment relation

- Non-medical examples:

- *My dollar bill is contained in my wallet*

- *My wallet is contained in my backpack*

- Medical examples

- *This volume of air is contained in my lung*
(now)

- *My lung is contained in my thorax*

????

my lung

Instance-of

Lung (FMA)

isA

Anatomical structure (FMA)

isA

Material anatomical entity (FMA)

My lung is a material container for the volume of air

Like my wallet is a material container for my dollar bill

The containment relation

- Non-medical examples:

- *My dollar bill is contained in my wallet*

- *My wallet is contained in my backpack*

- Medical examples

- *This volume of air is contained in my lung (now)*

- *My lung is contained in my thorax*

????



my thorax

Instance-of

Thorax (FMA)

isA

Anatomical structure (FMA)

isA

Material anatomical entity (FMA)

My thorax is a material container for my lung

Like my backpack is a material container for my wallet

Distinguishing parthood and containment

relation	Partial order	WSP
part-of	yes	
Contained-in	yes	

The (improper) partial ordering

- Between x and y the relation of (improper partial ordering holds iff

Between x and y the relation of **proper partial ordering** holds

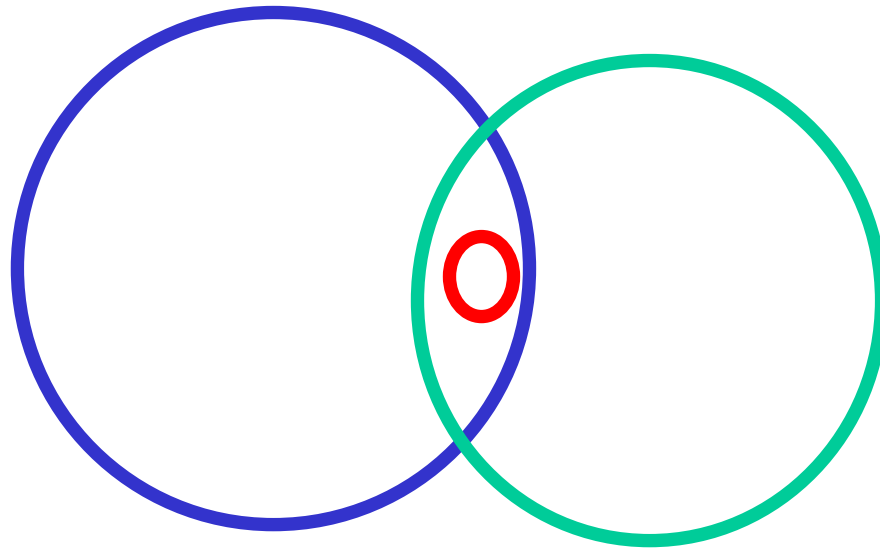
OR

x and y are **identical**

- $x \leq y$ IFF $x < y$ OR $x = y$

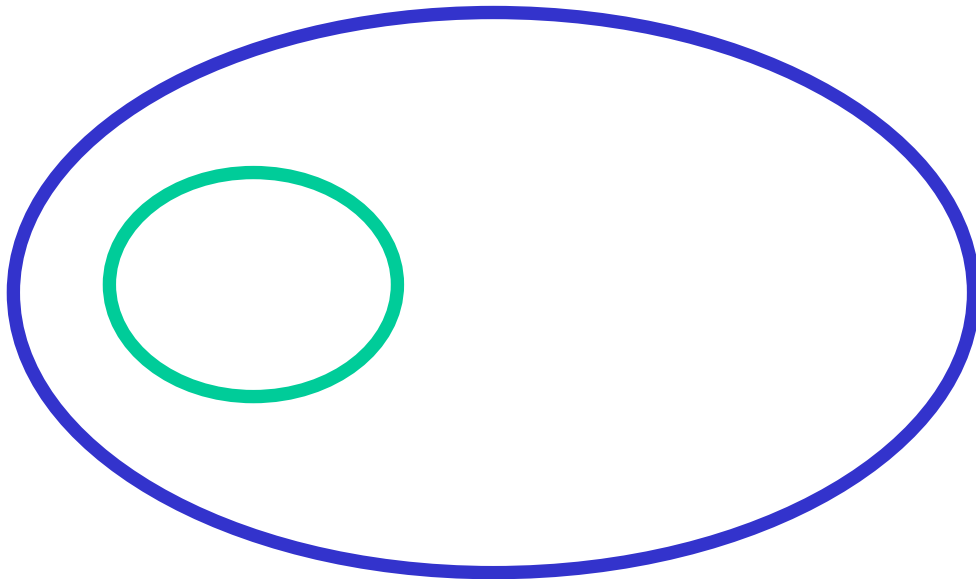
Definition of overlap

$D_0: O \ xy \text{ iff } (\exists z)(z \leq x \ \& \ z \leq y)$



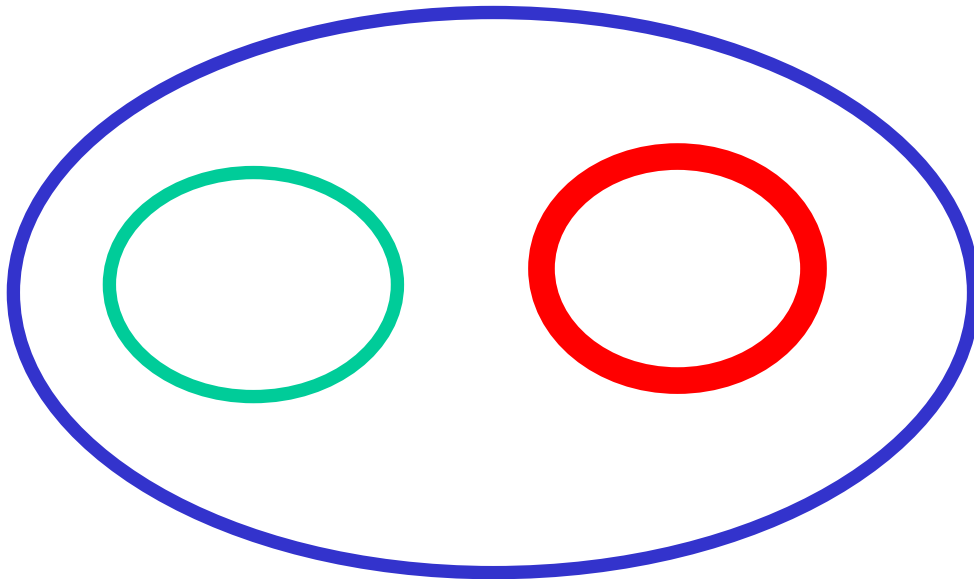
Weak supplementation principle

- $x < y \Rightarrow$



Weak supplementation principle

- $x < y \Rightarrow (\exists z)(z < y \text{ AND } \neg O zx)$



Weak supplementation principle for part-of

- $x < y \Rightarrow$
- If x is a *part-of* y then

Weak supplementation principle for part-of

- $x < y \Rightarrow (\exists z)$
- If x is a *part-of* y then there exists a z

Weak supplementation principle for part-of

- $x < y \Rightarrow (\exists z)(z < y$
- If x is a *part-of* y then there exists a z such that z is a *part-of* y

Weak supplementation principle for part-of

- $x < y \Rightarrow (\exists z)(z < y \text{ AND } \neg O zx)$
- If x is a *part-of* y then there exists a z such that z is a *part-of* y and x and z do not share a common part

Weak supplementation principle for part-of

- $x < y \Rightarrow (\exists z)(z < y \text{ AND } \neg O zx)$
- If x is a *part-of* y then there exists a z such that z is a *part-of* y and x and z do not share a common part
- There cannot be a whole with a single proper part

Weak supplementation principle for contained-in

- $x < y \Rightarrow (\exists z)(z < y \text{ AND } \neg O \ zx)$
- If x is *contained-in* y then there exists a z such that z is *contained-in* y and x and z do not share contained entities.
- There cannot be a container with a single contained entity ??????

WSP does not hold for contained-in !!!!

Distinguishing parthood and containment

relation	Partial order	WSP
part-of	yes	yes
Contained-in	yes	no

Reference framework BFO

- Basic categorial distinctions manifested in
 - Theory of individuals and universals
 - Theory of endurants and perdurants
 - Theory of material and non-material entities
- Theories of formal relations
 - Mereology
 - Topology
 - **Location**
 - Containment
 - Dependence

Location

- Casati & Varzi (parts and places)
- Lxy
 - x is an individual entity
 - y is a region of space/time/spacetime

Intuitive interpretation: Entities and their (spatial) location

- Two categories of things
 1. Entities: you, me, my computer, Arnold Schwarzenegger



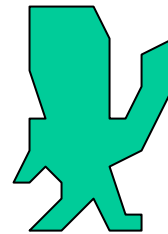
Entity

Intuitive interpretation: Entities and their (spatial) location

- Two categories of things
 1. Entities: you, me, my computer, Arnold Schwarzenegger
 2. Regions of space



Entity



Region

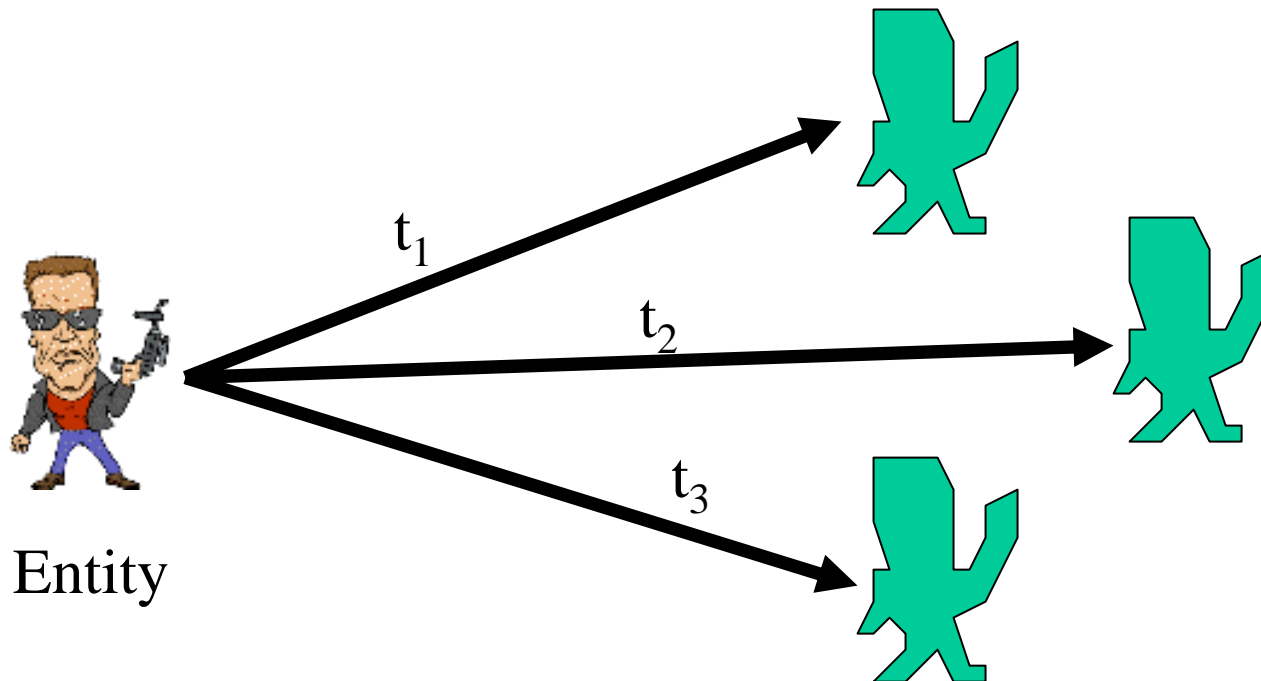
Intuitive interpretation: Entities and their (spatial) location

- At every moment in time and entity is located in a single region of space



Intuitive interpretation: Entities and their (spatial) location

- At different moments in time entities may be located in different regions



Abstract and concrete entities

Individual
entity

```
graph TD; A[Individual entity] --> B[Concrete]; A --> C[Abstract];
```

Concrete

- located at some region of space-time
- $CE\ x \equiv (\exists y) (Reg\ y\ AND\ L\ xy)$

Abstract

- not located in space-time
- $AE\ x \equiv \neg CE\ x$

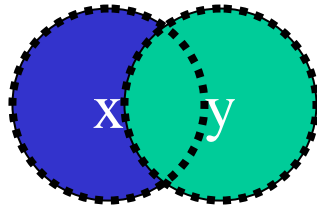
The Region Function

- Concrete individual entities:
 - Location is a function, i.e., every concrete entity is located at a single region of space at each moment in time (at which it exists)
- We write $r(x)=y$ iff $CE\ x$ AND $L\ xy$
- $r(x)$ is interpreted as **the region at which x is exactly located.**

Definitions Using the Region Function (Donnelly)

$\text{Coin}(x, y) =: O(r(x), r(y))$

x and y (partially) coincide: x's region
overlaps y's region

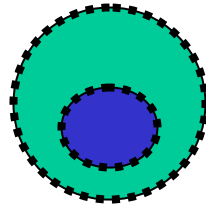


Example: A portion of food beginning to enter my stomach cavity partially coincides with my stomach cavity.

Definitions Using the Region Function

$$\text{CCoin}(x, y) =: P(r(x), r(y))$$

x completely coincides with y : x 's region is part of y 's region.



Example: A portion of food which is contained in my stomach
Completely coincides with my stomach cavity

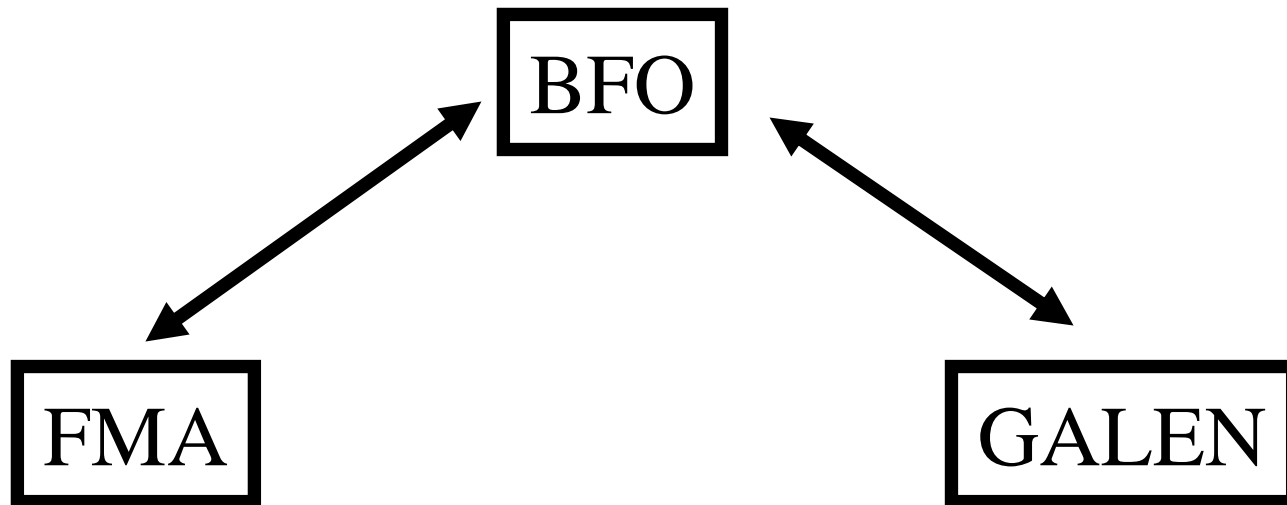
Reference framework BFO

- Basic categorial distinctions manifested in
 - Theory of individuals and universals
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 - Theory of material and non-material entities
- Theories of formal relations
 - Mereology
 - Topology
 - Location
 - Containment
 - Dependence

Reference framework

Basic Formal Ontology (BFO)

Full first order logic



Top-level categories in FMA and GALEN

Digital Anatomist

Foundational Model of Anatomy (FMA)

High level scheme

$$\text{FMA} = (\text{At}, \text{ASA}, \text{ATA}, \text{Mk})$$

where:

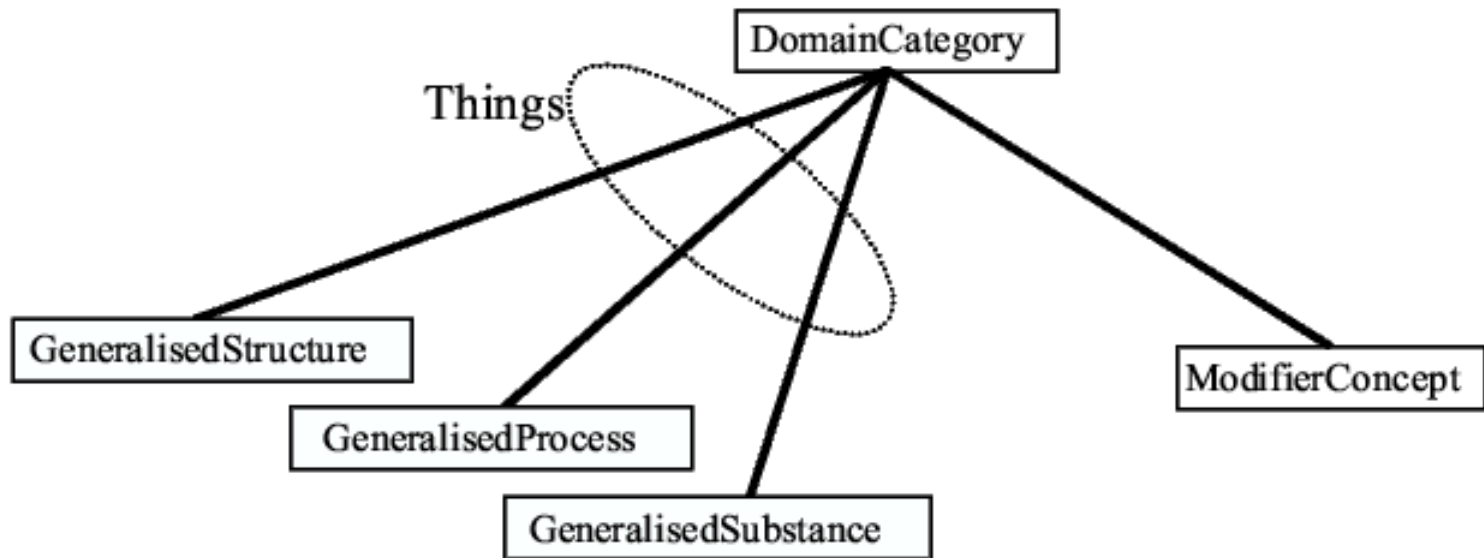
At ≡ Anatomy taxonomy

ASA ≡ Anatomical Structural Abstraction

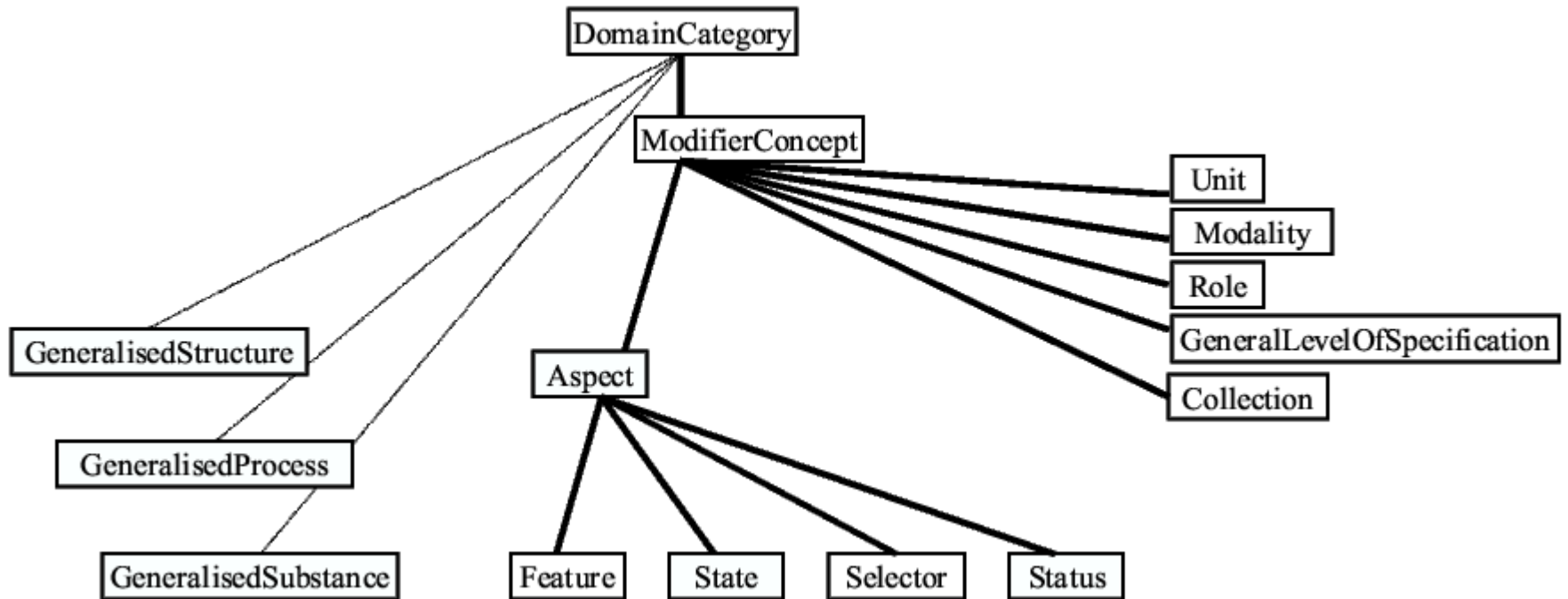
ATA ≡ Anatomical Transformation Abstraction

Mk ≡ Metaknowledge

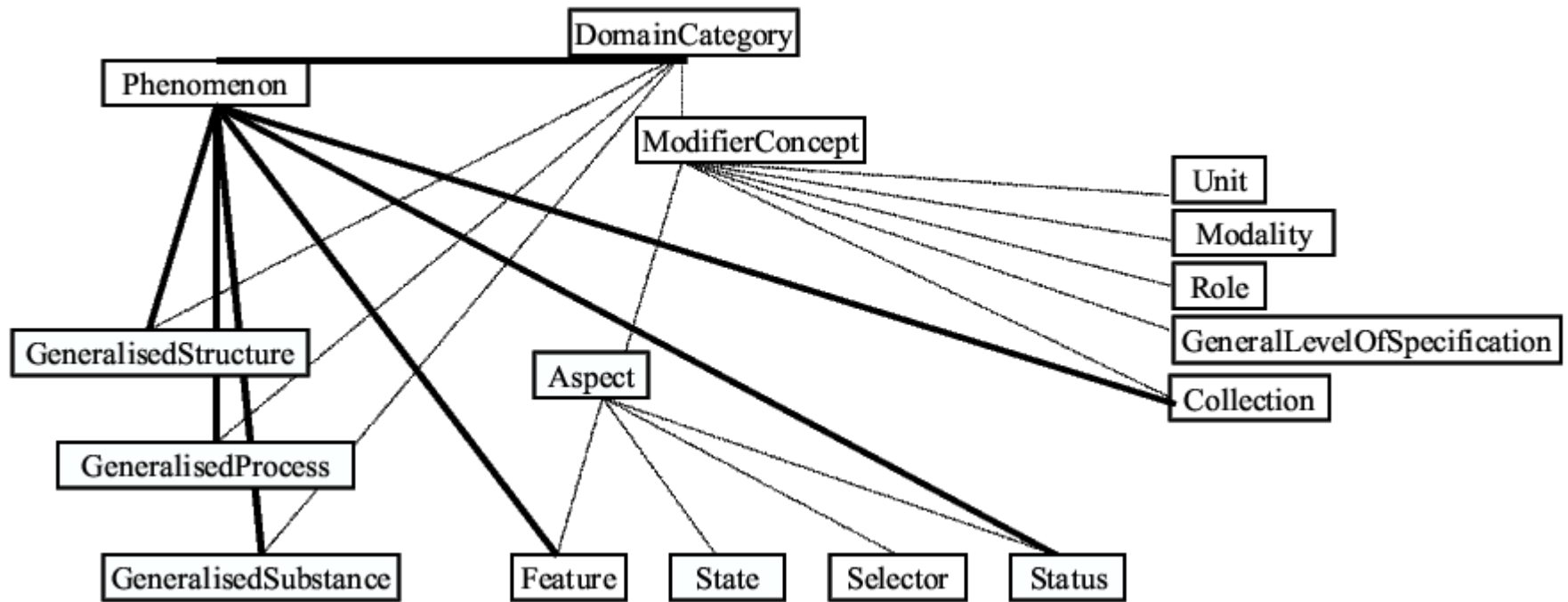
Top-level categories in GALEN

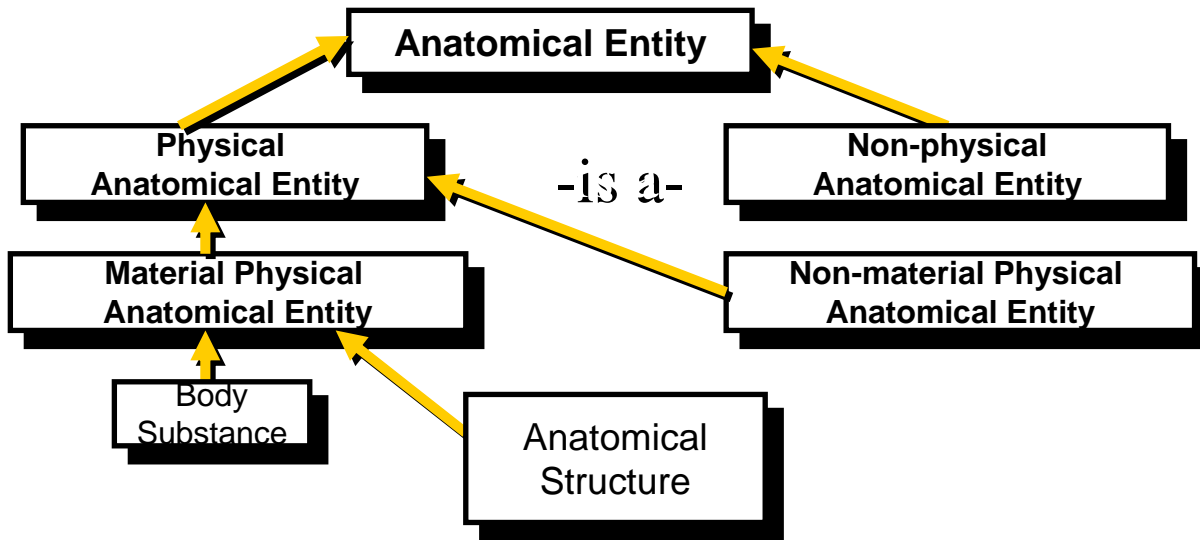


Top-level categories with modifiers



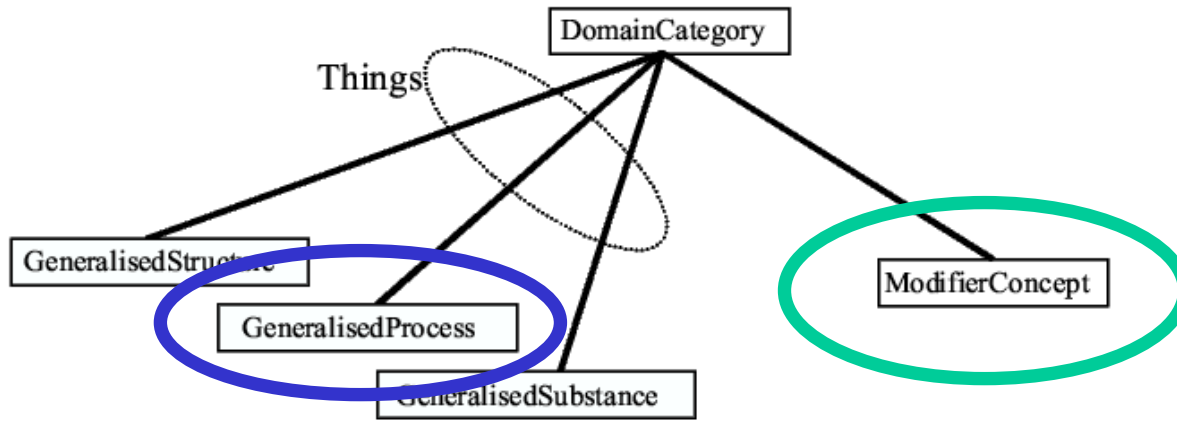
Secondary High Level Taxonomy





FMA:
Canonical anatomy

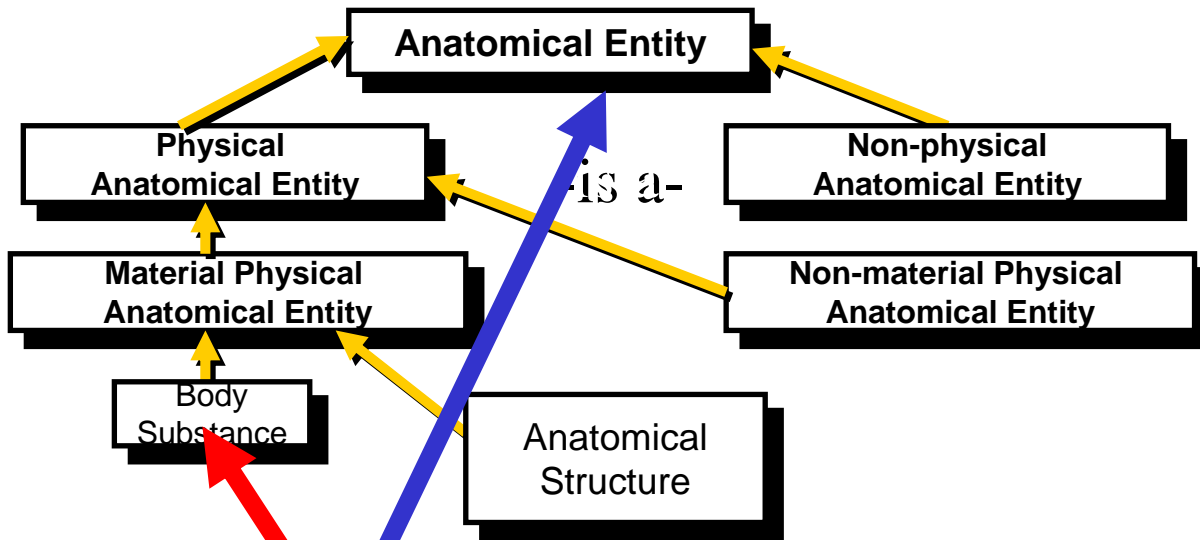
No processes
No pathology



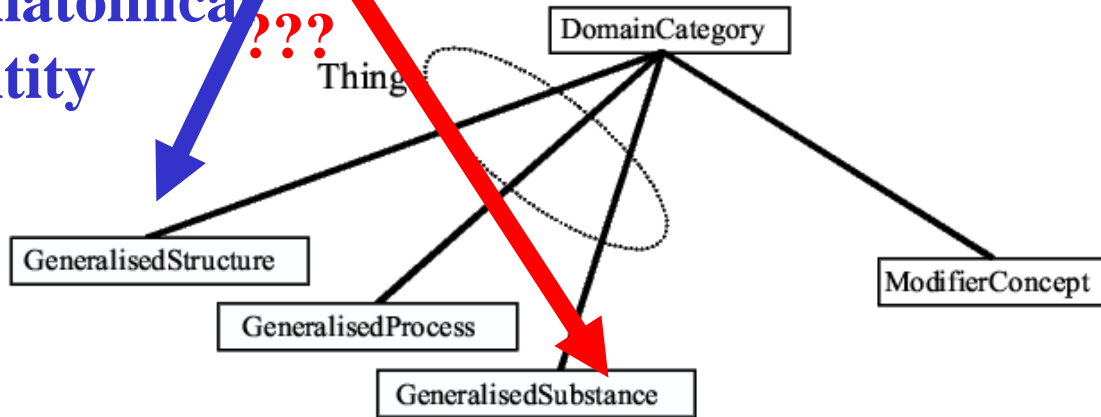
GALEN:
Anatomy + Diseases

Processes

- Non-normality
- Degrees of non-normality



**Enduring
Anatomical
entity** ???



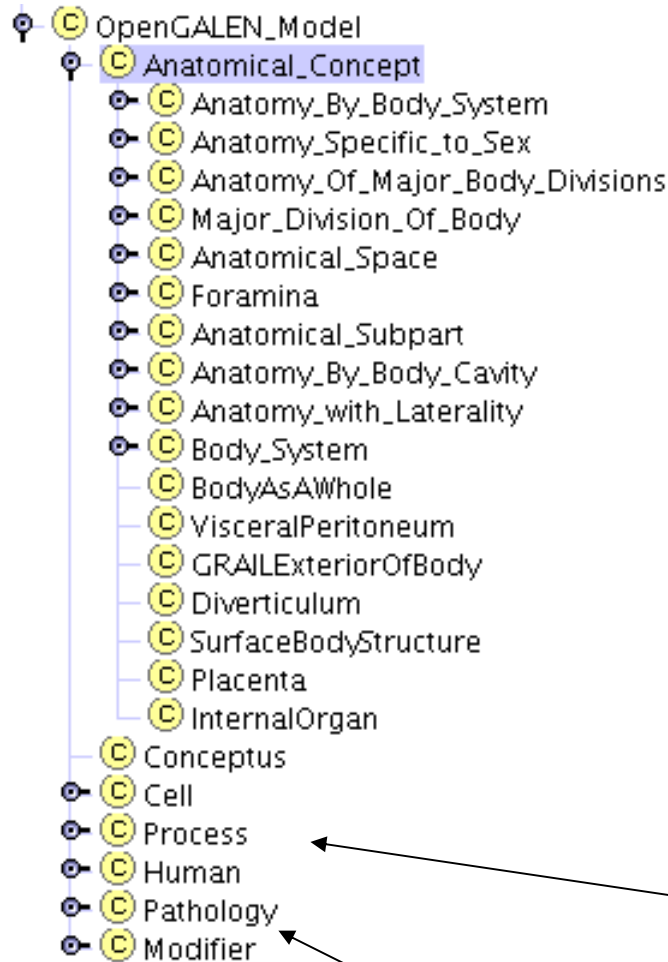
FMA:
Canonical anatomy

No processes
No pathology

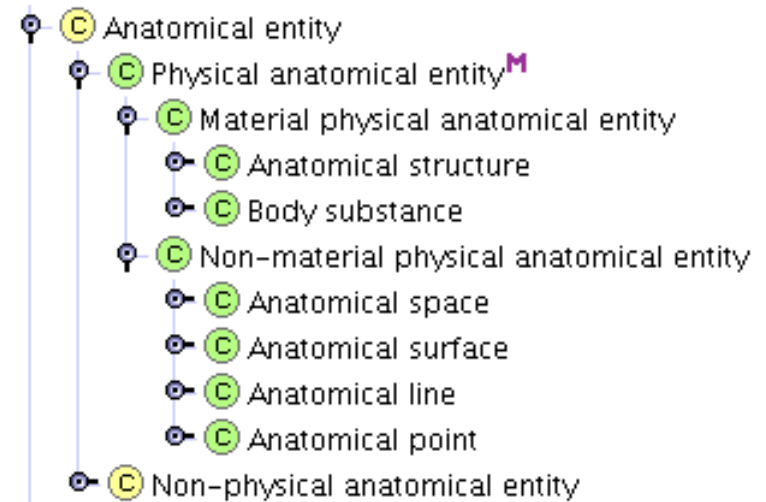
GALEN:
Anatomy + Diseases

Processes
Pathology
Diseases

GALEN



FMA

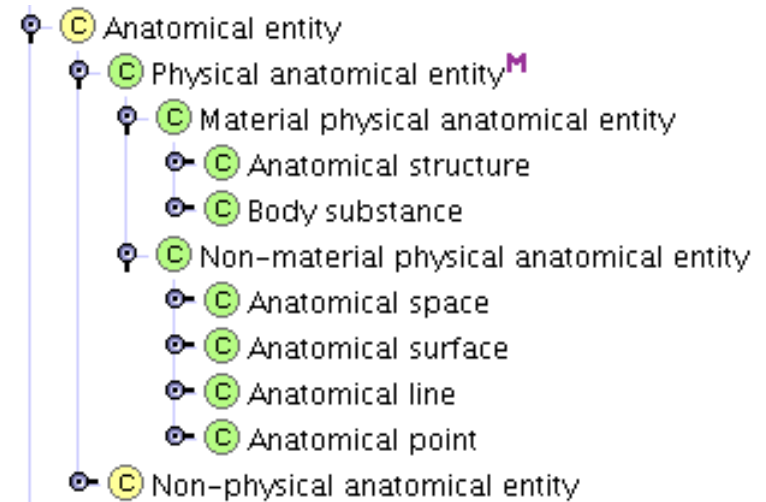
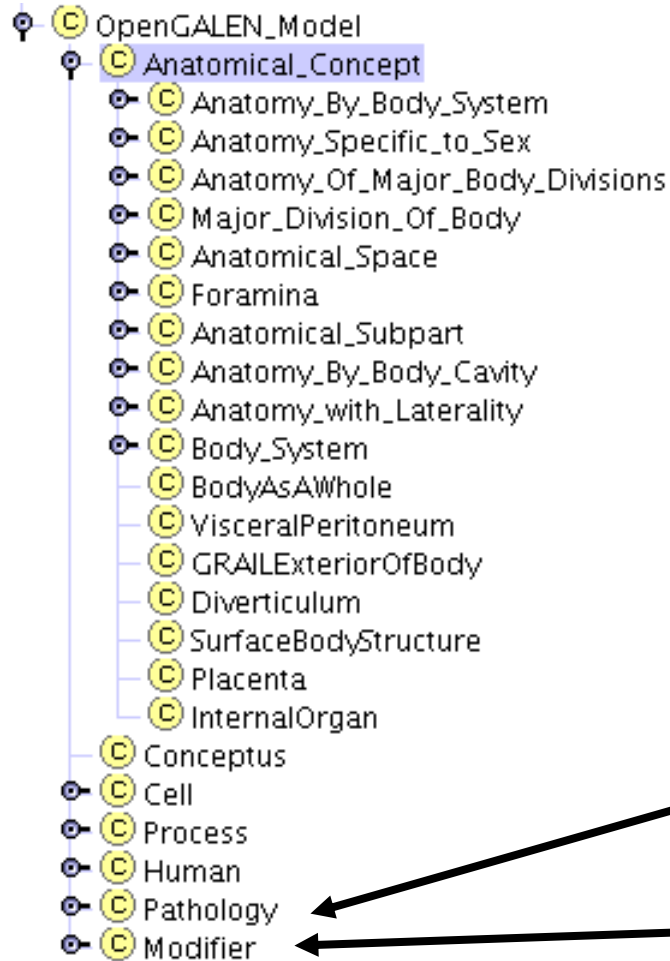


GALEN also deals with processes

Modifiers to characterize processes

GALEN

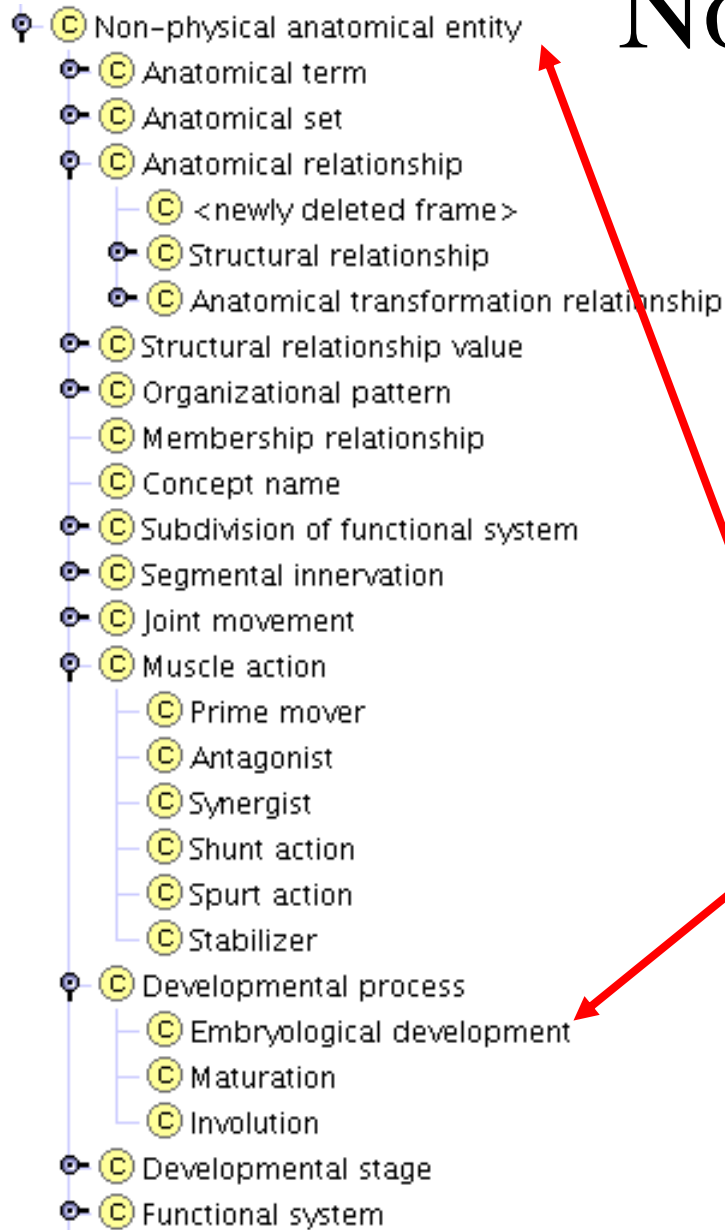
FMA



Pathology and non-normality

Characterize pathology/ non-norm.

No processes in FMA?

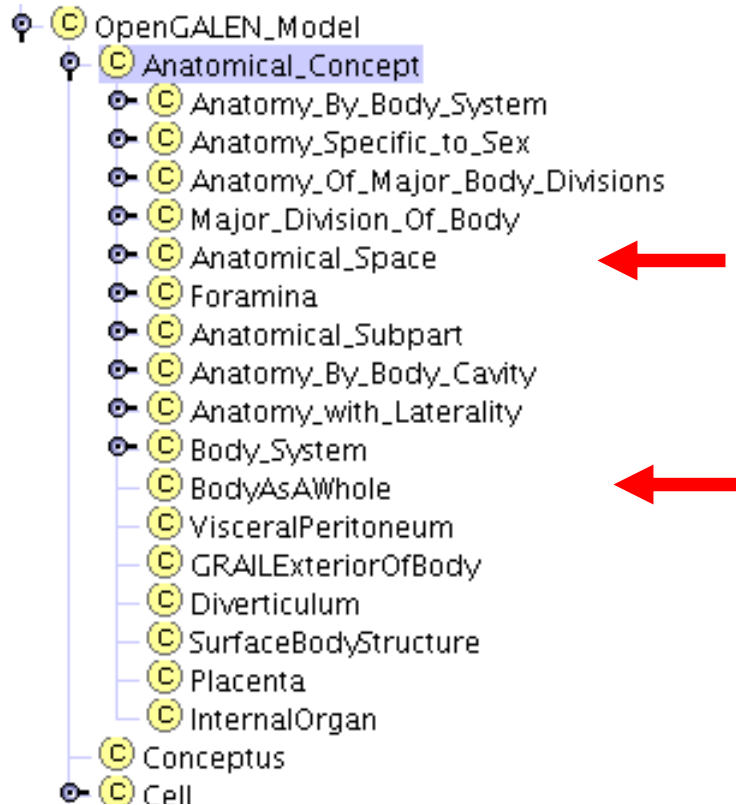


Processes as non-physical entities ?

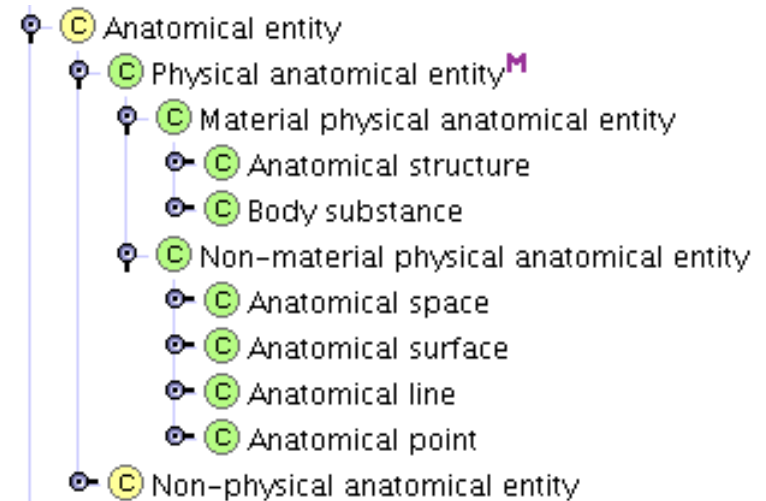
- clearly processes are extended in spacetime
- hasDimension should be true

Endurant categories

GALEN



FMA



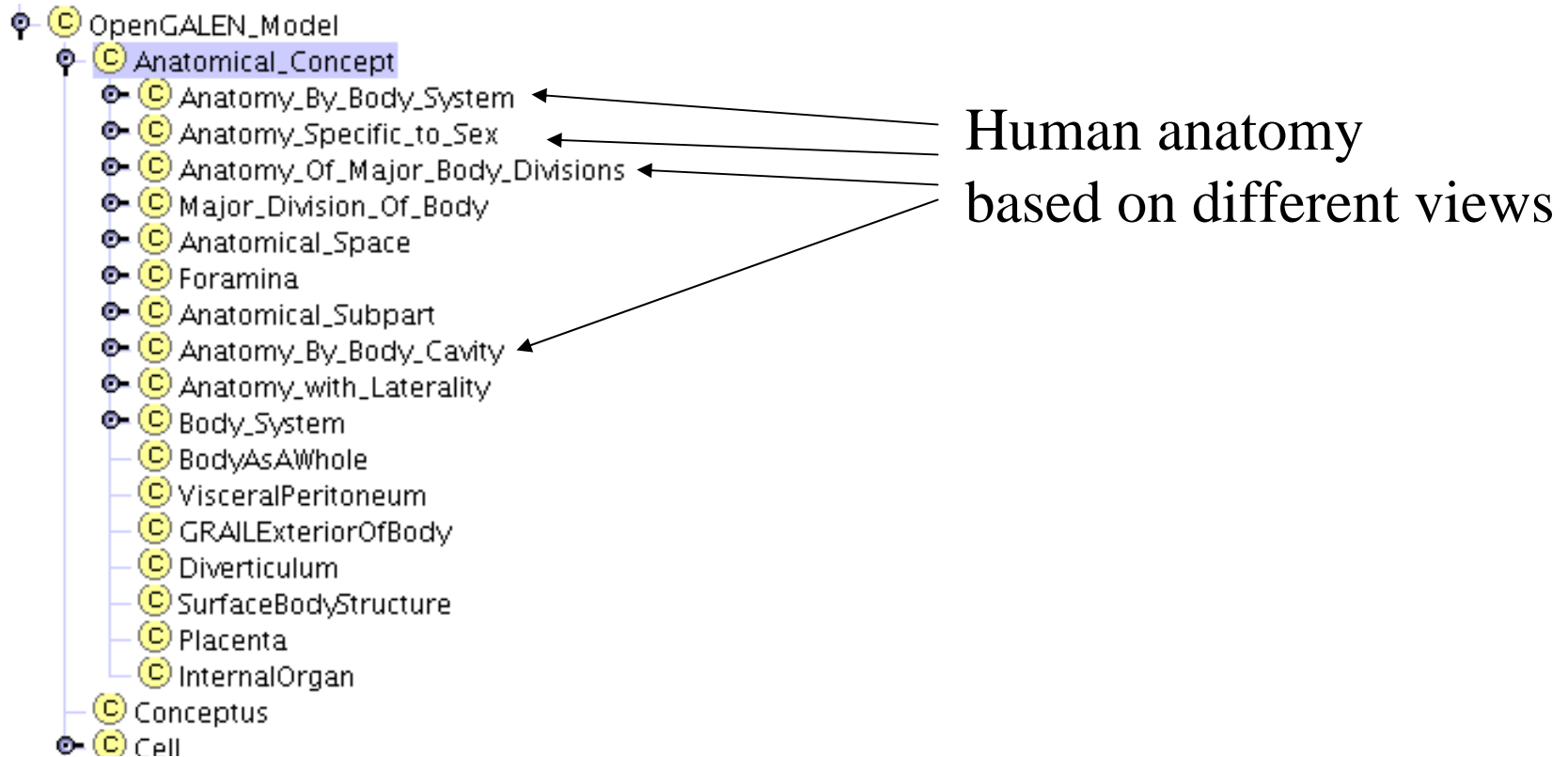
Top-distinctions

- physical / non-physical
(located in space-time / abstract)
- Material / non-material

Not explicitly represented
in GALEN ???

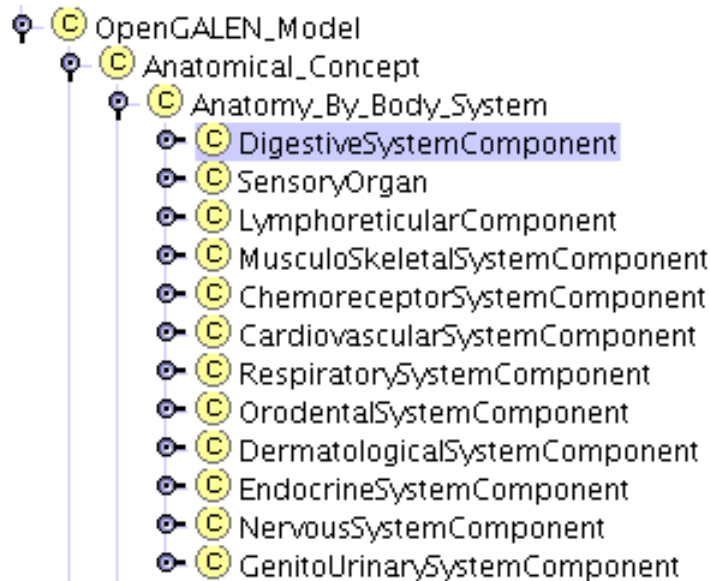
Endurant categories

GALEN

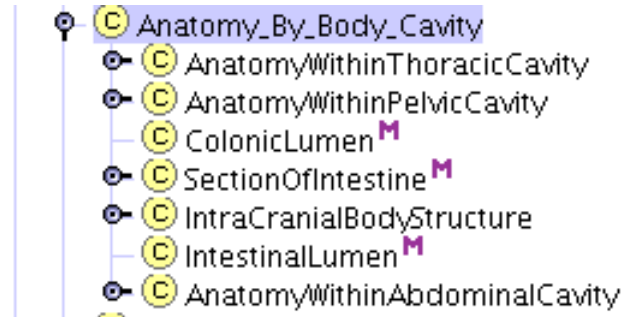


GALEN – anatomical views onto the human body

Anatomy by body system

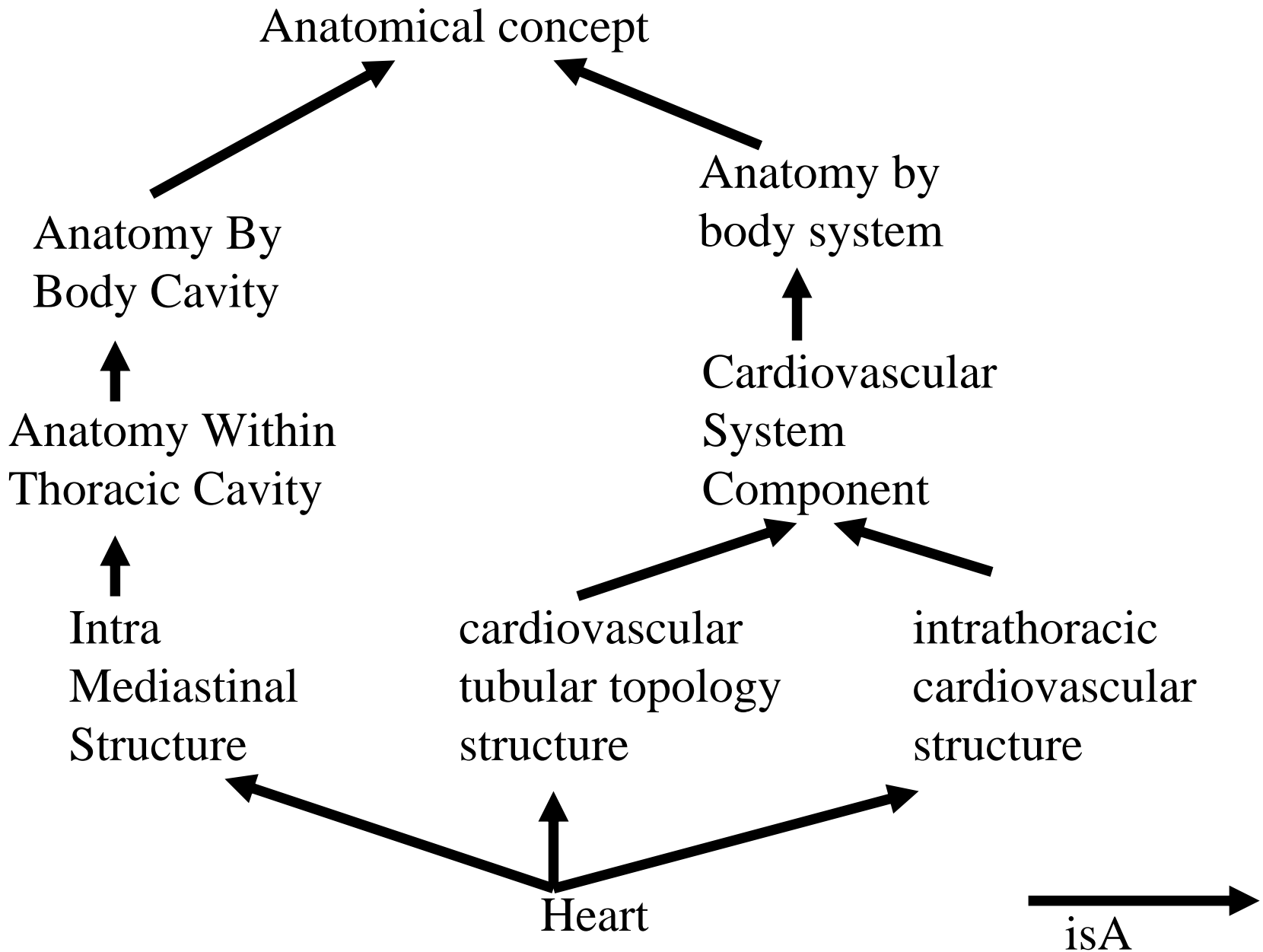


Anatomy by body cavity



GALEN – anatomical views

- Every view is a tree structure
- Trees (views) can overlap, i.e., share components
- The heart occurs in multiple views:
 - Anatomy by body site as **Intra Mediastinal Structure**, i.e., a structure within mediastinum
 - Anatomy by body system as **Tubular Cardiovascular Component**, i.e., cardiovascular tubular topology structure



Mereological relations

Anatomical Structural Abstraction

$$\mathbf{FMA} = (\mathbf{At}, \mathbf{ASA}, \mathbf{ATA}, \mathbf{Mk})$$

$$\mathbf{ASA} = (\mathbf{Dt}, \mathbf{Bn}, \mathbf{Pn}, \mathbf{SAn})$$

where:

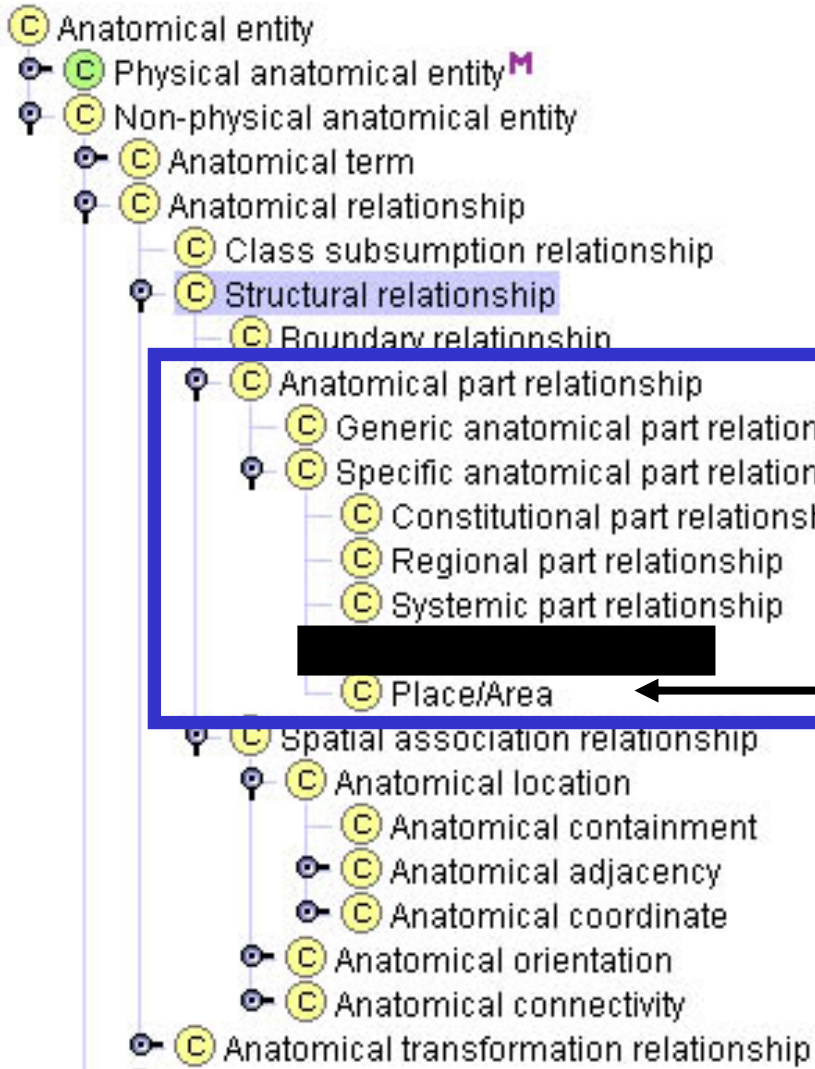
\mathbf{Dt} \equiv Dimensional taxonomy

\mathbf{Bn} \equiv Boundary network

\mathbf{Pn} \equiv Part-of network

\mathbf{SAn} \equiv Spatial Association network

Structural relations in FMA



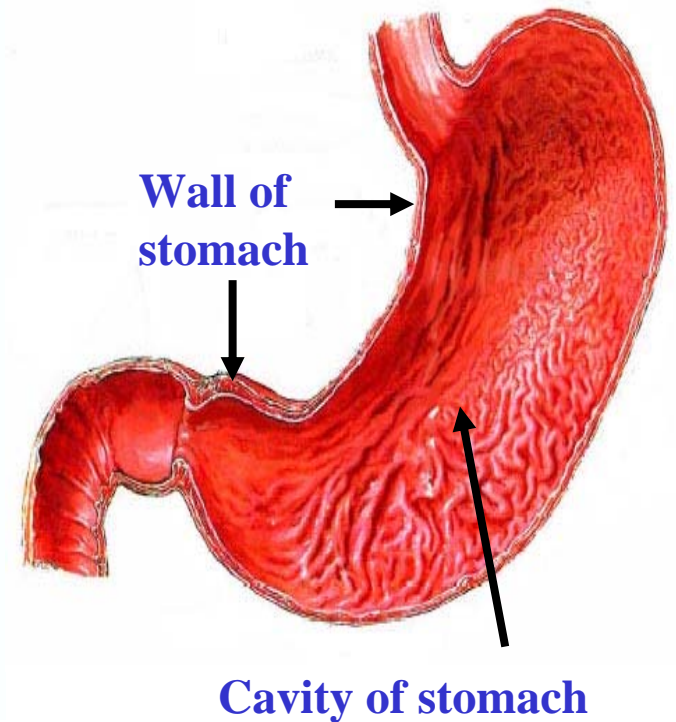
Partial ordering + WSP

Generic parthood +
Additional axioms

Parthood restricted
to spatial regions

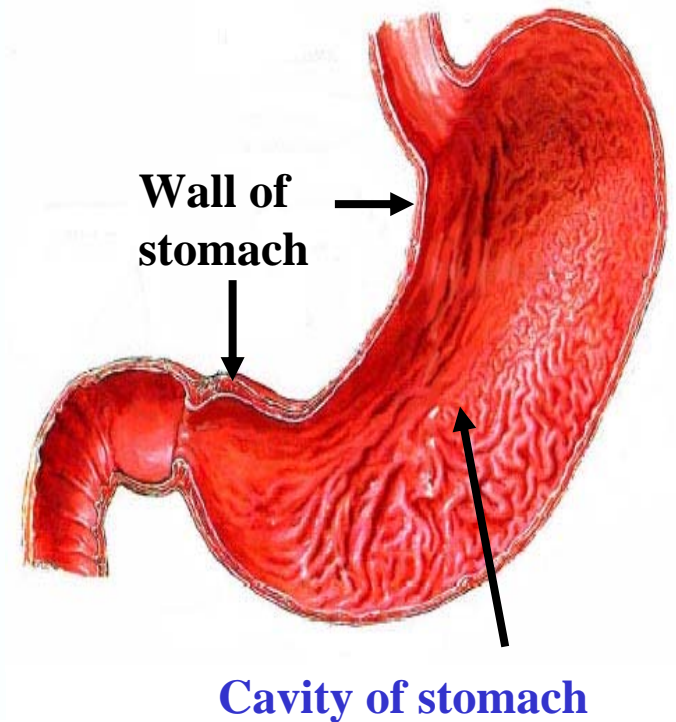
FMA: Regional vs. constitutional parts

		Regional part		
		Fundus	Body	Antrum
Constitutional part	Wall	Wall of fundus of stomach	Wall of body of stomach	Wall of antrum of stomach
	Cavity	Cavity of fundus of stomach	Cavity of body of stomach	Cavity of antrum of stomach



FMA: Regional vs. constitutional parts

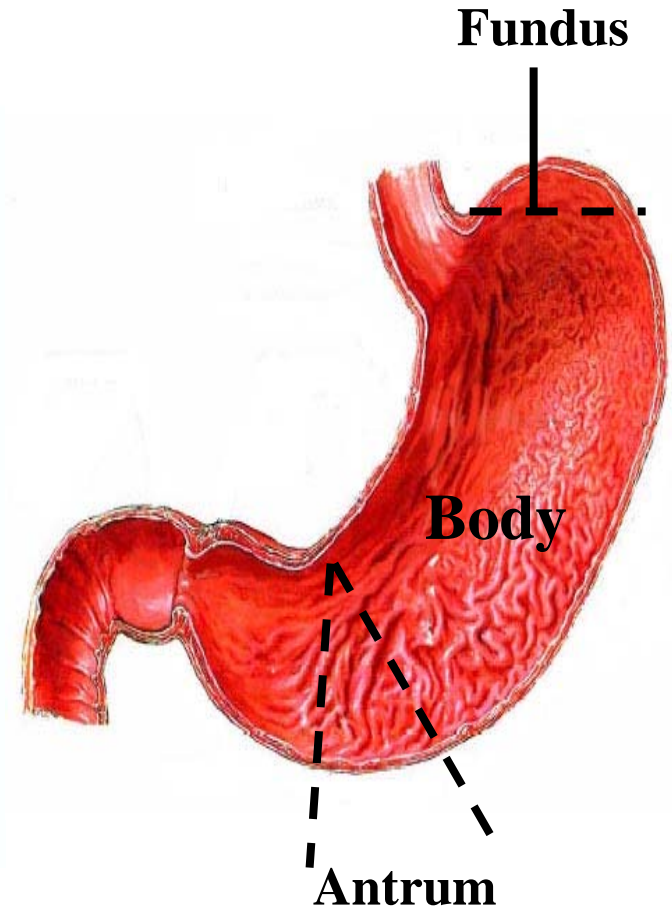
		Regional part		
		Fundus	Body	Antrum
Constitutional part	Wall	Wall of fundus of stomach	Wall of body of stomach	Wall of antrum of stomach
	Cavity	Cavity of fundus of stomach	Cavity of body of stomach	Cavity of antrum of stomach



The cavity of the stomach is a **non-material** part of the stomach

FMA: Regional vs. constitutional parts

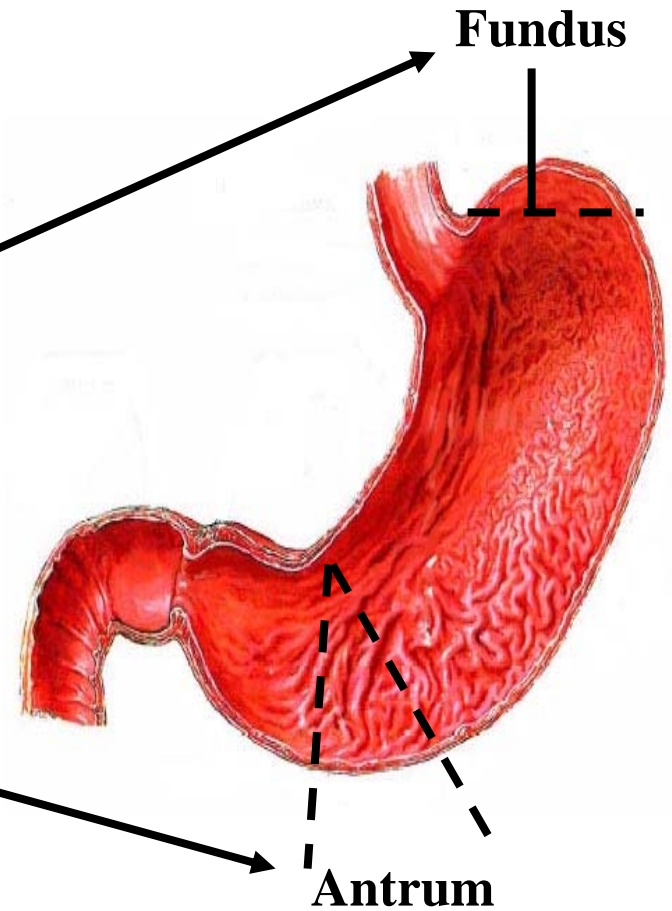
		Regional part		
		Fundus	Body	Antrum
Constitutional part	Wall	Wall of fundus of stomach	Wall of body of stomach	Wall of antrum of stomach
	Cavity	Cavity of fundus of stomach	Cavity of body of stomach	Cavity of antrum of stomach



GALEN: parthood relations

```
+ NAMEDGITractBodyPart
+ LinearSegmentOfUpperGastrointestinalTract
+ AbdominalSmoothMuscleStructure
+ (BodyStructure which < HasDivision Muscle >)
Stomach
```

```
Stomach
---conventional---
hasSolidDivision CurvatureOfStomach
hasSolidDivision GastricCorpus
hasSolidDivision ParsCardiacaGastris
hasSolidDivision GastricFundus
hasSolidDivision IncisuraAngularis
isLinearDivisionOf StomachToDuodenum
isStructuralComponentOf DigestiveSystem
specificallyNonPartitivelyContains Flatus
hasAlphaPartitiveConnection CardiacSphincter
hasStructuralComponent PyloricAntrum
hasStructuralComponent Pylorus
hasStructuralComponent SeromuscularLayerOfStomach
isNonPartitivelyContainedIn AbdominalCavity
isServedBy RightGastricArtery
```

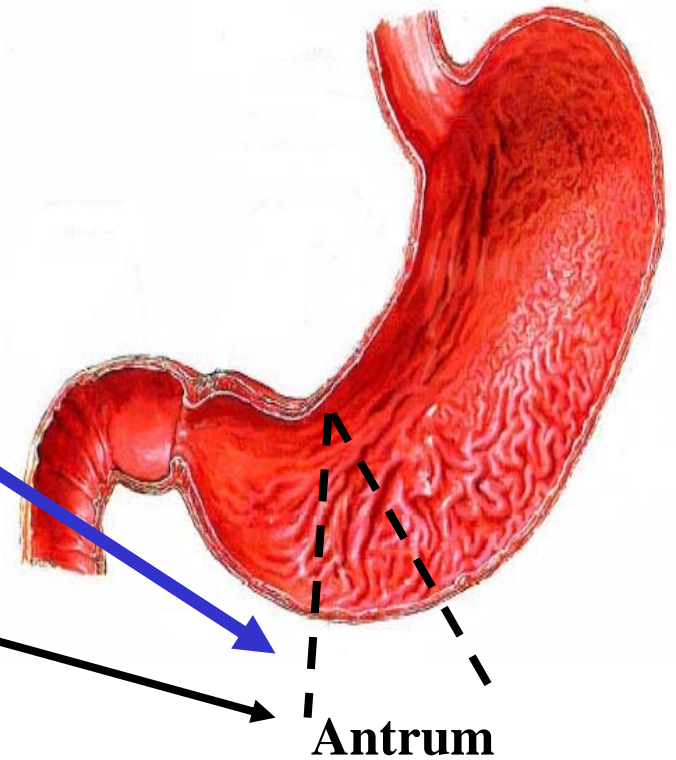


Parthood relations

FMA:
Regional part

?????!!!!!!

GALEN:
Structural component



Parthood relations

FMA

GALEN



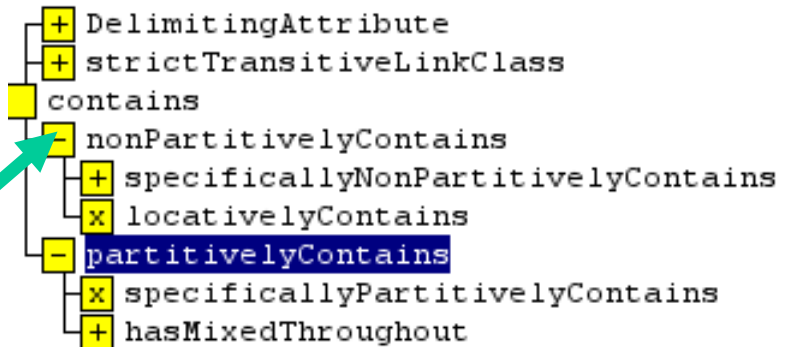
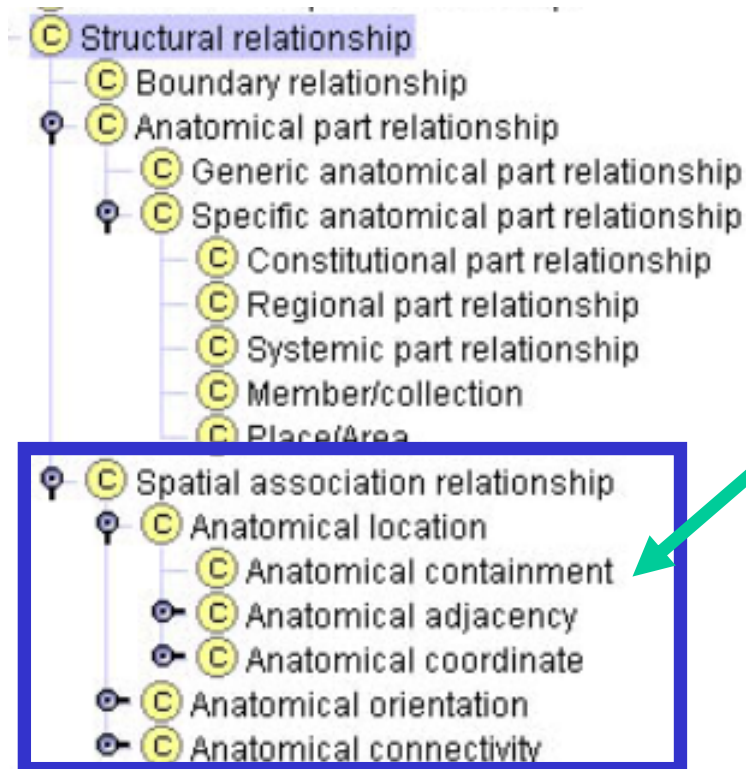
InversePartitiveAttribute	<i>part-of</i>
InverseStructuralPartitiveAttribute	
IsDivisionOf	<i>structure-part-of</i>
isArbitraryComponentOf	<i>arbitrary-part-of</i>
isLinearDivisionOf	<i>segment-of</i>
isSolidRegionOf	<i>solid-piece-of</i>
isBlindPouchDivisionOf	<i>pouch-of</i>
isLayerOf	<i>layer-of</i>
isSolidDivisionOf	<i>irregular-piece-of</i>
isStructuralComponentOf	<i>component-of</i>
isFunctionComponentOf	<i>func-component-of</i>
isPartitiveConnectionOf	
isPartitivelyContainedIn	
isMixedThroughout	<i>.portion-of</i>
isDissolvedWithin	<i>dissolved-in</i>
isInSuspensionWithin	<i>suspended-in</i>
isSurfaceDivisionOf	<i>surface-of</i>
makesUp	<i>stuff-of</i>
InverseProcessPartitiveAttribute	
IsSubprocessOf	<i>subprocess-of</i>

Containment

Containment

FMA

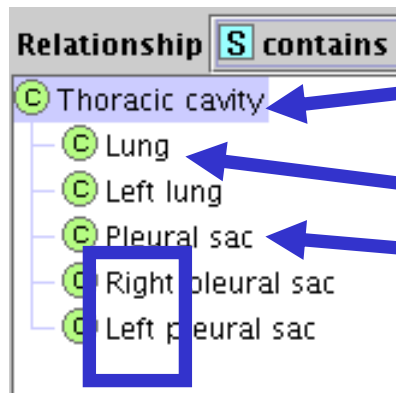
GALEN



Containment

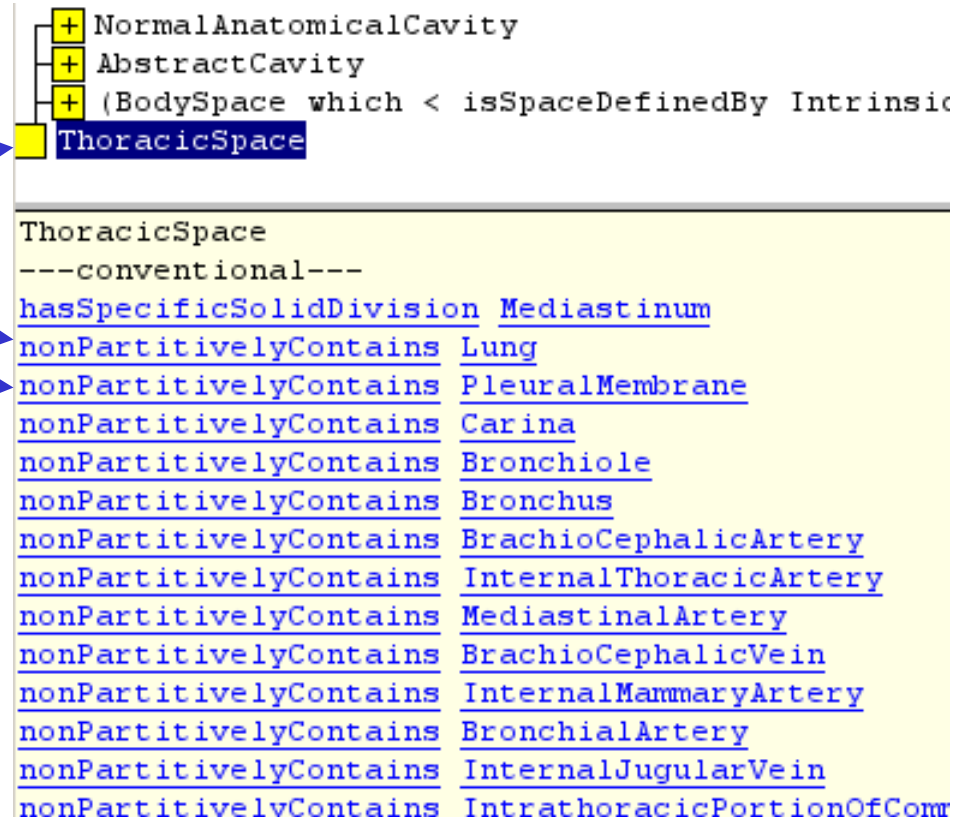
FMA

Anatomical containment



GALEN

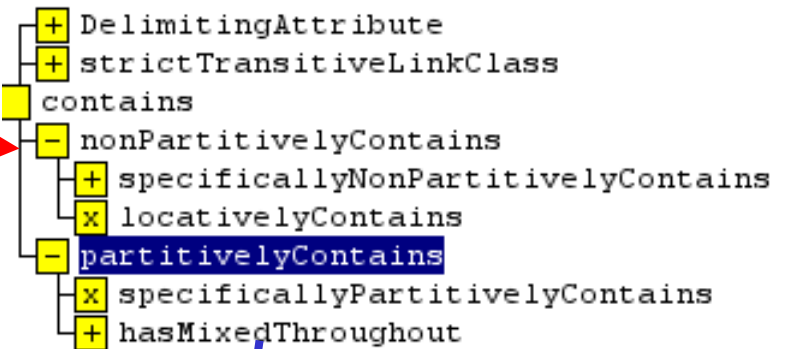
non-partitively contains



Partitively contains

GALEN

NOT WSP



Satisfies WSP:

- if something is a mixture then it has at least two components
- not a containment relation

Problems with treating
containment as a locative relation

or

Why my lung is NOT contained
in my **thoracic cavity**.

Properties of containers

- Containment is a relation between a material entity and a container (*my dollar bill contained-in my wallet*).
 - Containers **enclose** the contained
 - The enclosed **cannot penetrate** the boundary of the container.
- The wallet is a container because it keeps the bills in its inside.

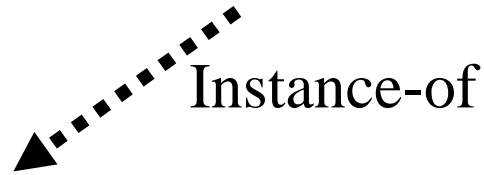
Properties of containers

- Containment is a relation between a material entity and a container (*my dollar bill contained-in my wallet*).
 - Containers **enclose** the contained
 - The enclosed **cannot penetrate** the boundary of the container.
- The backpack is a container because it keeps the wallet it its inside.

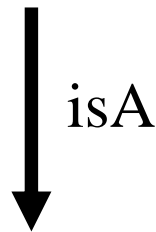
Properties of containers

- Containment is a relation between a material entity and a container (*my dollar bill contained-in my wallet*).
 - Containers **enclose** the contained
 - The enclosed **cannot penetrate** the boundary of the container.
- **My thorax is a container because it keeps my internal organs in its inside.**

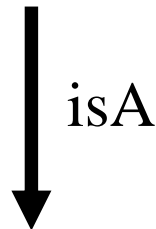
my thoracic cavity



Thoracic cavity (FMA)



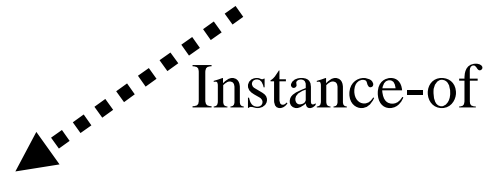
Anatomical space (FMA)



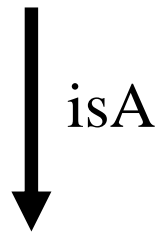
Non-material anatomical entity (FMA)

- Non-material entities **cannot be barriers** for material entities
- The **space** in your wallet **cannot keep your bills in place**
- The **space** in your backpack **cannot keep your shopping items in place.**

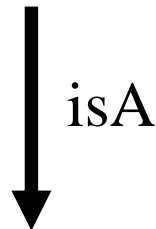
my thoracic cavity



Thoracic cavity (FMA)



Anatomical space (FMA)



Non-material anatomical entity (FMA)

- Non-material entities **cannot be barriers** for material entities
- **My thoracic cavity cannot hold my internal organs**
- **Therefore: my lung is not contained in my thoracic cavity**
- My lung is and my thoracic cavity **coincide**

Do not mix up containment and coincidence!!!

- x non-partitively-containment-in y roughly means:
 - The region of x is a part of the region of y
 - x and y do not overlap



Coincidence (see Donnelly)



Coincidence is a locative relation (based on the region-of function)

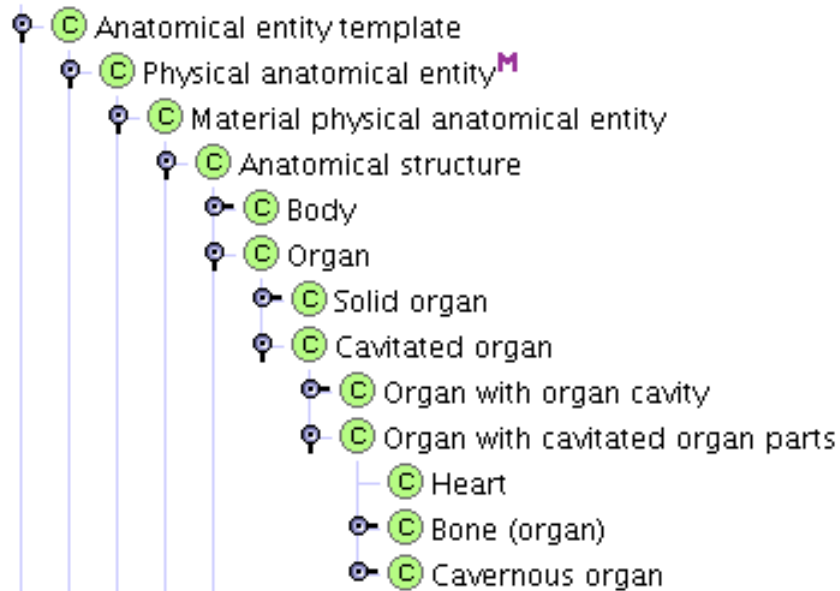
Reification of parthood

vs.

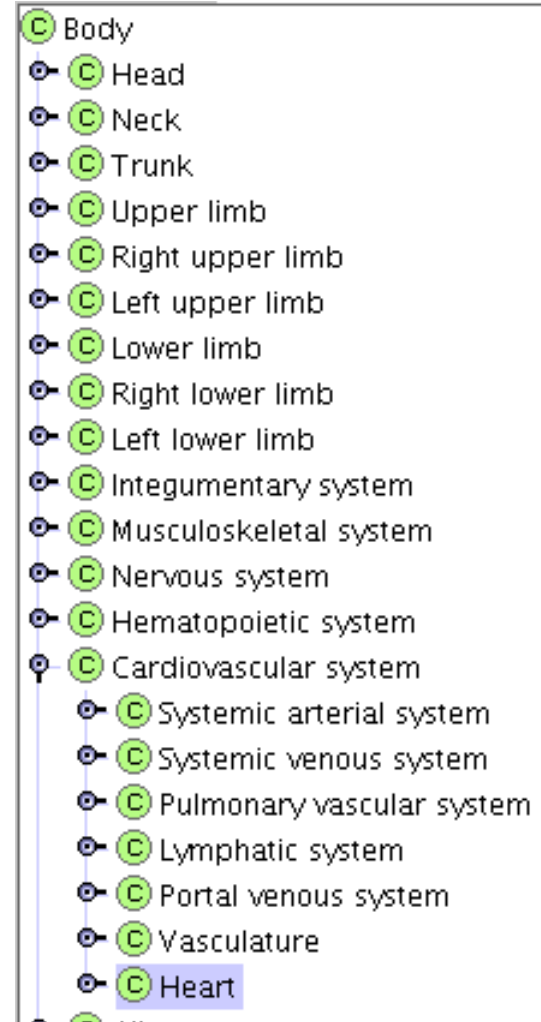
partonomic parthood between
classes

The heart in FMA

Is-a hierarchy

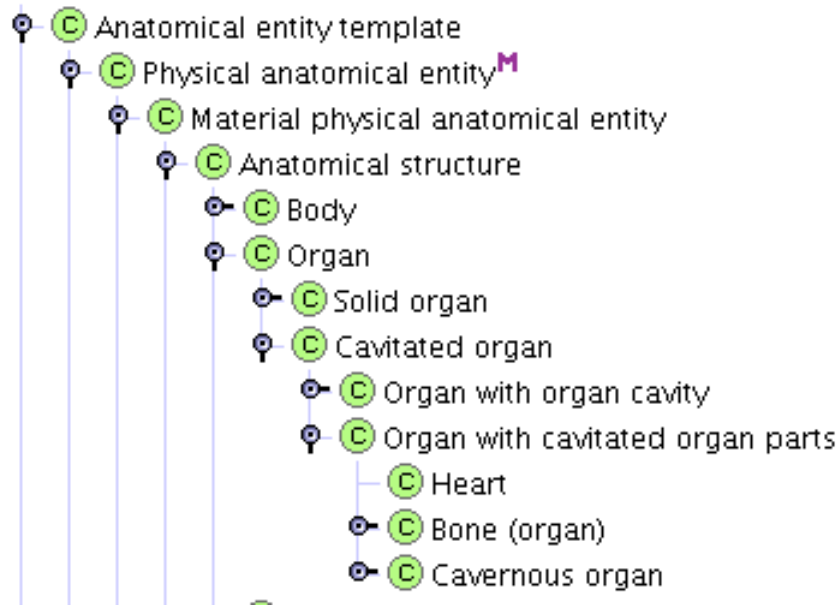


Partonomic-parthood hierarchy



The semantics of *isA*

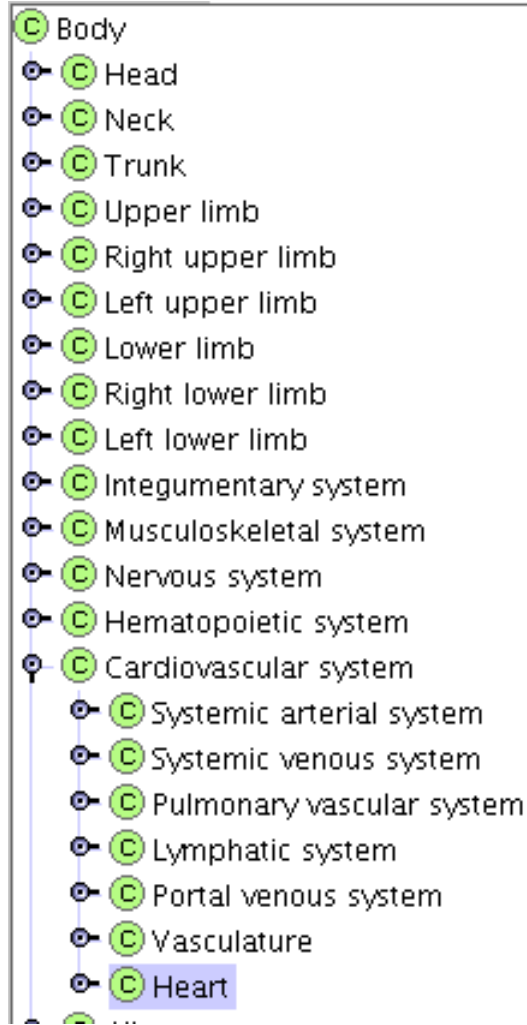
Is-a hierarchy



X *isA* Y iff

every instance of X
is an instance of Y

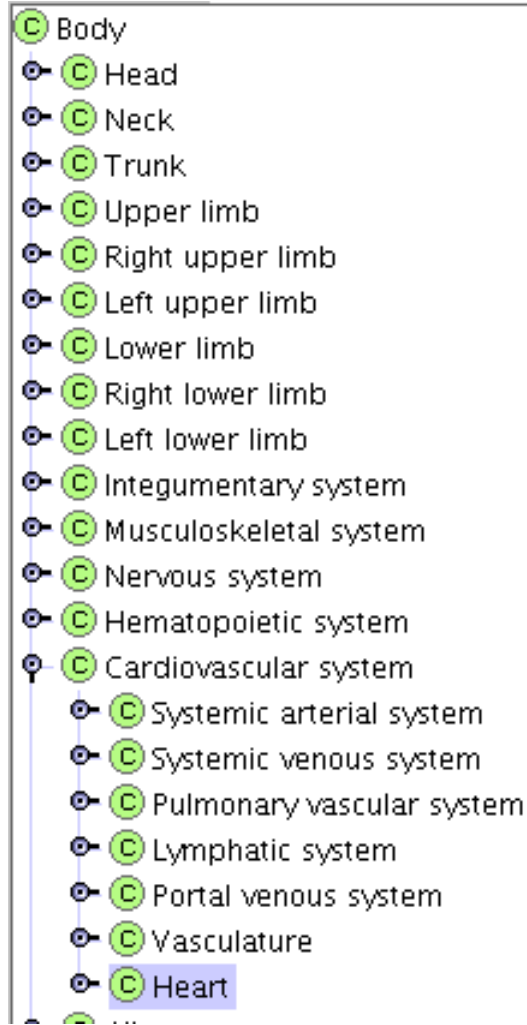
The semantics of partonomic parthood (1)



X *PART-OF* Y iff

For every instance x of X
There exists an instance
 y of Y such that
 x *part-of* y

The semantics of partonomic parthood (2)



X *PART-OF* Y iff

For every instance x of X
there exists an instance
 y of Y such that
 x *part-of* y

AND

For every instance y of Y
there exists an instance
 x of X such that
 x *part-of* y

PART-OF in canonical anatomy

- *Body* **PART-OF** *Head*
- *Heart* **PART-OF** *Cardiovascular System*

BUT **NOT**

– *Nucleus* **PART-OF** *Cell*

BUT

– *Nucleus* **PART-OF** *Cell*

Properties of PART-OF

- Reflexive

$X \text{ PART-OF } X$

- Transitive

IF $X \text{ PART-OF } Y$ AND $Y \text{ PART-OF } Z$
THEN $X \text{ PART-OF } Z$

- Antisymmetry

IF $X \text{ PART-OF } Y$ AND $Y \text{ PART-OF } X$
THEN $X = Y$


holds only if discrete instances of X and Y do not overlap

Reification

- Formation of classes like
 - PartOfHeart (GALEN)
 - OrganPart (FMA)
 - BodyPartSubdivision (FMA)
 - Organ subdivision (FMA)
- $\{ x \mid (\exists y) y \in Y \text{ AND } R \text{ } xy \}$
- $\text{PartOfHeart} \equiv \exists \text{hasPart.Heart}$
- $\text{PartOfHeart } x \equiv (\exists y)(\text{Heart } y \text{ AND has-part } xy)$

Problems with reification

OrganPart $x \equiv (\exists y)(\text{Organ } y \text{ AND has-part } xy)$



Name of the class contains a the names of the **class**
and of the **relation** that was used for the class formation


Often, what we have is only the name of the class and
we need to resort to linguistic analysis in order to **GUESS**
the underlying semantics.

Problems with reification

Assumption:
Name of the class
contains a the
names of the **class**
and of the **relation**
that was used for
the class formation

OrganPart

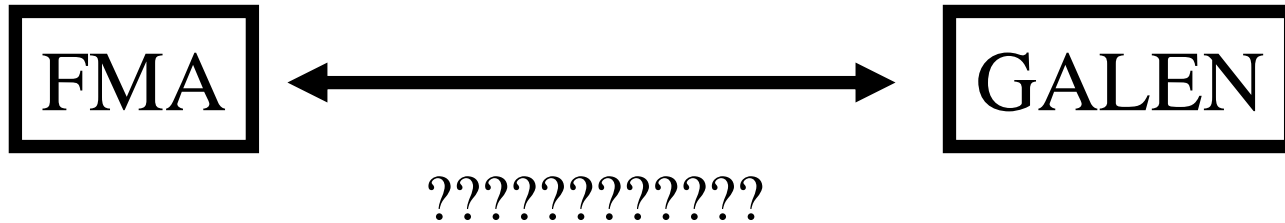
Linguistic
Analysis



$(\exists y)(\text{Organ } y \text{ AND has-part } xy)$

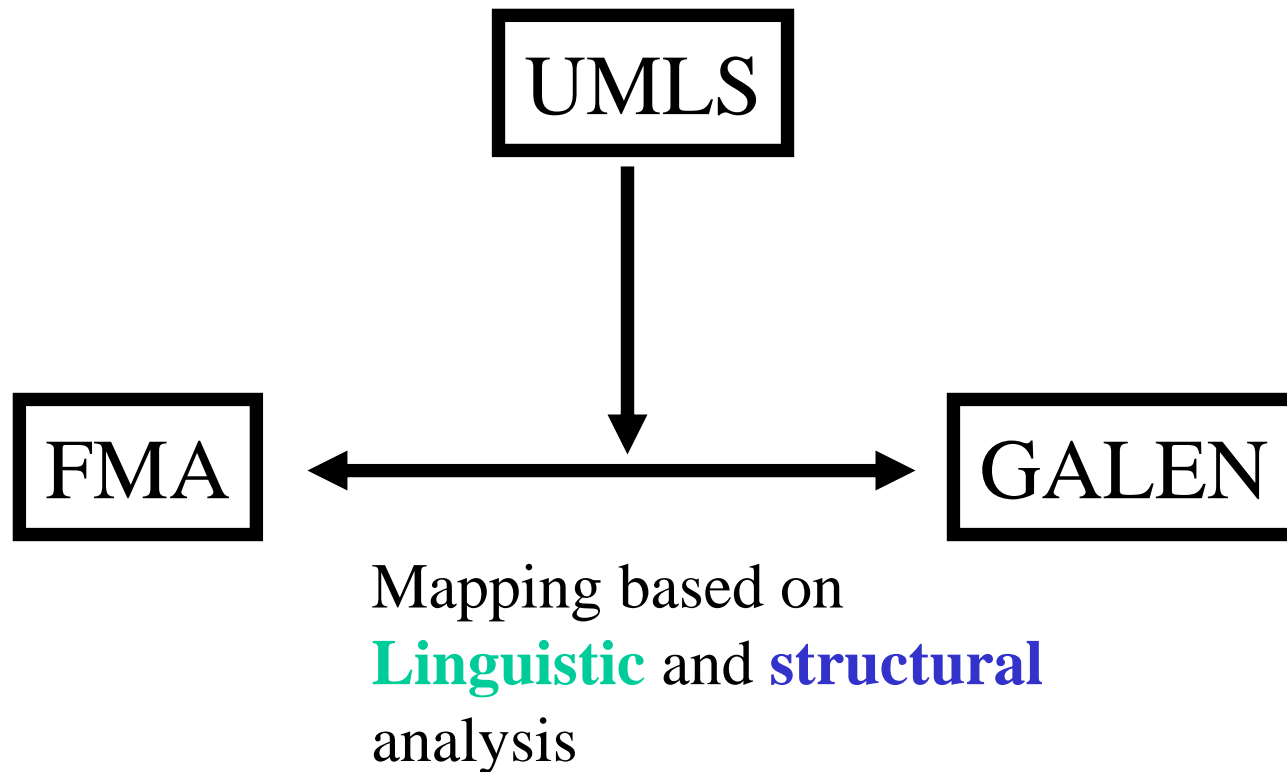
Conclusions

How to compare FMA and GALEN???

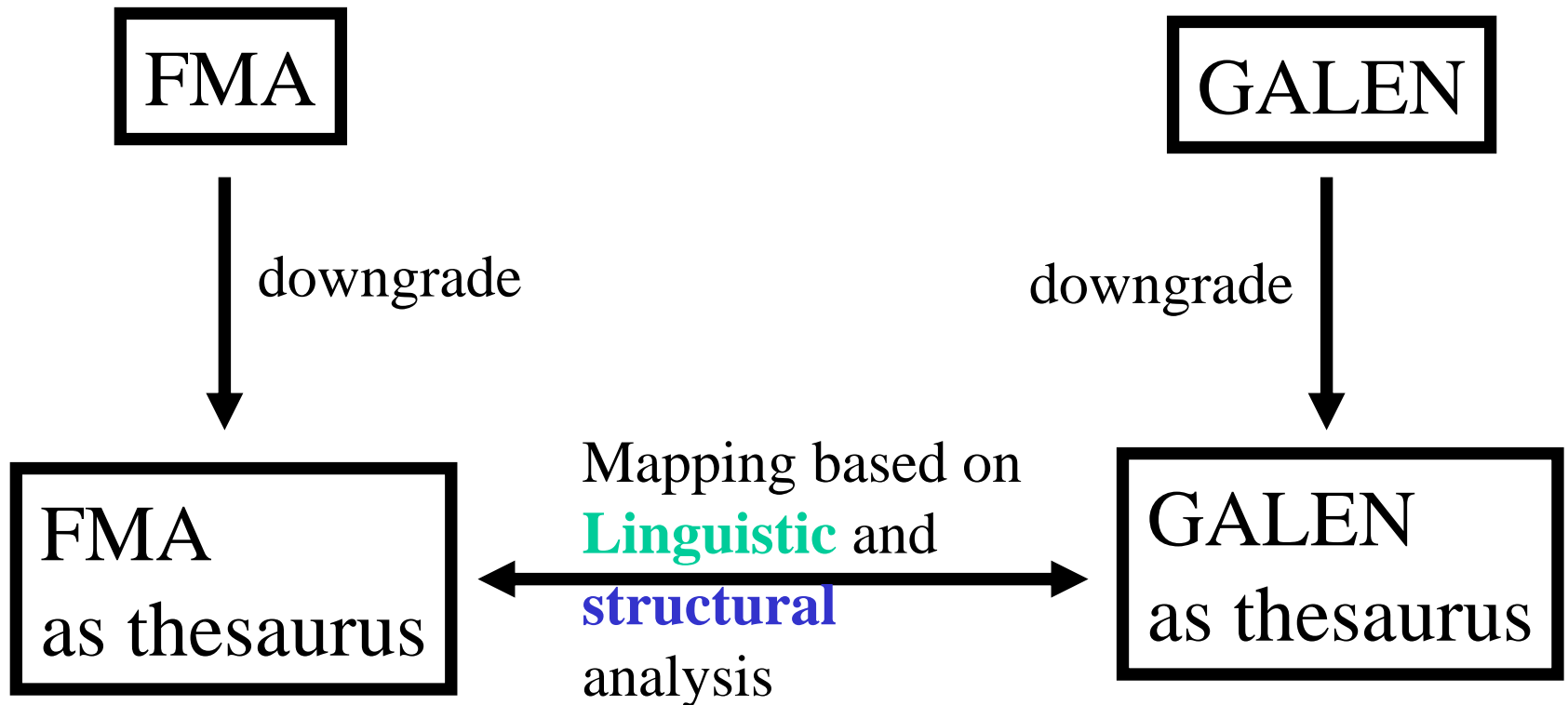


Linguistic approaches

Bodenreider et al.



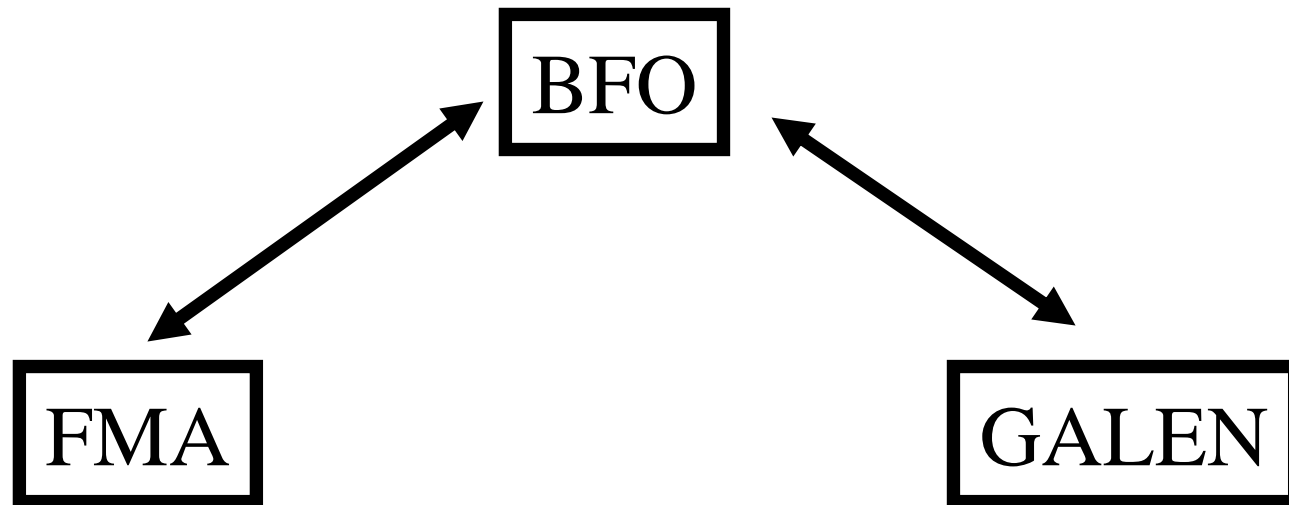
The fundamental problem of linguistic approaches:



Reference framework

Basic Formal Ontology (BFO)

Full first order logic

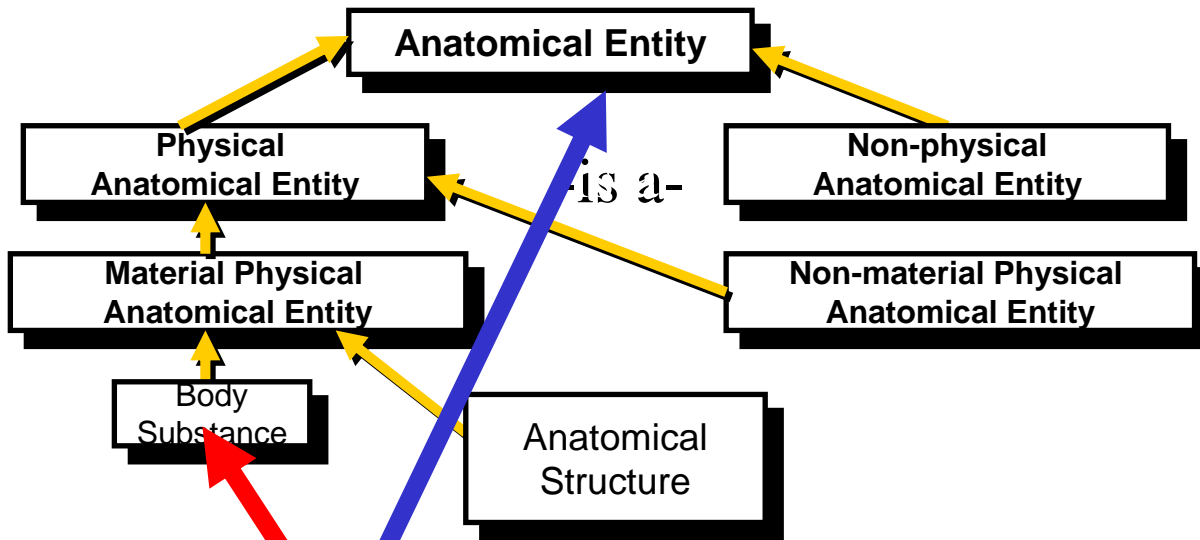


Protégé,
Frame system

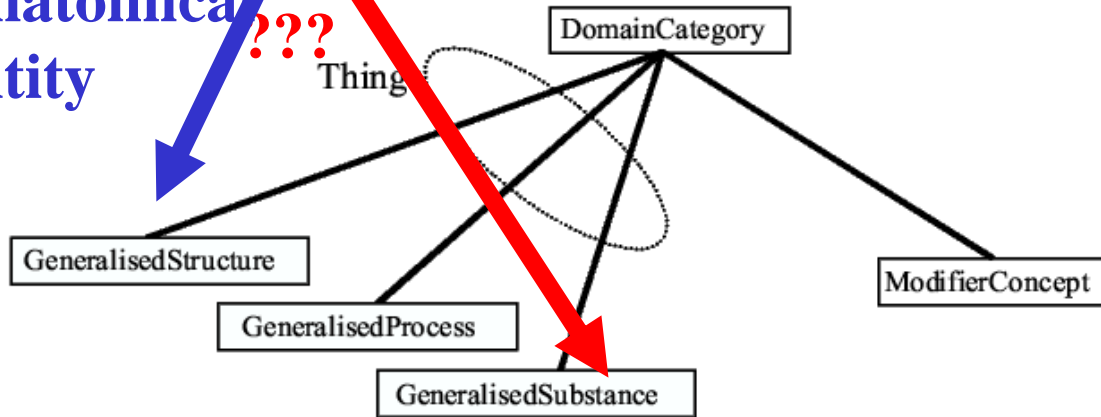
GRAIL
Description logic

Reference framework BFO

- Basic categorial distinctions manifested in
 - Theory of individuals and universals
 - Theory of endurants and perdurants
 - Theory of material and non-material entities
- Theories of formal relations
 - Mereology
 - Topology
 - Location
 - Containment
 - Dependence



**Enduring
Anatomical
entity** ???



FMA:
Canonical anatomy

No processes
No pathology

GALEN:
Anatomy + Diseases

Processes
Pathology
Diseases

Parthood relations

FMA

GALEN

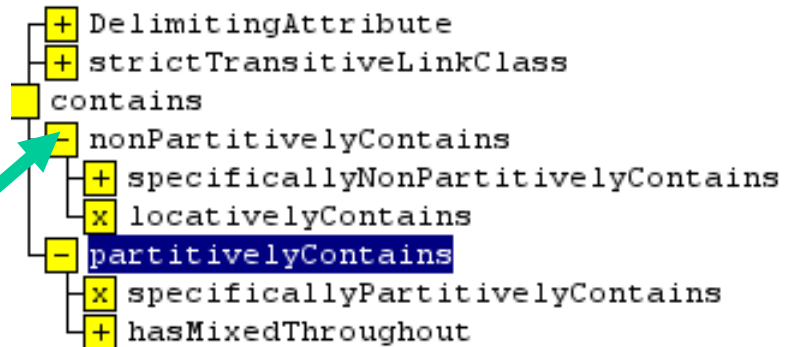
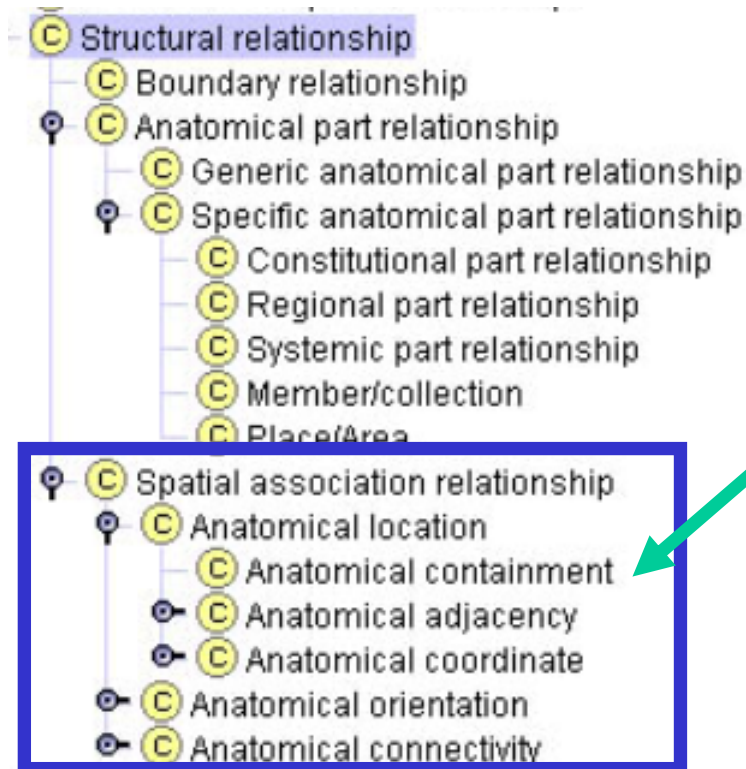


InversePartitiveAttribute	<i>part-of</i>
InverseStructuralPartitiveAttribute	
IsDivisionOf	<i>structure-part-of</i>
isArbitraryComponentOf	<i>arbitrary-part-of</i>
isLinearDivisionOf	<i>segment-of</i>
isSolidRegionOf	<i>solid-piece-of</i>
isBlindPouchDivisionOf	<i>pouch-of</i>
isLayerOf	<i>layer-of</i>
isSolidDivisionOf	<i>irregular-piece-of</i>
isStructuralComponentOf	<i>component-of</i>
isFunctionComponentOf	<i>func-component-of</i>
isPartitiveConnectionOf	
isPartitivelyContainedIn	
isMixedThroughout	<i>.portion-of</i>
isDissolvedWithin	<i>dissolved-in</i>
isInSuspensionWithin	<i>suspended-in</i>
isSurfaceDivisionOf	<i>surface-of</i>
makesUp	<i>stuff-of</i>
InverseProcessPartitiveAttribute	
IsSubprocessOf	<i>subprocess-of</i>

Containment

FMA

GALEN




Problems with reification

Assumption:
Name of the class
contains a the
names of the **class**
and of the **relation**
that was used for
the class formation

OrganPart

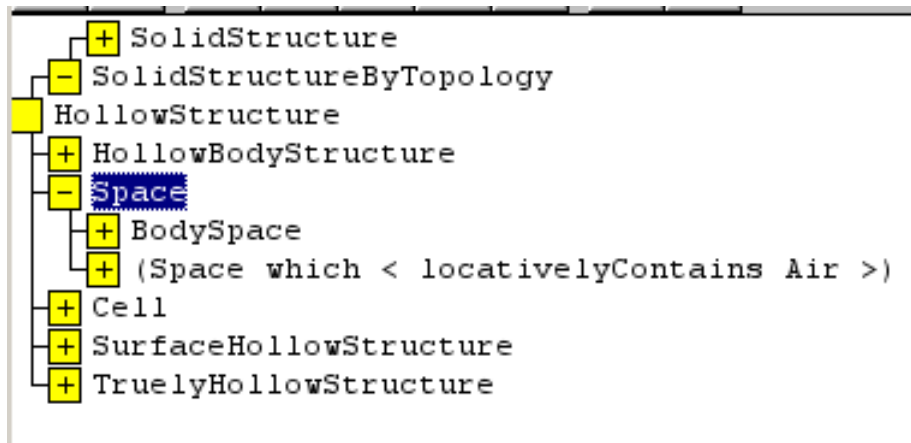
Linguistic
Analysis



$(\exists y)(\text{Organ } y \text{ AND has-part } xy)$

The end!

GALEN: Holes and space



Space

---conventional---

[hasTopology](#) [hollowTopology](#)

[hasCountability](#) [discrete](#)