Working Modularly with Ontologies

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And now . . .

Ontology

= collection of statements about a domain *(axioms)*

- Language used: usually logic, often *description logic (DL)*
- *Inferences* can be drawn from axioms

Domains:
biology, medicine, chemistry, business processes, natural language, ...

Example axioms + inferences

$$\underbrace{\mathsf{Arm}}_{\text{concept}} \sqsubseteq \underbrace{\exists \underbrace{\mathsf{hasPart}}_{\text{role}} . \underbrace{\mathsf{Hand}}_{\text{concept}}}_{\text{concept}} \qquad \forall x \Big(\mathsf{Arm}(x) \rightarrow \exists y \big(\mathsf{hasPart}(x,y) \wedge \mathsf{Hand}(y) \big) \Big)$$

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$$\models \quad \text{Limb} \sqcap \neg \text{Leg} \quad \sqsubseteq \quad \exists \, \text{hasPart.Hand}$$

$$\forall x \Big(\big(\text{Limb}(x) \wedge \neg \text{Leg}(x) \big) \rightarrow \exists y \big(\text{hasPart}(x, y) \wedge \text{Hand}(y) \big) \Big)$$

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$\underbrace{\mathit{LeftArm}}_{\text{individual}} : \text{Arm}$ $\quad \text{Arm}(\mathit{LeftArm})$

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$\underbrace{\mathit{LeftArm}}_{\text{individual}} : \text{Arm}$ $\quad \text{Arm}(\mathit{LeftArm})$

$\models \mathit{LeftArm} : \exists \text{hasPart.Hand}$ $\quad \exists y \big(\text{hasPart}(\mathit{LeftArm}, y) \wedge \text{Hand}(y)\big)$

Reasoning tasks

- *Consistency:*
  Does ontology $\mathcal{O}$ have a model?
- *Satisfiability:*
  Is there a model of $\mathcal{O}$ that interprets concept C as nonempty?
- *Subsumption:*
  Does $C \sqsubseteq D$ hold in every model of $\mathcal{O}$?
- *Instance checking:*
  Is individual x an instance of C in every model of $\mathcal{O}$?

Inter-reducible; optimised reasoners available

The Web Ontology Language OWL

- W3C-recommended standard since 2004
- OWL 2 published on 27 Oct. 2009

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OWL 2

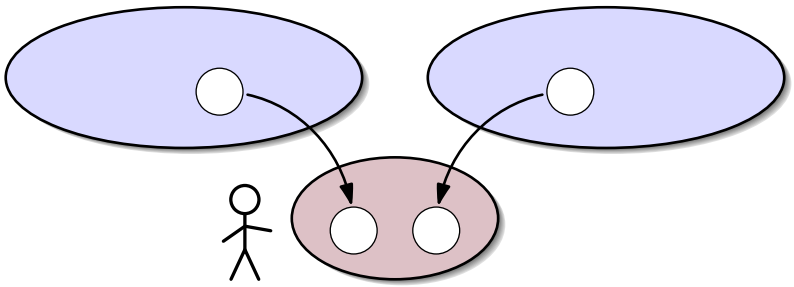
Based on DL $\mathcal{SROIQ}$
$\exists$, $\forall$, counting, role chains and hierarchies, transitivity, inverse roles, nominals

OWL 2 EL, QL, RL

Sub-profiles for efficient reasoning and application orientation

And now . . .

Three scenarios



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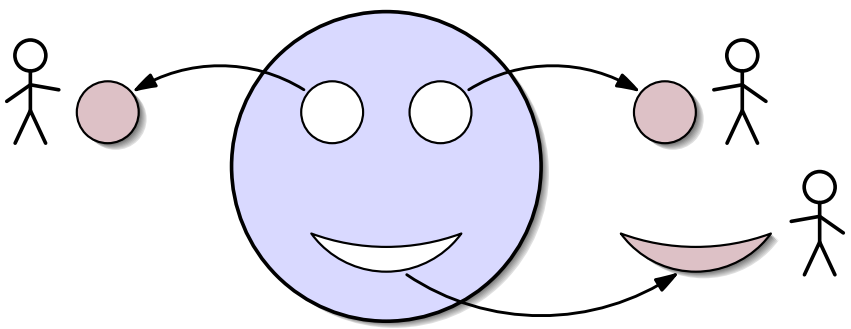
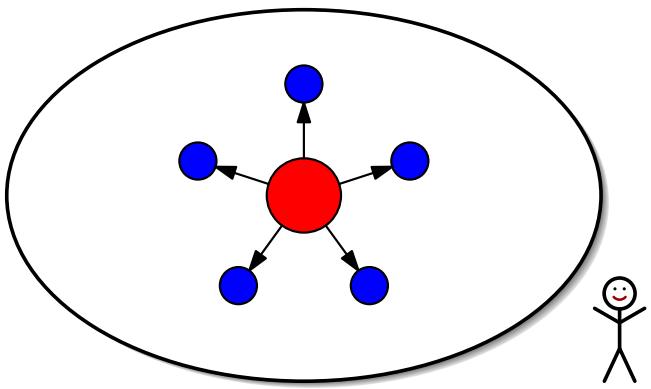
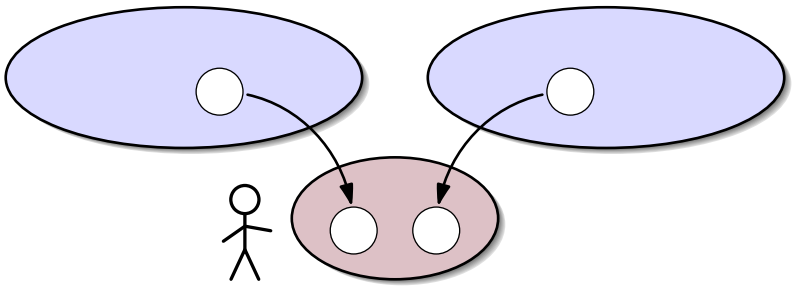


Collaboration



Understanding

Three scenarios



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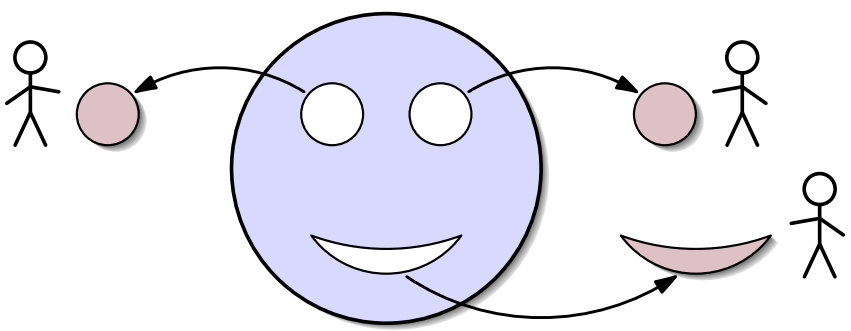

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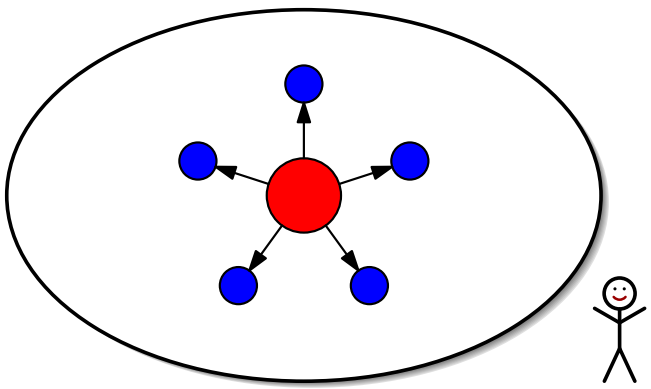

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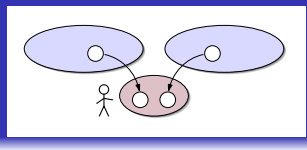
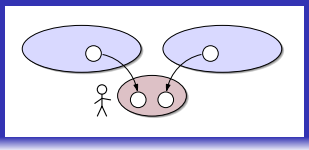
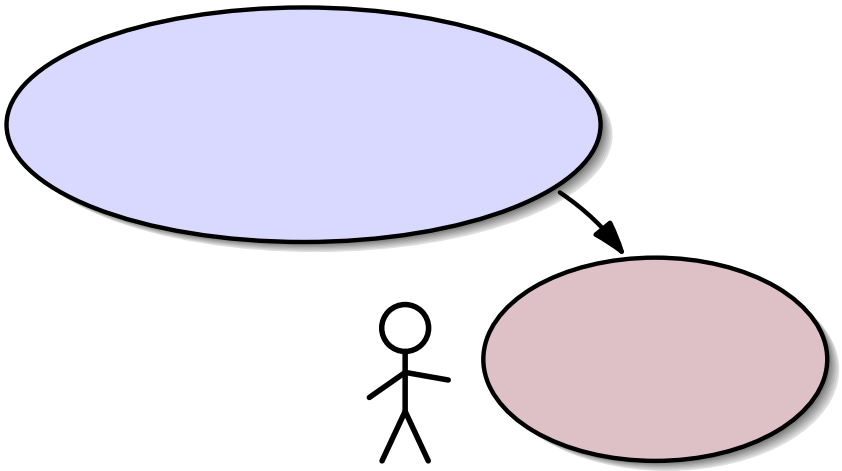


A reuse scenario



Import/reuse one external ontology



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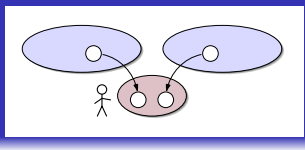

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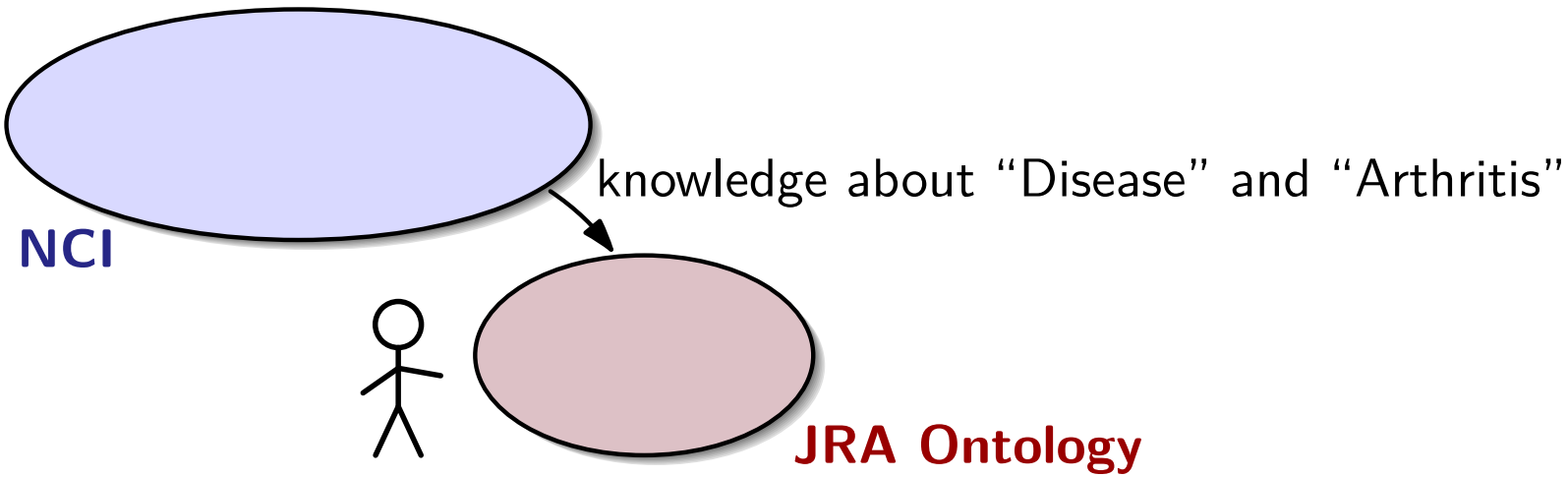

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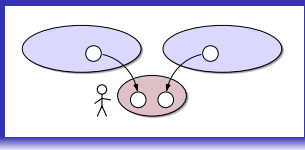

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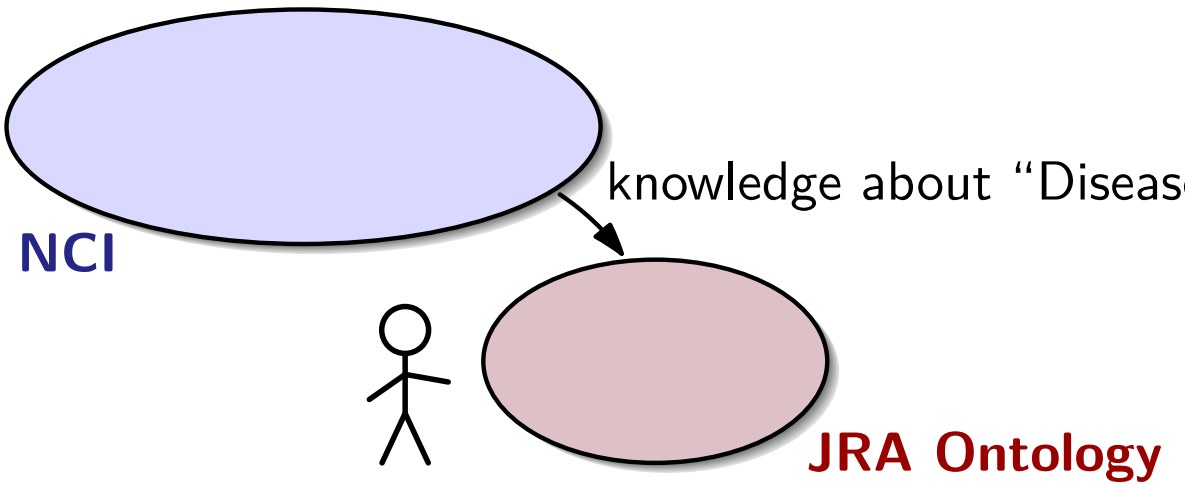
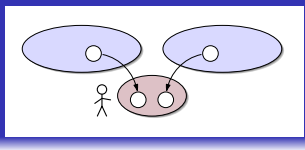
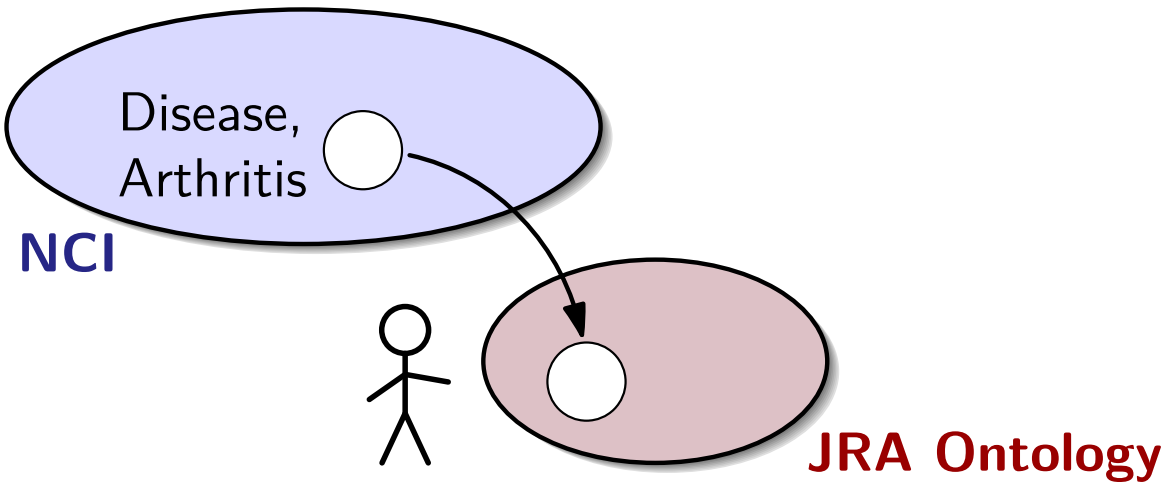


How much of **NCI** do we need?

A reuse scenario



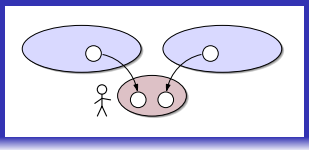
Import/reuse a part of an external ontology



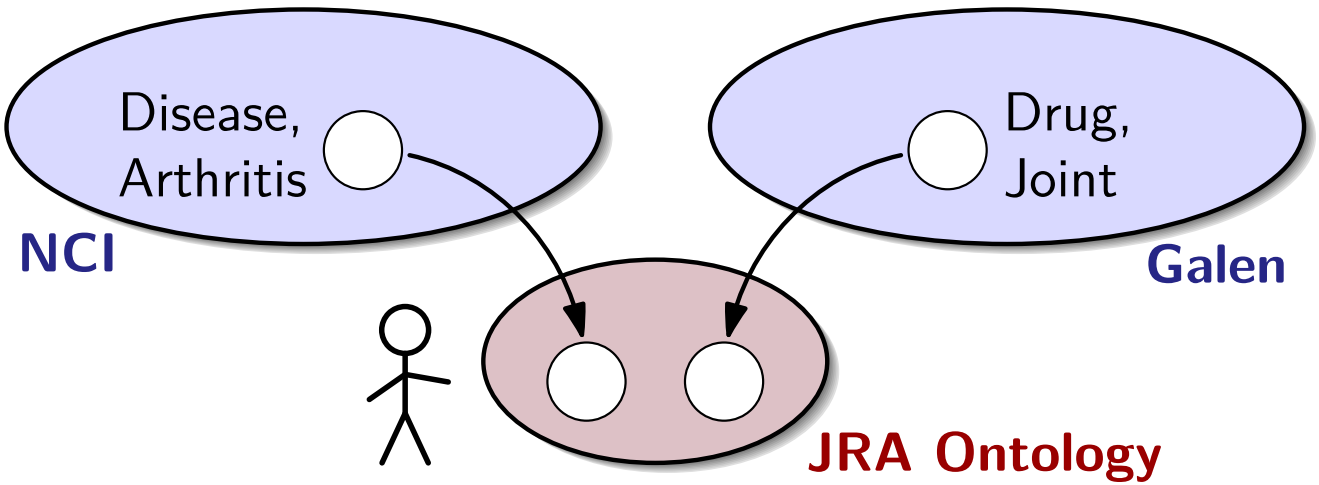
How much of **NCI** do we need?

- **Coverage:** Import *everything* relevant for the chosen terms.
- **Economy:** Import *only* what's relevant for them.
  Compute that part quickly.

A reuse scenario



Import/reuse parts of several external ontologies



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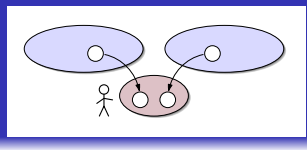
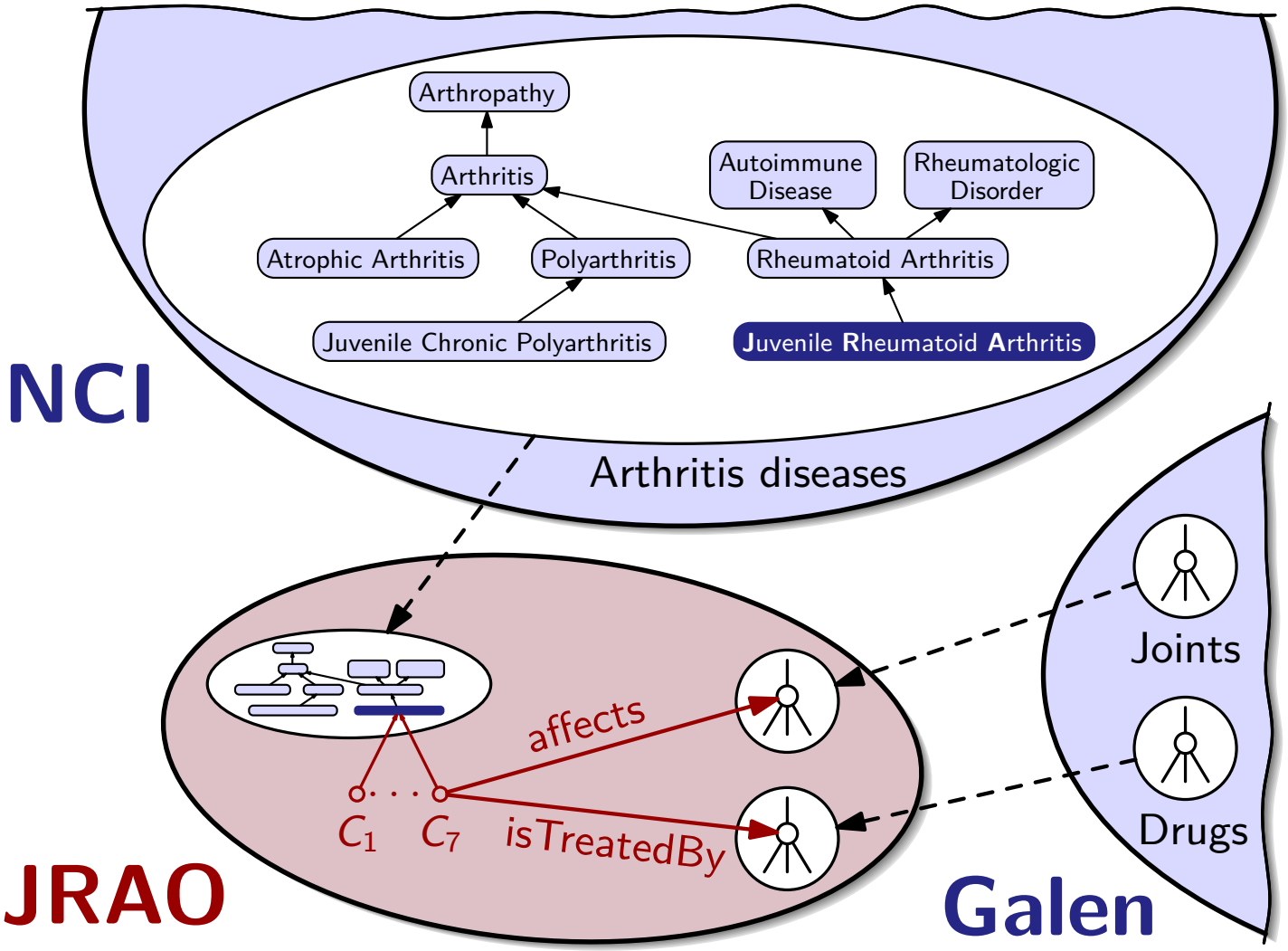
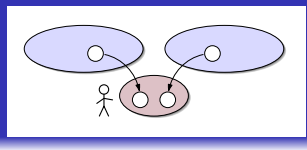
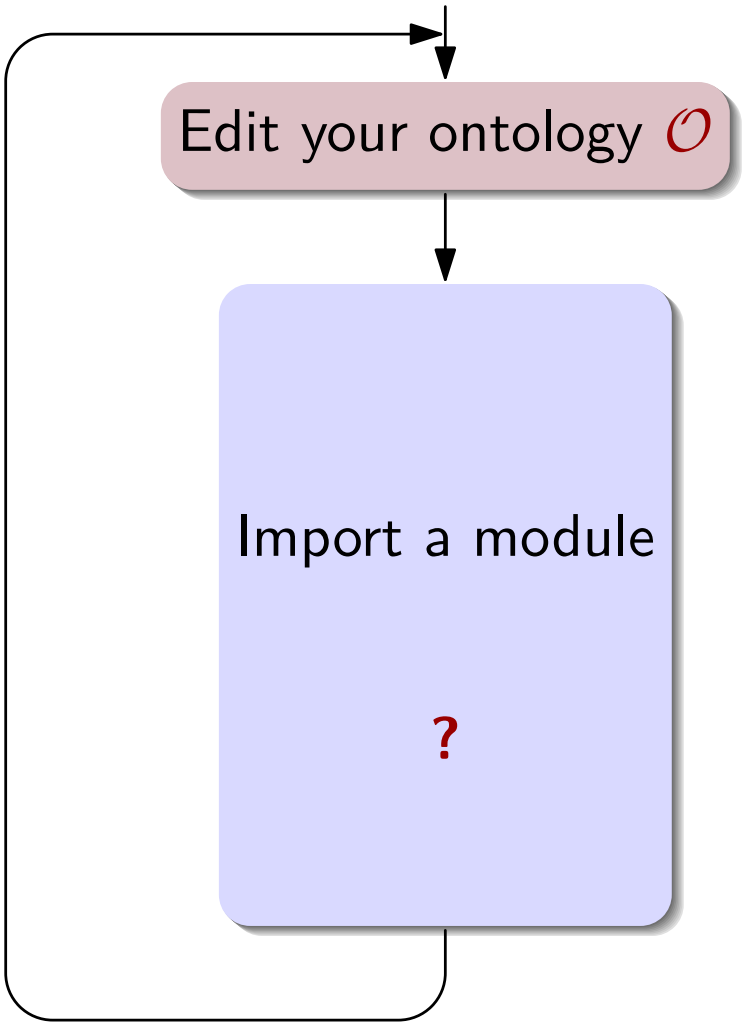




A working cycle





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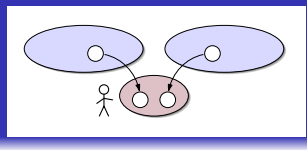

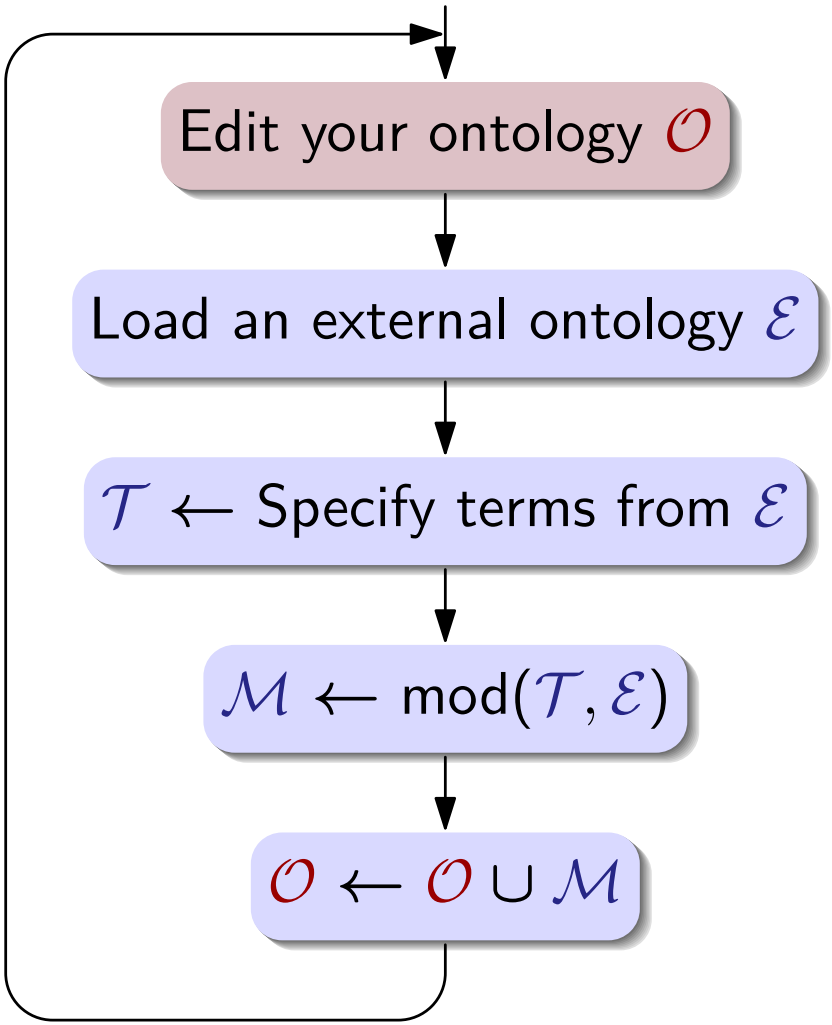

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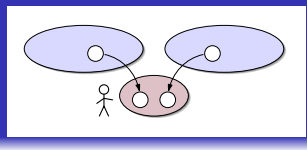
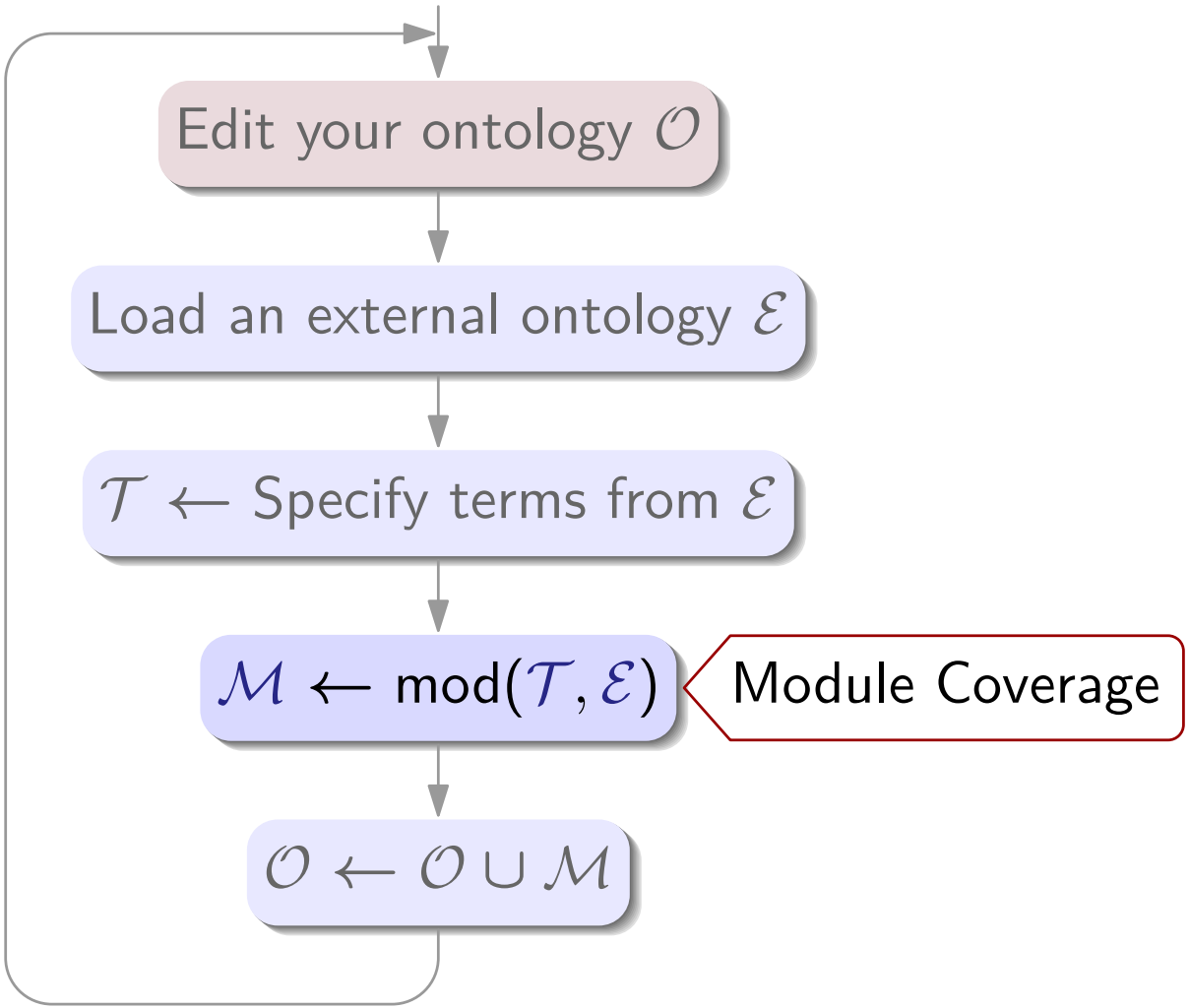
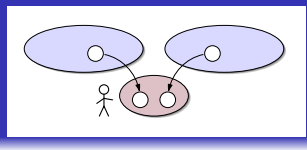




Module coverage



Goal: Import everything the external ontology knows about the topic that consists of the specified terms.

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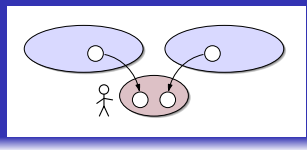

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Example 1:

- Topic: Arm, Hand, hasPart
- On-topic:

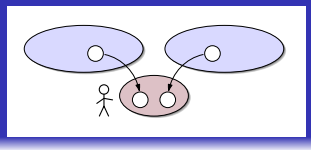
$$\begin{aligned} \text{Arm} &\sqsubseteq \forall\, \text{hasPart}.\text{Hand} \\ \text{Arm} \sqcup \text{Hand} &\sqsubseteq \exists\, \text{hasPart}.\top \\ \text{Hand} &\sqsubseteq \neg \text{Arm} \\ \text{Hand} &\sqsubseteq \text{Hand} \sqcup \text{Arm} \end{aligned}$$

Off-topic:

$$\text{HandWith4Fingers} \sqsubseteq \text{Hand}$$

- Goal = preserve all on-topic knowledge

Module coverage



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Question: Which axioms do we need to import?

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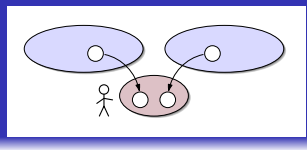

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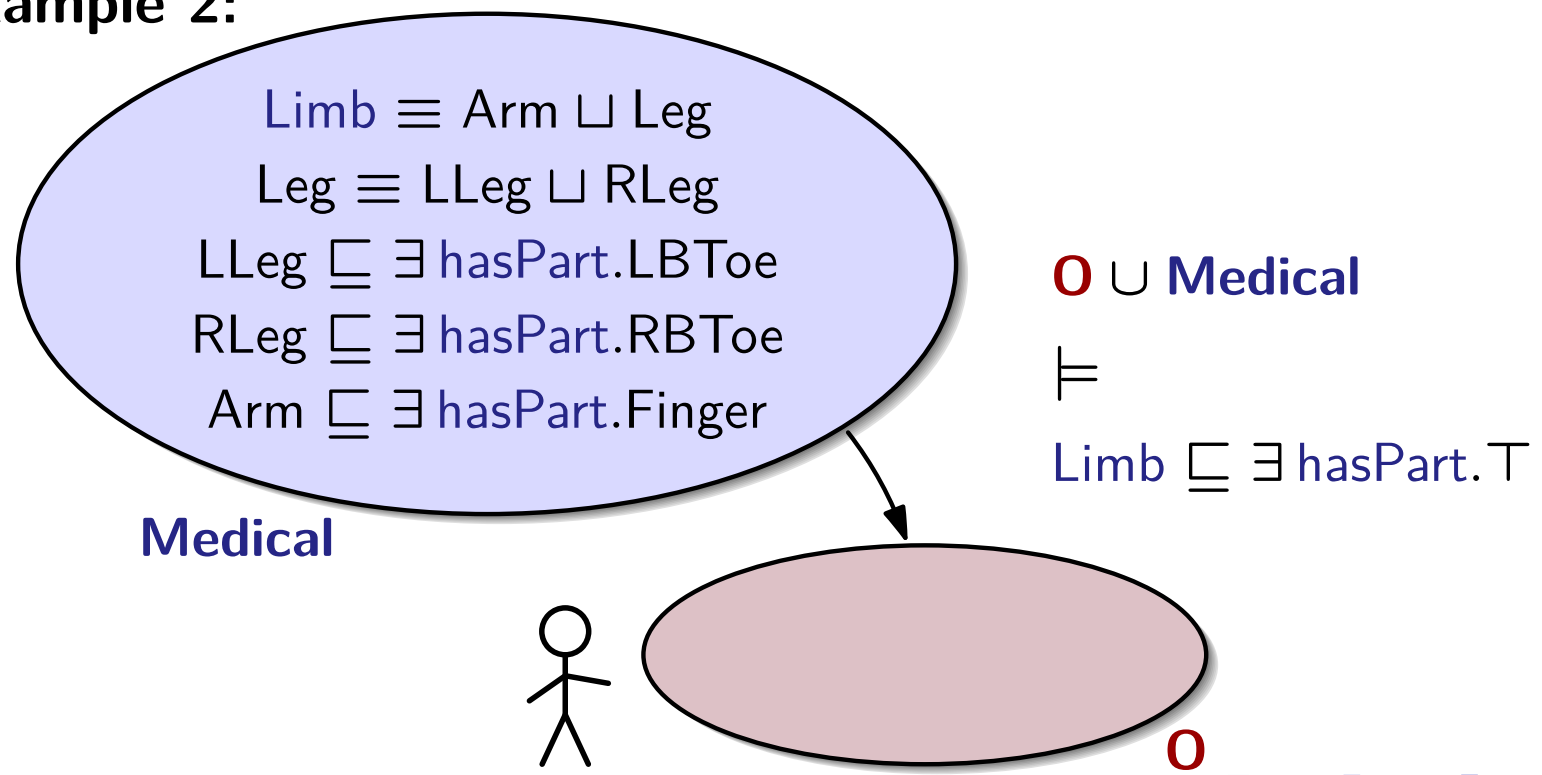

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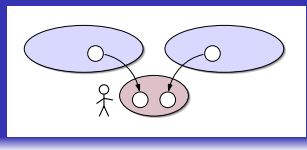

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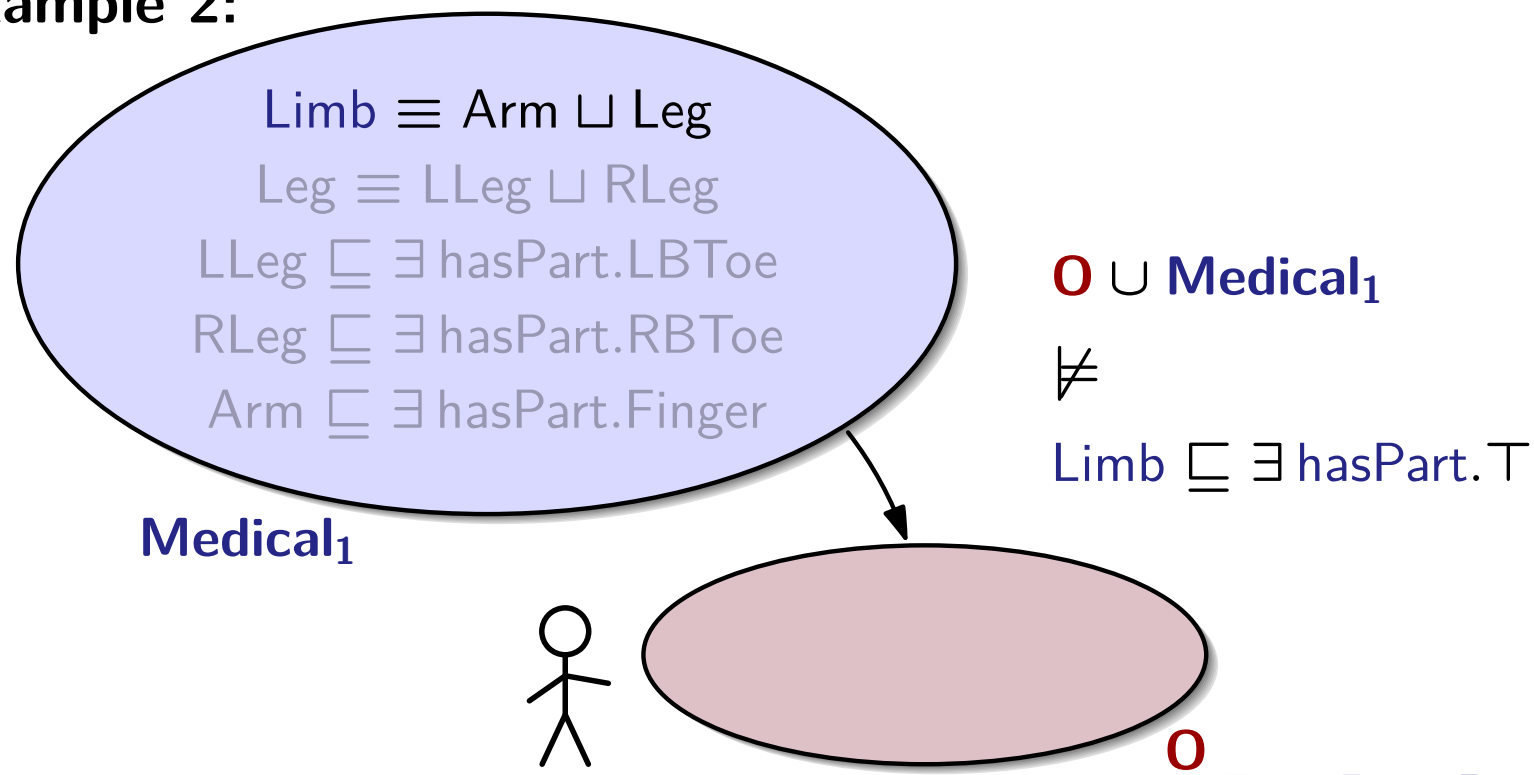

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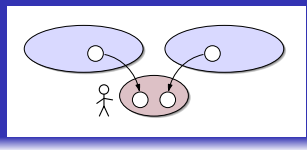

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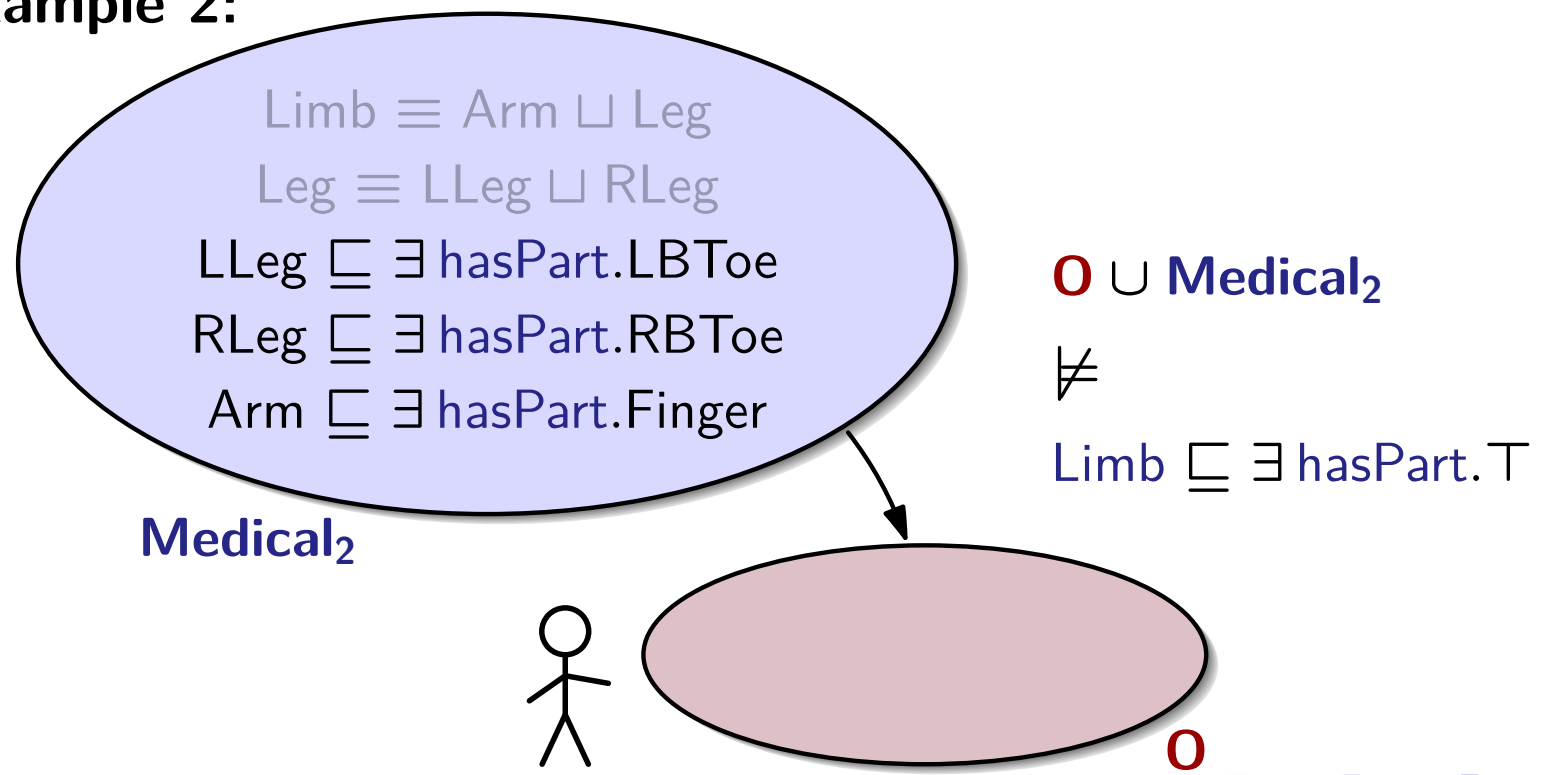

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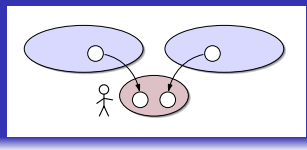

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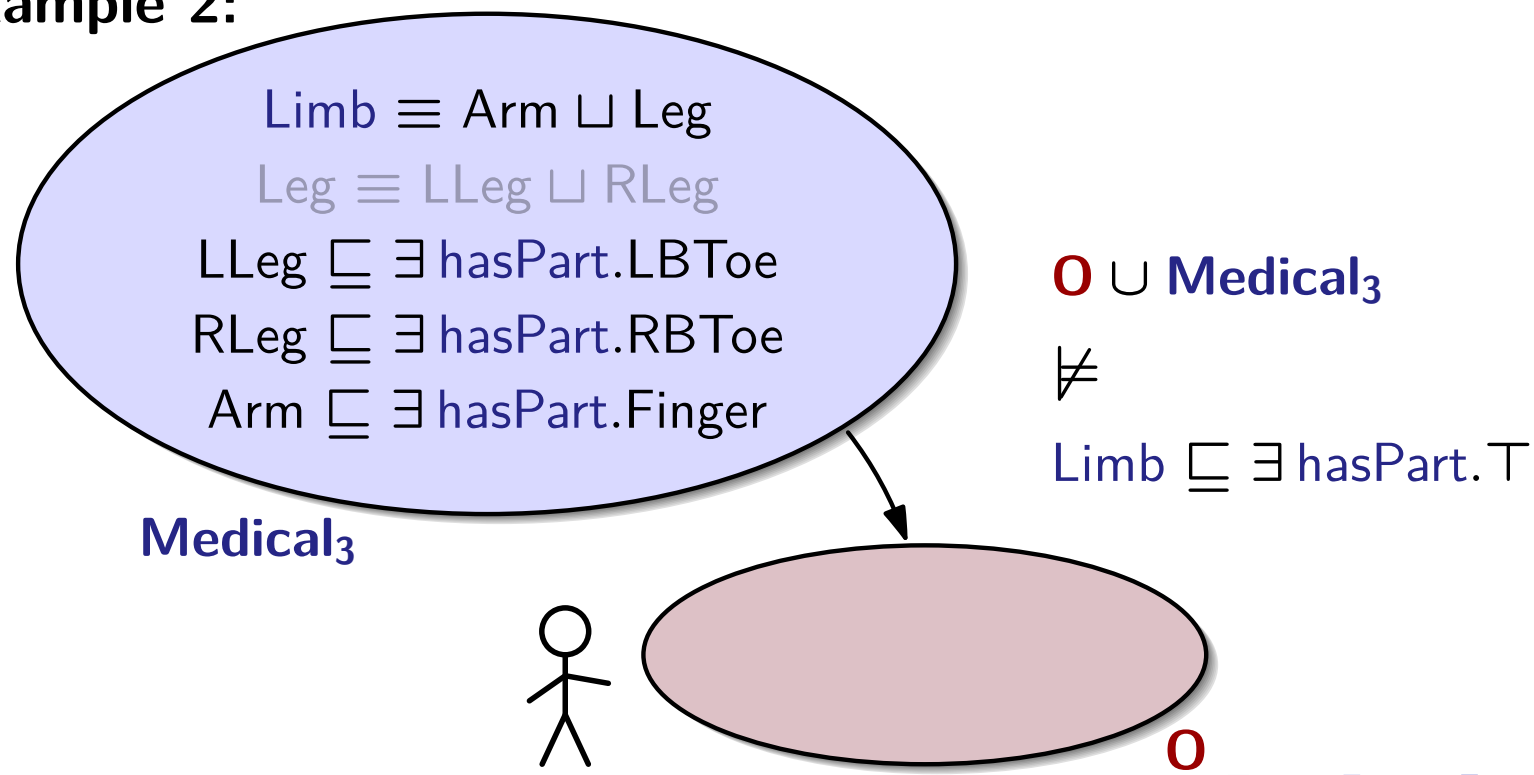

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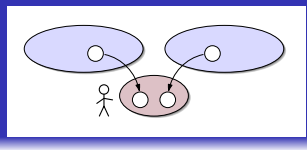

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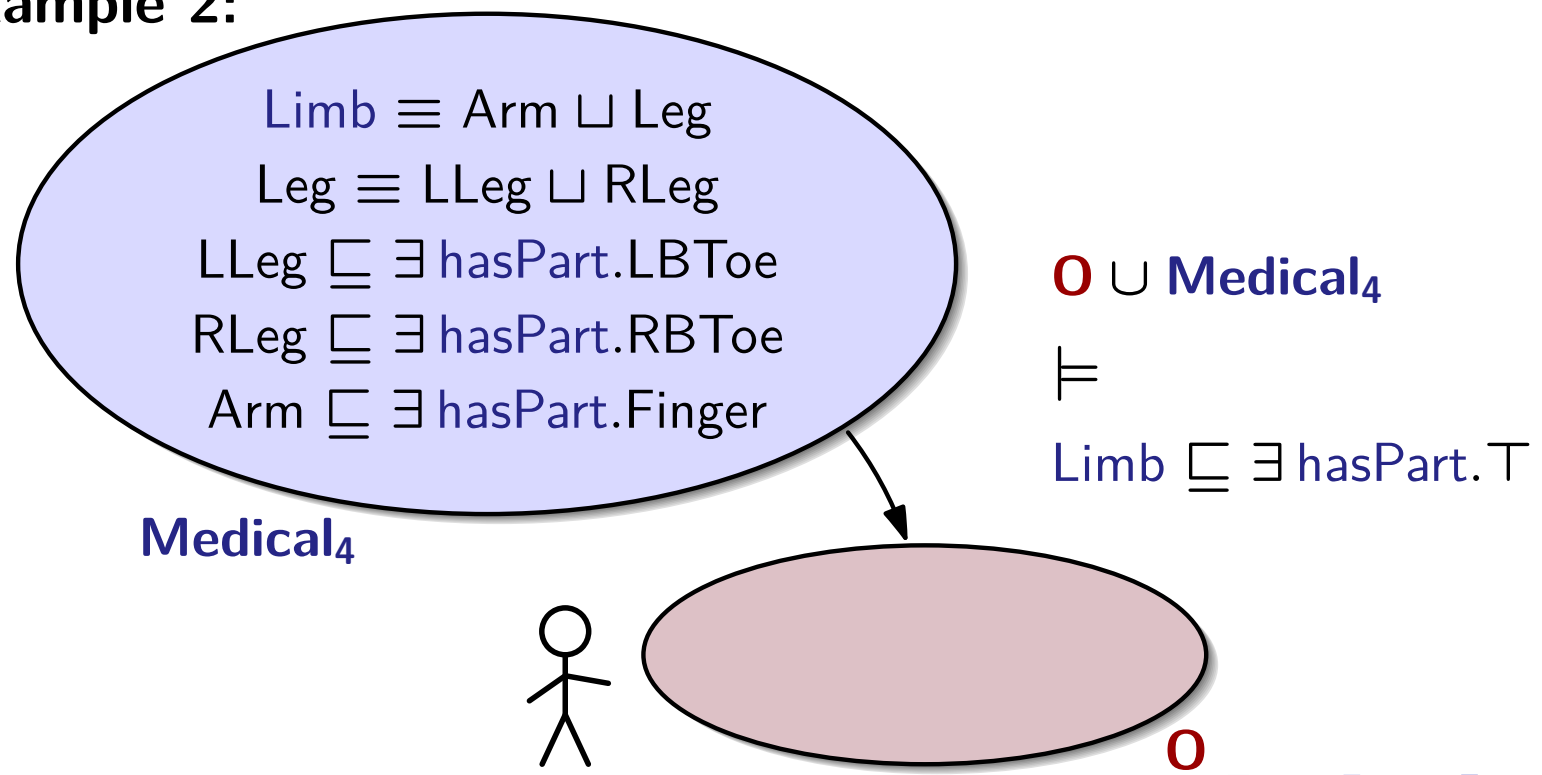

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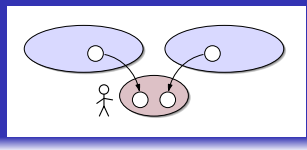
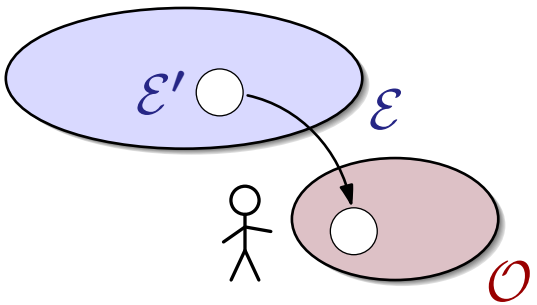


- Module $\mathcal{E}'$ covers ontology $\mathcal{E}$ for the specified topic $\mathcal{T}$ if for all concepts C, D built from terms in $\mathcal{T}$:

  if $\quad \mathcal{O} \cup \mathcal{E} \models \mathsf{C} \sqsubseteq \mathsf{D}$,
  then $\quad \mathcal{O} \cup \mathcal{E}' \models \mathsf{C} \sqsubseteq \mathsf{D}$.



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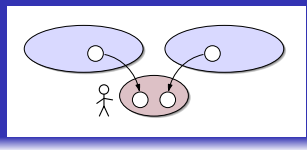

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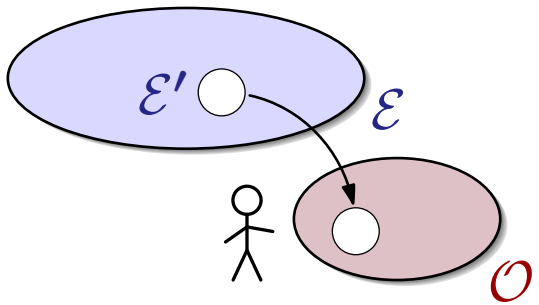
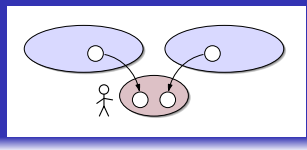


- Coverage $\hat{=}$ preserving entailments
- $\mathcal{O} \cup \mathcal{E}$ is called *conservative extension (CE)* of $\mathcal{O} \cup \mathcal{E}'$

Module coverage



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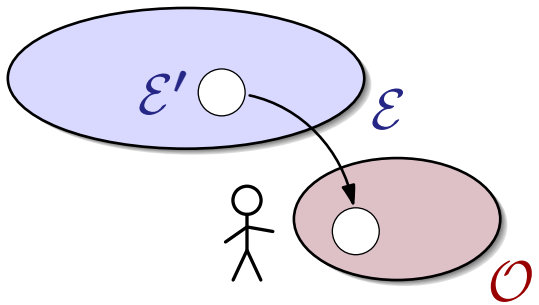
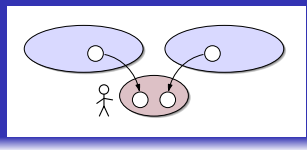


- Coverage $\hat{=}$ preserving entailments
- $\mathcal{O} \cup \mathcal{E}$ is called *conservative extension (CE)* of $\mathcal{O} \cup \mathcal{E}'$

- No coverage $\rightsquigarrow$ no encapsulation $\rightsquigarrow$ no *module*
- With coverage: trade-off minimality $\leftrightarrow$ computation time

Module coverage



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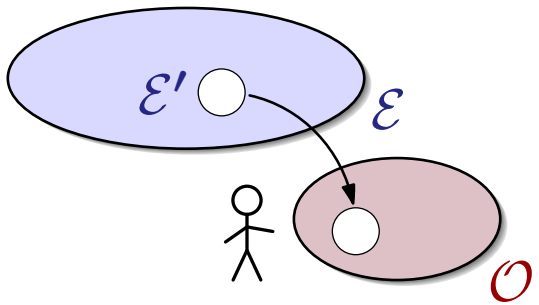
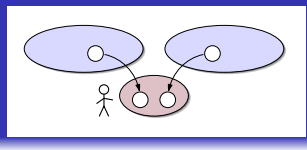
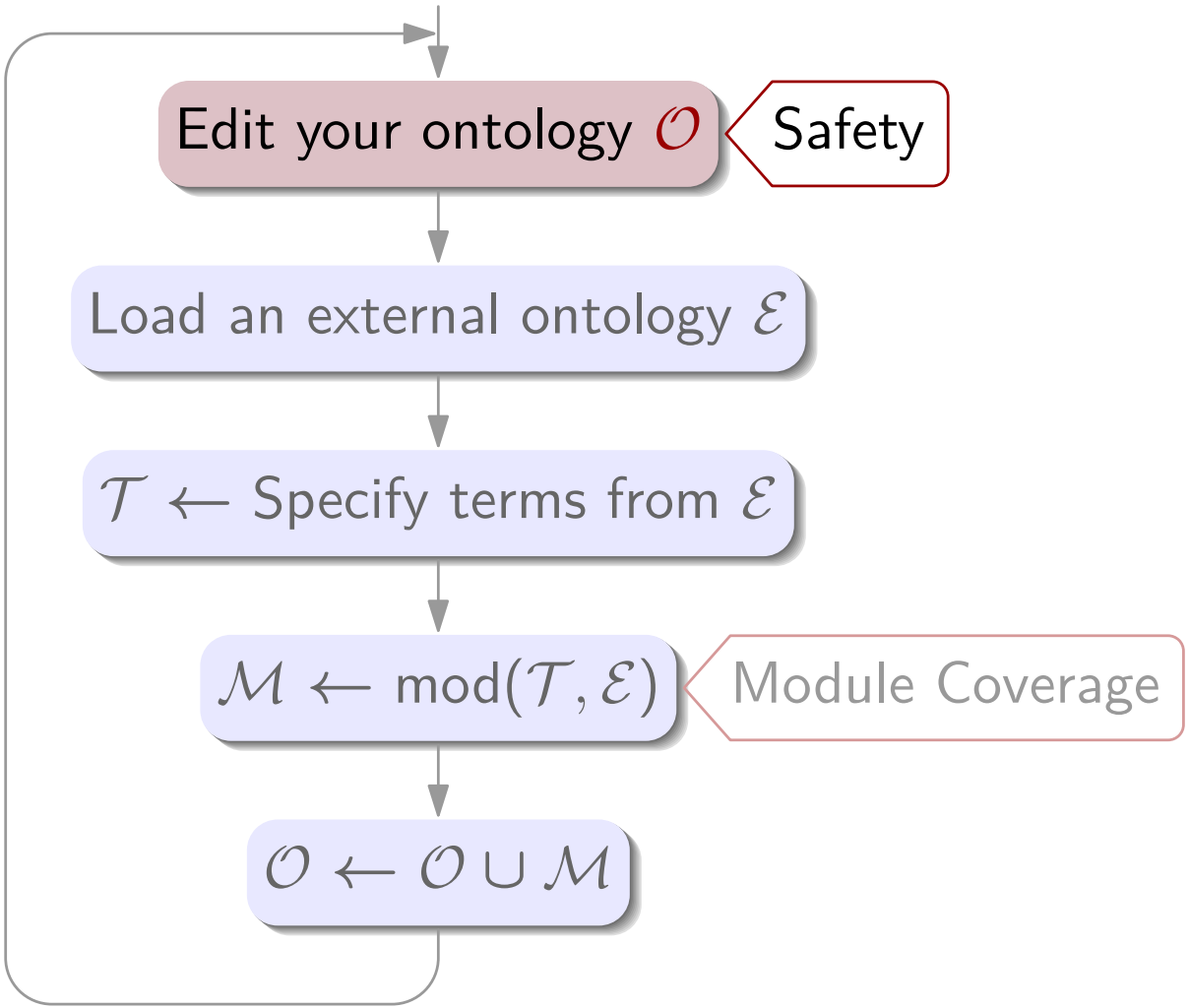


- Coverage $\hat{=}$ preserving entailments
- $\mathcal{O} \cup \mathcal{E}$ is called *conservative extension (CE)* of $\mathcal{O} \cup \mathcal{E}'$

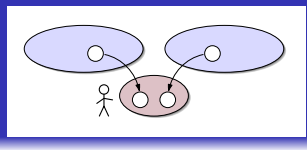
- Minmal covering modules via CEs
- CEs hard to impossible to decide
- Tractable approximation: syntactic locality

A working cycle





Safety



Goal: Don't change the meaning of imported terms.
= Don't add new knowledge about the imported topic.

Question: Which axioms are we allowed to write?

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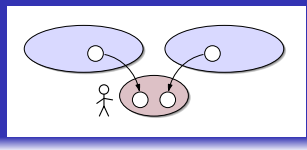

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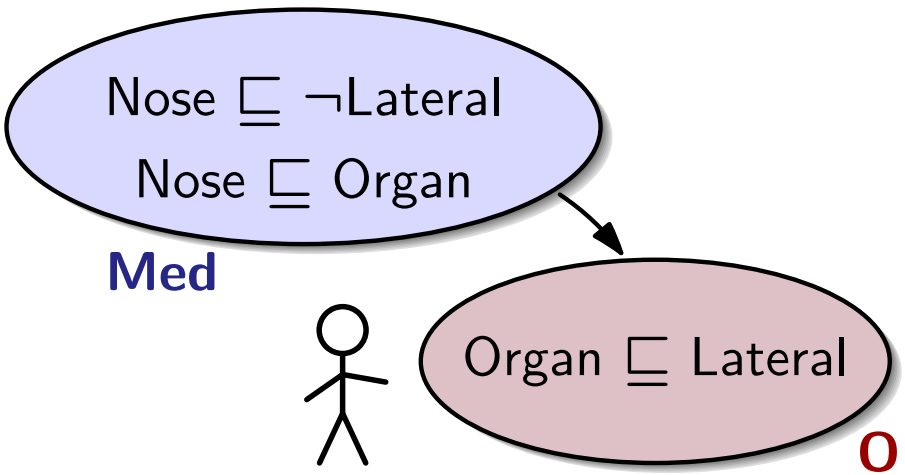

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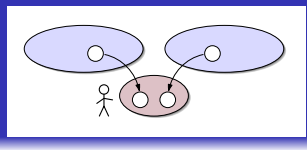

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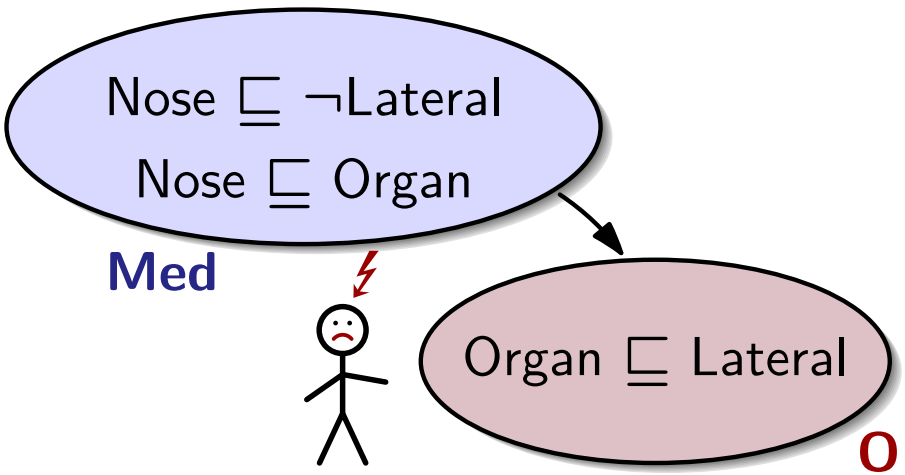

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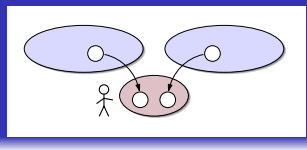

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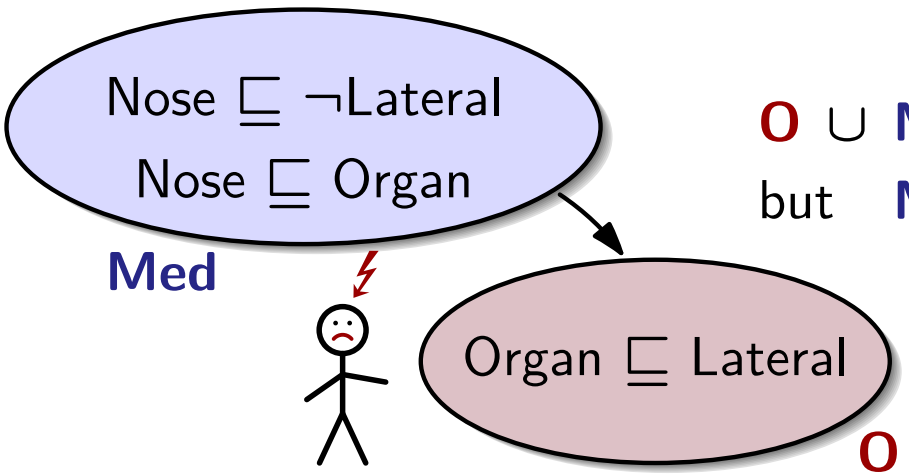
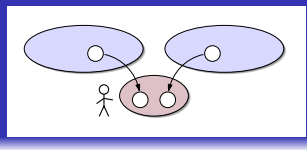


$\mathbf{O} \cup \mathbf{Med} \models \text{Organ} \sqsubseteq \text{Lateral}$
but $\mathbf{Med} \not\models \text{Organ} \sqsubseteq \text{Lateral}$

Safety



- *Our* ontology $\mathcal{O}$ uses the imported terms safely if for all concepts C, D built from the imported terms:

  if $\mathcal{E}' \not\models C \sqsubseteq D$,
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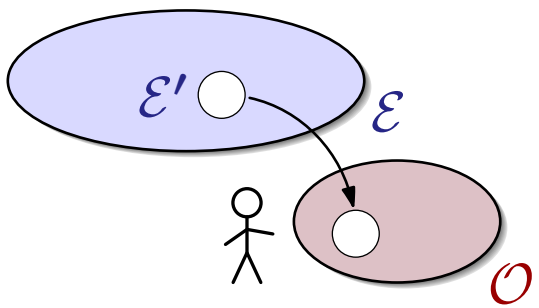
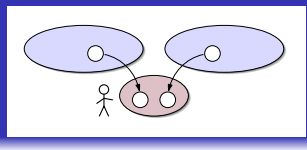


- Safety $\hat{=}$ preserving non-entailments

Comparison of different approaches



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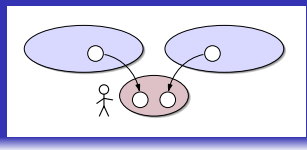

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E-connections	✓	✘	OWL 1	easy

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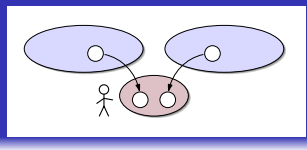

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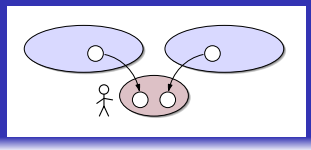
interpolants-based (no subsets!)	✓	✓✓	few	hard

Module extraction in Protégé 4



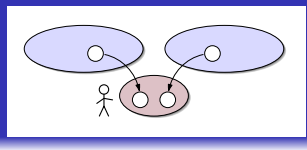
Nightly build:

http://owl.cs.manchester.ac.uk/2008/iswc-modtut/equinox.zip

- Realises import scenario
- Provides coverage via locality-based modules
- We're working on safety ...
- To be released as Protégé 4 plugin soon

(Thanks to Matthew Horridge.)

Web service for module extraction



http://owl.cs.manchester.ac.uk/modularity

MANCHESTER 1824

The University of Manchester

OWL Module Extractor

Ontology source

Paste your **ontology**, or enter a **URL** of a document, into the text box below.

http://www.co-ode.org/ontologies/pizza/pizza.owl

Signature

Enter a signature. Put each entity name on a new line. (Accepts full URIs or URI fragments)

Pizza

Modularity type

Select the module type

- ○ Top (lower) module
- ○ Bottom (upper) module
- ○ Bottom-of-top (upper-of-lower) module
- ◉ Top-of-bottom (lower-of-upper) module

☑ Show axioms view (instead of outputting RDF/XML)

Extract module

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The University of Manchester

Module: http://www.co-ode.org/ontologies/pizza/pizza.owl_module.owl

Selected signature

Pizza (http://www.co-ode.org/ontologies/pizza/pizza.owl#Pizza)

Module metrics

Number of axioms: 112
Number of logical axioms: 112
Number of classes: 35
Number of object properties: 7
Number of data properties: 0
Number of individuals: 5

Module axioms

CheeseTopping SubClassOf PizzaTopping
CheeseTopping DisjointWith FishTopping
CheeseTopping DisjointWith FruitTopping
CheeseTopping DisjointWith HerbSpiceTopping
CheeseTopping DisjointWith MeatTopping
CheeseTopping DisjointWith NutTopping
CheeseTopping DisjointWith SauceTopping
CheeseTopping DisjointWith VegetableTopping
CheeseyPizza EquivalentTo Pizza **and** (hasTopping **some** CheeseTopping)
Country EquivalentTo DomainConcept **and** ({America , England , France , Germany , Italy})
DeepPanBase SubClassOf PizzaBase
DeepPanBase DisjointWith ThinAndCrispyBase
DomainConcept DisjointWith ValuePartition
FishTopping SubClassOf PizzaTopping
FishTopping SubClassOf hasSpiciness **some** Mild
FishTopping DisjointWith FruitTopping
FishTopping DisjointWith HerbSpiceTopping
FishTopping DisjointWith MeatTopping
FishTopping DisjointWith NutTopping
FishTopping DisjointWith SauceTopping
FishTopping DisjointWith VegetableTopping
Food SubClassOf DomainConcept
FruitTopping SubClassOf PizzaTopping
FruitTopping DisjointWith HerbSpiceTopping
FruitTopping DisjointWith MeatTopping
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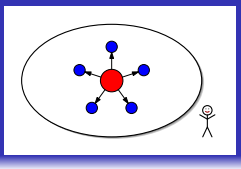
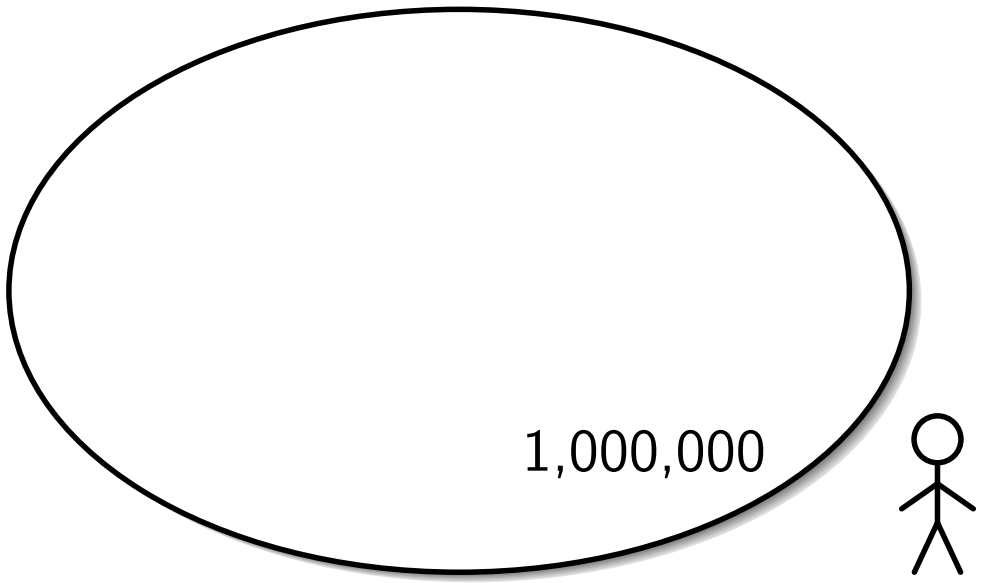
FruitTopping DisjointWith VegetableTopping
HerbSpiceTopping SubClassOf PizzaTopping

And now ...



Scenario: Understanding

Visualise the modular structure of an ontology



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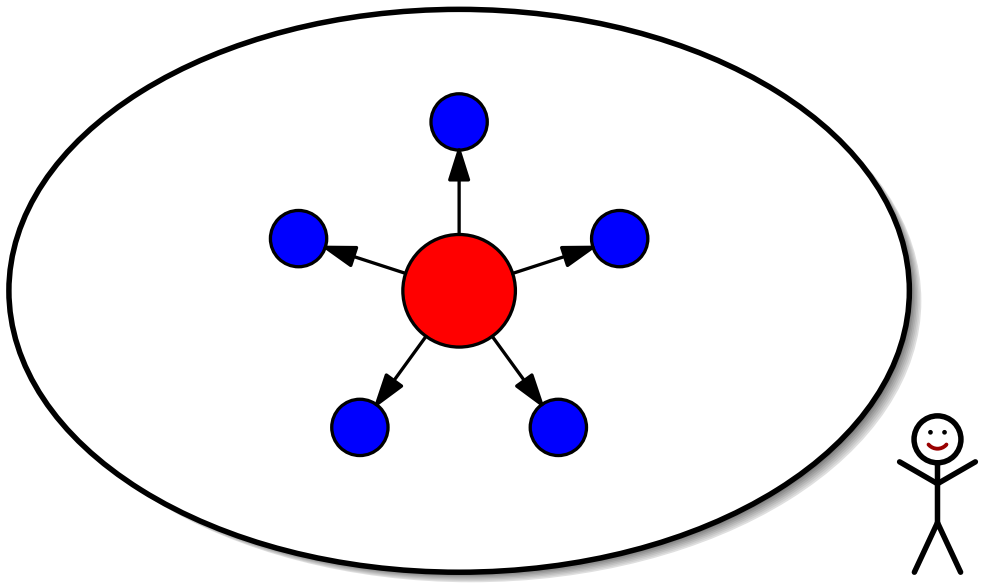
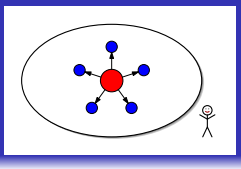


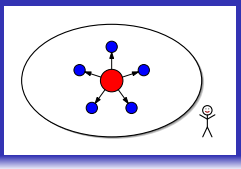
We're working on it.

We bet Robert Stevens . . .

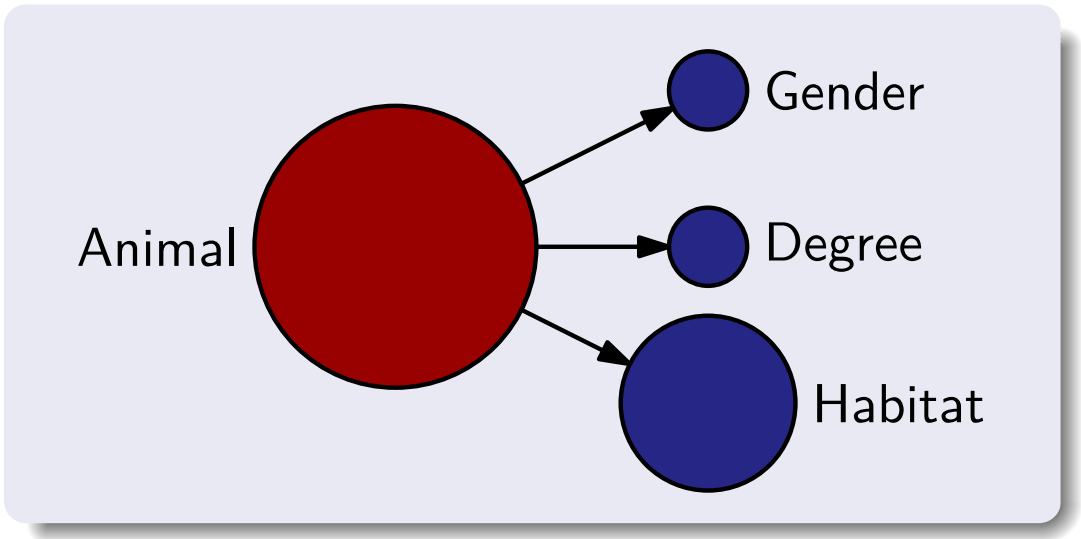


- Ontology about periodic table of the chemical elements
- What is its modular structure?
- What is “the meat” of it?
- We can find it using locality-based modules.

Impetus for the "Meat" idea



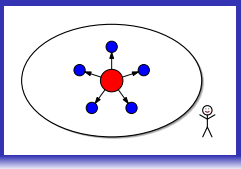
Partition of `koala.owl` via E-connections in Swoop

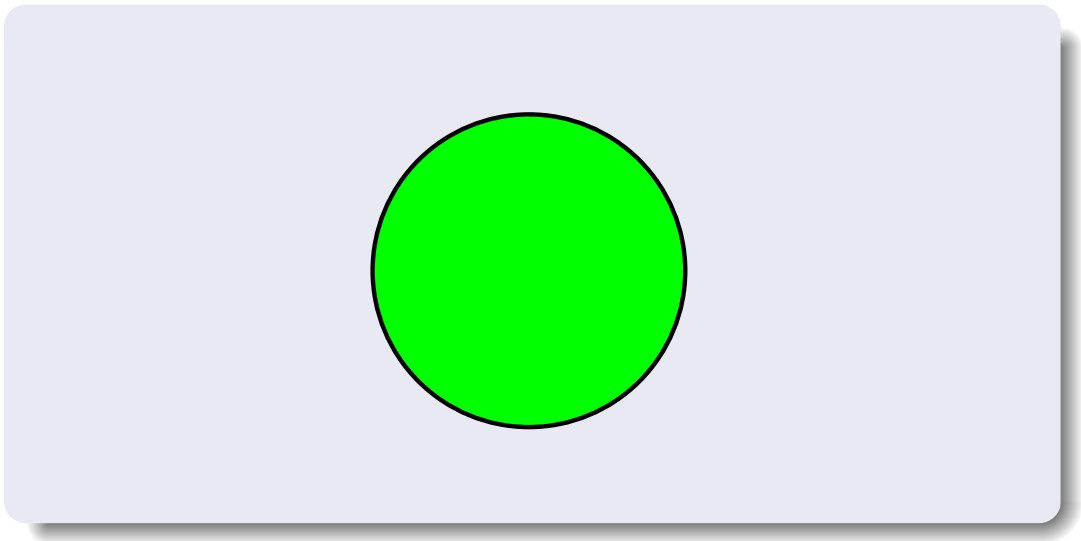


- importing part
- imported but non-importing part
- isolated part

→ "imports vocabulary from"

Partition for the periodic table ontology





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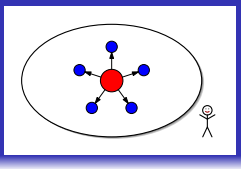
“Meat” via locality-based modules

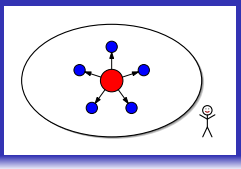


Hopes:

- Fine-grained analysis
- Guidance for users to choose the right topic(s)
- Draw conclusions on characteristics of an ontology:

  topicality, connectedness, axiomatic richness, superfluous parts, modelling

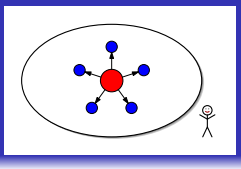
"Meat" via locality-based modules



Problem:

- Ontologies of size n can have up to 2^n modules
- But do real-life ontologies fall into the worst case?

Results so far



- Optimised algorithm to extract all modules

Ontology	#Ax	#Terms	**#mods**	Theor. Max.	Time
Koala	42	25	**3660**	33 554 432	9s
Mereology	44	25	**1952**	33 554 432	3min

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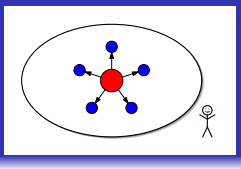

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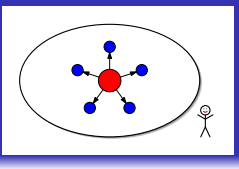
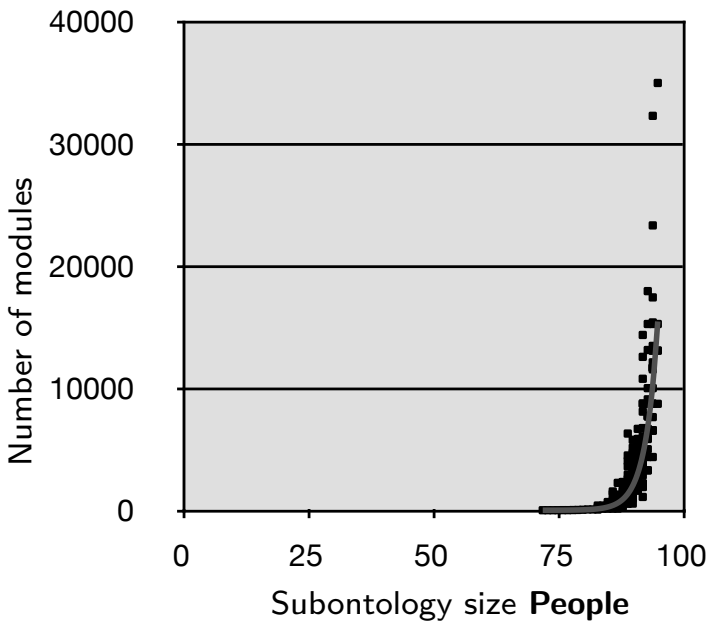
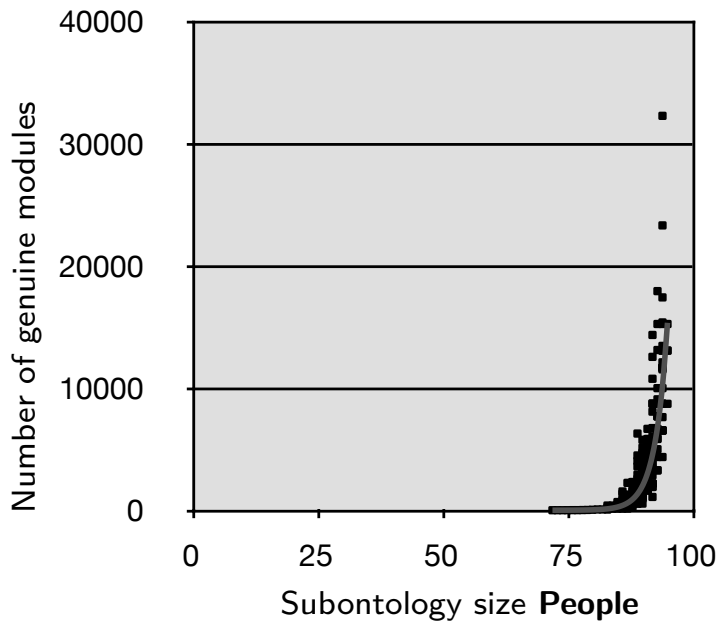
- Single module numbers don't say much
- Not scalable

Subset sampling



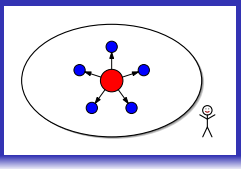
- Modularised randomly generated parts of 8 ontologies
- Example growth of module numbers:





Trendline equation: $y = O(1.5^x)$, confidence 0.96

Weight analysis



- Ordered all 3660 modules of Koala by weight

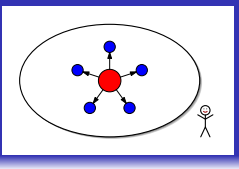
$$\text{Weight}(\mathcal{M}) = \text{PullingPower}(\mathcal{M}) \cdot \text{Cohesion}(\mathcal{M})$$

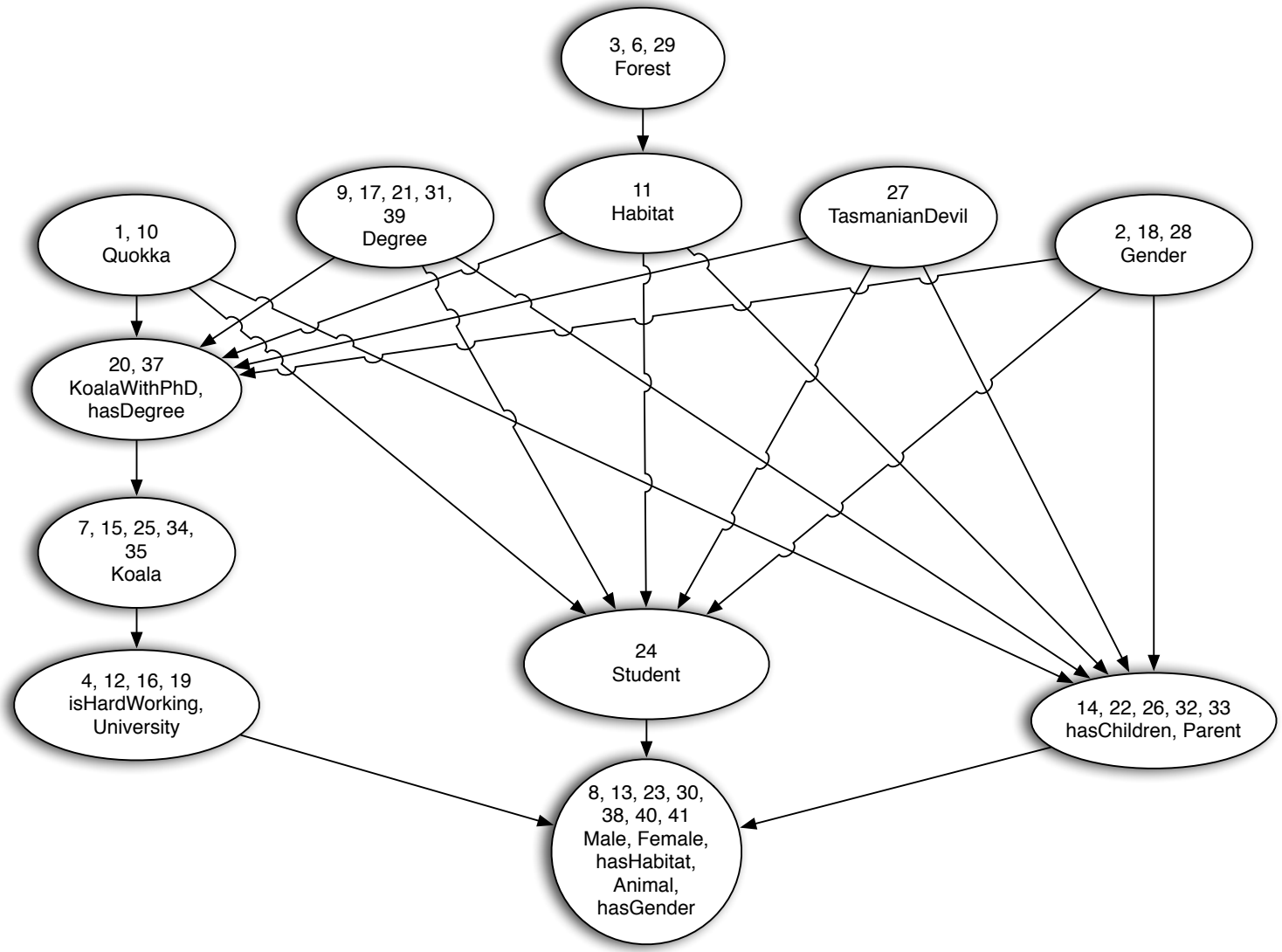
How many terms are needed to "pull" all the terms into $\mathcal{M}$?

How strongly are the terms in $\mathcal{M}$ held together?

- Inspected heaviest modules

Weight analysis





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- How many modules can ontologies have?
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Thank you.