

Introduction to Ontologies and Ontology Engineering

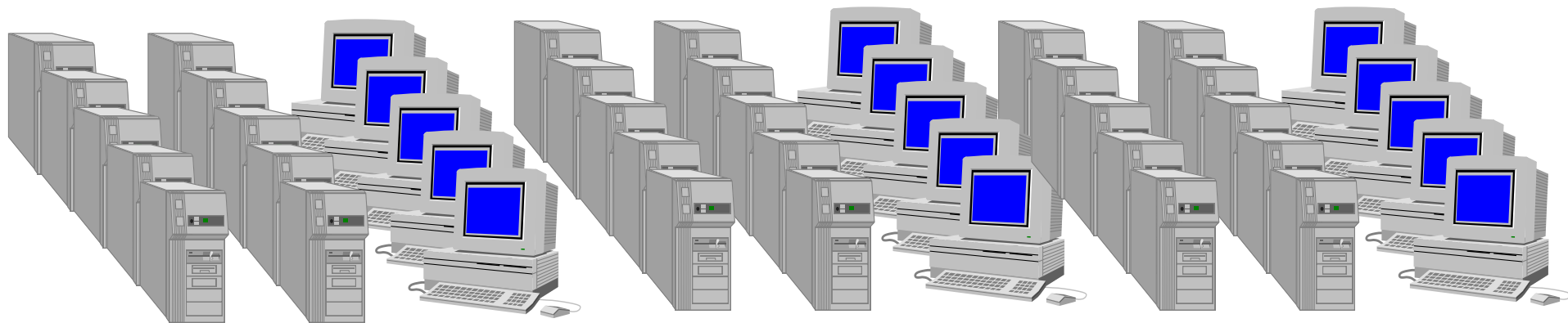
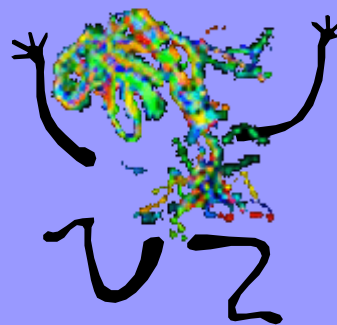
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My current research interests

- **Ontology engineering**
 - Theory, methods, tools for ontology alignment, completion, debugging; organization of workshops and competitions
 - Development of ontologies for different areas (materials science, animal health surveillance, crime investigation, ice hockey)
- **Sports analytics**

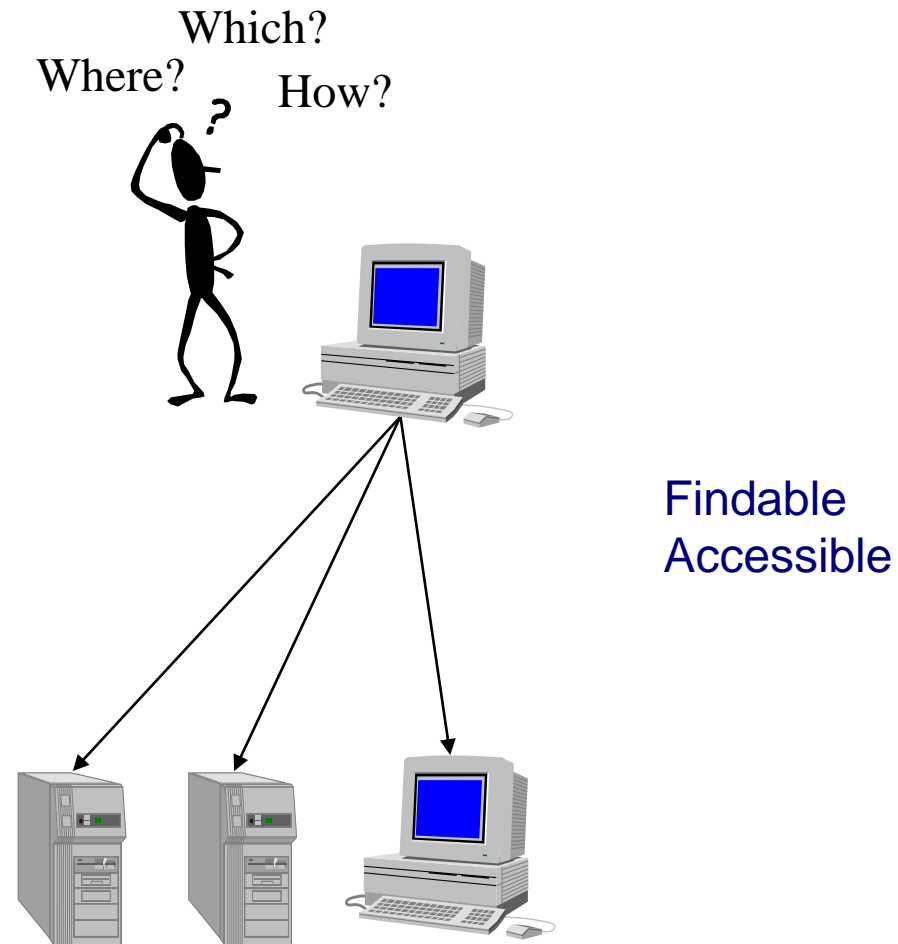
GET THAT PROTEIN!



Locating relevant information

Vision: Web services

- Databases and tools (service providers) announce their service capabilities
- Users request services which may be based on task descriptions
- Service matchers find relevant services (composition) based on user needs and user preferences, negotiate service delivery, and deliver results to user



Retrieving relevant information

Vision:

Based on the meaning of the query:

- only relevant information is retrieved
- all relevant information is retrieved

Findable
Accessible

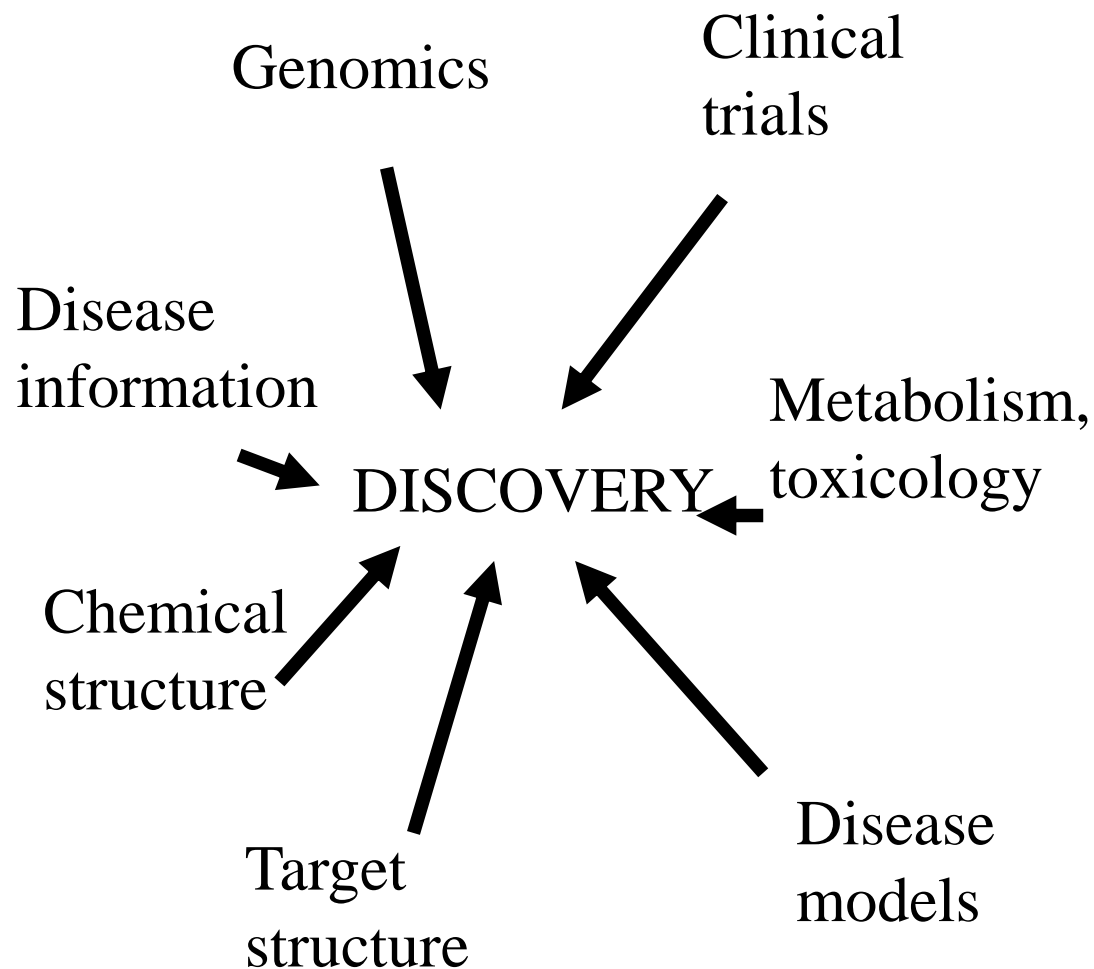


Integrating information

Vision:

Integrate data sources that are heterogeneous in content, data quality, data models, access methods, terminology

Interoperable
Reusable





THE SEMANTIC WEB

A new form of Web content
that is meaningful to computers
will unleash a revolution of new abilities

by
TIM BERNERS-LEE,
JAMES HENDLER and
ORA LASSILA

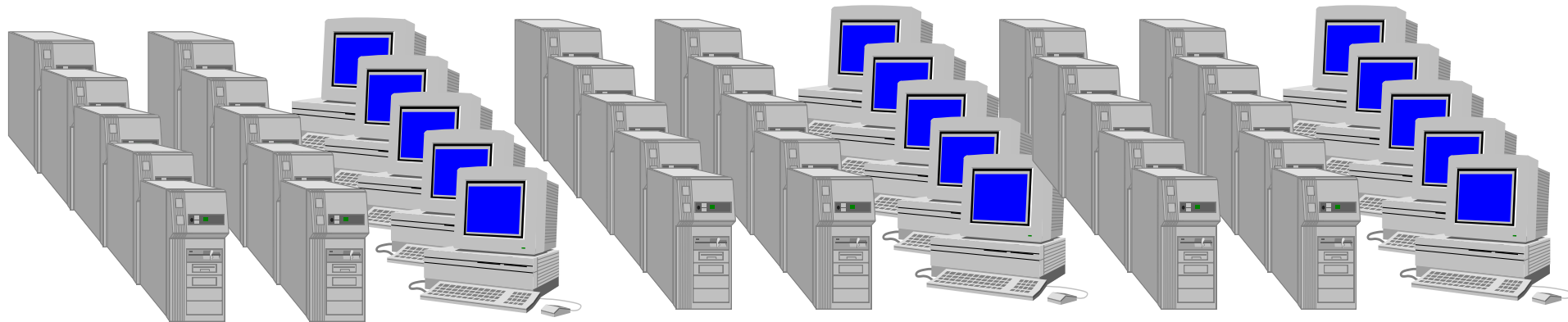
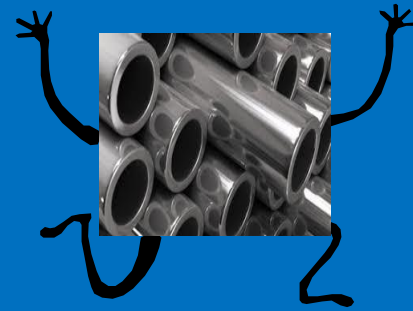
PHOTO CREDIT: HERE

- First step towards the vision:
adding semantic annotation to web resources

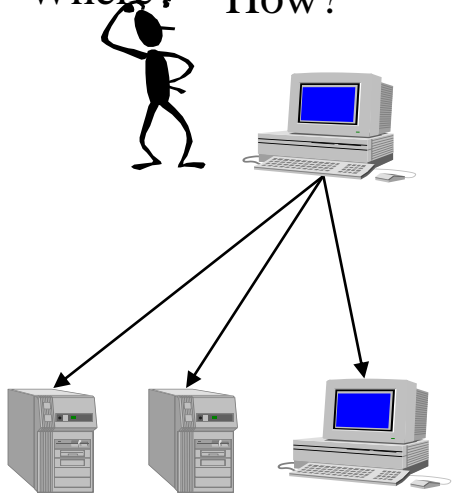
Semantic annotations based on ontologies

- Locating information
 - Web service descriptions use ontologies
 - Users use ontologies when formulating requests
 - Service matchers find services based on meaning
- Retrieving relevant information
 - Reduce non-relevant information (precision)
 - Find more relevant information (recall)
- Integrating information
 - Relating similar entities in different databases

GET THAT MATERIAL!



Which?
Where? How?

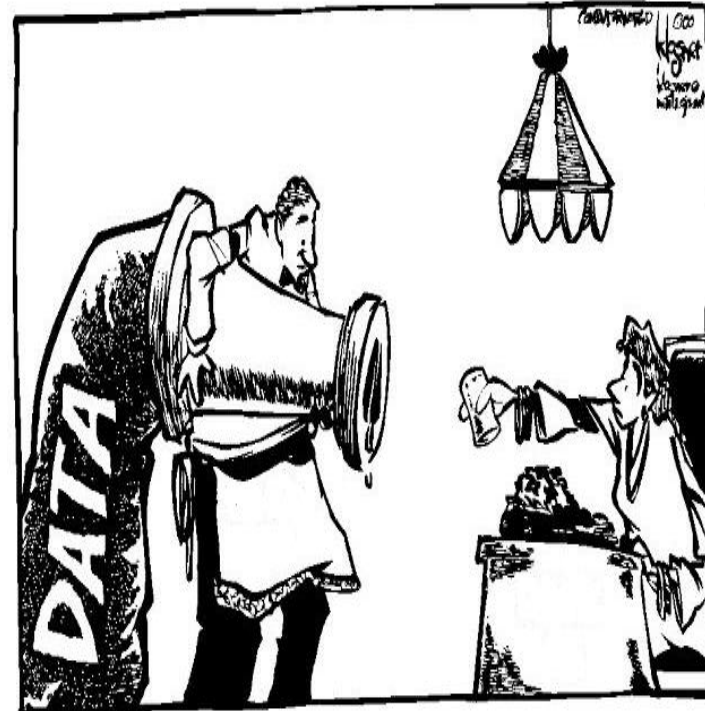


Cristal structure

Electronic structure

Materials design

Thermodynamic properties



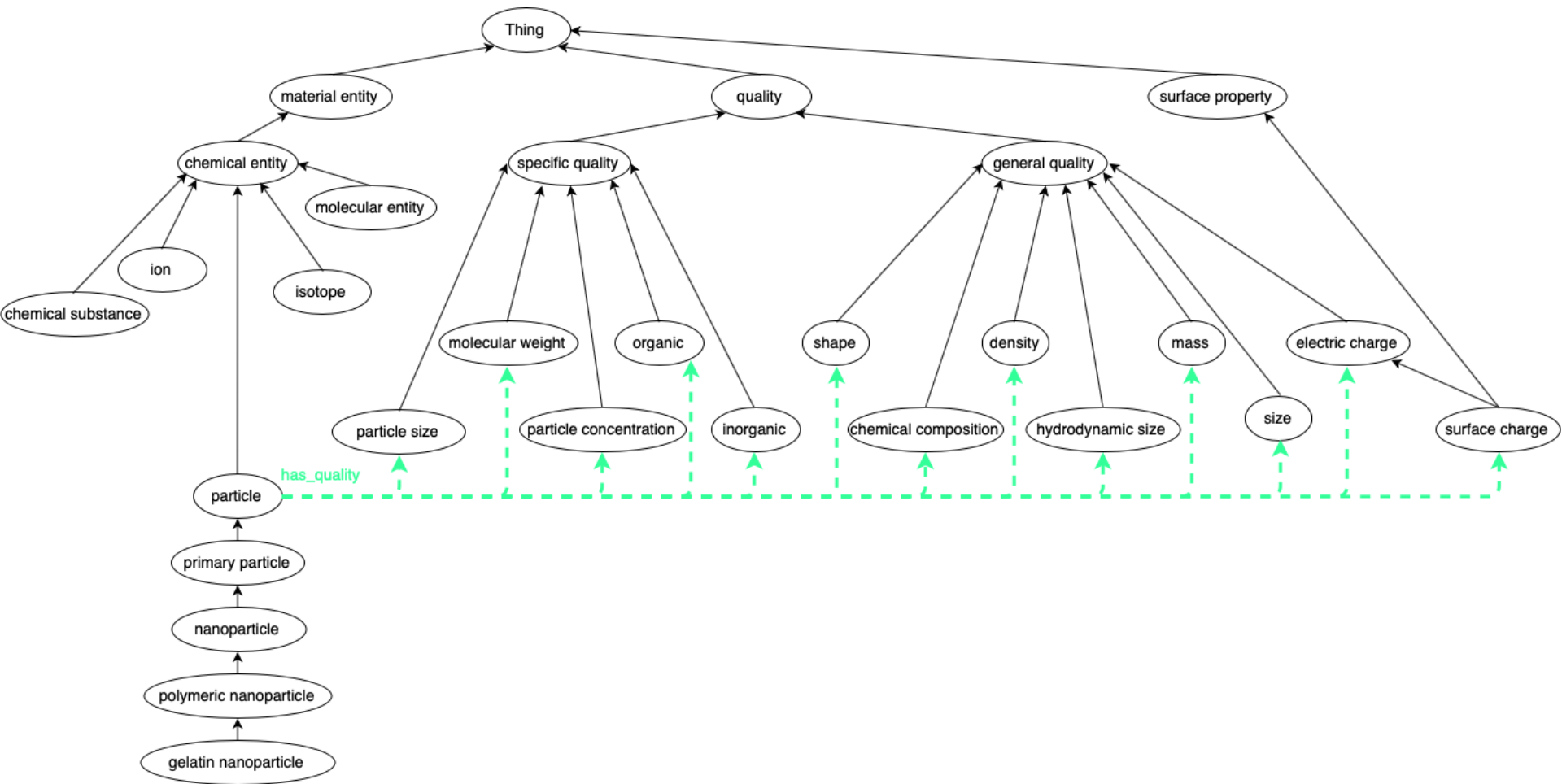
- Standardized terminology
- Relationships between terms

Ontologies

“Ontologies define the basic terms and relations comprising the vocabulary of a topic area, as well as the rules for combining terms and relations to define extensions to the vocabulary.”

(Neches, Fikes, Finin, Gruber, Senator, Swartout, 1991)

Nanoparticle Ontology



Ontologies used ...

- for communication between people and organizations
- for enabling knowledge reuse and sharing
- as basis for interoperability between systems
- as repository of information
- as query model for information sources

Key technology for the Semantic Web

Ontology-based querying

- With ontology.



Medical Subject
Headings (MeSH)

All MeSH Categories

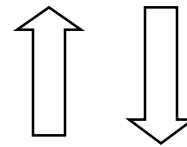
I Diseases Category

I Eye Diseases

I Scleral Diseases

I Scleritis

...



return 1617 articles



Ontology-based querying

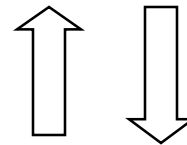
- Without ontology.



PubMed.gov
U.S. National Library of Medicine
National Institutes of Health

Search: PubMed ▾ Limits Advanced search Help

"Scleral Diseases" [MESH] Search Clear



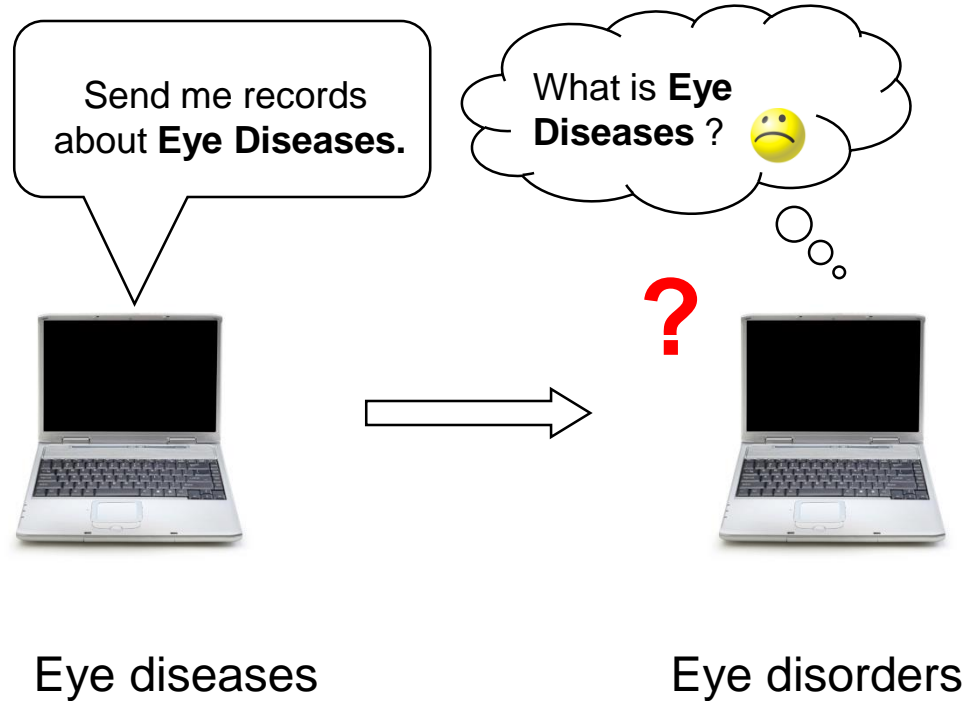
return 1617 articles

return 695 articles

57% results are missed !

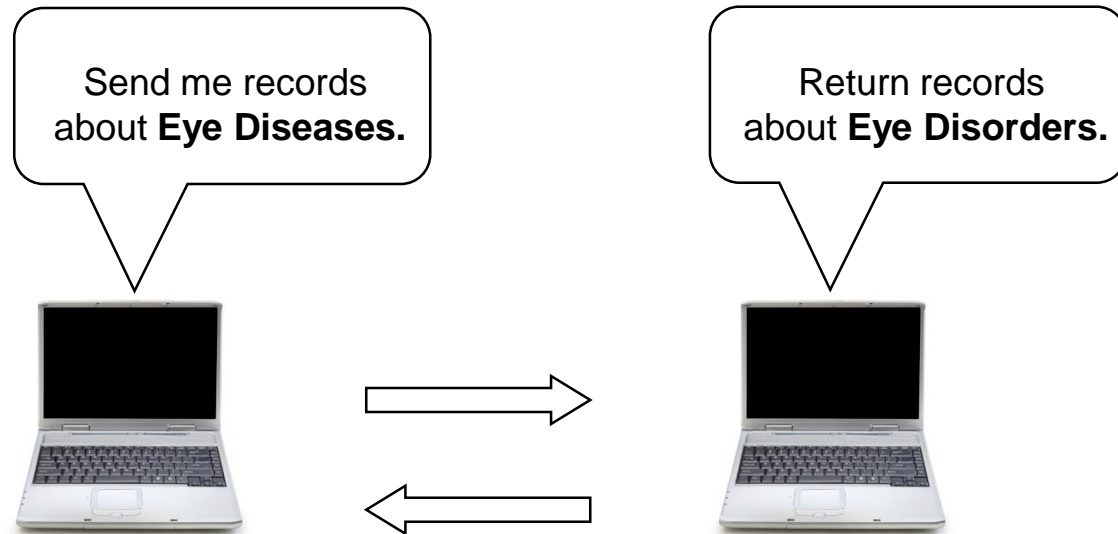


Integration of data sources



Integration of data sources

Eye diseases = Eye disorders



Components

- concepts

- represent a set or class of entities in a domain

Football-player

- organized in taxonomies
(hierarchies based on e.g. *is-a* or *is-part-of*)

Football-player is-a Athlete

- instances

Eden Hazard

- often not represented in an ontology
(instantiated ontology)

Components

- relations

$R: C1 \times C2 \times \dots \times Cn$

hasMember (between Sports-Team and Athlete)

hasMember (between Real Madrid and Eden Hazard)

Components

- axioms

‘facts that are always true’

The members of a football team are always football players.

Different kinds of ontologies

- **Controlled vocabularies**
Concepts
- **Taxonomies**
Concepts, is-a
- **Thesauri**
Concepts, predefined relations
- **Data models (e.g. EER, UML)**
Concepts, relations, axioms
- **Logics**
Concepts, relations, axioms



(Description) Logics

- Formal languages
 - Reasoning services
-
- OWL-DL / OWL2 are based on description logics

\mathcal{AL}

R atomic role, A atomic concept

$C, D \rightarrow A$ | (atomic concept)

T | (universal concept, top)

owl:thing

\perp | (bottom concept)

owl:nothing

$\neg A$ | (atomic negation)

owl:complementOf

$C \cap D$ | (conjunction)

owl:intersectionOf

$\forall R.C$ | (value restriction)

owl:allValuesFrom

$\exists R.T$ (limited existential quantification)

owl:someValuesFrom

$\mathcal{AL}[\mathcal{X}]$

$C \quad \neg C$ (concept negation) *owl:complementOf*

$\mathcal{U} \quad C \cup D$ (disjunction) *owl:unionOf*

$\mathcal{E} \quad \exists R.C$ (existential quantification)
owl:someValuesFrom

$\mathcal{N} \quad \geq n R, \leq n R$ (number restriction)
owl:maxCardinality, owl:minCardinality

$\mathcal{Q} \quad \geq n R.C, \leq n R.C$ (qualified number restriction)
owl:maxQualifiedCardinality, owl:minQualifiedCardinality

\mathcal{AL} (Semantics)

An interpretation \mathcal{I} consists of a non-empty set $\Delta^{\mathcal{I}}$ (the domain of the interpretation) and an interpretation function $\cdot^{\mathcal{I}}$ which assigns to every atomic concept A a set $A^{\mathcal{I}} \subseteq \Delta^{\mathcal{I}}$ and to every atomic role R a binary relation $R^{\mathcal{I}} \subseteq \Delta^{\mathcal{I}} \times \Delta^{\mathcal{I}}$.

The interpretation function is extended to concept definitions using inductive definitions.

\mathcal{AL} (Semantics)

universal concept: $\top^{\mathcal{J}} = \Delta^{\mathcal{J}}$

bottom concept: $\perp^{\mathcal{J}} = \emptyset$

atomic negation: $(\neg A)^{\mathcal{J}} = \Delta^{\mathcal{J}} \setminus A^{\mathcal{J}}$

conjunction: $(C \cap D)^{\mathcal{J}} = C^{\mathcal{J}} \cap D^{\mathcal{J}}$

value restriction: $(\forall R.C)^{\mathcal{J}} = \{a \in \Delta^{\mathcal{J}} \mid \forall b.(a,b) \in R^{\mathcal{J}} \rightarrow b \in C^{\mathcal{J}}\}$

limited existential quantification: $(\exists R.T)^{\mathcal{J}} = \{a \in \Delta^{\mathcal{J}} \mid \exists b.(a,b) \in R^{\mathcal{J}}\}$

\mathcal{ALC} (Semantics)

$$(\neg C)^{\mathcal{J}} = \Delta^{\mathcal{J}} \setminus C^{\mathcal{J}}$$

$$(C \cup D)^{\mathcal{J}} = C^{\mathcal{J}} \cup D^{\mathcal{J}}$$

$$(\geq n R)^{\mathcal{J}} = \{a \in \Delta^{\mathcal{J}} \mid \# \{b \in \Delta^{\mathcal{J}} \mid (a,b) \in R^{\mathcal{J}}\} \geq n\}$$

$$(\leq n R)^{\mathcal{J}} = \{a \in \Delta^{\mathcal{J}} \mid \# \{b \in \Delta^{\mathcal{J}} \mid (a,b) \in R^{\mathcal{J}}\} \leq n\}$$

$$(\exists R.C)^{\mathcal{J}} = \{a \in \Delta^{\mathcal{J}} \mid \exists b \in \Delta^{\mathcal{J}} : (a,b) \in R^{\mathcal{J}} \wedge b \in C^{\mathcal{J}}\}$$

Semantics

Individual i

$$i^{\mathcal{J}} \in \Delta^{\mathcal{J}}$$

Unique Name Assumption:

$$\text{if } i_1 \neq i_2 \text{ then } i_1^{\mathcal{J}} \neq i_2^{\mathcal{J}}$$

Concepts and relations

Team ← Concept/class
(Team)

¬Team
(**not** Team)

Team $\cap \geq 10$ hasMember
(Team **and at least** 10 members)

Team $\cap \leq 10$ hasMember
(Team **and at most** 10 members)

Relation/role/property

Concepts and relations

Team $\cap \forall$ hasMember.Football-player

(Team **and all** members **are** football players)

Team $\cap \exists$ hasMember.Football-player

(Team **and there is a** member **that is a** football player)

Axioms

$C \subseteq D$ ($R \subseteq S$)

rdfs:subClassOf / rdfs:subPropertyOf

Football-player \subseteq Athlete

(**Every** football player **is** an athlete)

$C = D$ ($R = S$)

owl:equivalentClass / owl:equivalentProperty

(disjoint C D)

owl:disjointWith

Axioms

C(a)

a rdf:type C

Team(Real Madrid)

(Real Madrid is an instance of Team)

R(a,b)

a R b

hasMember(Real Madrid , Eden Hazard)

(Real Madrid has member Eden Hazard)



Example

Teams have at least two members, while large teams have at least 10 members. Sports teams are teams which have only athletes as members. A football team is a team which has at least 11 members and all the members are football players. Football players are athletes. Real Madrid is a football team that has Eden Hazard as a member.

Example

Team $\subseteq \geq 2$ hasMember

Large-Team = Team $\cap \geq 10$ hasMember

Sports-team = Team $\cap \forall$ hasMember.Athlete

Football-Team = Team $\cap \geq 11$ hasMember

$\cap \forall$ hasMember.Football-player

Football-player \subseteq Athlete

Football-Team(Real Madrid)

hasMember(Real Madrid,Eden Hazard)



Example

Every team has at least 2 members

Every large team is a team and has at least 10 members

Every sports team is a team and has only athletes as members

Every football team is a team and has at least 11 members
and has only football players as members



Example

Every team has at least 2 members

Every large team is a team and has at least 10 members

Every sports team is a team and has only athletes as members

Every football team is a team and has at least 11 members
and has only football players as members

Reasoning:

Every football team is a large team

Every football team is a sports team



Example

Real Madrid is an instance of football team

Real Madrid has member Eden Hazard

Example

Reasoning:

Real Madrid is an instance of football team

Real Madrid is an instance of large team

Real Madrid is an instance of team

Real Madrid is an instance of sports team

Real Madrid has at least 11 members

All members in Real Madrid are football players

All members in Real Madrid are athletes

Real Madrid has member Eden Hazard

Eden Hazard is an instance of football player

Eden Hazard is an instance of athlete

Start

The screenshot displays a web browser window with the address bar showing the URL: `untitled-ontology-11 (http://www.semanticweb.org/patla00/ontologies/2019/6/untitled-ontology-11)`. The browser's address bar also contains a search field labeled "Search...".

The application interface includes a menu bar with the following items: File, Edit, View, Reasoner, Tools, Refactor, Window, and Help.

Below the menu bar, there are several tabs and panels:

- Active ontology:** A tab labeled "untitled-ontology-11 (http://www.semanticweb.org/patla00/ontologies/2019/6/untitled-ontology-11)".
- Class hierarchy:** A panel titled "Class hierarchy: owl:Thing" showing a tree view with a single node: `owl:Thing`.
- Class Annotations:** A panel titled "Class Annotations: owl:Thing" with a sub-tab "Class Usage". It contains an "Annotations" section with a plus sign (+) to expand it.
- Description:** A panel titled "Description: owl:Thing" listing various logical relationships, each with a plus sign (+) to expand it:
 - Equivalent To
 - Sub-Class Of
 - General class axioms
 - Sub-Class Of (Anonymous Ancestor)
 - Instances
 - Target for Key
 - Disjoint With
 - Disjoint Union Of

Create relation *hasMember*

The screenshot displays the Protégé ontology editor interface. A dialog box titled "Create a new Object property" is open in the foreground. The dialog contains the following fields and options:

- Name:** hasMember
- IRI:** http://www.semanticweb.org/patla00/ontologies/2019/6/untitled-ontology-11#hasMember
- New entity options...** (button)
- OK** (button)
- Cancel** (button)

In the background, the ontology editor shows the "Object properties" tab selected. The "Object property hierarchy" for `owl:topObjectProperty` is visible, and the "Annotations" panel for `owl:topObjectProperty` is also open. The main workspace shows the "owl:topObjectProperty" class selected.

Create relation *hasMember*

The screenshot shows a web browser window with the URL `http://www.semanticweb.org/patla00/ontologies/2019/6/untitled-ontology-11`. The browser's address bar and tabs show the current ontology. The interface includes a menu bar (File, Edit, View, Reasoner, Tools, Refactor, Window, Help) and a search bar. The main workspace is divided into several panes:

- Object property hierarchy: hasMember**: Shows a tree view where `owl:topObjectProperty` is expanded to reveal `hasMember`.
- Annotations: hasMember**: A pane for adding annotations to the property, currently empty.
- Characteristics: hasMem**: A list of checkboxes for property characteristics:
 - Functional
 - Inverse functional
 - Transitive
 - Symmetric
 - Asymmetric
 - Reflexive
 - Irreflexive
- Description: hasMember**: A list of relationship options, each with a plus sign for expansion:
 - Equivalent To +
 - SubProperty Of +
 - Inverse Of +
 - Domains (intersection) +
 - Ranges (intersection) +
 - Disjoint With +
 - SuperProperty Of (Chain) +

Create concept *Team*

The screenshot shows the Protégé ontology editor interface. At the top, the browser address bar displays the URL: `untitled-ontology-11 (http://www.semanticweb.org/patla00/ontologies/2019/6/untitled-ontology-11) : [http://www.semanticweb.org/patla00/ontologies/2019/6/untitled-ontology-11]`. The menu bar includes File, Edit, View, Reasoner, Tools, Refactor, Window, and Help. The address bar shows the current ontology: `untitled-ontology-11 (http://www.semanticweb.org/patla00/ontologies/2019/6/untitled-ontology-11)`. The interface is divided into several panes. On the left, the 'Class hierarchy' pane shows a tree structure with `owl:Thing` selected. The main central pane displays the details for the selected class, `owl:Thing`, with tabs for 'Class Annotations' and 'Class Usage'. The 'Annotations: owl:Thing' pane is currently empty. A 'Create a new Class' dialog box is open in the foreground, centered on the screen. The dialog has a title bar with a close button (X). Inside the dialog, the 'Name' field contains the text 'Team'. The 'IRI' field contains the text `http://www.semanticweb.org/patla00/ontologies/2019/6/untitled-ontology-11#Team`. There is a 'New entity options...' button to the right of the IRI field. At the bottom of the dialog, there are 'OK' and 'Cancel' buttons. In the background, the bottom part of the Protégé interface shows the 'SubClass Of (Anonymous Ancestor)' pane with options for 'Instances', 'Target for Key', 'Disjoint With', and 'Disjoint Union Of', each with a plus sign icon.

Edit concept *Team* using object restriction creator

The screenshot displays the Protégé interface for editing the *Team* concept in an ontology. The main window shows the class hierarchy with *Team* as a subclass of *owl:Thing*. The 'Description: Team' panel is active, showing various class axioms like 'Equivalent To', 'SubClass Of', and 'General class axioms'. The 'Object restriction creator' dialog is open, allowing the user to define a restriction on the *hasMember* property. The dialog includes a 'Restricted property' section with a tree view showing *owl:Thing* and *hasMember*. The 'Restriction filler' section is currently empty. The 'Restriction type' section is set to 'Min (min cardinality)' with a cardinality of 2. The dialog has 'OK' and 'Cancel' buttons at the bottom.

untitled-ontology-11 (http://www.semanticweb.org/patla00/ontologies/2019/6/untitled-ontology-11) : [http://www.semanticweb.org/patla00/ontologies/2019/6/untitled-ontology-11]

File Edit View Reasoner Tools Refactor Window Help

< > untitled-ontology-11 (http://www.semanticweb.org/patla00/ontologies/2019/6/untitled-ontology-11) Search...

Team

Active ontology x Entities x Individuals by class x DL Query x

Classes Object properties Data properties Annotation properties Datatypes Individuals

Class hierarchy: Team

Annotations: Team

Annotations +

Description: Team

Equivalent To +

SubClass Of +

General class axioms +

SubClass Of (Anonymous Ancestor)

Instances +

Target for Key +

Disjoint With +

Disjoint Union Of +

Team

Data restriction creator Class expression editor Object restriction creator Class hierarchy

Restricted property

owl:Thing
└─ hasMember

Restriction filler

owl:Thing

Restriction type

Min (min cardinality) Cardinality 2

OK Cancel

Edit concept *Team* using object restriction creator

The screenshot shows a web browser window with the URL `http://www.semanticweb.org/patla00/ontologies/2019/6/untitled-ontology-11`. The browser's address bar and the page title both display the URL. The browser's menu bar includes `File`, `Edit`, `View`, `Reasoner`, `Tools`, `Refactor`, `Window`, and `Help`. Below the menu bar, there is a search bar and a breadcrumb trail: `untitled-ontology-11 (http://www.semanticweb.org/patla00/ontologies/2019/6/untitled-ontology-11) > Team`. The main interface is divided into several panels. On the left, the **Class hierarchy** panel shows a tree structure with `owl:Thing` as the root and `Team` as a child. The top navigation bar includes tabs for `Classes`, `Object properties`, `Data properties`, `Annotation properties`, `Datatypes`, and `Individuals`. The `Classes` tab is active, and the `Team` class is selected. The right-hand side of the interface is divided into two main sections. The top section, titled **Annotations: Team**, has tabs for `Class Annotations` and `Class Usage`. Below this, there are sections for **Description: Team**, **Equivalent To**, **SubClass Of**, **General class axioms**, **SubClass Of (Anonymous Ancestor)**, **Instances**, **Target for Key**, **Disjoint With**, and **Disjoint Union Of**. The **SubClass Of** section is currently expanded, showing a restriction: `hasMember min 2 owl:Thing`. The restriction is represented by a yellow circle icon, followed by the text `hasMember min 2 owl:Thing`. The `min` is in red, and `2` is in blue. There are also icons for help, refresh, and close next to the restriction text.

Create concept *Large-Team*

The screenshot shows the Protégé ontology editor interface. At the top, the title bar reads "untitled-ontology-15 (http://www.semanticweb.org/patla00/ontologies/2019/6/untitled-ontology-15) : [http://www.semanticweb.org/patla00/ontologies/2019/6/untitled-ontology-15]". The menu bar includes "File", "Edit", "View", "Reasoner", "Tools", "Refactor", "Window", and "Help". The address bar shows the current ontology URI. The main workspace is divided into several panes:

- Class hierarchy:** Shows a tree view with "owl:Thing" as the root and "Team" as a child class.
- Annotations:** A pane for "owl:Thing" with an "Annotations" tab selected, showing a plus sign to add annotations.
- SubClass Of (Anonymous Ancestor):** A list of relationships with plus signs to add "Instances", "Target for Key", "Disjoint With", and "Disjoint Union Of".

A "Create a new Class" dialog box is open in the foreground. It contains the following fields and buttons:

- Name:** A text field containing "Large-Team".
- IRI:** A text field containing "http://www.semanticweb.org/patla00/ontologies/2019/6/untitled-ontology-15#Large-Team".
- Buttons:** "OK", "Cancel", and "New entity options..." (located to the right of the IRI field).

Edit concept *Large-Team* using class expression editor

The screenshot displays the Protege ontology editor interface. The main window shows the class hierarchy for 'Large-Team', which is a subclass of 'Team'. The 'Class expression editor' tab is active, showing the class expression 'Team and hasMember min 10'. A dialog box titled 'Large-Team' is open, allowing the user to edit the class expression. The dialog has tabs for 'Data restriction creator', 'Class expression editor', 'Class hierarchy', and 'Object restriction creator'. The 'Class expression editor' tab is selected, and the expression 'Team and hasMember min 10' is visible. The dialog also includes a 'Help...' button and 'OK' and 'Cancel' buttons.

untitled-ontology-15 (http://www.semanticweb.org/patla00/ontologies/2019/6/untitled-ontology-15) : [http://www.semanticweb.org/patla00/ontologies/2019/6/untitled-ontology-15]

File Edit View Reasoner Tools Refactor Window Help

untitled-ontology-15 (http://www.semanticweb.org/patla00/ontologies/2019/6/untitled-ontology-15) Search...

Large-Team

Active ontology x Entities x Individuals by class x DL Query x

Classes Object properties Data properties Annotation properties Datatypes Individuals

Class hierarchy: Large-Team

Annotations Usage

Annotations: Large-Team

Annotations +

Description: Large-Team

Equivalent To +

SubClass Of +

General class axioms +

SubClass Of (Anonymous Ancestor)

Instances +

Target for Key +

Disjoint With +

Disjoint Union Of +

Large-Team

Data restriction creator Class expression editor Class hierarchy Object restriction creator

Team and hasMember min 10

Help...

OK Cancel

Edit concept *Large-Team* using class expression editor

The screenshot shows a web browser window with the URL `http://www.semanticweb.org/patla00/ontologies/2019/6/untitled-ontology-15`. The browser's address bar and search bar are visible. The main content area is divided into several panels:

- Class hierarchy:** Shows a tree view starting with `owl:Thing`, which has a child `Team`, which in turn has a child `Large-Team`.
- Annotations:** A panel for editing annotations for the selected class, currently empty.
- Description:** A panel for editing the class description. It contains the following axioms:
 - Equivalent To: `Team and hasMember min 10`
 - SubClass Of: (empty)
 - General class axioms: (empty)
 - SubClass Of (Anonymous Ancestor): `hasMember min 2 owl:Thing`
 - Instances: (empty)
 - Target for Key: (empty)
 - Disjoint With: (empty)
 - Disjoint Union Of: (empty)

Reasoning

The screenshot displays a web browser window with the address bar showing the URL: `http://www.semanticweb.org/patla00/ontologies/2019/6/untitled-ontology-15`. The browser's address bar also contains the text `untitled-ontology-15 (http://www.semanticweb.org/patla00/ontologies/2019/6/untitled-ontology-15)`. The browser's menu bar includes `File`, `Edit`, `View`, `Reasoner`, `Tools`, `Refactor`, `Window`, and `Help`. The browser's address bar also contains a search box with the text `Search...`.

The browser's content area displays the ontology editor interface for the class `Large-Team`. The interface is divided into several panels:

- Class hierarchy: Large-Team**: A tree view showing the class hierarchy. The root is `owl:Thing`, which has a child `Team`, which in turn has a child `Large-Team`.
- Annotations: Large-Team**: A panel showing the annotations for the class `Large-Team`. It contains a search box and a list of annotations.
- Description: Large-Team**: A panel showing the description of the class `Large-Team`. It contains several sections:
 - Equivalent To**: `Team and hasMember min 10`
 - SubClass Of**: `Team`
 - General class axioms**: (empty)
 - SubClass Of (Anonymous Ancestor)**: `hasMember min 2 owl:Thing`
 - Instances**: (empty)
 - Target for Key**: (empty)
 - Disjoint With**: (empty)
 - Disjoint Union Of**: (empty)

After adding all other concepts and reasoning

The screenshot displays a Semantic Web editor interface for an ontology. The main window shows the class hierarchy for 'Football-Team' on the left and its description on the right.

Class Hierarchy:

- owl:Thing
 - Athlete
 - Football-player
 - Team
 - Football-Team** (selected)
 - Sports-Team
 - Large-Team

Description: Football-Team

- Equivalent To: Team and hasMember min 11 and hasMember only Football-player
- SubClass Of:
 - Large-Team
 - Sports-Team
- General class axioms: (None listed)
- SubClass Of (Anonymous Ancestor):
 - hasMember min 2 owl:Thing
 - Team and hasMember min 10
 - Team and hasMember only Athlete
- Instances: (None listed)
- Target for Key: (None listed)
- Disjoint With: (None listed)
- Disjoint Union Of: (None listed)

Creating individual *Real-Madrid* and asserting it is a *Football-Team*

The screenshot displays the Protégé interface for an ontology named "untitled-ontology-15". The main window shows the "Individuals" tab for the class "Real-Madrid", with "Real-Madrid" listed as an individual. A dialog box titled "Real-Madrid" is open, showing the "Class hierarchy" tab. The hierarchy is as follows:

- owl:Thing
 - Athlete
 - Team
 - Football-Team** (highlighted)
 - Large-Team
 - Sports-Team

The dialog box also includes tabs for "Data restriction creator", "Object restriction creator", and "Class expression editor". The "Asserted" dropdown is set to "Asserted". The background interface shows the "Annotations" tab for "Real-Madrid" and the "Property assertions" panel on the right, which is currently empty.

Creating individual *Real-Madrid* and asserting it is a *Football-Team*

The screenshot displays a web browser window with the URL `http://www.semanticweb.org/patla00/ontologies/2019/6/untitled-ontology-15`. The browser's address bar and the application's menu bar (File, Edit, View, Reasoner, Tools, Refactor, Window, Help) are visible at the top. Below the browser window, the application interface is divided into several panes:

- Active ontology:** Shows tabs for "Entities", "Individuals by class", and "DL Query".
- Classes:** A tabbed interface with "Object properties", "Data properties", "Annotation properties", "Datatypes", and "Individuals". The "Individuals" tab is active, showing a list with "Real-Madrid".
- Annotations: Real-Madrid:** A pane with a sub-tab "Usage" and a main area containing a plus sign (+) for adding annotations.
- Description: Real-Madrid:** A pane with a sub-tab "Types" showing "Football-Team" as a type. Below it are "Same Individual As" and "Different Individuals" options, each with a plus sign (+).
- Property assertions: Real-Madrid:** A pane with sub-tabs for "Object property assertions", "Data property assertions", "Negative object property assertions", and "Negative data property assertions", each with a plus sign (+).

Creating individual *Eden-Hazard*

The screenshot shows a web browser window displaying a Semantic Web editor interface. The browser's address bar shows the URL: `http://www.semanticweb.org/patla00/ontologies/2019/6/untitled-ontology-15`. The editor's menu bar includes **File**, **Edit**, **View**, **Reasoner**, **Tools**, **Refactor**, **Window**, and **Help**. The main interface is divided into several panes:

- Classes:** A list of classes, with **Real-Madrid** selected.
- Annotations:** A pane for adding annotations to the selected class.
- Property assertions:** A pane for adding property assertions, including object, data, negative object, and negative data property assertions.

A modal dialog box titled "Create a new Named individual" is open in the foreground. It contains the following fields and buttons:

- Name:** A text input field containing "Eden-Hazard".
- IRI:** A text input field containing the URI `http://www.semanticweb.org/patla00/ontologies/2019/6/untitled-ontology-15#Eden-Hazard`.
- Buttons:** "OK" and "Cancel" buttons at the bottom.
- Additional:** A "New entity options..." button next to the IRI field.

Creating individual *Eden-Hazard*

The screenshot displays a web browser window with the URL `http://www.semanticweb.org/patla00/ontologies/2019/6/untitled-ontology-15`. The browser's address bar shows the current page is `untitled-ontology-15`. The browser's menu bar includes `File`, `Edit`, `View`, `Reasoner`, `Tools`, `Refactor`, `Window`, and `Help`. Below the browser window, the application interface is visible, showing the active ontology `untitled-ontology-15` and the current view `Individuals by class`. The `Individuals` tab is selected, showing a list of individuals: `Eden-Hazard` (highlighted in blue) and `Real-Madrid`. The `Eden-Hazard` individual is currently selected. The right-hand side of the interface is divided into several panels: `Annotations: Eden-Hazard` (with a `+` icon), `Description: Eden-Hazard` (with `Types`, `Same Individual As`, and `Different Individuals` sections, each with a `+` icon), and `Property assertions: Eden-Hazard` (with `Object property assertions`, `Data property assertions`, `Negative object property assertions`, and `Negative data property assertions` sections, each with a `+` icon).

Asserting the relation *hasMember* between *Real-Madrid* and *Eden-Hazard*

The screenshot shows a web browser window with the URL `http://www.semanticweb.org/patla00/ontologies/2019/6/untitled-ontology-15`. The browser's address bar and search bar are visible. The main interface is a Semantic Web editor with a menu bar (File, Edit, View, Reasoner, Tools, Refactor, Window, Help) and a toolbar. The editor is divided into several panes:

- Active ontology:** `untitled-ontology-15`
- Classes:** `Real-Madrid`
- Individuals:** `Eden-Hazard` and `Real-Madrid`
- Annotations:** `Real-Madrid`
- Description:** `Real-Madrid` (includes `Football-Team`)
- Property assertions:** `Real-Madrid`

A dialog box titled "Real-Madrid" is open in the foreground, showing the process of asserting the `hasMember` property. The dialog has two input fields: the first contains `hasMember` and the second contains `Eden-Hazard`. Below the fields is a tip: "(Tip: Use CTRL+Space to auto-complete names)". At the bottom of the dialog are "OK" and "Cancel" buttons.

Asserting the relation *hasMember* between *Real-Madrid* and *Eden-Hazard*

The screenshot shows a web browser window displaying a Semantic Web editor interface. The browser's address bar shows the URL: `http://www.semanticweb.org/patla00/ontologies/2019/6/untitled-ontology-15`. The editor's menu bar includes `File`, `Edit`, `View`, `Reasoner`, `Tools`, `Refactor`, `Window`, and `Help`. The main interface is divided into several panes:

- Individuals: Real-Madrid:** A list of individuals, with `Eden-Hazard` and `Real-Madrid` visible.
- Annotations: Real-Madrid:** A pane for adding annotations to the selected individual.
- Description: Real-Madrid:** A pane showing the class hierarchy, with `Football-Team` listed as a type.
- Property assertions: Real-Madrid:** A pane for adding property assertions. It shows an assertion for the `hasMember` property with the value `Eden-Hazard`.

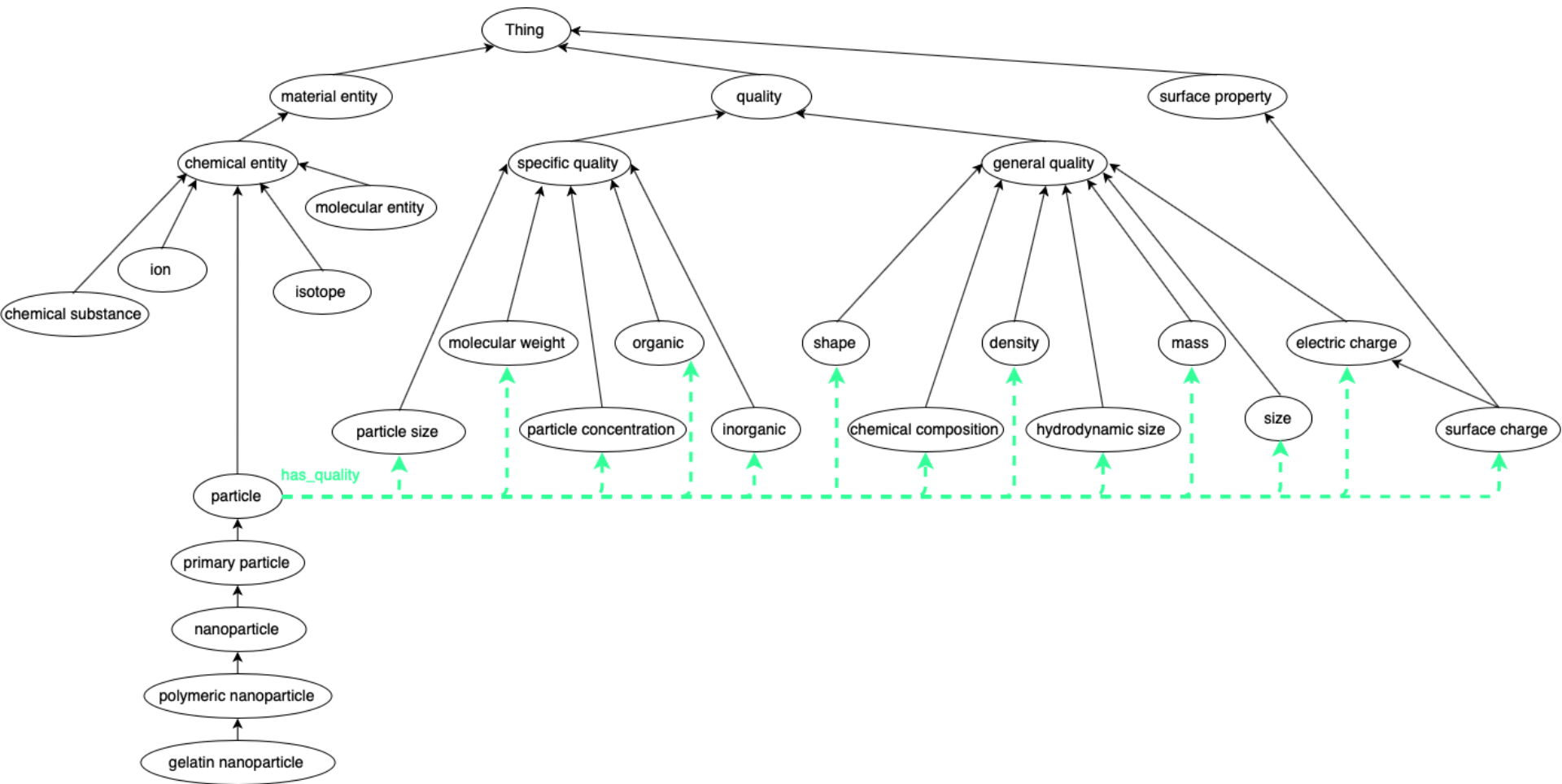
Reasoning

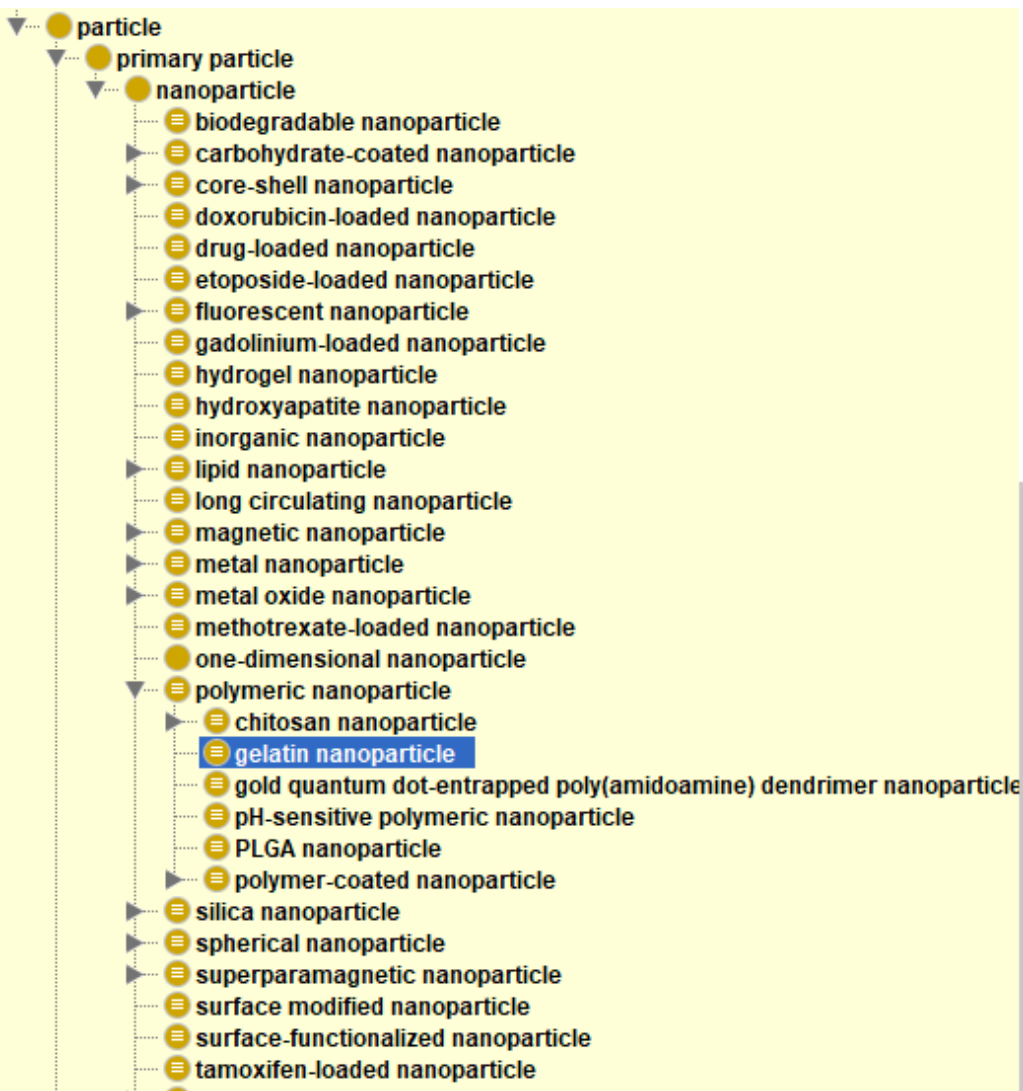
The screenshot shows a web browser window with the address bar displaying "untitled-ontology-15 (http://www.semanticweb.org/patla00/ontologies/2019/6/untitled-ontology-15) : [C:\Users\patla00\Documents\ontologies\football.owl]". The browser has a menu bar with "File", "Edit", "View", "Reasoner", "Tools", "Refactor", "Window", and "Help". Below the menu bar is a search bar containing "untitled-ontology-15 (http://www.semanticweb.org/patla00/ontologies/2019/6/untitled-ontology-15)" and a "Search..." button.

The main interface is divided into several panes:

- Active ontology:** Includes tabs for "Entities", "Individuals by class", and "DL Query".
- Classes:** A horizontal bar with tabs for "Object properties", "Data properties", "Annotation properties", "Datatypes", and "Individuals".
- Individuals: Eden-Hazard:** A list of individuals, with "Eden-Hazard" selected and "Real-Madrid" listed below it.
- Annotations: Eden-Hazard:** A panel with a tab for "Usage" and a sub-panel for "Annotations" containing a "+" icon.
- Description: Eden-Hazard:** A panel with a sub-panel for "Types" containing a yellow bar for "Football-player" with "?" and "@" icons. Below it are "Same Individual As" and "Different Individuals" sections, each with a "+" icon.
- Property assertions: Eden-Hazard:** A panel with four sections, each with a "+" icon: "Object property assertions", "Data property assertions", "Negative object property assertions", and "Negative data property assertions".

Nanoparticle Ontology





Description: gelatin nanoparticle

Equivalent To

nanoparticle and (has_component_part some gelatin)

SubClass Of

'polymeric nanoparticle'

General class axioms

SubClass Of (Anonymous Ancestor)

- has_part some 'surface of nanoparticle'
- has_quality some 'particle size'
- has_quality some shape
- has_part some (coat or core or shell)
- has_quality some 'particle concentration'
- has_quality some 'chemical composition'
- has_quality some density
- has_quality some mass
- has_quality some ('electric charge' or 'surface charge')
- has_quality some size
- has_quality some (inorganic or organic)
- has_quality some 'hydrodynamic size'
- has_quality some 'molecular weight'
- nanoparticle and (has_component_part some polymer)

```
1 <!-- http://purl.bioontology.org/ontology/npo#NPO_1555 -->
2 <owl:Class rdf:about="#NPO_1555">
3   <rdfs:label rdf:datatype="&xsd:string">gelatin nanoparticle</rdfs:label>
4   <owl:equivalentClass>
5     <owl:Class>
6       <owl:intersectionOf rdf:parseType="Collection">
7         <rdf:Description rdf:about="#NPO_707"/> <!-- nanoparticle -->
8         <owl:Restriction>
9           <owl:onProperty rdf:resource="#has_component_part"/>
10          <owl:someValuesFrom rdf:resource="#NPO_1554"/> <!-- gelatin -->
11        </owl:Restriction>
12      </owl:intersectionOf>
13    </owl:Class>
14  </owl:equivalentClass>
15  <rdfs:subClassOf rdf:resource="#NPO_1375"/> <!-- polymeric nanoparticle -->
16 </owl:Class>
```

1

```
1 <!-- http://purl.bioontology.org/ontology/npo#NPO_1375 -->
2 <owl:Class rdf:about="#NPO_1375">
3   <rdfs:label rdf:datatype="&xsd:string">polymeric nanoparticle</rdfs:label>
4   <owl:equivalentClass>
5     <owl:Class>
6       <owl:intersectionOf rdf:parseType="Collection">
7         <rdf:Description rdf:about="#NPO_707"/> <!-- nanoparticle -->
8         <owl:Restriction>
9           <owl:onProperty rdf:resource="#has_component_part"/>
10          <owl:someValuesFrom rdf:resource="&CHEBI;CHEBI_33839"/> <!-- polymer -->
11        </owl:Restriction>
12      </owl:intersectionOf>
13    </owl:Class>
14  </owl:equivalentClass>
15  <rdfs:subClassOf rdf:resource="#NPO_707"/>
16 </owl:Class>
```

2

Defining ontologies is not so easy ...

The Celestial Emporium of Benevolent Knowledge, Borges

"On those remote pages it is written that animals are divided into:

- a. those that belong to the Emperor
- b. embalmed ones
- c. those that are trained
- d. suckling pigs
- e. mermaids
- f. fabulous ones
- g. stray dogs
- h. those that are included in this classification
- i. those that tremble as if they were mad
- j. innumerable ones
- k. those drawn with a very fine camel's hair brush
- l. others
- m. those that have just broken a flower vase
- n. those that resemble flies from a distance"

Defining ontologies is not so easy ...

Dyirbal classification of objects in the universe

- Bayi: men, kangaroos, possums, bats, most snakes, most fishes, some birds, most insects, the moon, storms, rainbows, boomerangs, some spears, etc.
- Balan: women, anything connected with water or fire, bandicoots, dogs, platypus, echidna, some snakes, some fishes, most birds, fireflies, scorpions, crickets, the stars, shields, some spears, some trees, etc.
- Balam: all edible fruit and the plants that bear them, tubers, ferns, honey, cigarettes, wine, cake.
- Bala: parts of the body, meat, bees, wind, yamsticks, some spears, most trees, grass, mud, stones, noises, language, etc.

Difficulties

- Knowledge engineering

- Is-a vs part-of
- Concept vs individual
- Synonyms as concepts, unconnected terms, cycles in the hierarchy, domain and range problems, missing disjointness ...
<http://oops.linkeddata.es/catalogue.jsp>

→ Domain expert + knowledge engineer



Difficulties

- **Completeness**
 - Missing information

- **Correctness**
 - Incoherence
 - Inconsistency



Ontology tools

- Ontology development tools
- Ontology completion and debugging tools
- Ontology alignment tools
- Ontology evaluation tools
- Ontology-based annotation tools
- Ontology storage and querying tools
- Ontology learning tools

Debugging and Completing Ontologies

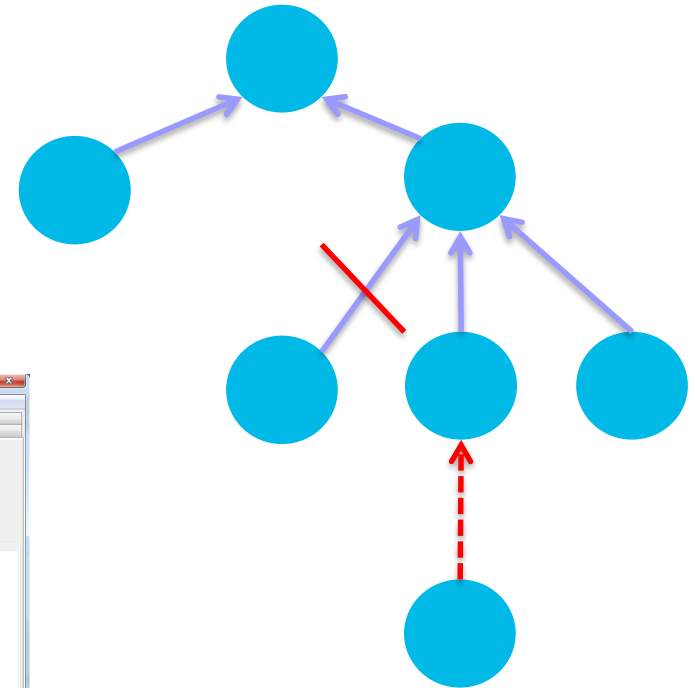
The image displays three overlapping screenshots of the RepOSE (Repair Ontology) software interface, illustrating the process of debugging and completing ontologies.

- Top Screenshot:** Shows the main interface with a file path and a dropdown menu for a relation type. A button labeled "Generate Repairing Actions" is visible. Below, there are sections for "Repairing Actions" and "Recommendation".
- Middle Screenshot:** Shows a "Sets of candidate missing mappings" section with a network diagram of terms like "Booklet", "MasterThesis", "Misc", "PhDthesis", "Entry", "InCollection", "InBook", and "Article". A "Justifications of selected mapping" section is also present.
- Bottom Screenshot:** Shows a "Justifications of current relation" section with a diagram of terms like "TechReport", "TechReport", "Informal", and "Informal". It also includes a "Recommendation" section with checkboxes for "Wordnet" and "UMLS".

Annotations on the screenshots include:

- A blue box labeled "Publisher" with an arrow pointing to "Publisher" in the top screenshot.
- A blue box labeled "Publishe" with an arrow pointing to "Publisher" in the middle screenshot.
- A blue box labeled "Institution" with an arrow pointing to "Institution" in the top screenshot.
- A blue box labeled "P1" with an arrow pointing to "Publisher" in the middle screenshot.

RepOSE





Ontology tools

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- Ontology storage and querying tools
- Ontology learning tools

Aligning Ontologies



Mapping Suggestion Details

mouse	human
pericardium Id: MA_0000099 definition: Synonym: Part of:	Pericardium Id: NCI_C13005 definition: Synonym: Part of:

comment on the mapping new name for the mapping

nose_MA	nose_MeSH
nose p- nasalis i- external_naris i- internal_naris p- nasal_capsule p- nasal_cavity (nasal_cavity) p- nasal_cavity epithelium	nose i- nasal_bone i- nasal_cavity (nasal_cavity) i- nasal_mucosa i- olfactory_mucosa i- goblet_cell i- olfactory_receptor_neuron

Align Concept in mouse and human

matchers: 1.0 NGram
1.0 TermBasic
1.0 TermWN
1.0 UMLSM
1.0 Naive Bayes

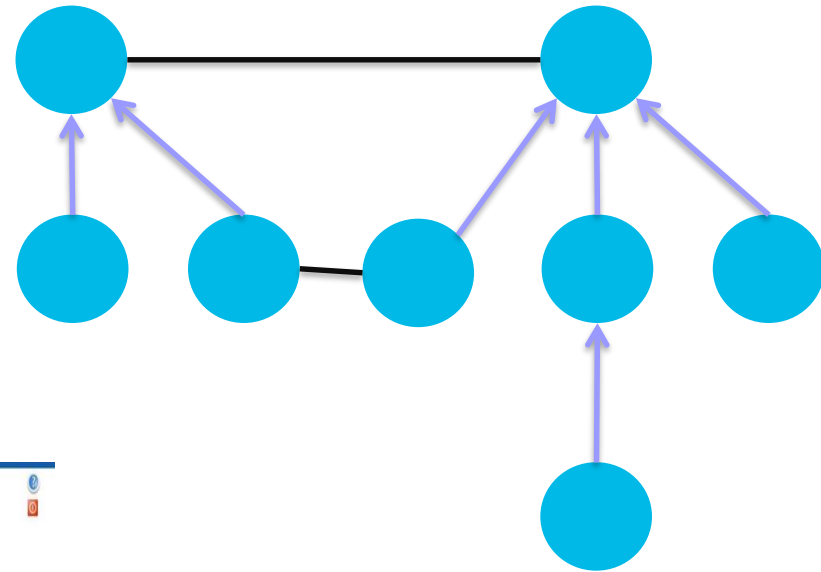
single threshold: 0.6
double threshold: upper 0.6 lower 0.4

weighted-sum combination
maximum-based combination

use preprocessed data

Start Computation Finish Computation Interrupt Computation interrupt at: 1000

Use recommendations from predefined strategies

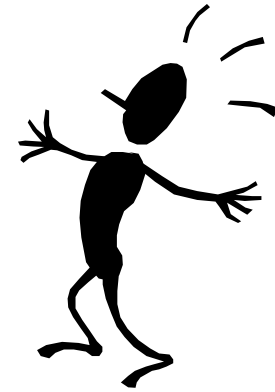
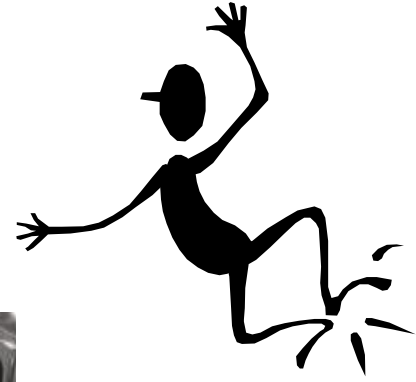
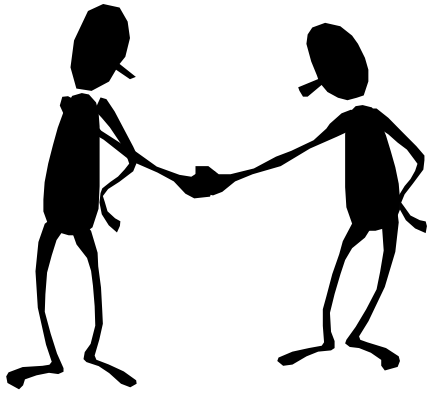


SAMBO



Ontology tools

- Ontology development tools
- Ontology completion and debugging tools
- Ontology alignment tools
- Ontology evaluation tools
- Ontology-based annotation tools
- Ontology storage and querying tools
- Ontology learning tools





Further reading

Ontologies

Staab and Studer, *Handbook on Ontologies*, 2nd ed, Springer, 2009.

Lambrix, Strömbäck, Tan, Information integration in bioinformatics with ontologies and standards, in Bry, Maluszynski (eds), *Semantic Techniques for the Web: The REVERSE perspective*, chapter 8, 343-376, 2009.

Further reading

Description logics

Baader, Calvanese, McGuinness, Nardi, Patel-Schneider.
The Description Logic Handbook, Cambridge University Press, 2003.

Donini, Lenzerini, Nardi, Schaerf, Reasoning in description logics. *Principles of knowledge representation*, CSLI publications, pp 191-236. 1996.

dl.kr.org

www.w3.org



Further reading

OWL

<https://www.w3.org/TR/owl-guide/>

OWL2

<https://www.w3.org/TR/owl2-primer/>

Further reading

Tools

■ Development

- Protégé <https://protege.stanford.edu/>

■ Pitfalls

- OOPS <http://oops.linkeddata.es/>

■ Debugging and completion

- Repose
<https://www.ida.liu.se/~patla00/research/RepOSE/>

■ Ontology alignment

- <http://www.ontologymatching.org/>
- <http://oaei.ontologymatching.org/>