Ontology Engineering

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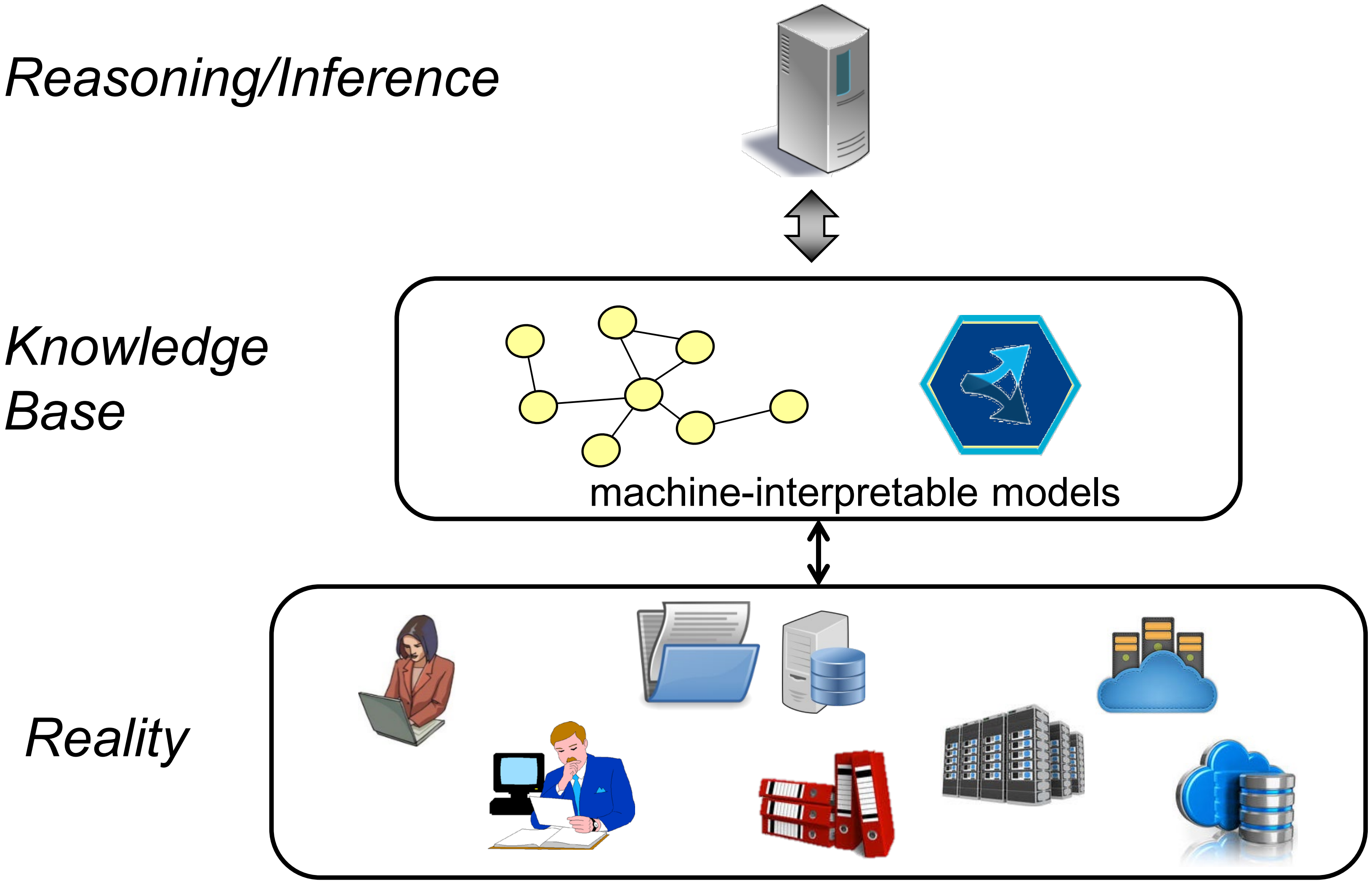
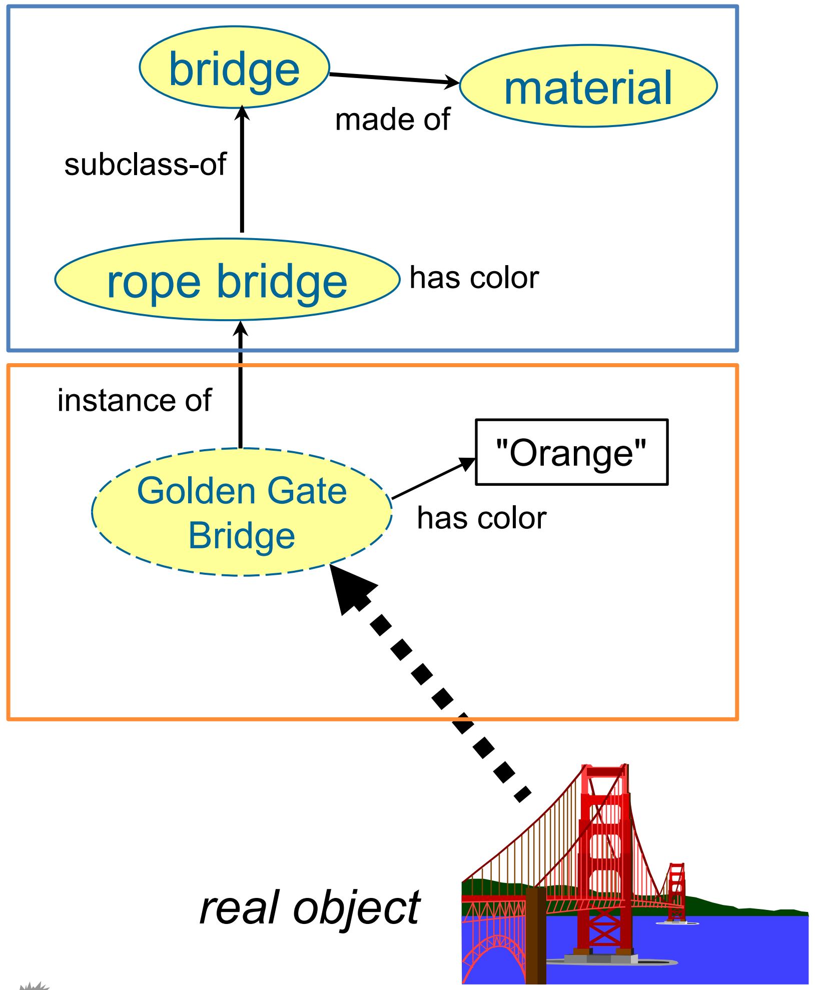
Knowledge-Representation and Reasoning



An Ontology – very informal



An ontology is a formal explicit description of concepts in a domain of discourse

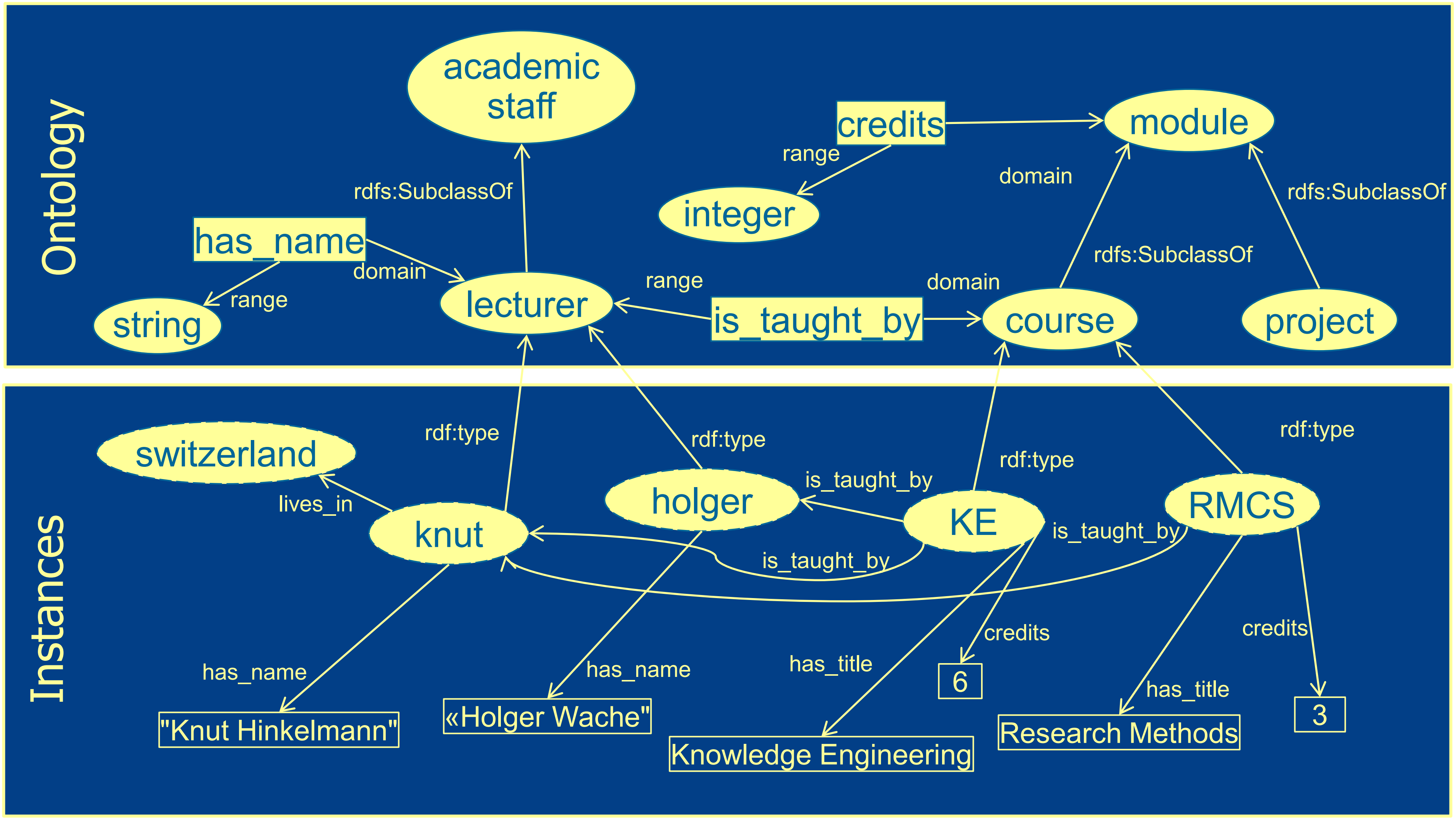
- An ***ontology*** consists of
  - Concepts (Classes),
  - Relationships (Object Properties) between concepts
  - Attributes (Data Properties) of concepts
  - Constraints that hold between/for the concepts,
- An ontology together with a set of individual instances constitutes a ***knowledge base***

https://people.cs.uct.ac.za/~mkeet/OEbook/slides/L1IntroOE19.pptx ontology engineering

is

knowledge engineering

Example of an Ontology

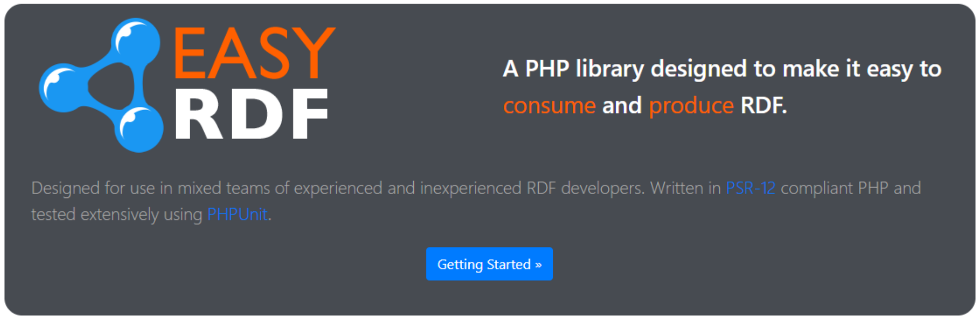


Ontology Representation Formalisms

- Representations of Ontologies
  - ***RDF(S)*** Our focus
  - OWL
  - Neo4J
  - …

Tools: Examples of Programming Libraries

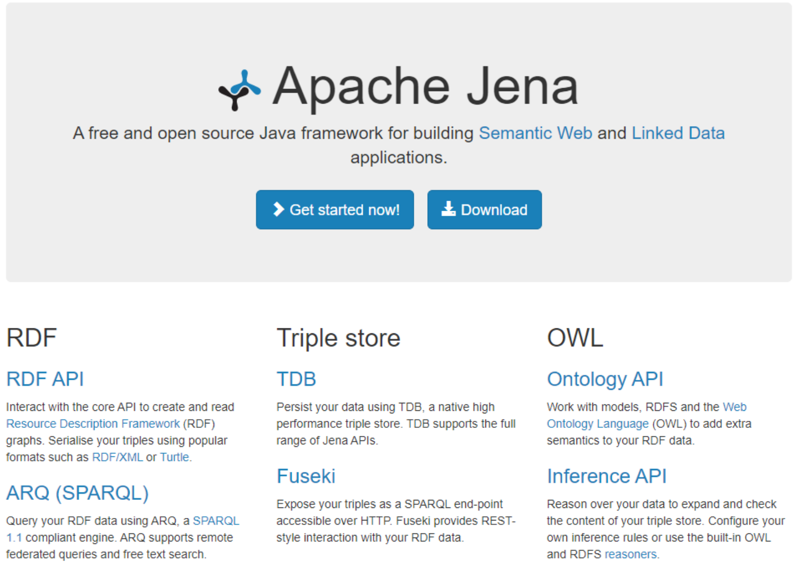
EasyRDF for PHP: https://www.easyrdf.org/



A PHP library designed to make it easy to consume and produce RDF.

Designed for use in mixed teams of experienced and inexperienced RDF developers. Written in PSR-12 compliant PHP and tested extensively using PHPUnit.

Apache Jena for Java: https://jena.apache.org/



A free and open source Java framework for building Semantic Web and Linked Data applications.

RDF

RDF API

Interact with the core API to create and read Resource Description Framework (RDF) graphs. Serialise your triples using popular formats such as RDF/XML or Turtle.

ARQ (SPARQL)

Query your RDF data using ARQ, a SPARQL 1.1 compliant engine. ARQ supports remote federated queries and free text search.

Triple store

TDB

Persist your data using TDB, a native high performance triple store. TDB supports the full range of Jena APIs.

Fuseki

Expose your triples as a SPARQL end-point accessible over HTTP. Fuseki provides REST-style interaction with your RDF data.

OWL

Ontology API

Work with models, RDFS and the Web Ontology Language (OWL) to add extra semantics to your RDF data.

Inference API

Reason over your data to expand and check the content of your triple store. Configure your own inference rules or use the built-in OWL and RDFS reasoners.

RDFLib for Python: https://rdflib.readthedocs.io/en/stable/

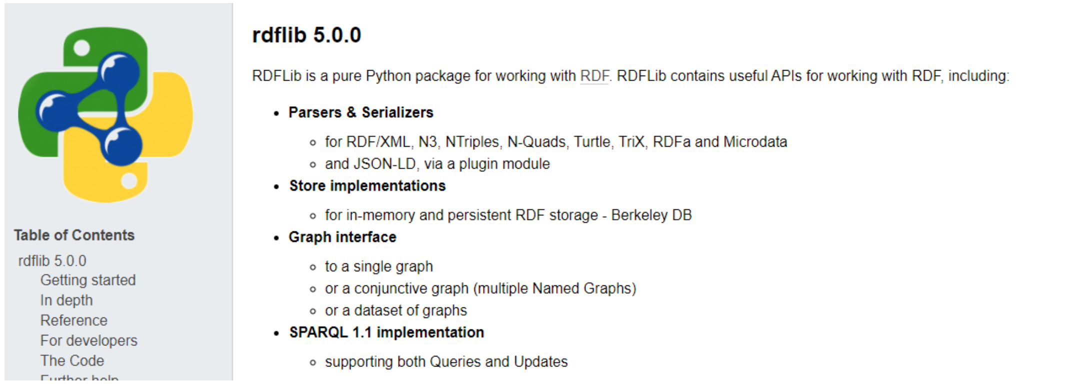


Table of Contents

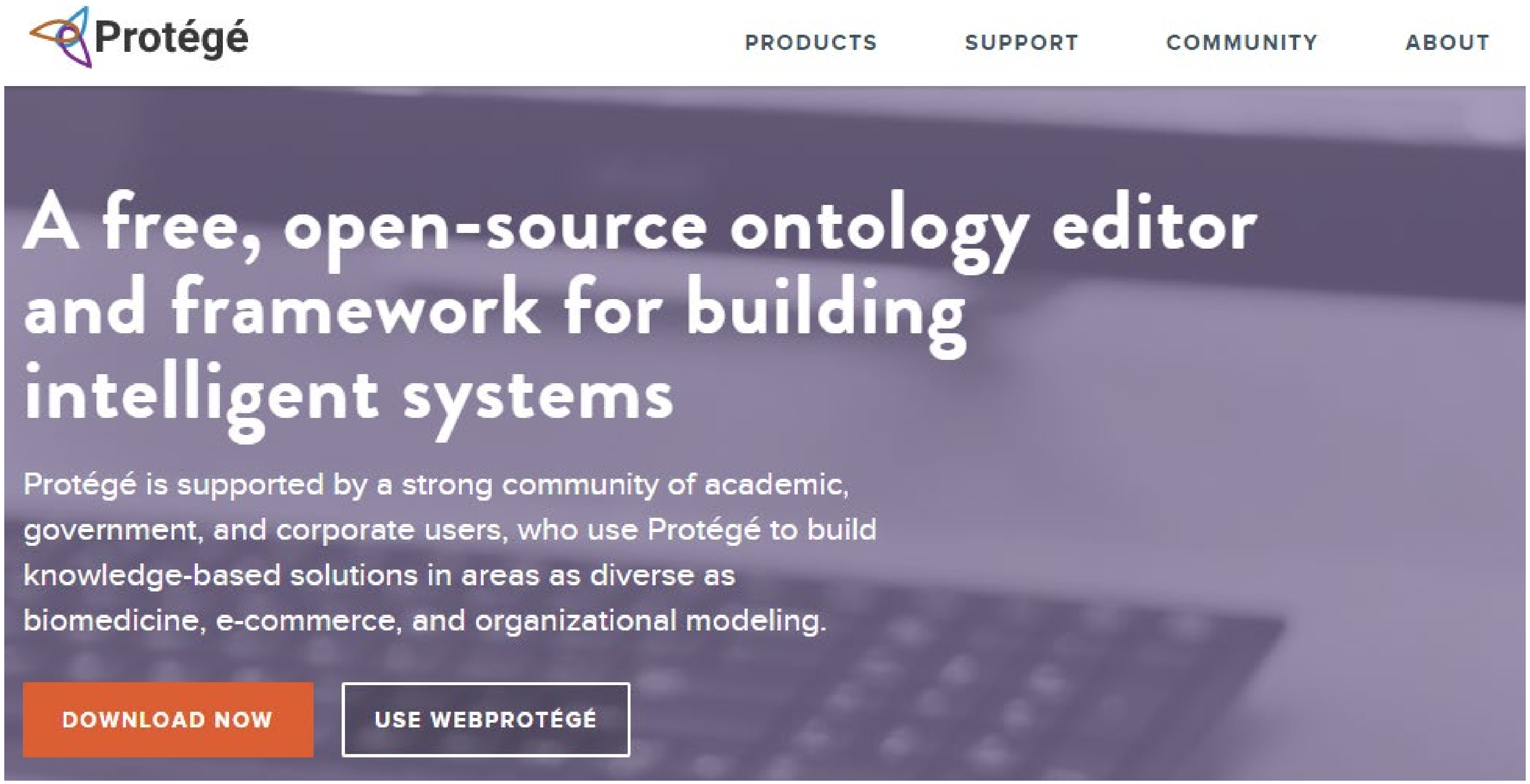
rdflib 5.0.0

RDFLib is a pure Python package for working with RDF. RDFLib contains useful APIs for working with RDF, including:

- **Parsers & Serializers**
  - for RDF/XML, N3, NTriples, N-Quads, Turtle, TriX, RDFa and Microdata
  - and JSON-LD, via a plugin module
- **Store implementations**
  - for in-memory and persistent RDF storage - Berkeley DB
- **Graph interface**
  - to a single graph
  - or a conjunctive graph (multiple Named Graphs)
  - or a dataset of graphs
- **SPARQL 1.1 implementation**
  - supporting both Queries and Updates

Tool: Ontology Engineering

https://protege.stanford.edu/



A free, open-source ontology editor and framework for building intelligent systems

Protégé is supported by a strong community of academic, government, and corporate users, who use Protégé to build knowledge-based solutions in areas as diverse as biomedicine, e-commerce, and organizational modeling.

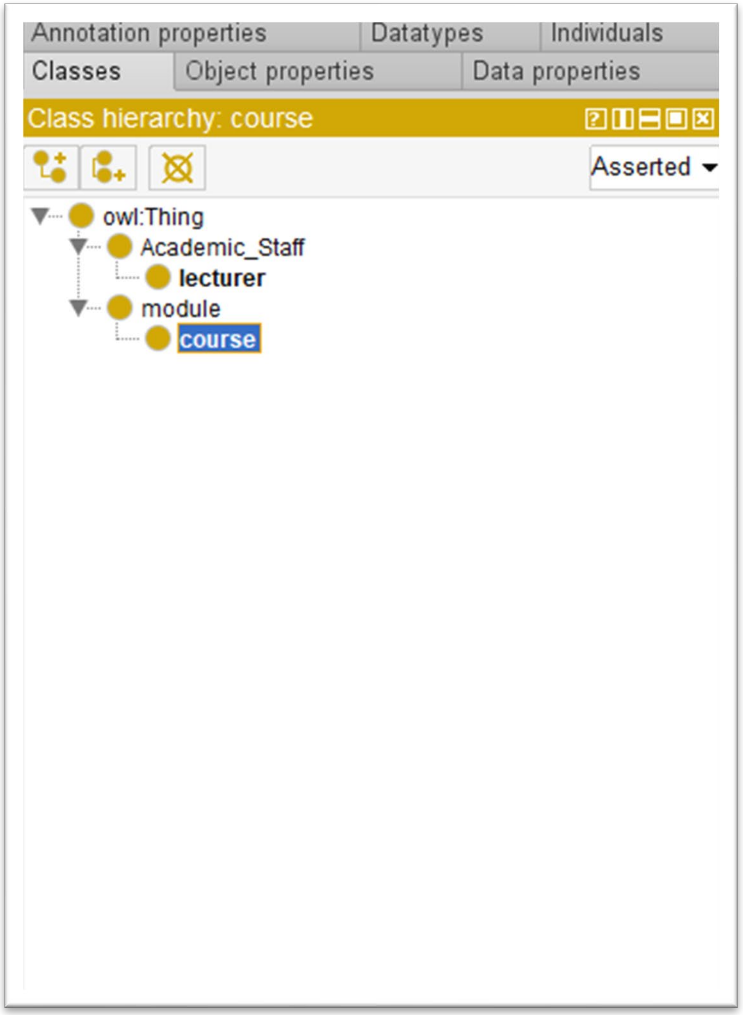
Creating an Ontology

- Defining classes in the ontology
- Arranging the classes in a taxonomic (subclass-superclass) hierarchy
- Defining properties and describing allowed values for the properties
- Creating instances and filling the values for properties

Define Classes and Class Hierarchy

- There are several approaches
  - Top-down: Start with the most general concept, and work your way down
  - Bottom-up: Start with the most specific, and work your way up
  - Combination

```
:Academic_Staff rdf:type owl:Class .
:lecturer rdf:type owl:Class ;
          rdfs:subClassOf :Academic_Staff .
:module rdf:type owl:Class .
:course rdf:type owl:Class ;
        rdfs:subClassOf :module .
```



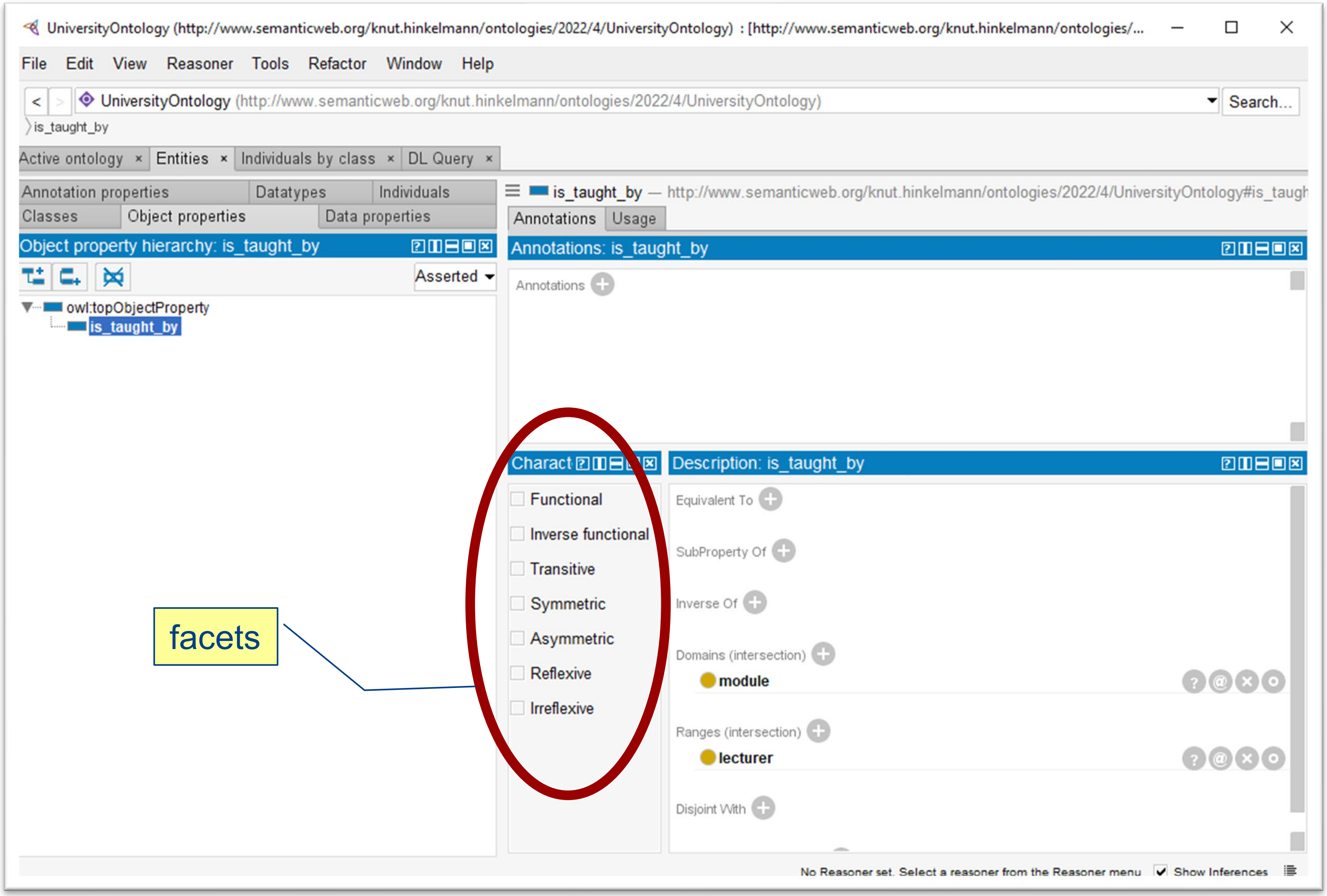
```
owl:Thing
  Academic_Staff
    lecturer
  module
    course
```

Define Properties of Classes

- Describe the internal structure of concepts
  - Data Properties: Attributes
    - Range are data types like String, Integer, …
  - Object Properties: Relations to other concepts
    - Range are Classes
- Desribe facets: Characteristics of Properties
- Inheritance to Subclasses

Object Property

```
:is_taught_by rdf:type owl:DatatypeProperty ;
              rdfs:subPropertyOf owl:topObjectProperty ;
              rdfs:domain :module;
              rdfs:range :lecturer .
```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UniversityOntology (http://www.semanticweb.org/knut.hinkelmann/ontologies/2022/4/UniversityOntology)

is_taught_by

is_taught_by — http://www.semanticweb.org/knut.hinkelmann/ontologies/2022/4/UniversityOntology#is_taugh

Object property hierarchy: is_taught_by

- owl:topObjectProperty
  - is_taught_by

Annotations: is_taught_by

Characteristics:
- [ ] Functional
- [ ] Inverse functional
- [ ] Transitive
- [ ] Symmetric
- [ ] Asymmetric
- [ ] Reflexive
- [ ] Irreflexive

Description: is_taught_by

Equivalent To

SubProperty Of

Inverse Of

Domains (intersection)
- module

Ranges (intersection)
- lecturer

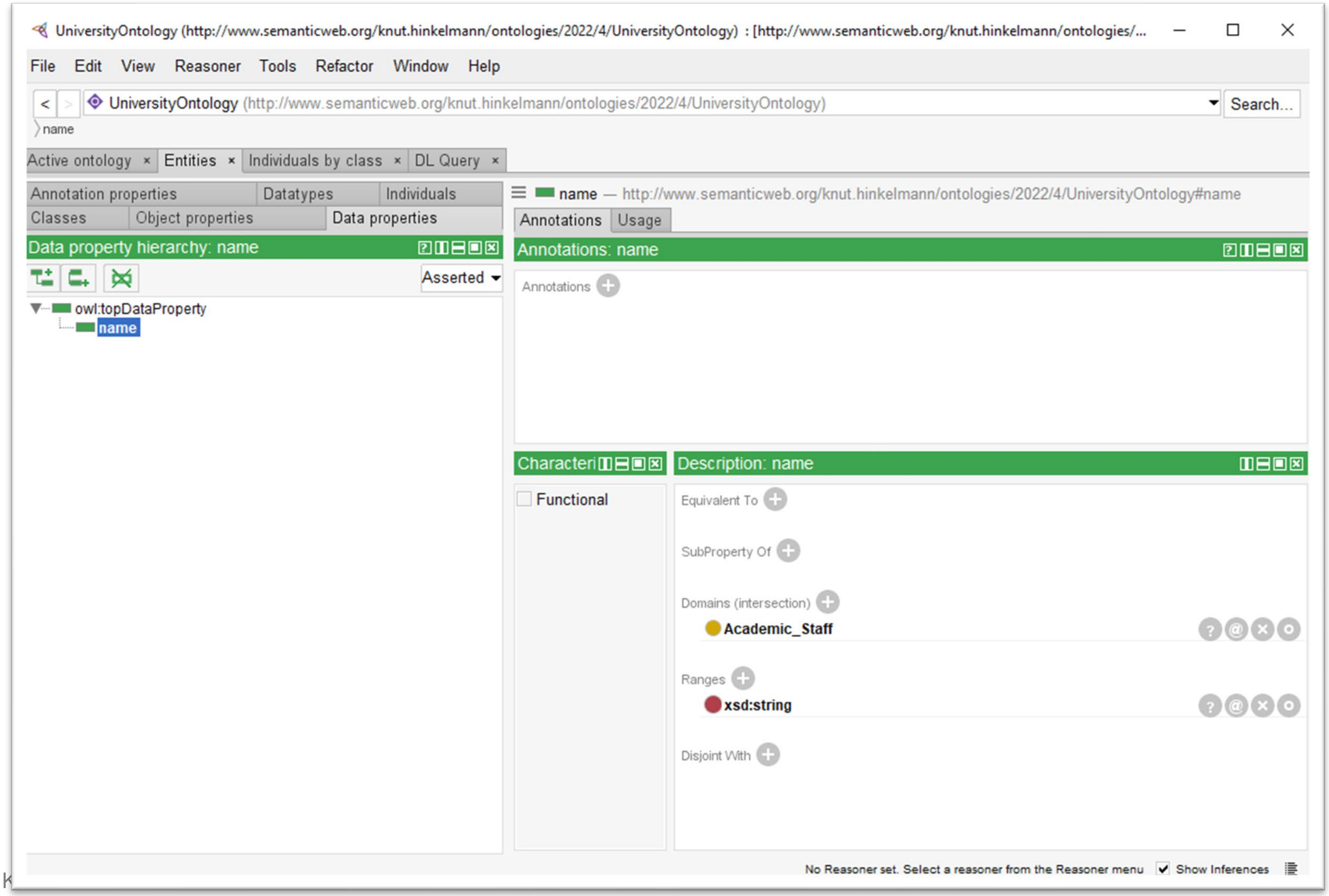
Disjoint With

No Reasoner set. Select a reasoner from the Reasoner menu [✓ Show Inferences]

facets

Data Property

```
:name rdf:type owl:DatatypeProperty ;
      rdfs:subPropertyOf owl:topDataProperty ;
      rdfs:domain :Academic_Staff ;
      rdfs:range xsd:string .
```



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UniversityOntology (http://www.semanticweb.org/knut.hinkelmann/ontologies/2022/4/UniversityOntology)

Search...

name

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

Annotation properties | Datatypes | Individuals | Classes | Object properties | Data properties

Data property hierarchy: name

Asserted

- owl:topDataProperty
  - name

name — http://www.semanticweb.org/knut.hinkelmann/ontologies/2022/4/UniversityOntology#name

Annotations | Usage

Annotations: name

Annotations

Characteri

☐ Functional

Description: name

Equivalent To

SubProperty Of

Domains (intersection)

Academic_Staff

Ranges

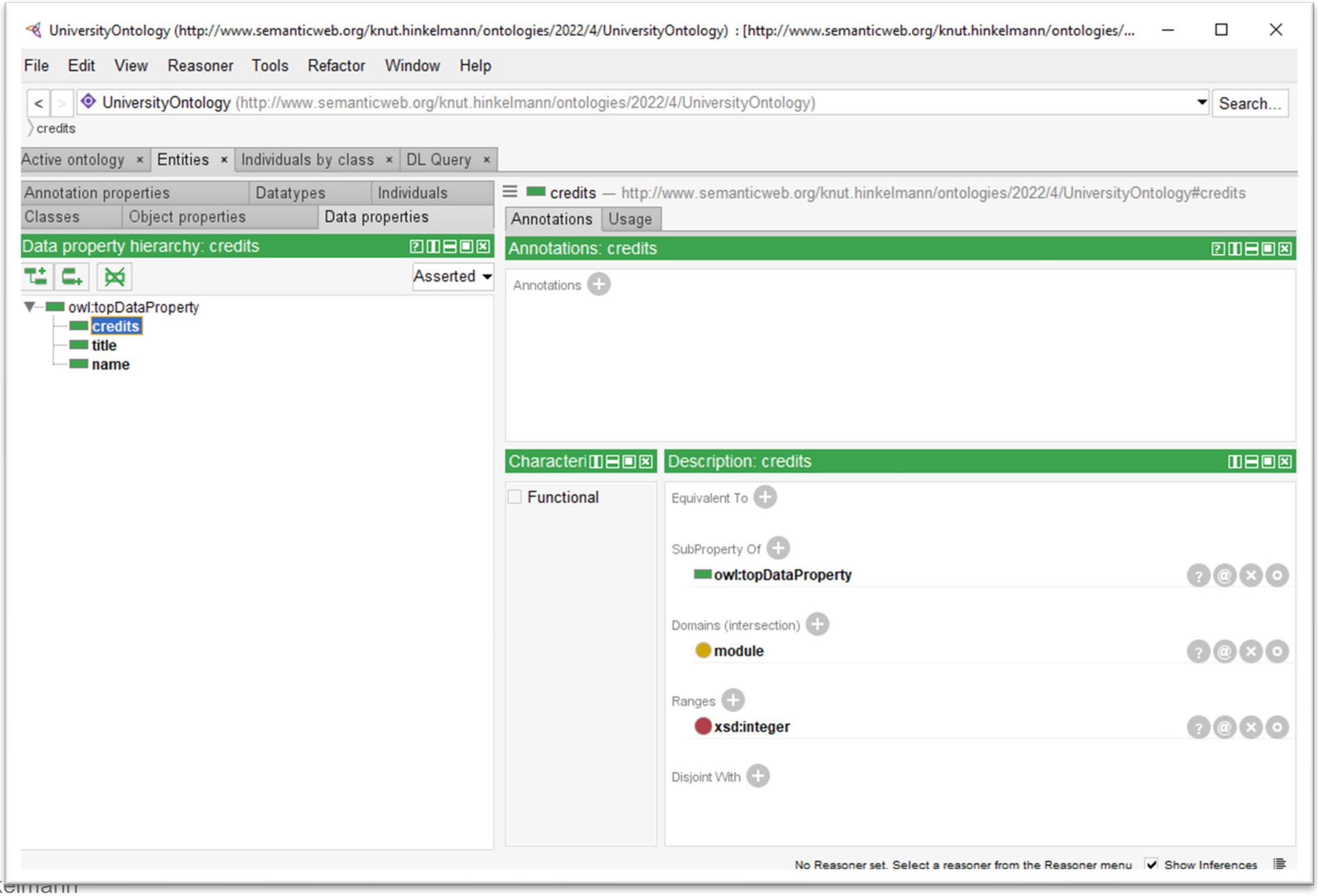
xsd:string

Disjoint With

No Reasoner set. Select a reasoner from the Reasoner menu ✓ Show Inferences

Data Property

```
:credits rdf:type owl:DatatypeProperty ;
         rdfs:subPropertyOf owl:topDataProperty ;
         rdfs:domain :module;
         rdfs:range xsd:integer .
```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Search...
credits
Active ontology Entities Individuals by class DL Query
Annotation properties Datatypes Individuals
Classes Object properties Data properties
Data property hierarchy: credits
Asserted

owl:topDataProperty
- credits
- title
- name

credits — http://www.semanticweb.org/knut.hinkelmann/ontologies/2022/4/UniversityOntology#credits

Annotations Usage
Annotations: credits
Annotations
Characteri
Description: credits

Functional

Equivalent To

SubProperty Of
owl:topDataProperty

Domains (intersection)
module

Ranges
xsd:integer

Disjoint With

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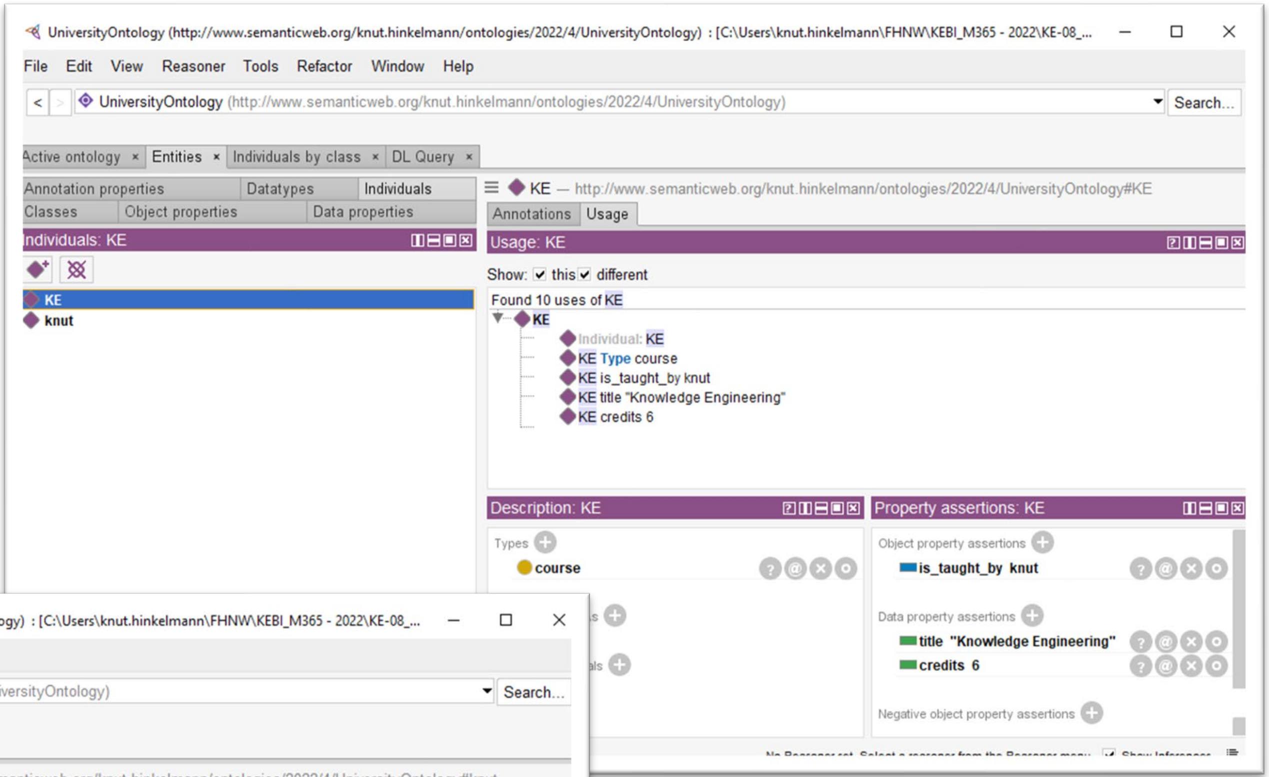
Individuals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Search...
Active ontology × Entities × Individuals by class × DL Query ×
Annotation properties Datatypes Individuals
Classes Object properties Data properties
Individuals: KE
KE — http://www.semanticweb.org/knut.hinkelmann/ontologies/2022/4/UniversityOntology#KE
Annotations Usage
Usage: KE
Show: ✓ this ✓ different
Description: KE
Property assertions: KE
Types
Object property assertions
Data property assertions
Negative object property assertions

KE
knut

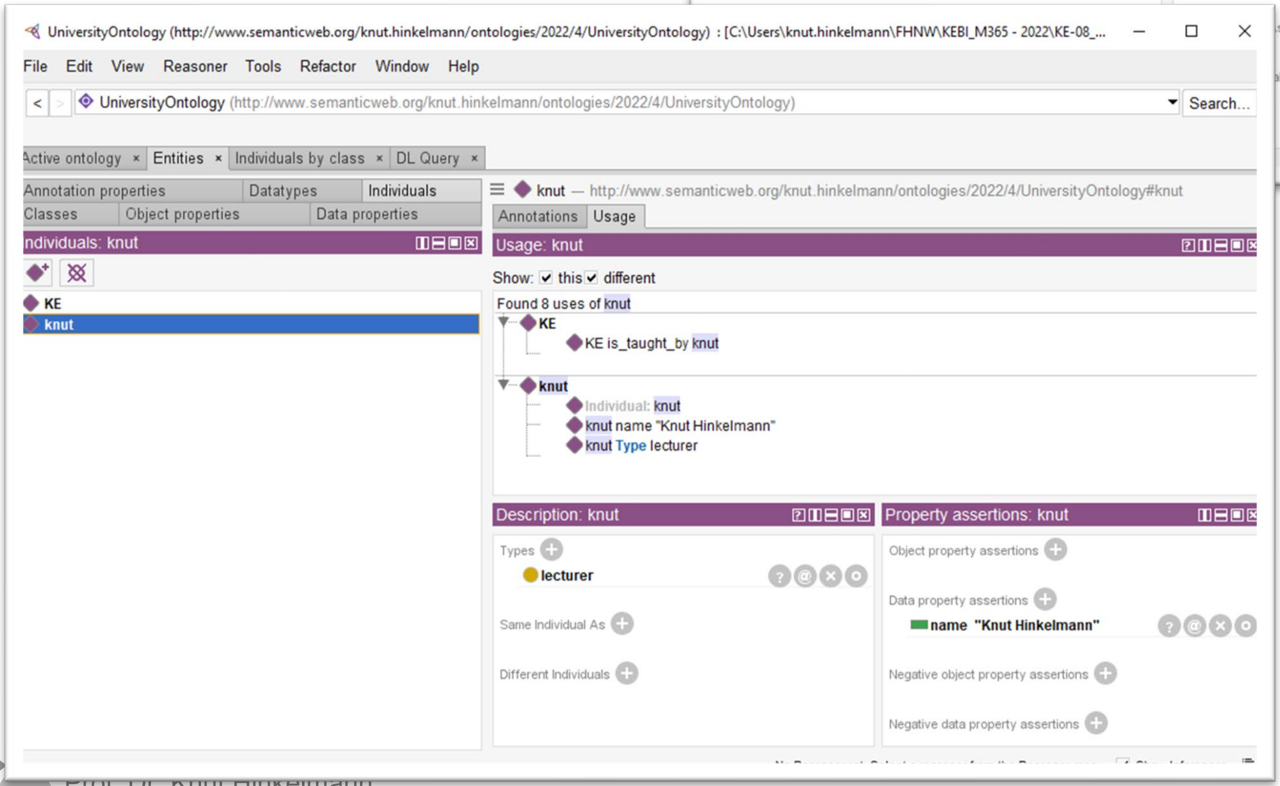
Found 10 uses of KE

```
KE
    Individual: KE
    KE Type course
    KE is_taught_by knut
    KE title "Knowledge Engineering"
    KE credits 6
```

Types: course

Object property assertions: is_taught_by knut

Data property assertions: title "Knowledge Engineering"; credits 6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Search...
Active ontology × Entities × Individuals by class × DL Query ×
Annotation properties Datatypes Individuals
Classes Object properties Data properties
Individuals: knut
knut — http://www.semanticweb.org/knut.hinkelmann/ontologies/2022/4/UniversityOntology#knut
Annotations Usage
Usage: knut
Show: ✓ this ✓ different
Description: knut
Property assertions: knut
Types
Same Individual As
Different Individuals
Object property assertions
Data property assertions
Negative object property assertions
Negative data property assertions

KE
knut

Found 8 uses of knut

```
KE
    KE is_taught_by knut
knut
    Individual: knut
    knut name "Knut Hinkelmann"
    knut Type lecturer
```

Types: lecturer

Data property assertions: name "Knut Hinkelmann"

```
:KE rdf:type owl:NamedIndividual ,
                 :course ;
    :is_taught_by :knut ;
    :credits 6 ;
     :title "Knowledge Engineering" .
:knut rdf:type owl:NamedIndividual ,
                   :lecturer ;
      :name "Knut Hinkelmann" .
```

Exercise

- Add new class: country
- Add a property: A lecturer lives in a country
- Add new instance: Knut lives in Switzerland
- Add new classes and properties for the following knowledge
  - A project is a module
  - A Master Thesis is a project
  - Supervisor is a lecturer
  - A project has a supervisor
  - A project is performed by a student
- Add new instances
  - Giordano is a student who is performing a master thesis that is supervised by knut

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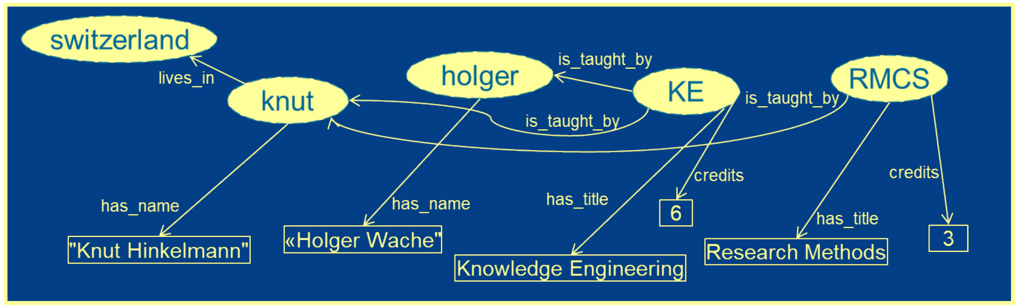
Querying an Ontology



- Queries are mostly about navigating the graph in search of some patterns
- Sample types of queries
  - Navigating along a graph path, e.g who are the lecturers of KE

    SELECT ?x WHERE {:KE :is_taught_by ?x}
  - Navigating along a graph path with intermediate values, e.g. what are the names of the lecturers of KE

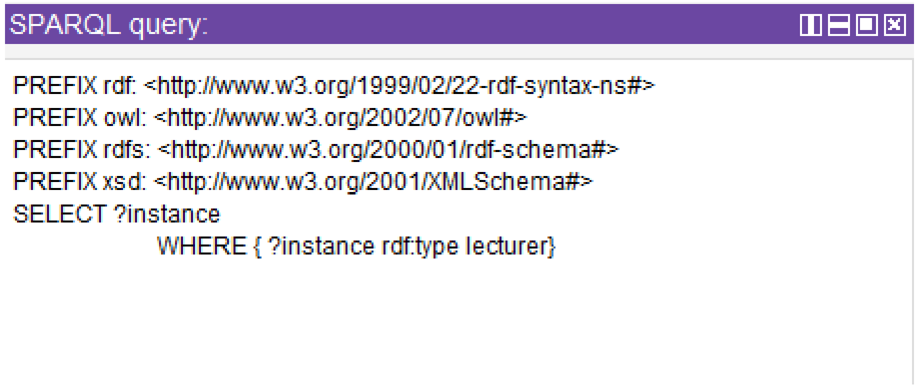
    SELECT ?x ?y WHERE {:KE :is_taught_by ?x.
    ?x :has_name ?y}
  - Navigating a path in reverse, e.g which modules is knut teaching

    SELECT ?x WHERE {?x :is_taught_by :knut}
  - Discover relationships, what is the relationship between KE and knut

    SELECT ?rel WHERE {:KE ?rel :knut}
  - Chain of relationships, what chain exists between KE and switzerland

    SELECT ?rel1 ?y ?rel2 WHERE {:KE ?rel1 ?y.
    ?y ?rel2 :switzerland}

Querying


SPARQL query:

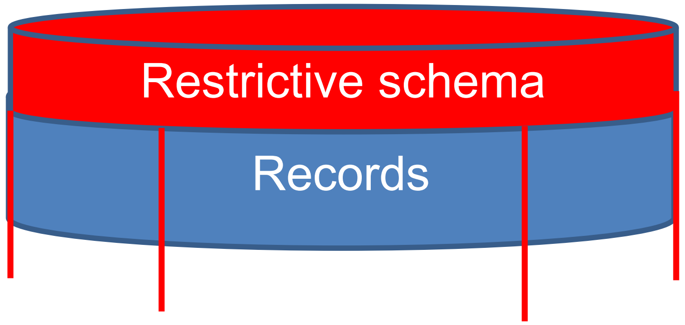
```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
SELECT ?instance
            WHERE { ?instance rdf:type lecturer}
```

- Query Language: SPARQL
  - Variables: ?x
- Elements are denoted as URI
  - Prefixes for Abbrevations
    - Example: PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
- Sample query: Select all lecturers:

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
PREFIX uo: <http://www.semanticweb.org/knut.hinkelmann/ontologies/2020/4/UniversityOntology#>
SELECT ?subject
         WHERE { ?subject rdf:type uo:lecturer }
```

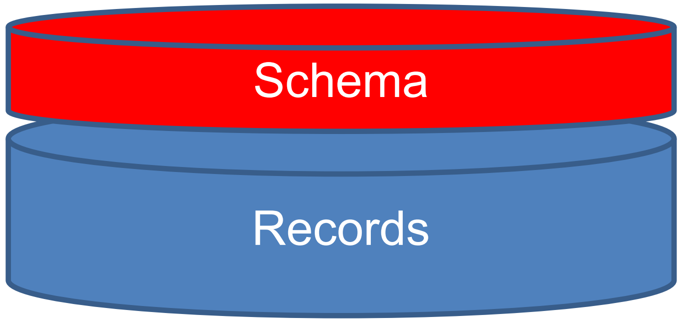
RDF Graphs vs Databases

In SQL databases, you cannot do anything before having a schema (the "DB structure")



In RDF graphs, ***schema is decoupled from "records"***

- Schema can be created after data
- Schema is optional (data can be queried in the absence of a schema)



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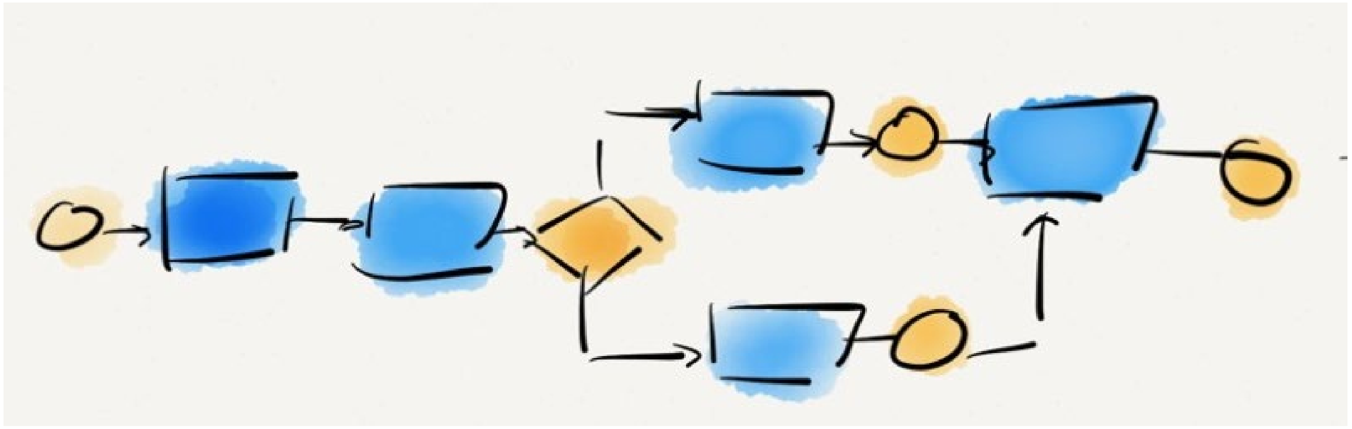
Exercise: Modeling Process Knowledge in an Ontology

Exercise: Modeling Process Knowledge in an Ontology

- We create a knowledge base for process knowledge
  - ♦ Define the ontology
  - ♦ Represent knowledge of a process



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Ontology Development 101

- Determine the domain and scope of the ontology
- Consider reusing existing ontologies
- Enumerate important terms
- Define classes and class hierarchy
- Define the data and object properties of classes
- Define the facets of properties
- Create instances

7

Determine the domain and scope of the ontology

- What is the domain that the ontology will cover?
- For what we are going to use the ontology?
- For what types of questions the information in the ontology should provide answers? → Competency questions
- Who will use and maintain the ontology?

Competency Questions

- One of the ways to determine the scope of the ontology is to sketch a list of questions that a knowledge base based on the ontology should be able to answer (Gruninger and Fox 1995)
  - Does the ontology contain enough information to answer these types of questions?
  - Do the answers require a particular level of detail or representation of a particular area?

- Exercise: We want to represent knowledge about
  - the process flow
  - Responsibilies for tasks
- Competency Questions:
  - Who executes task X?
  - Which task is executed after task X?
  - When can task X start?
- Sample process:

The waiter serves the beverages. Then the waiter serves the food. When the guests are finished, the waiter presents the bill.

Consider reusing existing ontologies

- It is always worth considering what others have done, and check if their work can be refined and extended for our particular domain and task
- Mandatory if the system needs to interact with other applications that have already committed to particular ontologies or controlled vocabularies

Enumerate important terms in the ontology

- What are the terms we would like to talk about?
- What are their properties?
- What would we like to say about those terms?

Define Classes and Class Hierarchy

- Several possible approaches in developing a class hierarchy:
  - Top-down: General to specific concepts
  - Bottom-up: Specific to general concepts
  - Combination: Salient to general and specific concepts
- Classes for
  - Modeling Objects
  - Relations

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Define the properties of classes

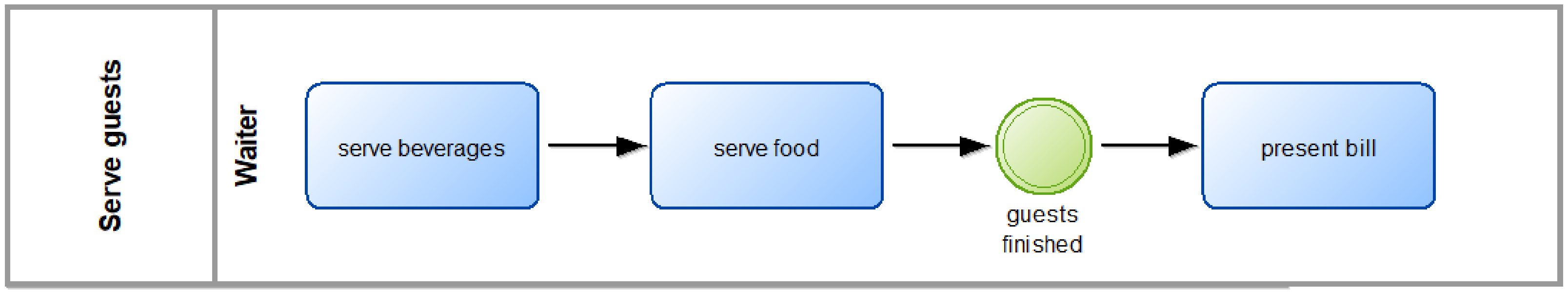
- Describe the internal structure of concepts
  - ♦ Data Properties: Attributes
    - Range are data typles like String, Integer, …
  - ♦ Object Properties: Relations to other concepts
    - Range are Classes
- Inheritance to Subclasses

Create Instances

- Model a business process in an ontology

The waiter serves the beverages. Then the waiter serves the food. When the guests are finished, the waiter presents the bill.

Modeling Business Processes as graphical models is more adequate



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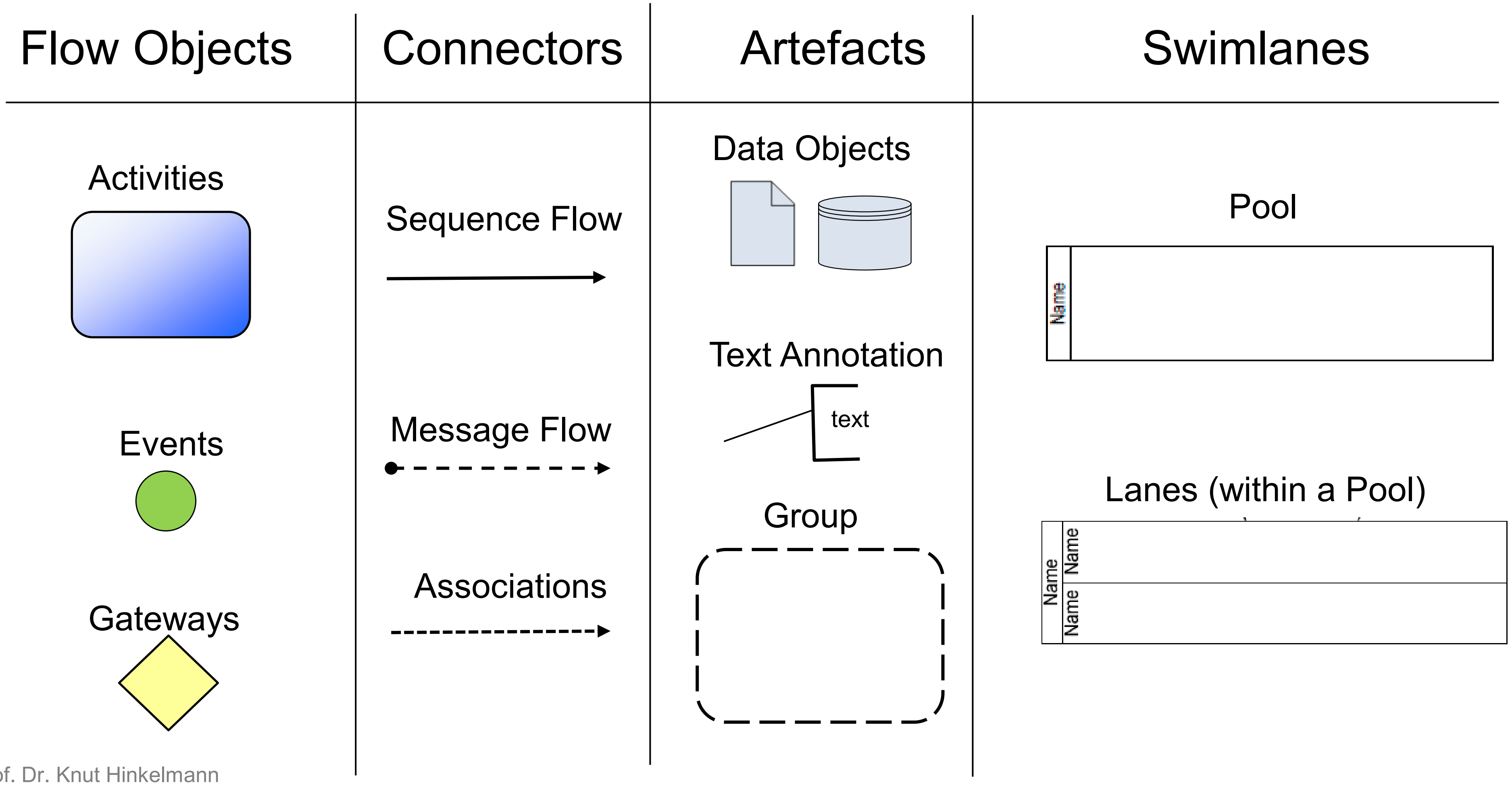
Elements of BPMN

Elements of BPMN can be divided into 4 categories:



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