TECHNISCHE UNIVERSITÄT DRESDEN

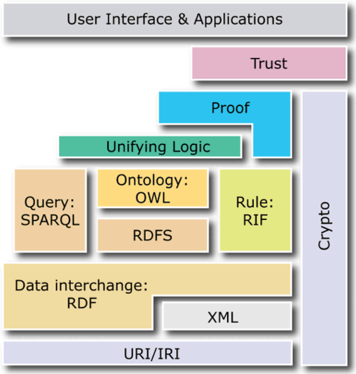
FOUNDATIONS OF SEMANTIC WEB TECHNOLOGIES

OWL – Syntax & Intuition

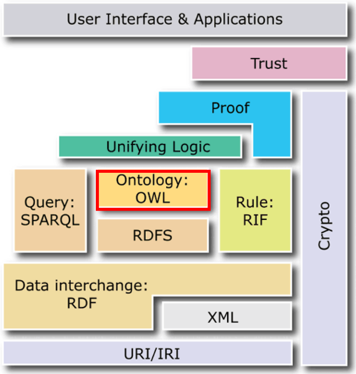
Sebastian Rudolph

DRESDEN concept
Exzellenz aus Wissenschaft und Kultur

OWL


User Interface & Applications
Trust
Proof
Unifying Logic
Query: SPARQL
Ontology: OWL
RDFS
Rule: RIF
Crypto
Data interchange: RDF
XML
URI/IRI

OWL



User Interface & Applications
Trust
Proof
Unifying Logic
Ontology: OWL
Query: SPARQL
RDFS
Rule: RIF
Crypto
Data interchange: RDF
XML
URI/IRI

Agenda

- Motivation
- OWL – General Remarks
- Classes, Roles and Individuals
- Class Relationships
- Complex Classes
- Role Characteristics
- OWL Variants
- OWL Ontologies: Reasoning Tasks

Agenda

- Motivation
- OWL – General Remarks
- Classes, Roles and Individuals
- Class Relationships
- Complex Classes
- Role Characteristics
- OWL Variants
- OWL Ontologies: Reasoning Tasks

Ontology in Philosophy

- notion exists only in sigular (no “ontologies”)
- denotes the “study of being”
- can be found in philosophical writings of Aristotle (Socrates), Thomas Aquinas, Descartes, Kant, Hegel, Wittgenstein, Heidegger, Quine, . . .
- term first mentioned in 17th century

Ontology in Computer Science

Gruber (1993):

"An Ontology is a

formal specification	$\Rightarrow$ interpretable by machines
of a shared	$\Rightarrow$ based on consensus
conceptualization	$\Rightarrow$ describes relevant notions
of a domain of interest"	$\Rightarrow$ referring to a "topic"

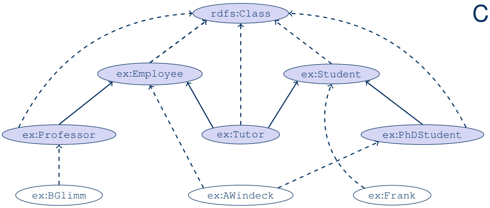
TECHNISCHE UNIVERSITÄT DRESDEN

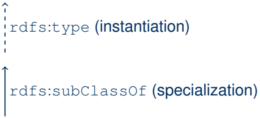
Ontologies in Practice
Some Requirements

- instantiation of classes by individuals
- conceptual hierarchies (taxonomies, “inheritance”): classes, concepts
- binary relations between individuals: properties, roles
- characteristics of relations (z.B. range, transitive)
- datatypes (e.g. numbers): concrete domains
- logical operators
- clear semantics

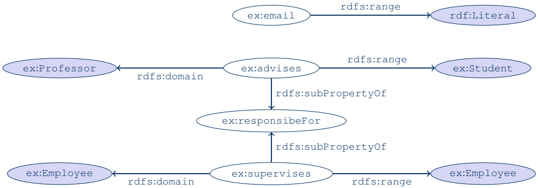
RDFS – Simple Ontologies

Classes





Relations



RDF Schema as Ontology Language?

- appropriate for simple ontologies
- advantage: automated inferencing relatively efficient
- but: not appropriate for more complex modeling
- resort to more expressive languages, like
  - OWL
  - RIF ...

Agenda

- Motivation
- OWL – General Remarks
- Classes, Roles and Individuals
- Class Relationships
- Complex Classes
- Role Characteristics
- OWL Variants
- OWL Ontologies: Reasoning Tasks

OWL – General Remarks

- W3C Recommendation since 2004
- semantic fragment of FOL
- three variants:
  - OWL Lite
  - OWL DL
  - OWL Full
- no reification in OWL DL

$\rightsquigarrow$ RDFS is fragment of OWL Full

- OWL DL is decidable
  corresponds to description logic SHOIN(D)
- W3C documents contain details that cannot all be covered here

OWL 1 Variants

- OWL Full
  - contains OWL DL and OWL Lite
  - contains all of RDFS (as the only OWL variant)
  - semantics contains some aspects that are problematic from a logical perspective
  - undecidable
  - limited support by tools

OWL 1 Variants

- OWL Full
  - contains OWL DL and OWL Lite
  - contains all of RDFS (as the only OWL variant)
  - semantics contains some aspects that are problematic from a logical perspective
  - undecidable
  - limited support by tools
- OWL DL
  - contains OWL Lite and is sublanguage of OWL Full
  - widely supported by tools
  - complexity NExpTime (worst-case)

OWL 1 Variants

- OWL Full
  - contains OWL DL and OWL Lite
  - contains all of RDFS (as the only OWL variant)
  - semantics contains some aspects that are problematic from a logical perspective
  - undecidable
  - limited support by tools
- OWL DL
  - contains OWL Lite and is sublanguage of OWL Full
  - widely supported by tools
  - complexity NExpTime (worst-case)
- OWL Lite
  - sublanguage of OWL DL and OWL Full
  - low expressivity
  - complexity ExpTime (worst-case)

OWL Documents

- are RDF documents
  (at least in the standard syntax; there are others)
- consist of
  - head with general information
  - rest with actual ontology

Head of an OWL Document

definition of name spaces in the root

```
<rdf:RDF
  xmlns="http://example.org/exampleontology#"
  xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
  xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
  xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
  xmlns:owl="http://www.w3.org/2002/07/owl#">
  ...
</rdf:RDF>
```

Head of an OWL Document

general information

```
<owl:Ontology rdf:about="">
  <rdfs:comment
    rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
   SWRC ontology, version of June 2007
  </rdfs:comment>
  <owl:versionInfo>v0.7.1</owl:versionInfo>
  <owl:imports rdf:resource="http://www.example.org/foo" />
  <owl:priorVersion
    rdf:resource="http://ontoware.org/projects/swrc" />
</owl:Ontology>
```

Head of an OWL Document

taken from RDFS

`rdfs:comment`
`rdfs:label`
`rdfs:seeAlso`
`rdfs:isDefinedBy`

in addition

`owl:imports`

for versioning

`owl:versionInfo`
`owl:priorVersion`
`owl:backwardCompatibleWith`
`owl:incompatibleWith`
`owl:DeprecatedClass`
`owl:DeprecatedProperty`

Agenda

- Motivation
- OWL – General Remarks
- Classes, Roles and Individuals
- Class Relationships
- Complex Classes
- Role Characteristics
- OWL Variants
- OWL Ontologies: Reasoning Tasks

Classes, Roles and Individuals

three building blocks of ontology axioms

- classes
  - comparable with classes in RDFS
- individuals
  - comparable with “proper” instances in RDFS
- roles
  - comparable with properties in RDFS

Classes

definition

- `<owl:Class rdf:about =¨Professor¨/>`
- equivalent to

```
<rdf:Description rdf:about="#Professor">
  <rdf:type
    rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
</rdf:Description>
```

pre-defined

- `owl:Thing`
- `owl:Nothing`

Individuals

definition via class membership

```
<rdf:Description rdf:about="rudiStuder">
  <rdf:type rdf:resource="#Professor"/>
</rdf:Description>
```

equivalent:

```
<Professor rdf:about="rudiStuder"/>
```

Abstract Roles

abstract roles are defined in a way similar to classes

```
<owl:ObjectProperty rdf:about="hasAffiliation" />
```

domain and range of abstract roles

```
<owl:ObjectProperty rdf:about="hasAffiliation">
  <rdfs:domain rdf:resource="Person" />
  <rdfs:range rdf:resource="Organization" />
</owl:ObjectProperty>
```

Concrete Roles

concrete roles have datatypes as range

```
<owl:DatatypeProperty rdf:about="firstName" />
```

domain and range of concrete roles

```
<owl:DatatypeProperty rdf:about="firstName">
  <rdfs:domain rdf:resource="Person" />
  <rdfs:range rdf:resource="&xsd;string" />
</owl:DatatypeProperty>
```

many XML datatypes can be used

Individuals and Roles

```
<Person rdf:about="rudiStuder">
   <hasAffiliation rdf:resource="aifb" />
   <hasAffiliation rdf:resource="fzi" />
   <firstName rdf:datatype="&xsd;string">
     Rudi
   </firstName>
</Person>
```

in general roles are not functional

Agenda

- Motivation
- OWL – General Remarks
- Classes, Roles and Individuals
- Class Relationships
- Complex Classes
- Role Characteristics
- OWL Variants
- OWL Ontologies: Reasoning Tasks

TECHNISCHE UNIVERSITÄT DRESDEN

Simple Class Relationships

```
<owl:Class rdf:about="Professor">
 <rdfs:subClassOf rdf:resource="FacultyMember" />
</owl:Class>
<owl:Class rdf:about="FacultyMember">
 <rdfs:subClassOf rdf:resource="Person" />
</owl:Class>
```

it follows by inference that `Professor` is a subclass of `Person`

Simple Class Relationships

```
<owl:Class rdf:about="Professor">
  <rdfs:subClassOf rdf:resource="FacultyMember" />
</owl:Class>
<owl:Class rdf:about="Book">
  <rdfs:subClassOf rdf:resource="Publication" />
</owl:Class>
<owl:Class rdf:about="FacultyMember">
  <owl:disjointWith rdf:resource="Publication" />
</owl:Class>
```

it follows by inference that `Professor` and `Book` are also disjoint classes

Simple Class Relationships

```
<owl:Class rdf:about="Man">
  <rdfs:subClassOf rdf:resource="Person" />
</owl:Class>
<owl:Class rdf:about="Person">
  <owl:equivalentClass rdf:resource="Human" />
</owl:Class>
```

it follows by inference that `Man` is a subclass of `Human`

Individuals and Class Relationships

```
<Book rdf:about="http://semantic-web-book.org/uri">
<author rdf:resource="pascalHitzler" />
<author rdf:resource="markusKroetzsch" />
<author rdf:resource="sebastianRudolph" />
</Book>
<owl:Class rdf:about="Book">
<rdfs:subClassOf rdf:resource="Publication" />
</owl:Class>
```

it follows by inference that `Foundations of Semantic Web Technologies` is a `Publication`.

TECHNISCHE UNIVERSITÄT DRESDEN

Relationships between Individuals

```
<Professor rdf:about="rudiStuder" />
  <rdf:Description rdf:about="rudiStuder">
  <owl:sameAs rdf:resource="professorStuder" />
</rdf:Description>
```

it follows by inference that `rudiStuder` is a `Professor`
distinctness of individuals expressed via `owl:differentFrom`.

Relationships between Individuals

```
<owl:AllDifferent>
<owl:distinctMembers rdf:parseType="Collection">
<Person rdf:about="rudiStuder" />
<Person rdf:about="dennyVrandecic" />
<Person rdf:about="peterHaase" />
</owl:distinctMembers>
</owl:AllDifferent>
```

abbreviated notation instead of using several `owl:differentFrom`

usage of `owl:AllDifferent` and `owl:distinctMembers` exclusively for this purpose

TECHNISCHE UNIVERSITÄT DRESDEN

Closed Classes

```
<owl:Class rdf:about="SecretariesOfStuder">
  <owl:oneOf rdf:parseType="Collection">
    <Person rdf:about="giselaSchillinger" />
    <Person rdf:about="anneEberhardt" />
  </owl:oneOf>
</owl:Class>
```

tells that there are only exactly these two `SecretariesOfStuder`

Agenda

- Motivation
- OWL – General Remarks
- Classes, Roles and Individuals
- Class Relationships
- Complex Classes
- Role Characteristics
- OWL Variants
- OWL Ontologies: Reasoning Tasks

Logical Class Constructors

- logical `and` (conjunction):
  `owl:intersectionOf`
- logical `or` (disjunction):
  `owl:unionOf`
- logical `not` (negation):
  `owl:complementOf`
- used to construct complex classes from simple classes

TECHNISCHE UNIVERSITÄT DRESDEN

Conjunction

```
<owl:Class rdf:about="SecretariesOfStuder">
  <owl:intersectionOf rdf:parseType="Collection">
    <owl:Class rdf:about="Secretaries" />
    <owl:Class rdf:about="MembersOfStudersGroup" />
  </owl:intersectionOf>
</owl:Class>
```

it follows by inference that all `SecretariesOfStuder` are also `Secretaries`

Disjunction

```
<owl:Class rdf:about="Professor">
  <rdfs:subClassOf>
    <owl:Class>
      <owl:unionOf rdf:parseType="Collection">
        <owl:Class rdf:about="ActivelyTeaching" />
        <owl:Class rdf:about="Retired" />
      </owl:unionOf>
    </owl:Class>
  </rdfs:subClassOf>
</owl:Class>
```

Negation

```
<owl:Class rdf:about="FacultyMember">
  <rdfs:subClassOf>
    <owl:Class>
      <owl:complementOf rdf:resource="Publication" />
    </owl:Class>
  </rdfs:subClassOf>
</owl:Class>
```

semantically equivalent:

```
<owl:Class rdf:about="FacultyMember">
  <owl:disjointWith rdf:resource="Publication" />
</owl:Class>
```

Role Restrictions (allValuesFrom)

used to define complex classes via roles

```
<owl:Class rdf:about="Exam">
  <rdfs:subClassOf>
    <owl:Restriction>
      <owl:onProperty rdf:resource="hasExaminer" />
      <owl:allValuesFrom rdf:resource="Professor" />
    </owl:Restriction>
  </rdfs:subClassOf>
</owl:Class>
```

i.e., all examiners of an exam have to be professors

Role Restrictions (someValuesFrom)

```
<owl:Class rdf:about="Exam">
  <rdfs:subClassOf>
    <owl:Restriction>
      <owl:onProperty rdf:resource="hasExaminer" />
      <owl:someValuesFrom rdf:resource="Person" />
    </owl:Restriction>
  </rdfs:subClassOf>
</owl:Class>
```

i.e., every exam must have at least one examiner

TECHNISCHE UNIVERSITÄT DRESDEN

Role Restrictions (Cardinalities)

```
<owl:Class rdf:about="Exam">
  <rdfs:subClassOf>
    <owl:Restriction>
      <owl:onProperty rdf:resource="hasExaminer"/>
      <owl:maxCardinality
        rdf:datatype="&xsd;nonNegativeInteger">
        2
      </owl:maxCardinality>
    </owl:Restriction>
  </rdfs:subClassOf>
</owl:Class>
```

an exam may have at most two examiners

Role Restrictions (Cardinalities)

```
<owl:Class rdf:about="Exam">
  <rdfs:subClassOf>
    <owl:Restriction>
      <owl:onProperty rdf:resource="hasTopic"/>
      <owl:minCardinality
        rdf:datatype="&xsd;nonNegativeInteger">3
      </owl:minCardinality>
    </owl:Restriction>
  </rdfs:subClassOf>
</owl:Class>
```

an exam must cover at least three topics

Role Restrictions (Cardinalities)

```
<owl:Class rdf:about="Exam">
  <rdfs:subClassOf>
    <owl:Restriction>
      <owl:onProperty rdf:resource="hasTopic"/>
      <owl:cardinality
        rdf:datatype="&xsd;nonNegativeInteger">3
      </owl:cardinality>
    </owl:Restriction>
  </rdfs:subClassOf>
</owl:Class>
```

an exam must cover exactly three topics

Role Restrictions (hasValue)

```
<owl:Class rdf:about="ExamStuder">
  <owl:equivalentClass>
    <owl:Restriction>
      <owl:onProperty rdf:resource="hasExaminer" />
      <owl:hasValue rdf:resource="rudiStuder" />
    </owl:Restriction>
  </owl:equivalentClass>
</owl:Class>
```

`owl:hasValue` always refers to one singular individual
the above is equivalent to the example on the next slide

Role Restrictions (hasValue)

```
<owl:Class rdf:about="ExamStuder">
  <owl:equivalentClass>
    <owl:Restriction>
      <owl:onProperty rdf:resource="hasExaminer" />
      <owl:someValuesFrom>
        <owl:oneOf rdf:parseType="Collection">
          <owl:Thing rdf:about="rudiStuder" />
        </owl:oneOf>
      </owl:someValuesFrom>
    </owl:Restriction>
  </owl:equivalentClass>
</owl:Class>
```

Agenda

- Motivation
- OWL – General Remarks
- Classes, Roles and Individuals
- Class Relationships
- Complex Classes
- Role Characteristics
- OWL Variants
- OWL Ontologies: Reasoning Tasks

Role Relationships

```
<owl:ObjectProperty rdf:about="hasExaminer">
  <rdfs:subPropertyOf rdf:resource="hasParticipant" />
</owl:ObjectProperty>
```

likewise: `owl:equivalentProperty`

roles can be inverses of each other:

```
<owl:ObjectProperty rdf:about="hasExaminer">
  <owl:inverseOf rdf:resource="examinerOf"/>
</owl:ObjectProperty>
```

Role Characteristics

- domain
- range
- transitivity, i.e.
  `r(a, b)` and `r(b, c)` imply `r(a, c)`
- symmetry, i.e.
  `r(a, b)` implies `r(b, a)`
- functionality
  `r(a, b)` and `r(a, c)` imply `b = c`
- inverse functionality
  `r(a, b)` and `r(c, b)` imply `a = c`

Domain and Range

```
<owl:ObjectProperty rdf:about="isMemberOf">
  <rdfs:range rdf:resource="Organization" />
</owl:ObjectProperty>
```

equivalent to:

```
<owl:Class rdf:about="&owl;Thing">
  <rdfs:subClassOf>
    <owl:Restriction>
      <owl:onProperty rdf:resource="isMemberOf" />
      <owl:allValuesFrom rdf:resource="Organization" />
    </owl:Restriction>
  </rdfs:subClassOf>
</owl:Class>
```

Domain and Range: Caution!

```
<owl:ObjectProperty rdf:about="isMemberOf">
  <rdfs:range rdf:resource="Organization" />
</owl:ObjectProperty>
<number rdf:about="five">
  <isMemberOf rdf:resource="PrimeNumbers" />
</number>
```

it follows that `PrimeNumbers` are an Organization!

Role Characteristics

```
<owl:ObjectProperty rdf:about="hasColleague">
  <rdf:type rdf:resource="&owl;TransitiveProperty" />
  <rdf:type rdf:resource="&owl;SymmetricProperty" />
</owl:ObjectProperty>
<owl:ObjectProperty rdf:about="hasProjectLeader">
  <rdf:type rdf:resource="&owl;FunctionalProperty" />
</owl:ObjectProperty>
<owl:ObjectProperty rdf:about="isProjectLeaderFor">
  <rdf:type rdf:resource="&owl;InverseFunctionalProperty" />
</owl:ObjectProperty>
<Person rdf:about="peterHaase">
  <hasColleague rdf:resource="philippCimiano" />
  <hasColleague rdf:resource="steffenLamparter" />
  <isProjectLeaderFor rdf:resource="neOn" />
</Person>
<Project rdf:about="x-Media">
  <hasProjectLeader rdf:resource="philippCimiano" />
  <hasProjectLeader rdf:resource="cimianoPhilipp" />
</Project>
```

Consequences from the Example

- `steffenLamparter` `hasColleague` `peterHaase`
- `steffenLamparter` `hasColleague` `philippCimiano`
- `philippCimiano` `owl:sameAs` `cimianoPhilipp`

Agenda

- Motivation
- OWL – General Remarks
- Classes, Roles and Individuals
- Class Relationships
- Complex Classes
- Role Characteristics
- OWL Variants
- OWL Ontologies: Reasoning Tasks

OWL 1 Variants

- OWL Full
  - contains OWL DL and OWL Lite
  - contains all of RDFS (as the only OWL variant)
  - semantics contains some aspects that are problematic from a logical perspective
  - undecidable
  - limited support by tools

OWL 1 Variants

- OWL Full
  - contains OWL DL and OWL Lite
  - contains all of RDFS (as the only OWL variant)
  - semantics contains some aspects that are problematic from a logical perspective
  - undecidable
  - limited support by tools
- OWL DL
  - contains OWL Lite and is sublanguage of OWL Full
  - widely supported by tools
  - complexity NExpTime (worst-case)

OWL 1 Variants

- OWL Full
  - contains OWL DL and OWL Lite
  - contains all of RDFS (as the only OWL variant)
  - semantics contains some aspects that are problematic from a logical perspective
  - undecidable
  - limited support by tools
- OWL DL
  - contains OWL Lite and is sublanguage of OWL Full
  - widely supported by tools
  - complexity NExpTime (worst-case)
- OWL Lite
  - sublanguage of OWL DL and OWL Full
  - low expressivity
  - complexity ExpTime (worst-case)

TECHNISCHE UNIVERSITÄT DRESDEN

OWL Full

- unrestricted use of all OWL and RDFS language elements (has to be valid RDFS)
- difficult e.g.: non-existent type separation (classes, roles, individuals), thus:
  - `owl:Thing` becomes the same as `rdfs:resource`
  - `owl:Class` becomes the same as `rdfs:Class`
  - `owl:DatatypeProperty` becomes a subclass of `owl:ObjectProperty`
  - `owl:ObjectProperty` becomes the same as `rdf:Property`

Example for Confusion of Types in OWL Full

```
<owl:Class rdf:about="Book">
  <germanName rdf:datatype="&xsd;string">Buch</germanName>
  <frenchName rdf:datatype="&xsd;string">livre</frenchName>
</owl:Class>
```

inferences about such constructs are rarely needed in practice

OWL DL

- only usage of RDFS language elements that are explicitly allowed (like those in our examples)
  not allowed: `rdfs:Class`, `rdfs:Property`
- type separation: classes and roles have to be explicitly declared
- concrete roles must not be specified as transitive, symmetric, inverse or inverse functional
- number restrictions must not be used with transitive roles, their subroles, or inverses thereof

OWL Lite

- all restrictions of OWL DL
- moreover:
  - not allowed: `oneOf`, `unionOf`, `complementOf`, `hasValue`, `disjointWith`
  - number restrictions only allowed with 0 and 1
  - some constraints referring to anonymous (complex) classes, e.g., only in the subject of `rdfs:subClassOf`

Agenda

- Motivation
- OWL – General Remarks
- Classes, Roles and Individuals
- Class Relationships
- Complex Classes
- Role Characteristics
- OWL Variants
- OWL Ontologies: Reasoning Tasks

Terminological Queries to OWL Ontologies

- class equivalence
- subclass relationships
- disjointness of classes
- global consistency (aka satisfiability)
- class consistency: a class is inconsistent if it is equivalent to `owl:Nothing` – this hints to a modeling error:

```
<owl:Class rdf:about="Book">
  <owl:subClassOf rdf:resource="Publication"/>
  <owl:disjointWith rdf:resource="Publication"/>
</owl:Class>
```

Assertional Queries to OWL Ontologies

- instance checking: does a given individual belong to a given class?
- search for all individuals that are members of a given class
- are two given individuals linked by a role?
- search for all individual pairs that are linked by a certain role
- ... caution: only “provable” answers will be given!

OWL 1 Language Elements

head

- rdfs:comment
- rdfs:label
- rdfs:seeAlso
- rdfs:isDefinedBy
- owl:versionInfo
- owl:priorVersion
- owl:backwardCompatibleWith
- owl:incompatibleWith
- owl:DeprecatedClass
- owl:DeprecatedProperty
- owl:imports

relationships between individuals

- owl:sameAs
- owl:differentFrom
- owl:AllDifferent
- owl:distinctMembers

pre-defined datatypes (OWL 1)

- xsd:strong
- xsd:integer

OWL Language Elements

class constructors and -relationships

- `owl:Class`
- `owl:Thing`
- `owl:Nothing`
- `rdfs:subClassOf`
- `owl:disjointWith`
- `owl:equivalentClass`
- `owl:intersectionOf`
- `owl:unionOf`
- `owl:complementOf`

role restrictions

- `owl:allValuesFrom`
- `owl:someValuesFrom`
- `owl:hasValue`
- `owl:cardinality`
- `owl:minCardinality`
- `owl:maxCardinality`
- `owl:oneOf`

OWL Language Elements

role constructors, relationships and characteristics

- owl:ObjectProperty
- owl:DatatypeProperty
- rdfs:subPropertyOf
- owl:equivalentProperty
- owl:inverseOf
- rdfs:domain
- rdfs:range
- owl:TransitiveProperty
- owl:SymmetricProperty
- owl:FunctionalProperty
- owl:InverseFunctionalProperty

Further Literature

- `http://www.w3.org/2004/OWL/`
  central W3C web page for OWL
- `http://www.w3.org/TR/owl-features/`
  overview over OWL
- `http://www.w3.org/TR/owl-ref/`
  comprehensive description of the OWL language components
- `http://www.w3.org/TR/owl-guide/`
  introduction into OWL knowledge modeling
- `http://www.w3.org/TR/owl-semantics/`
  describes the semantics of OWL and the abstract syntax for OWL DL ($\rightsquigarrow$ later lecture)