U N I K A S S E L
V E R S I T Ä T

ENDOWED CHAIR OF THE HERTIE FOUNDATION
Knowledge and Data Engineering
ELECTRICAL ENGINEERING & COMPUTER SCIENCE, UNIVERSITY OF KASSEL

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Teil IV: Wissensrepräsentation im WWW

Kap.11: Semantic Web

Dieses Kapitel basiert weitgehend auf Material von Pascal Hitzler. Weitere Infos gibt es in dem Buch [Grigoris Antoniou, Frank von Harmelen: A Semantic Web Primer, MIT Press, Cambridge 2004]

Semantic Web

In diesem Kapitel betrachten wir, wie Wissensrepräsentation aus dem World Wide Web ein Semantic Web machen kann.

Das Semantic Web ist eine Vision von Tim Berners-Lee, dem Erfinder des WWW.

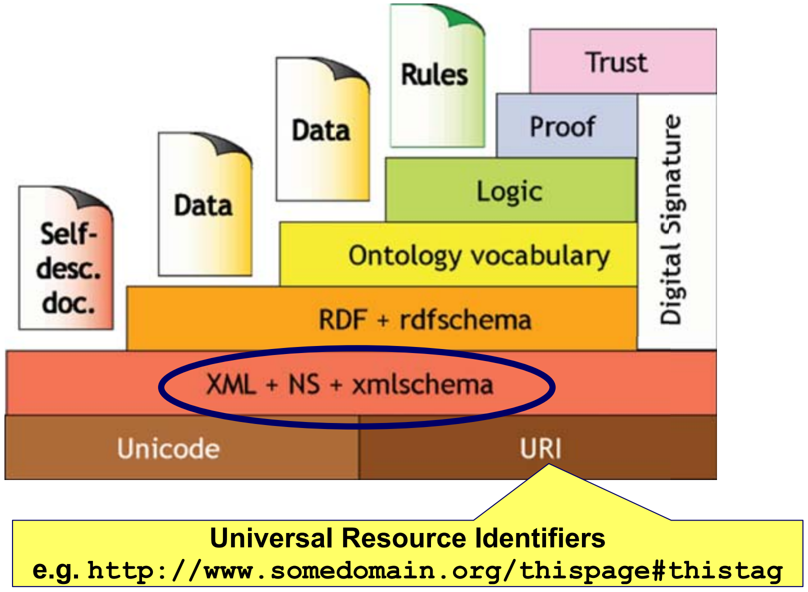
Die Kernidee ist die explizite Repräsentation von Wissen im WWW, so dass es von Such- und anderen Maschinen verwendet werden kann.

Unsere Darstellung basiert auf den Kapiteln 1 bis 4 des Buchs

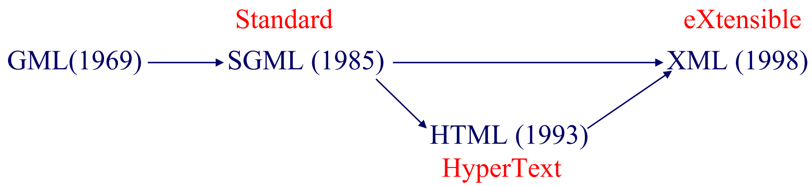
Grigoris Antoniou, Frank von Harmelen: A Semantic Web Primer, MIT Press, Cambridge 2004

Unter http://www.semanticwebprimer.org sind Folien, Beispiele etc. online zu finden. Auf diesem Foliensatz basieren auch die nachfolgenden Abschnitte.

The semantic web layer cake



XML



- eXtensible Markup Language
- Web standard (W3C) for data exchange:
  - Description of in- and output data of applications
  - Reduces degrees of freedom for industrial data description standards
- Complementary to HTML:
  - HTML describes presentation
  - XML describes content
- Database perspective: XML as data model for semi-structured data.

XML syntax (1) - XML element

XML element:

- Desription of an object, which is embraced by matching tags like <author> and </author>.
- Content of an element: Text and/or other (sub)elements.
- Elements can be nested
- Elements can be empty: <year></year> (short: <year/>)

Start tag → `<author>`

subelements:

```
<author>
  <firstname> Bernhard </firstname>
  <lastname> Ganter </lastname>
  <email> ganter@tu-dresden.de </email>
  email address may be wrong!
</author>
```

text → email address may be wrong!

End tag → `</author>`

Element author

XML syntax (2) - XML attribute

XML attribute:

- Name-string pair
- Associated with an element
- Alternative way for describing data

Attribute email

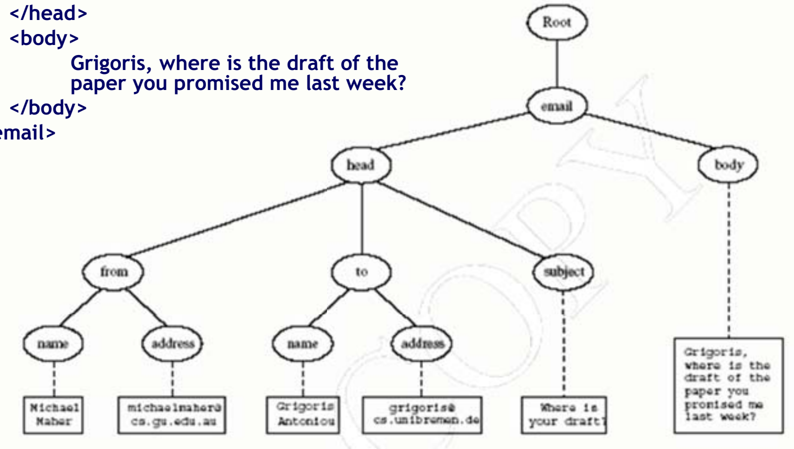
```
<author email="ganter@tu-dresden.de">
  <firstname> Bernhard </firstname>
  <lastname> Ganter </lastname>
</author>
```

Alternative description of the same(?) data:

```
<author firstname="Bernhard" lastname="Ganter" email="ganter@tu-dresden.de"/>
```


The Tree Model of XML Documents: An Example

```
<email>
    <head>
        <from name="Michael Maher"
                address="michaelmaher@cs.gu.edu.au"/>
        <to name="Grigoris Antoniou"
                address="grigoris@cs.unibremen.de"/>
        <subject>Where is your draft?</subject>
    </head>
    <body>
        Grigoris, where is the draft of the
        paper you promised me last week?
    </body>
</email>
```



The Tree Model of XML Docs

The tree representation of an XML document is an ordered labeled tree:

- There is exactly one root
- There are no cycles
- Each non-root node has exactly one parent
- Each node has a label.
- The order of elements is important
- … but the order of attributes is not important

Path Expressions in XPath

XPath is core for XML query languages.
Language for addressing parts of an XML document.

- It operates on the tree data model of XML.
- It has a non-XML syntax .

Examples

- Address all books with title "Artificial Intelligence"
  /book[@title="Artificial Intelligence"]
- Address the first author element node in the XML document
  //author[1]
- Address the last book element within the first author element node in the document
  //author[1]/book[last()]
- Address all book element nodes without a title attribute
  //book[not @title]

XML Schema

Complex language for data description:

- Many standardised base types,
  e.g. float, double, decimal, boolean
  in particular: string and integer
- Types and typed references
- Class hierarchy and inheritance
- Consistency constraints

Standard („W3C Recommendation") as extension to XML

Namespaces

An XML document may use more than one DTD or schema
Prefixes are used to avoid name clashes.

Prefixes have URIs as values.
They usually point to a description of the namespace syntax.

Example:

```
    <vu:instructors   xmlns:vu="http://www.vu.com/empDTD"
                      xmlns:gu="http://www.gu.au/empDTD"
                      xmlns:unik="http://www.unik.de/empDTD">

     <unik:dozent     unik:title="Dr."
                      unik:name="Andreas Hotho"
                      unik:department="Computer Science"/>

<gu:academicStaff     gu:title="lecturer"
                            gu:name="Mate Jones"
                            gu:school="Information Technology"/>
</vu:instructors>
```


Style Sheets

Move data and metadata from one XML representation to another,

eg, when applications that use different DTDs or schemas need to communicate.

The *extensible stylesheet language* XSL includes

- a transformation language (XSLT)
- a formatting language

XSLT specifies rules with which an input XML document is transformed to

- another XML document
- an HTML document
- plain text

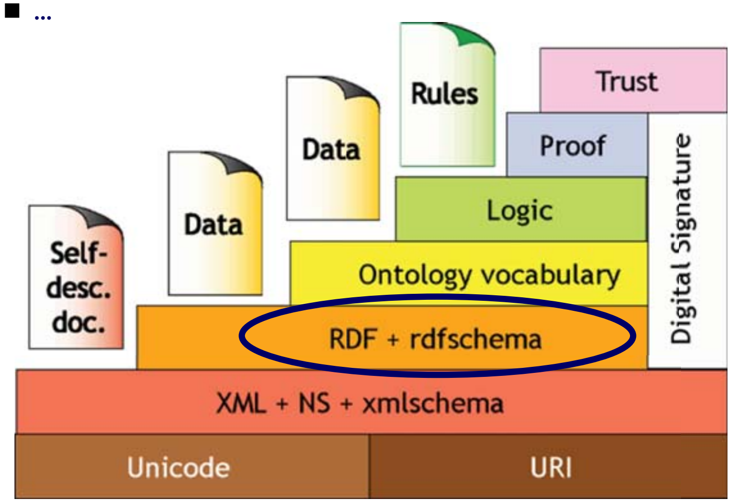
The output document may use the same DTD or schema, or a completely different vocabulary.

XSLT can be used independently of the formatting language.

The semantic web layer cake

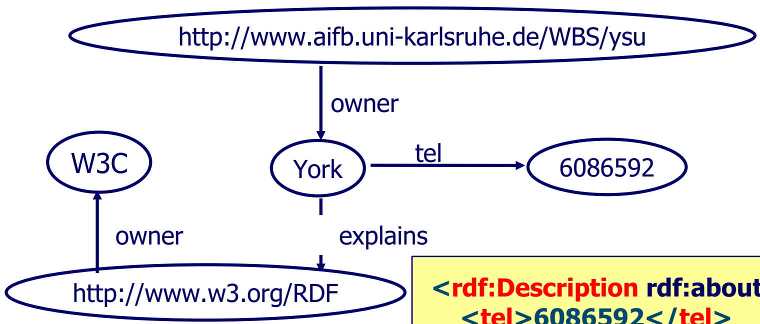
RDF Recommendation consists of several parts

- RDF Primer (http://www.w3.org/TR/rdf-primer/)
- RDF Schema (http://www.w3.org/TR/rdf-schema/)
- …



RDF - Resource Description Framework

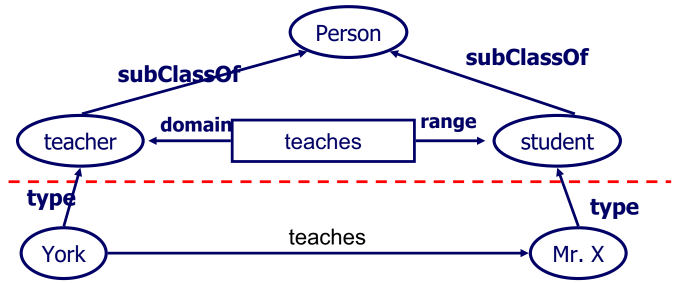
- RDF provides metadata about web resources
- key component: **Object -> Attribute -> Value** triple
- Interconnected triples constitute a labelled **graph**
- RDF uses XML syntax




```
<rdf:Description rdf:about="#York">
  <tel>6086592</tel>
</rdf:Description>
```


RDF Schema

- RDFS defines **vocabulary** for RDF
- Vocabulary is organised as **type hierarchy**
  - Class, subClassOf
  - type
  - Property, subPropertyOf
  - domain, range



RDF Schema syntax in XML

```
<rdf:Description ID="Person">
   <rdf:type resource="http://www.w3.org/...#Class"/>
   <rdfs:subClassOf rdf:resource="http://www.w3.org/...#Resource"/>
  </rdf:Description>

<rdf:Description ID=" Teacher">
   <rdf:type resource="http://www.w3.org/...#Class"/>
   <rdfs:subClassOf rdf:resource="#Person"/>
</rdf:Description>

<rdf:Description ID="teaches">
   <rdf:type resource="http://www.w3.org/...#Property"/>
   <rdfs:domain rdf:resource="#Teacher"/>
   <rdfs:range rdf:resource="#Student"/>
</rdf:Description>

<rdf:Description ID="teaches well">
   <rdf:type resource="http://www.w3.org/...#Property"/>
   <rdfs:subPropertyOf rdf:resource="#teaches"/>
</rdf:Description>
```

RDFS - logical

Classes: unary predicates
subClassOf relation: implication

$\boxed{\text{tutor} \sqsubseteq \text{student}}$

$(\forall x)\ (\text{tutor}(x) \rightarrow \text{student}(x))$

Properties: binary predicates
subPropertyOf relation: implication

$\boxed{\text{supervises} \sqsubseteq \text{responsibleFor}}$

$(\forall x)(\forall y)\ (\text{supervises}(x,y) \rightarrow \text{responsibleFor}(x,y))$

RDF statements are triples (Object, Property, Object)

- Objects can be
  - URIs — constants
  - classes — unary predicates
  - properties — binary predicates
  - triples(!) — -- (→ reification, i.e. second-order)

RDF Schema as ontology language

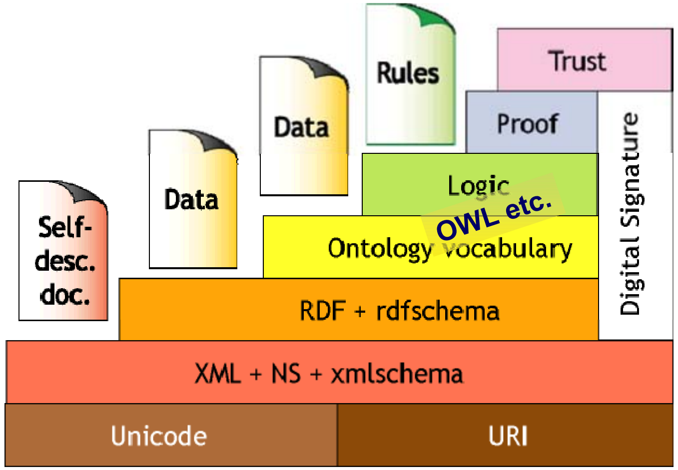
RDF(S) is useful for simple ontologies, but not for complex modelling

→ „Need for more expressivity!“

More expressive languages:

- OWL (based on description logics)
- F-Logic (based on logic programming)
- Hybrids and rules extensions for OWL

The Semantic Web layer cake



OWL - general info

- W3C Recommendation since 2004
- Semantic fragment of FOL (First-order predicate logic)
- Three variants: OWL Lite ⊆ OWL DL ⊆ OWL Full
- RDFS is fragment of OWL Full.
- No reification in OWL DL.
- OWL DL is decidable
- OWL DL = SHOIN(D)

OWL - contents

Head of a document

Classes, roles and Individuals

Class relationships

Complex class definitions

- Boolean class constructors
- Role restrictions

Role properties

OWL documents

OWL documents are RDF Documents.

They consist of

- Head with general information
- Rest with the ontology

Head of an OWL document

Definition of namespaces in the root

```
<rdf:RDF
    xmlns  ="http://www.semanticweb-grundlagen.de/beispielontologie#"
    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>
```

General information

```
<owl:Ontology rdf:about="">
    <rdfs:comment    rdf:datatype="http://www.w3.org/2001/XMLSchema#string“>
    SWRC Ontology December 2005
    </rdfs:comment>
  <owl:versionInfo>v0.5</owl:versionInfo>
  <owl:imports rdf:resource="http://www.semanticweb- grundlagen.de/foo"/>
  <owl:priorVersion    rdf:resource="http://ontoware.org/projects/swrc"/>
 </owl:Ontology>
```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Role properties

Classes, roles and individuals

Basic components of OWL ontologies:

Classes
- like resources in RDFS
- like classes in DL

Individuals
- like resources in RDFS
- like individuals in DL

Roles
- like attributes in RDFS
- like roles in DL

Classes

Definition

```
<owl:Class rdf:ID="Professor"/>
```

- predefined:
  - **owl:Thing** $\boxed{\top}$
  - **owl:Nothing** $\boxed{\bot}$

Individuals

Definition by class membership

```
<rdf:Description rdf:ID="RudiStuder">
  <rdf:type rdf:resource="#Professor"/>
</rdf:Description>
```

Professor(RudiStuder)

- equivalent:

```
<Professor rdf:ID="RudiStuder"/>
```


Abstract Roles

Abstract roles defined like classes

```
<owl:ObjectProperty
         rdf:ID=„Affiliation"/>
```

Domain and Range of abstract Roles

```
<owl:ObjectProperty rdf:ID=„Affiliation">
  <rdfs:domain rdf:resource="#Person"/>
  <rdfs:range rdf:resource="#Organisation"/>
</owl:ObjectProperty>
```

Domain: $\exists \text{Affiliation}.\top \sqsubseteq \text{Person}$
Range: $\top \sqsubseteq \forall \text{Affiliation}.\text{Organisation}$

Concrete Roles

Concrete roles have datatypes in range

```
<owl:DatatypeProperty rdf:ID=„firstname"/>
```

Domain and range of concrete roles

```
<owl:DatatypeProperty rdf:ID=„firstname">
  <rdfs:domain rdf:resource="#Person" />
  <rdfs:range  rdf:resource="&xsd;string"/>
</owl:DatatypeProperty>
```

One can use many XML Schema Datatypes.
The standard requires at least `integer` and `string`.

Individuals and Roles

```
<Person rdf:ID="RudiStuder">
  <Affiliation rdf:resource="#AIFB"/>
  <Affiliation rdf:resources="#ontoprise"/>
  <firstname rdf:datatype="&xsd;string">Rudi</firstname>
</Person>
```

Affiliation(RudiStuder,AIFB)
Affiliation(RudiStuder,ontoprise)
Firstname(RudiStuder,“Rudi“)

Roles are in general not functional.

OWL - contents

Head of a document
Classes, roles and Individuals
Class relationships
Complex class definitions

- Boolean class constructors
- Role restrictions

Role properties

Simple class relationships

```
<owl:Class rdf:ID="Professor">
  <rdfs:subClassOf
            rdf:resource="#Faculty"/>
</owl:Class>
```

Professor $\sqsubseteq$ Faculty

```
<owl:Class rdf:ID=„Faculty">
  <rdfs:subClassOf rdf:resource="#Person"/>
</owl:Class>
```

Faculty $\sqsubseteq$ Person

It can be inferrred that `Professor` is a subclass of `Person`.

Simple class relationships

```
<owl:Class rdf:ID="Professor">
  <rdfs:subClassOf rdf:resource="#Faculty"/>
</owl:Class>
<owl:Class rdf:ID=„Book">
  <rdfs:subClassOf rdf:resource="#Publication"/>
</owl:Class>
<owl:Class rdf:about="#Faculty">
  <owl:disjointWith rdf:resource="#Publication"/>
</owl:Class>
```

Professor $\sqsubseteq$ Faculty

Book $\sqsubseteq$ Publication

Faculty $\sqcap$ Publication $\equiv \bot$

We infer that `Professor` and `Book` are also disjoint classes.

Simple class relationships

```
<owl:Class rdf:ID=„Book">
  <rdfs:subClassOf
  rdf:resource="#Publication"/>
</owl:Class>

<owl:Class rdf:about="#Publication">
  <owl:equivalentClass
     rdf:resource="#Publikation"/>
</owl:Class>
```

Book $\sqsubseteq$ Publication

Publication $\equiv$ Publikation

We infer that `Book` is a subclass of `Publikation`.

Individuals and class relationships

Author(SemanticWebGrundlagen,YorkSure)
Author(SemanticWebGrundlagen,PascalHitzler)

```
<Book rdf:ID="SemanticWebGrundlagen">
  <Author rdf:resource="#YorkSure"/>
  <Author rdf:resource="#PascalHitzler"/>
</Book>
<owl:Class rdf:about="#Book">
  <rdfs:subClassOf rdf:resource="#Publication"/>
</owl:Class>
```

Book $\sqsubseteq$ Publication

We infer that `SemanticWebGrundlagen` is a `Publication`.

Relationships between individuals

```
<Professor rdf:ID="RudiStuder"/>
<rdf:Description rdf:about="#RudiStuder">
  <owl:sameAs
     rdf:resource="#ProfessorStuder"/>
</rdf:Description>
```

Professor(RudiStuder)
RudiStuder = ProfessorStuder

We infer that `ProfessorStuder` is a `Professor`.

Inequality of individuals expressed using
`owl:differentFrom`.

Relationships between individuals

```
<owl:AllDifferent>
  <owl:distinctMembers
           rdf:parseType="Collection">
    <Person rdf:about="#RudiStuder"/>
    <Person rdf:about="#YorkSure"/>
    <Person rdf:about="#PascalHitzler"/>
  </owl:distinctMembers>
</owl:AllDifferent>
```

Shortcut for multiple usage of `owl:differentFrom`.

Closed classes (nominals)

```
<owl:Class rdf:about=#SecretaryOfStuder>
  <owl:oneOf rdf:parseType="Collection">
    <Person rdf:about="#GiselaSchillinger"/>
    <Person rdf:about="#AnneEberhardt"/>
  </owl:oneOf>
</owl:Class>
```

There are **exactly those two** Individuals in the class `SecretaryOfStuder`.

$$\boxed{\textbf{SecretaryOfStuder} \equiv \{\textbf{GiselaSchillinger},\textbf{AnneEberhardt}\}}$$

OWL - contents

Head of a document
Classes, roles and Individuals
Class relationships
Complex class definitions

- **Boolean class constructors**
- Role restrictions

Role properties

Boolean class constructors

Conjunction:
`owl:intersectionOf`

Disjunction:
`owl:unionOf`

Negation:
`owl:complementOf`

Can be used to construct complex classes from class names.

Conjunction

$\text{SecretaryOfStuder} \equiv \text{Secretary} \sqcap \text{MemberAGStuder}$

```
<owl:Class rdf:about="#SecretaryOfStuder">
  <owl:equivalentClass>
    <owl:intersectionOf
            rdf:parseType="Collection">
      <owl:Class rdf:about="#Secretary"/>
      <owl:Class
            rdf:about="#MemberAGStuder"/>
    </owl:intersectionOf>
  </owl:equivalentClass>
</owl:Class>
```

We infer that all individuals in `SecretaryOfStuder` are also in `Secretary`.

Disjunction

```
<owl:Class rdf:about="#Professor">
  <owl:subClassOf>
    <owl:unionOf rdf:parseType="Collection">
      <owl:Class rdf:about="#activeTeacher"/>
      <owl:Class rdf:about="#retired"/>
    </owl:unionOf>
  </owl:subClassOf>
</owl:Class>
```

$\text{Professor} \sqsubseteq \text{activeTeacher} \sqcup \text{retired}$

Negation

```
<owl:Class rdf:about="#Faculty">
  <owl:subClassOf>
    <owl:complementOf rdf:resource="#Publication"/>
  </owl:subClassOf>
</owl:Class>
```

$\text{Faculty} \sqsubseteq \neg\text{Publication}$

This is a complicated way of saying the following:

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

$\text{Faculty} \sqcap \text{Publication} \equiv \bot$

OWL - contents

- Head of a document
- Classes, roles and Individuals
- Class relationships
- Complex class definitions
  - Boolean class constructors
  - **Role restrictions**
- Role properties

Role restrictions (allValuesFrom)

Using roles for defining complex classes

```
<owl:Class rdf:ID=„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 must be professors.

$\text{Exam} \sqsubseteq \forall\text{hasExaminer.Professor}$

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. each exam must have *at least one* examiner.

$\text{Exam} \sqsubseteq \exists\text{hasExaminer.Person}$

Number 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>
```

$\text{Exam} \sqsubseteq \leq 2\ \text{hasExaminer}$

An exam must have *at most two* examiners.

Number 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>
```

$\text{Exam} \sqsubseteq \geq 3\ \text{hasTopic}$

An exam must cover *at least three* topics.

Number 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>
```

$Exam \sqsubseteq {=}3\ hasTopic$

An exam must cover *exactly three* topics.

Role restrictions (hasValue)

```
<owl:Class rdf:ID=„examProfStuder">
  <rdfs:equivalentClass>
    <owl:Restriction>
      <owl:onProperty rdf:resource="#hasExaminer"/>
      <owl:hasValue rdf:resource="#RudiStuder"/>
    </owl:Restriction>
  </rdfs:subClassOf>
</owl:Class>
```

`owl:hasValue` always points to an individual. This is equivalent to the example on the next slide.

Role restrictions (hasValue)

```
<owl:Class rdf:ID=„examProfStuder">
  <rdfs: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>
  </rdfs:subClassOf>
</owl:Class>
```

$examProfStuder \equiv \exists hasExaminer.\{RudiStuder\}$

OWL - contents

- Head of a document
- Classes, roles and Individuals
- Class relationships
- Complex class definitions
  - Boolean class constructors
  - Role restrictions
- **Role properties**

Role relationships

$\textbf{hasExaminer} \sqsubseteq \textbf{hasParticipant}$

```
<owl:ObjectProperty rdf:ID=„hasExaminer">
  <rdfs:subPropertyOf
            rdf:resource="#hasParticipant"/>
</owl:ObjectProperty>
```

Similar: `owl:equivalentProperty`

Roles can be inverse to each other:

```
<owl:ObjectProperty rdf:ID=„hasExaminer">
  <owl:inverseOf rdf:resource="#examinerOf"/>
</owl:ObjectProperty>
```

$\textbf{hasExaminer} \equiv \textbf{examinerOf}^{-}$

Role properties

- Domain
- Range
- Transitivity   i.e. (a,b) and r(b,c) implies r(a,c)
- Symmetry   i.e. r(a,b) implies r(b,a)
- Functionality   i.e. r(a,b) and r(a,c) implies b=c
- Inverse functionality

Domain and Range

```
<owl:ObjectProperty rdf:ID=„Affiliation">
  <rdfs:range rdf:resource="#Organisation"/>
</owl:ObjectProperty>
```

Is equivalent to the following:

```
<owl:Class rdf:about="\&owl;Thing">
  <rdfs:subClassOf>
    <owl:Restriction>
      <owl:onProperty rdf:resource="#Affiliation"/>
      <owl:allValuesFrom rdf:resource="#Organisation"/>
    </owl:Restriction>
  </rdfs:subClassOf>
</owl:Class>
```

Range: $\top \sqsubseteq \forall\textbf{Affiliation.Organisation}$

Domain and Range

```
<owl:ObjectProperty rdf:ID=„Affiliation">
  <rdfs:range rdf:resource="#Organisation"/>
</owl:ObjectProperty>
<Number rdf:ID=„Five">
  <Affiliation rdf:resource="#PrimeNumber"/>
</Number>
```

It follows that `PrimeNumber` is an Organisation!

$\top \sqsubseteq \forall\textbf{Affiliation.Organisation}$
Number(Five)
Affiliation(Five,PrimeNumber)

Role properties

```
<owl:ObjectProperty rdf:ID="hasColleague">
  <rdf:type rdf:resource="&owl;TransitiveProperty"/>
  <rdf:type rdf:resource="&owl;SymmetricProperty"/>
</owl:ObjectProperty>
<owl:ObjectProperty rdf:ID="hasProjectLeader">
  <rdf:type rdf:resource="&owl;FunctionalProperty"/>
</owl:ObjectProperty>
<owl:ObjectProperty rdf:ID="isProjectLeaderFor">
  <rdf:type rdf:resource="&owl;InverseFunctionalProperty"/>
</owl:ObjectProperty>
<Person rdf:ID="YorkSure">
  <hasColleague rdf:resource="#PascalHitzler"/>
  <hasColleague rdf:resource="#AnupriyaAnkolekar"/>
  <isProjectLeaderFor rdf:resource="#SEKT"/>
</Person>
<Projekt rdf:ID="SmartWeb">
  <hasProjectLeader rdf:resource="#PascalHitzler"/>
  <hasProjectLeader rdf:resource="#HitzlerPascal"/>
</Projekt>
```

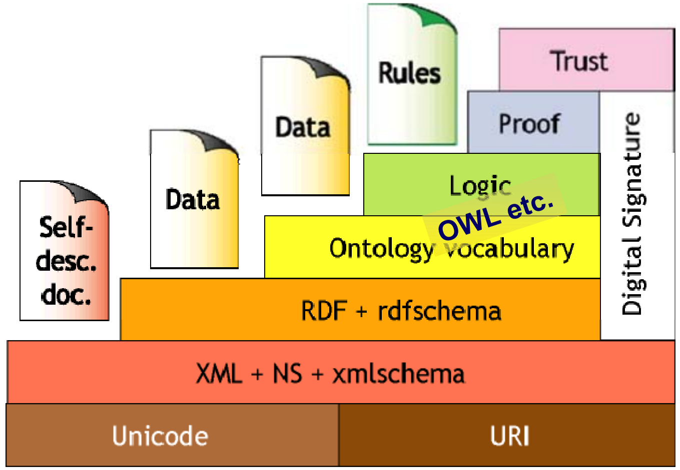
Logical consequences from example

```
AnupriyaAnkolekar hasCollegue YorkSure

AnupriyaAnkolekar hasCollegue PascalHitzler

PascalHitzler owl:sameAs HitzlerPascal
```


The Semantic Web layer cake



OWL variants

OWL Full
- Contains OWL DL and OWL Lite
- Contains all of RDFS
- Undecidable
- Limited support by existing software

OWL DL (= SHOIN(D))
- Contains OWL Lite and is contained in OWL Full
- decidable
- Tools available
- complexity NExpTime (worst-case)

OWL Lite (= SHIF(D))
- Is contained in OWL DL and OWL Full
- decidable.
- Less expressive.
- Complexity ExpTime (worst-case)

OWL Full

Unlimited usage of all OWL and RDFS constructs (must be valid RDFS).

Difficult is e.g. the non-existent type separation (Classes, Roles, Individuals), hence:

- `owl:Thing` is the same as `rdfs:resource`
- `owl:Class` is the same as `rdfs:Class`
- `owl:DatatypeProperty` subclass of `owl:ObjectProperty`
- `owl:ObjectProperty` is the same as `rdf:Property`

Why types are not seperated in OWL Full

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

One often does not really need inferencing over such information.

OWL DL

- is SHOIN(D).
- Allowed are only certain RDFS constructs (like those in the examples.
  Not allowed: `rdfs:Class`, `rdfs:Property`
- Type seperation. Classes and Roles must be declared explicitly.
- Concrete Roles must not be transitive, symmetric, inverse or inverse functional.
- Number restrictions must not be used with transitive roles, their subroles, or their inverses.

OWL Lite

- is SHIF(D).
- All restrictions for OWL DL apply.
- Not allowed: `oneOf`, `unionOf`, `complementOf`, `hasValue`, `disjointWith`
- Number restrictions only allowed with 0 and 1.
- Some restrictions on the occurrence of anonymous (complex) classes apply, e.g. they must not occur in the subject of `rdfs:subClassOf`.

OWL Tools

Editors

- Protegé, http://protege.stanford.edu
- SWOOP, http://www.mindswap.org/2004/SWOOP/
- OWL Tools, http://owltools.ontoware.org/

Inference engines

- Pellet, http://www.mindswap.org/2003/pellet/index.shtml
- KAON2, http://kaon2.semanticweb.org
- FACT++, http://owl.man.ac.uk/factplusplus/
- Racer, http://www.racer-systems.com/
- Cerebra, http://www.cerebra.com/index.html

Appendix: OWL language components

Head

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

Relations between individuals

`owl:sameAs`
`owl:differentFrom`
`owl:AllDifferent`
(together with
`owl:distinctMembers`)

Required datatypes

`xsd:strong`
`xsd:integer`

Appendix: OWL language components

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`

Appendix: OWL language components

Role constructors, relations and propeties

`owl:ObjectProperty`
`owl:DatatypeProperty`
`rdfs:subPropertyOf`
`owl:equivalentProperty`
`owl:inverseOf`
`rdfs:domain`
`rdfs:range`
`rdf:resource="&owl;TransitiveProperty"`
`rdf:resource="&owl;SymmetricProperty"`
`rdf:resource="&owl;FunctionalProperty"`
`rdf:resource="&owl;InverseFunctionalProperty"`

OWL as DL: Class Constructors

Constructor	DL Syntax	Example	FOL Syntax
intersectionOf	$C_1 \sqcap \ldots \sqcap C_n$	Human $\sqcap$ Male	$C_1(x) \wedge \ldots \wedge C_n(x)$
unionOf	$C_1 \sqcup \ldots \sqcup C_n$	Doctor $\sqcup$ Lawyer	$C_1(x) \vee \ldots \vee C_n(x)$
complementOf	$\neg C$	$\neg$Male	$\neg C(x)$
oneOf	$\{x_1\} \sqcup \ldots \sqcup \{x_n\}$	{john} $\sqcup$ {mary}	$x = x_1 \vee \ldots \vee x = x_n$
allValuesFrom	$\forall P.C$	$\forall$hasChild.Doctor	$\forall y.P(x,y) \rightarrow C(y)$
someValuesFrom	$\exists P.C$	$\exists$hasChild.Lawyer	$\exists y.P(x,y) \wedge C(y)$
maxCardinality	$\leqslant nP$	$\leqslant$1hasChild	$\exists^{\leqslant n} y.P(x,y)$
minCardinality	$\geqslant nP$	$\geqslant$2hasChild	$\exists^{\geqslant n} y.P(x,y)$

XMLS datatypes as well as classes in $\forall$P.C and $\exists$P.C

- E.g., $\exists$hasAge.nonNegativeInteger

Arbitrarily complex nesting of constructors

- E.g., Person $\sqcap$ $\forall$hasChild.Doctor $\sqcup$ $\exists$hasChild.Doctor

RDFS Syntax

E.g., Person $\sqcap$ $\forall$hasChild.Doctor $\sqcup$ $\exists$hasChild.Doctor:

```
<owl:Class>
  <owl:intersectionOf rdf:parseType=" collection">
    <owl:Class rdf:about="#Person"/>
    <owl:Restriction>
      <owl:onProperty rdf:resource="#hasChild"/>
      <owl:toClass>
        <owl:unionOf rdf:parseType=" collection">
          <owl:Class rdf:about="#Doctor"/>
          <owl:Restriction>
            <owl:onProperty rdf:resource="#hasChild"/>
            <owl:hasClass rdf:resource="#Doctor"/>
          </owl:Restriction>
        </owl:unionOf>
      </owl:toClass>
    </owl:Restriction>
  </owl:intersectionOf>
</owl:Class>
```


OWL as DL: Axioms

Axiom	DL Syntax	Example
subClassOf	$C_1 \sqsubseteq C_2$	Human $\sqsubseteq$ Animal $\sqcap$ Biped
equivalentClass	$C_1 \equiv C_2$	Man $\equiv$ Human $\sqcap$ Male
disjointWith	$C_1 \sqsubseteq \neg C_2$	Male $\sqsubseteq$ $\neg$Female
sameIndividualAs	$\{x_1\} \equiv \{x_2\}$	{President_Bush} $\equiv$ {G_W_Bush}
differentFrom	$\{x_1\} \sqsubseteq \neg\{x_2\}$	{john} $\sqsubseteq$ $\neg${peter}
subPropertyOf	$P_1 \sqsubseteq P_2$	hasDaughter $\sqsubseteq$ hasChild
equivalentProperty	$P_1 \equiv P_2$	cost $\equiv$ price
inverseOf	$P_1 \equiv P_2^-$	hasChild $\equiv$ hasParent$^-$
transitiveProperty	$P^+ \sqsubseteq P$	ancestor$^+$ $\sqsubseteq$ ancestor
functionalProperty	$\top \sqsubseteq \leqslant 1P$	$\top \sqsubseteq \leqslant$1hasMother
inverseFunctionalProperty	$\top \sqsubseteq \leqslant 1P^-$	$\top \sqsubseteq \leqslant$1hasSSN$^-$

Axioms (mostly) reducible to inclusion ($\sqsubseteq$)

- $C \equiv D$ iff both $C \sqsubseteq D$ and $D \sqsubseteq C$

Obvious FOL equivalences

- E.g., $C \equiv D$ iff $\forall x.\ C(x) \Leftrightarrow D(x)$,
- $C \sqsubseteq D$ iff $\forall x.\ C(x) \Rightarrow D(x)$