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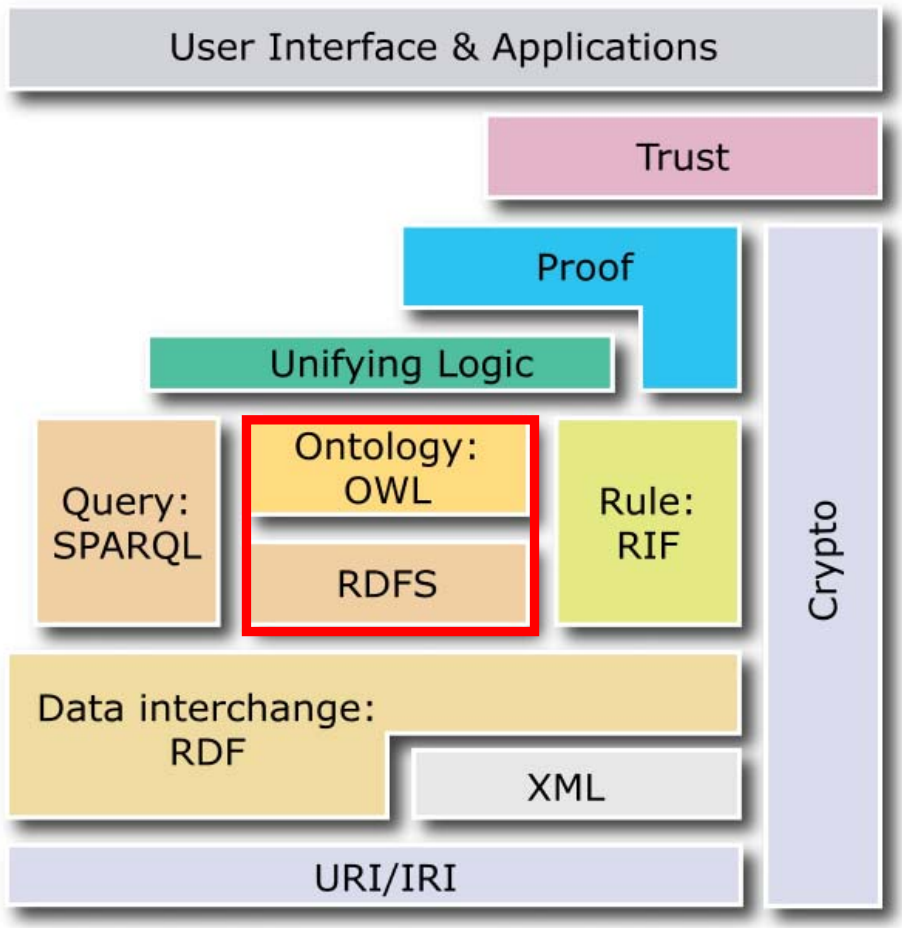
RDFS and OWL

1st Semantic Web Services Winter Retreat

Semantic Web Stack



Overview

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- RDF Schema
  - Principles
  - Vocabulary
- RDF(S) Semantics
- Expressivity limitations of RDFS
- Web Ontology Language OWL
  - OWL Layering
  - OWL and Description Logics
  - OWL Syntaxes

How to represent the semantics of data models

THE RDF SCHEMA (RDFS)

RDF Vocabulary Description Language 1

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- Types in RDF:

  `<#john, rdf:type, #Student>`
- What is a "**`#Student`**"?

- A language for defining RDF types:
  - Define classes:
    - "***`#Student`*** *is a class*"
  - Relationships between classes:
    - "***`#Student`*** *is a sub-class of* ***`#Person`***"
  - Properties of classes:
    - "***`#Person`*** *has a property* ***`hasName`***"

- RDF Schema is such a language

RDF Vocabulary Description Language 2

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- Classes:
  `<#Student, rdf:type, #rdfs:Class>`
- Class hierarchies:
  `<#Student, rdfs:subClassOf, #Person>`

- Properties:
  `<#hasName, rdf:type, rdf:Property>`
- Property hierarchies:
  `<#hasMother, rdfs:subPropertyOf, #hasParent>`

- Associating properties with classes (a):
  - "The property `#hasName` only applies to `#Person`"
    `<#hasName, rdfs:domain, #Person>`

- Associating properties with classes (b):
  - "The type of the property `#hasName` is `#xsd:string`"
    `<#hasName, rdfs:range, xsd:string>`

RDF Vocabulary Revisited

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- Classes:
  - `rdf:Property`, `rdf:Statement`, `rdf:XMLLiteral`
  - `rdf:Seq`, `rdf:Bag`, `rdf:Alt`, `rdf:List`
- Properties:
  - `rdf:type`, `rdf:subject`, `rdf:predicate`, `rdf:object`,
  - `rdf:first`, `rdf:rest`, `rdf:_n`
  - `rdf:value`
- Resources:
  - `rdf:nil`

RDFS Vocabulary

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- RDFS Extends the RDF Vocabulary
- RDFS vocabulary is defined in the namespace:

  http://www.w3.org/2000/01/rdf-schema#

RDFS Classes

- **rdfs:Resource**
- **rdfs:Class**
- **rdfs:Literal**
- **rdfs:Datatype**
- **rdfs:Container**
- **rdfs:ContainerMembershipProperty**

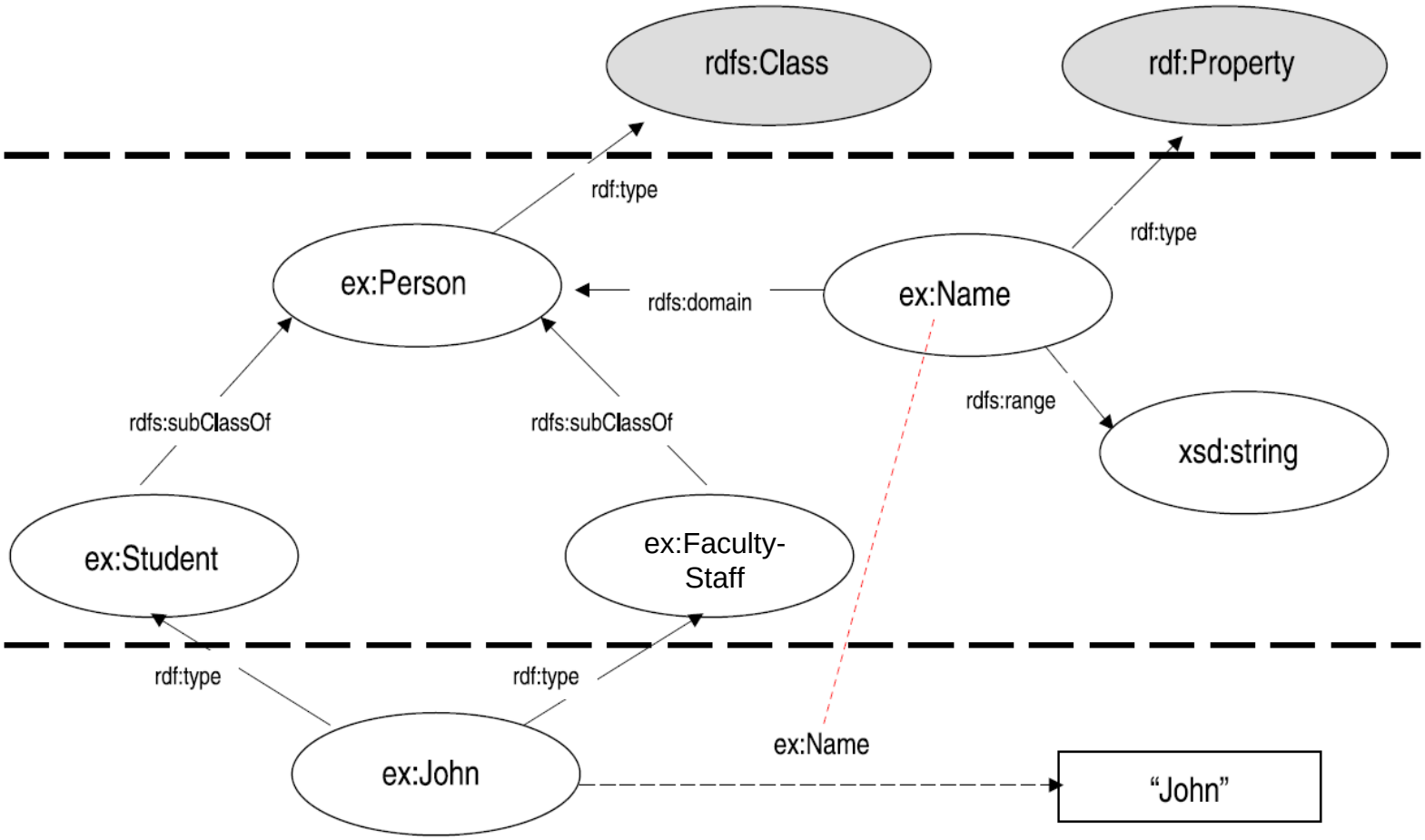
RDFS Properties

- **rdfs:domain**
- **rdfs:range**
- **rdfs:subPropertyOf**
- **rdfs:subClassOf**
- **rdfs:member**
- **rdfs:seeAlso**
- **rdfs:isDefinedBy**
- **rdfs:comment**
- **rdfs:label**

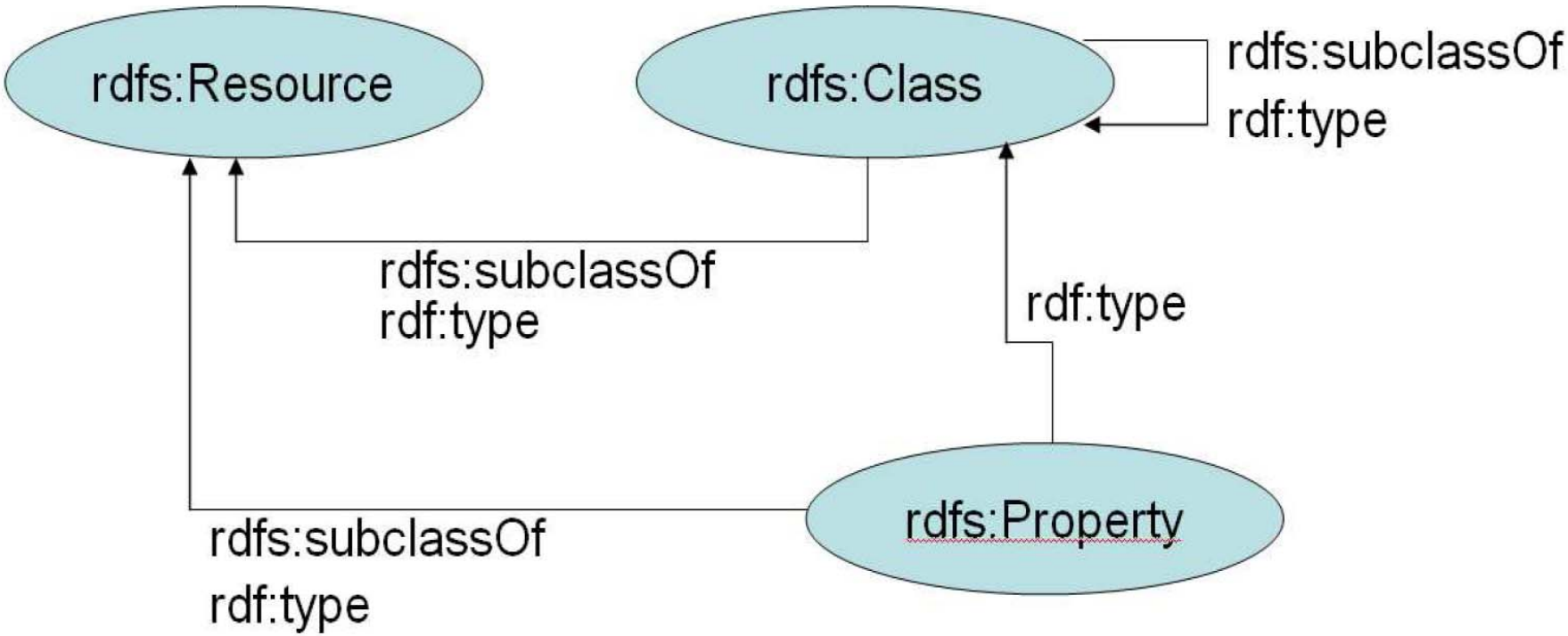
RDFS Principles

- **Resource**
  - All resources are implicitly instances of `rdfs:Resource`
- **Class**
  - Describe sets of resources
  - Classes are resources themselves - e.g. Webpages, people, document types
    - Class hierarchy can be defined through `rdfs:subClassOf`
    - Every class is a member of `rdfs:Class`
- **Property**
  - subset of RDFS Resources that are properties
    - **Domain**: class associated with property: `rdfs:domain`
    - **Range**: type of the property values: `rdfs:range`
    - Property hierarchy defined through: `rdfs:subPropertyOf`

RDFS Example



RDFS Vocabulary Example



RDFS Metadata Properties

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- Metadata is “data about data”
- Any meta-data can be attached to a resource, using:
  - **`rdfs:comment`**
    - Human-readable description of the resource, e.g.

      ⟨`<ex:Person>, rdfs:comment, ”A person is any human being”`⟩
  - **`rdfs:label`**
    - Human-readable version of the resource name, e.g.

      ⟨`<ex:Person>, rdfs:label, ”Human being”`⟩
  - **`rdfs:seeAlso`**
    - Indicate additional information about the resource, e.g.

      ⟨`<ex:Person>, rdfs:seeAlso, <http://xmlns.com/wordnet/1.6/Human>`⟩
  - **`rdfs:isDefinedBy`**
    - A special kind of **`rdfs:seeAlso`**, e.g.

      ⟨`<ex:Person>,rdfs:isDefinedBy,<http://xmlns.com/wordnet/1.6/Human>`⟩

RDF Literals Revisited

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- Plain literals
  - E.g. `"any string"`
  - Optional language tag, e.g. `"Hello, how are you?"@en-GB`
- Typed literals
  - E.g. `"hello"^^xsd:string`, `"1"^^xsd:integer`
  - Recommended datatypes:
    - XML Schema datatypes
- Only as *object* of a triple

Literals in RDFS

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- Each literal is an **`rdfs:Literal`**
- Say, we have: **`<#john, #hasName, “John”>`**
- Does this mean:

  `<“John”, rdf:type, rdfs:Literal>`

  – No! Literals may not occur as subject
- Add:
  - **`<#john, #hasName, _:X>`**
  - **`<_:X, rdf:type, rdfs:Literal>`**

Semantics

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- RDF(S) vocabulary has built-in “meaning”
- RDF(S) Semantics
  - Makes meaning explicit
  - Defines what follows from an RDF graph
- Semantic notions
  - Subgraph
  - Instance
  - Entailment

Subgraph

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- *E* is a subgraph of *S* if and only if *E* predicates are a subset of *S* predicates

```
⟨<#john>, <#hasName>, _:johnsname⟩
⟨<_:johnsname, <#firstName>, ”John”^^xsd:string⟩
⟨<_:johnsname, <#lastName>, ”Smith”^^xsd:string⟩
```

- Subgraphs:

```
⟨<#john>,<#hasName>, _:johnsname⟩
⟨_:johnsname, <#firstName>, ”John”^^xsd:string⟩

⟨_:johnsname, <#firstName>, ”John”^^xsd:string⟩
⟨_:johnsname, <#lastName>, ”Smith”^^xsd:string⟩

⟨<#john>, <#hasName>, _:johnsname⟩
```

Instance

- *S' is an instance of S if and only if some blank nodes in S are replaced with blank nodes, literals or URIs*

```
⟨<#john>, <#hasName>, _:johnsname⟩
⟨_:johnsname, <#firstName>, "John"^^xsd:string⟩
⟨_:johnsname, <#lastName>, "Smith"^^xsd:string⟩
```

- Instances:

```
⟨<#john>, <#hasName>, <#abc>⟩
⟨<#abc>, <#firstName>, "John"^^xsd:string⟩
⟨<#abc>, <#lastName>, "Smith"^^xsd:string⟩

⟨<#john>, <#hasName>, _:X⟩
⟨_:X, <#firstName>, "John"^^xsd:string⟩
⟨_:X, <#lastName>, "Smith"^^xsd:string⟩

⟨<#john>, <#hasName>, _:johnsname⟩
⟨_:johnsname, <#firstName>, "John"^^xsd:string⟩
⟨_:johnsname, <#lastName>, "Smith"^^xsd:string⟩
```

- Every graph is an instance of itself!

Entailment

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- S entails E if E logically follows from S
  - Written: **S |= E**
- A graph entails all it subgraphs
  - If S' is a subgraph of S: **S |= S′**
- All instances of a graph S entail S
  - If S'' is an instance of S: **S″ |= S**

RDFS Entailment

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<http://example.org/#john> rdf:type <http://example.org/#Student>
<http://example.org/#Student> rdfs:subClassOf <http://example.org/#Person>

entails

<http://example.org/#john> rdf:type <http://example.org/#Person>

<http://example.org/#hasName> rdfs:domain <http://example.org/#Student>
<http://example.org/#mary> <http://example.org/#hasName> “Mary”

entails

<http://example.org/#mary> rdf:type <http://example.org/#Student>

<http://example.org/#john> <http://example.org/#hasMother> <http://example.org/#mary>
<http://example.org/#hasMother> rdfs:subPropertyOf <http://example.org/#hasParent>

entails

<http://example.org/#john> <http://example.org/#hasParent <http://example.org/#mary>

RDFS Entailment

<http://example.org/#john> rdf:type <http://example.org/#Student>
<http://example.org/#Student> rdfs:subClassOf <http://example.org/#Person>

entails

<http://example.org/#john> rdf:type <http://example.org/#Person>

<http://example.org/#hasName> rdfs:domain <http://example.org/#Student>
<http://example.org/#mary> <http://example.org/#hasName> “Mary”

entails

<http://example.org/#mary> rdf:type <http://example.org/#Student>

<http://example.org/#john> <http://example.org/#hasMother> <http://example.org/#mary>
<http://example.org/#hasMother> rdfs:subPropertyOf <http://example.org/#hasParent>

entails

<http://example.org/#john> <http://example.org/#hasParent <http://example.org/#mary>

RDFS Entailment

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<http://example.org/#john> rdf:type <http://example.org/#Student>
<http://example.org/#Student> rdfs:subClassOf <http://example.org/#Person>

entails

<http://example.org/#john> rdf:type <http://example.org/#Person>

<http://example.org/#hasName> rdfs:domain <http://example.org/#Student>
<http://example.org/#mary> <http://example.org/#hasName> "Mary"

entails

<http://example.org/#mary> rdf:type <http://example.org/#Student>

<http://example.org/#john> <http://example.org/#hasMother> <http://example.org/#mary>
<http://example.org/#hasMother> rdfs:subPropertyOf <http://example.org/#hasParent>

entails

<http://example.org/#john> <http://example.org/#hasParent <http://example.org/#mary>

Entailment Rules

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- Semantics defined through *entailment rules*
- Rule:
  - If *S* contains `<triple pattern>` then add `<triple>`
- Executing all entailment rules yields *realization* of S
- S entails E if E is a subgraph of the realization of S
- Axiomatic triple are always added

RDF Axiomatic Triples

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```
<rdf:type, rdf:type, rdf:Property>
<rdf:subject, rdf:type, rdf:Property>
<rdf:predicate, rdf:type, rdf:Property>
<rdf:object, rdf:type, rdf:Property>
<rdf:first, rdf:type, rdf:Property>
<rdf:rest, rdf:type, rdf:Property>
<rdf:value, rdf:type, rdf:Property>
<rdf:_1, rdf:type, rdf:Property>
<rdf:_2, rdf:type, rdf:Property>
...
<rdf:nil, rdf:type, rdf:List>
```

RDFS Axiomatic Triples 1

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<rdf:type, rdfs:domain, rdfs:Resource>
<rdfs:domain, rdfs:domain, rdf:Property>
<rdfs:range, rdfs:domain, rdf:Property>
<rdfs:subPropertyOf, rdfs:domain, rdf:Property>
<rdfs:subClassOf, rdfs:domain, rdfs:Class>
<rdf:subject, rdfs:domain, rdf:Statement>
<rdf:predicate, rdfs:domain, rdf:Statement>
<rdf:object, rdfs:domain, rdf:Statement>
<rdfs:member, rdfs:domain, rdfs:Resource>
<rdf:first, rdfs:domain, rdf:List>
<rdf:rest, rdfs:domain, rdf:List>
<rdfs:seeAlso, rdfs:domain, rdfs:Resource>
<rdfs:isDefinedBy, rdfs:domain, rdfs:Resource>
<rdfs:comment, rdfs:domain, rdfs:Resource>

RDFS Axiomatic Triples 2

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```
<rdfs:label, rdfs:domain, rdfs:Resource>
<rdf:value, rdfs:domain, rdfs:Resource>
<rdf:type, rdfs:range, rdfs:Class>
<rdfs:domain, rdfs:range, rdfs:Class>
<rdfs:range, rdfs:range, rdfs:Class>
<rdfs:subPropertyOf, rdfs:range, rdf:Property>
<rdfs:subClassOf, rdfs:range, rdfs:Class>
<rdf:subject, rdfs:range, rdfs:Resource>
<rdf:predicate, rdfs:range, rdfs:Resource>
<rdf:object, rdfs:range, rdfs:Resource>
<rdfs:member, rdfs:range, rdfs:Resource>
<rdf:first, rdfs:range, rdfs:Resource>
<rdf:rest, rdfs:range, rdf:List>
<rdfs:seeAlso, rdfs:range, rdfs:Resource>
```

RDFS Axiomatic Triples 3

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```
<rdfs:isDefinedBy, rdfs:range, rdfs:Resource>
<rdfs:comment, rdfs:range, rdfs:Literal>
<rdfs:label, rdfs:range, rdfs:Literal>
<rdf:value, rdfs:range, rdfs:Resource>

<rdf:Alt, rdfs:subClassOf, rdfs:Container>
<rdf:Bag, rdfs:subClassOf, rdfs:Container>
<rdf:Seq, rdfs:subClassOf, rdfs:Container>
<rdfs:ContainerMembershipProperty, rdfs:subClassOf, rdf:Property>

<rdfs:isDefinedBy, rdfs:subPropertyOf, rdfs:seeAlso>

<rdf:XMLLiteral, rdf:type, rdfs:Datatype>
<rdf:XMLLiteral, rdfs:subClassOf, rdfs:Literal>
<rdfs:Datatype, rdfs:subClassOf, rdfs:Class>

<rdf:_1, rdf:type, rdfs:ContainerMembershipProperty>
```

RDFS Axiomatic Triples 4

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```
<rdf:_1, rdfs:domain, rdfs:Resource>
<rdf:_1, rdfs:range, rdfs:Resource>
<rdf:_2, rdf:type, rdfs:ContainerMembershipProperty>
<rdf:_2, rdfs:domain, rdfs:Resource>
<rdf:_2, rdfs:range, rdfs:Resource>
...
```

RDF Entailment

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- **if** E **contains** `<A, B, C>`
  then add `<B, rdf:type, rdf:Property>`

- **if** E **contains** `<A, B, l>` (l is a valid XML literal)
  then add `<_:X, rdf:type, rdf:XMLLiteral>`

where `_:X` identifies to blank node allocated to `l`

RDFS Entailment 1

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everything in the subject is a resource:
if E **contains** `<A,B,C>`
then add `<A, rdf:type, rdfs:Resource>`

every non-literal in the object is a resource:
if E **contains** `<A,B,C>` (C is not a literal)
then add `<C, rdf:type, rdfs:Resource>`

every class is subclass of ***rdfs:Resource****:*
if E **contains** `<A, rdf:type, rdfs:Class>`
then add `<A, rdfs:subClassOf, rdfs:Resource>`

inheritance:
if E **contains** `<A, rdf:type, B>`, `<B, rdfs:subClassOf, C>`
then add `<A, rdf:type, C>`

rdfs:subClassOf *is transitive:*
if E **contains** `<A, rdfs:subClassOf, B>, <B, rdfs:subClassOf, C>`
then add `<A, rdfs:subClassOf, C>`

RDFS Entailment 2

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rdfs:subClassOf is reflexive:
if E **contains** `<A, rdf:type, rdfs:Class>`
then add `<A, rdfs:subClassOf, A>`

rdfs:subPropertyOf is transitive:
if E **contains** `<A, rdfs:subPropertyOf, B>`, `<B, rdfs:subPropertyOf, C>`
then add `<A, rdfs:subPropertyOf, C>`

rdfs:subPropertyOf is reflexive:
if E **contains** `<P, rdf:type, rdf:Property>`
then add `<P, rdfs:subPropertyOf, P>`

domain of properties:
if E **contains** `<P, rdfs:domain, C>`, `<A, P, B>`
then add `<A, rdf:type, C>`

range of properties:
if E **contains** `<P, rdfs:range, C>`, `<A, P, B>`
then add `<B, rdf:type, C>`

RDFS Entailment 3

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every literal is a member of rdfs:Literal:

if E **contains** `<A, B, l>` (l is a plain literal)

then add `<_:X, rdf:type, rdfs:Literal>`

every datatype is subclass of rdfs:Literal:

if E **contains** `<A, rdf:type, rdfs:Datatype>`

then add `<A, rdfs:subClassOf, rdfs:Literal>`

More on literals

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Recall:

if E **contains** `<A, B, l>` (l is a valid XML literal)
then add `<_:X, rdf:type, rdf:XMLLiteral>`

every literal is a member of rdfs:Literal:

if E **contains** `<A, B, l>` (l is a plain literal)
then add `<_:X, rdf:type, rdfs:Literal>`

---

allocating blank nodes to literals:

if E **contains** `<A, B, l>` (`l` is a literal)
then add `<A, B, _:n>`
`_:n` is allocated to `l`

"dereferencing" blank nodes:

if E **contains** `<A, B,_:n>` (`_:n` is allocated to a literal `l`)
then add `<A, B, l>`

Why do we need more expressive power?

LIMITATION OF RDFS

What we discussed so far…

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- RDF Schema
  - RDFS Vocabulary
  - RDFS Metadata
  - Literals and Datatypes in RDFS
- Semantics of RDF and RDF Schema
  - Semantic notions
  - RDF(S) Entailment
- SPARQL
  - SPARQL Queries
  - Query Answer

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RDF Vocabulary

Classes:
rdf:Property, **rdf:Statement**,
rdf:XMLLiteral
rdf:Seq, **rdf:Bag**, **rdf:Alt**, **rdf:List**

Properties:
rdf:type, **rdf:subject**, **rdf:predicate**,
rdf:object,
rdf:first, **rdf:rest**, **rdf:_n**
rdf:value

Resources:
rdf:nil

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rdf:first, **rdf:rest**, **rdf:_n**
rdf:value

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RDFS Vocabulary

RDFS Classes
rdfs:Resource
rdfs:Class
rdfs:Literal
rdfs:Datatype
rdfs:Container
rdfs:ContainerMembershipProperty

RDFS Vocabulary

RDFS Properties
rdfs:domain
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rdfs:subClassOf
rdfs:member
rdfs:seeAlso
rdfs:isDefinedBy
rdfs:comment
rdfs:label

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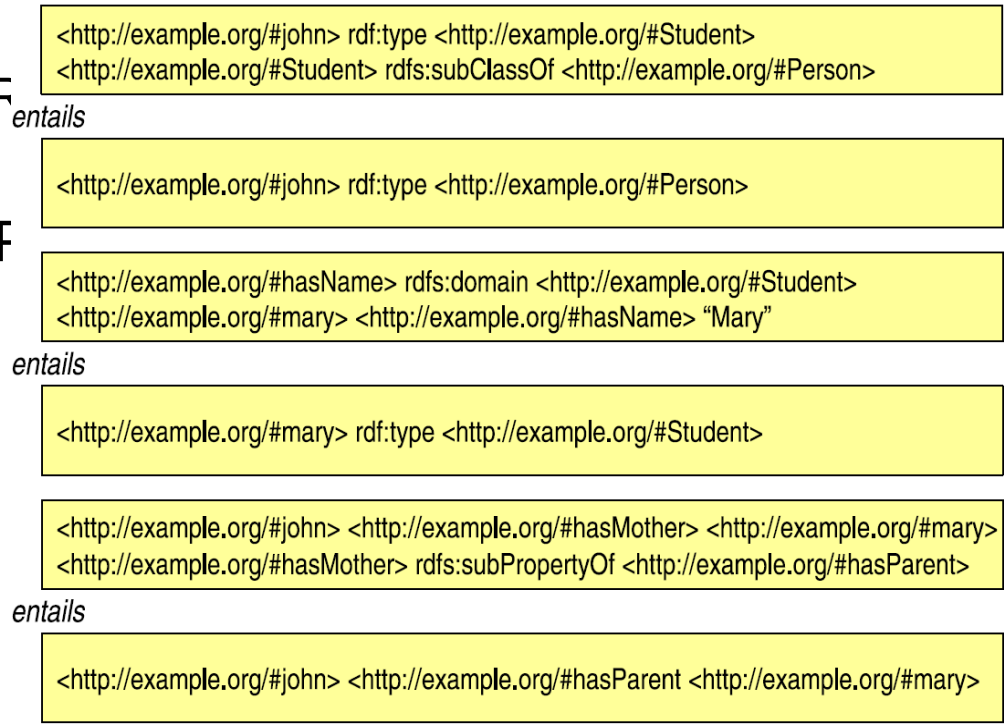

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```
PREFIX vCard: <http://www.w3.org/2001/vcard-rdf/3.0#>
SELECT ?fullName
WHERE {?x vCard:FN ?fullName}
```

Requirements for Ontology Languages

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- Well-defined syntax
- Convenience of expression
- Formal semantics
  - Needed in reasoning, e.g.:
    - Class membership
    - Equivalence of classes
    - Consistency
    - Classification
- Efficient reasoning support
- Sufficient expressive power

Limitations of the Expressive Power of RDF Schema

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- Local scope of properties
  - rdfs:range defines the range of a property (e.g. eats) for all classes
  - In RDF Schema we cannot declare range restrictions that apply to some classes only
    - E.g. we cannot say that cows eat only plants, while other animals may eat meat, too

Limitations of the Expressive Power of RDF Schema (cont')

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- Disjointness of classes
  - Sometimes we wish to say that classes are disjoint (e.g. male and female)
- Boolean combinations of classes
  - Sometimes we wish to build new classes by combining other classes using union, intersection, and complement
    - E.g. person is the disjoint union of the classes male and female

Limitations of the Expressive Power of RDF Schema (cont')

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- Cardinality restrictions
  - E.g. a person has exactly two parents, a course is taught by at least one lecturer
- Special characteristics of properties
  - Transitive property (like "greater than")
  - Unique property (like "is mother of")
  - A property is the inverse of another property (like "eats" and "is eaten by")

Other Limitations of RDFS

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- No semantics for:
  - Containers
  - Collections
  - Reification
- Domain and range of property *infer* information rather than *check* data
- RDF/XML syntax very verbose

RDFS as an Ontology Language

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- Classes
- Properties
- Class hierarchies
- Property hierarchies
- Domain and range restrictions

Expressiveness limitations of RDF(S)

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- Only binary relations

- Characteristics of Properties
  - e.g. *inverse*, *transitive*, *symmetric*
- Local range restrictions
  - e.g. for class *Person*, the property *hasName* has range *xsd:string*
- Complex concept descriptions
  - e.g. *Person* is defined by *Man* and *Woman*
- Cardinality restrictions
  - e.g. a *Person* may have at most 1 *name*
- Disjointness axioms
  - e.g. nobody can be both a *Man* and a *Woman*

Stack of Languages

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- XML
  - Surface syntax, no semantics
- XML Schema
  - Describes structure of XML documents

- RDF
  - Datamodel for “relations” between “things”
- RDF Schema
  - RDF Vocabulary Definition Language

- OWL
  - A more expressive Vocabulary Definition Language

This and following slides in part due to Frank van Harmelen
http://www.cs.vu.nl/~frankh/spool/SemWebSlides/OWL.ppt

RDF Schema Recap

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- RDFS provides
  - Classes
  - Class hierarchies
  - Properties
  - Property hierarchies
  - Domain and range restrictions
- RDFS does not provide
  - Property characteristics (inverse, transitive, ...)
  - Local range restrictions
  - Complex concept definitions
  - Cardinality restrictions
  - Disjointness axioms

Extending RDF Schema

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- OWL extends RDF Schema to a full-fledged knowledge representation language for the Web
  - logical expressions (and, or, not)
  - (in)equality
  - local properties
  - required/optional properties
  - required values
  - enumerated classes
  - symmetry, inverse

Design Goals for OWL

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- **Shareable**
- **Changing** over time
- **Interoperability**
- **Inconsistency** detection
- Balancing **expressivity and complexity**
- **Ease of use**
- Compatible with **existing standards**
- **Internationalization**

Requirements for OWL

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- Ontologies are **object on the Web**
- with **their own meta-data**, versioning, etc...
- Ontologies are **extendable**

```
<owl:Ontology rdf:about="">
  <rdfs:comment>An example OWL ontology</rdfs:comment>
  <owl:priorVersion
        rdf:resource="http://www.mydomain.org/uni-ns-old"/>
  <owl:imports
        rdf:resource="http://www.mydomain.org/persons"/>
  <rdfs:label>University Ontology</rdfs:label>
</owl:Ontology>
```

*From **Grigoris Antoniou and Frank van Harmelen: A Semantic Web Primer, MIT Press 2004***

Requirements for OWL

- Ontologies are **object on the Web**
- with **their own meta-data**, versioning, etc...
- Ontologies are **extendable**
- They contain **classes**, **properties**, **data-types**, **range/domain**, **individuals**
- **Equality** (for classes, for individuals)
- **Classes as instances**
- **Cardinality** constraints
- **XML** syntax

Language Layers of OWL

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- OWL Lite
  - Classification hierarchy
  - Simple constraints
- OWL DL
  - Maximal expressiveness while maintaining tractability
  - Standard formalization in a DL
- OWL Full
  - Very high expressiveness
  - Losing tractability
  - All syntactic freedom of RDF (self-modifying)

Features of OWL language layers

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- OWL Lite
  - (sub)classes, individuals
  - (sub)properties, domain, range
  - conjunction
  - (in)equality
  - cardinality 0/1
  - datatypes
  - *inverse*, *transitive*, *symmetric* properties
  - *someValuesFrom*
  - *allValuesFrom*
- OWL DL
  - Negation
  - Disjunction
  - Full cardinality
  - Enumerated types
  - *hasValue*
- OWL Full
  - Meta-classes

OWL Full

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- **No restriction on use of vocabulary** (as long as legal RDF)
  - Classes as instances (and much more)
- **RDF style model theory**
  - Reasoning using FOL engine
  - Semantics should correspond to OWL DL for restricted KBs

OWL DL

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- Use of vocabulary restricted
  - No classes as instances
  - Defined by abstract syntax
- Standard DL-based model theory
  - Direct correspondence with a DL
  - Partial reasoning via DL engines

OWL Lite

- No explicit negation or union
- Restricted cardinality (0/1)
- No nominals (oneOf)

- DL-based semantics
  - Reasoning via DL engines (+ datatypes)

- Semantically, only small restriction on OWL DL
  - No nominals
  - No arbitrary cardinality

OWL constructs

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OWL Construct	DL	Example
intersectionOf	$C_1 \sqcap ... \sqcap C_n$	$Human \sqcap Male$
unionOf	$C_1 \sqcup ... \sqcup C_n$	$Doctor \sqcup Lawyer$
complementOf	$\neg C$	$\neg Male$
oneOf	$\{o_1, ..., o_n\}$	$\{john, mary\}$
allValuesFrom	$\forall P.C$	$\forall hasChild.Doctor$
someValuesFrom	$\exists P.C$	$\exists hasChild.Lawyer$
value	$\exists P.\{o\}$	$\exists citizenOf.USA$
minCardinality	$\geq nP.C$	$\geq 2 hasChild.Lawyer$
maxCardinality	$\leq nP.C$	$\leq 1 hasChild.Male$
cardinality	$= nP.C$	$= 1 hasParent.Female$

OWL Axioms

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OWL Axiom	DL	Example
SubClassOf	$C_1 \sqsubseteq C_2$	$Human \sqsubseteq Animal \sqcap Biped$
EquivalentClasses	$C_1 \equiv ... \equiv C_n$	$Man \equiv Human \sqcap Male$
SubPropertyOf	$P_1 \sqsubseteq P_2$	$hasDaughter \sqsubseteq hasChild$
EquivalentProperties	$P_1 \equiv ... \equiv P_n$	$cost \equiv price$
SameIndividual	$o_1 = ... = o_n$	$President\_Bush = G\_W\_Bush$
DisjointClasses	$C_i \sqsubseteq \neg C_j$	$Male \sqsubseteq \neg Female$
DifferentIndividuals	$o_i \neq o_j$	$john \neq peter$
inverseOf	$P_1 \equiv P_2^-$	$hasChild \equiv hasParent^-$
Transitive	$P^+ \sqsubseteq P$	$ancestor^+ \sqsubseteq ancestor$
Symmetric	$P \equiv P^-$	$connectedTo \equiv connectedTo^-$

Syntaxes of OWL

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- RDF
  - Official exchange syntax
  - Hard for humans
  - RDF parsers are hard to write
- UML
  - Large user base
- XML
  - Not the RDF syntax
  - Better for humans
  - More XML than RDF tools available
- Abstract syntax
  - Not defined for OWL Full
  - Human readable

OWL in RDF/XML

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Example from [OwlGuide]:

```
<!ENTITY vin ”http://www.w3.org/TR/2004/REC-owl-guide-20040210/wine#” >
<!ENTITY food ”http://www.w3.org/TR/2004/REC-owl-guide-20040210/food#” >
...
<rdf:RDF xmlns:vin=”http://www.w3.org/TR/2004/REC-owl-guide-20040210/wine#”
         xmlns:food=”http://www.w3.org/TR/2004/REC-owl-guide-20040210/food#”
                                                                    ... >
    <owl:Class rdf:ID=”Wine”>
          <rdfs:subClassOf rdf:resource=”&food;PotableLiquid”/>
          <rdfs:label xml:lang=”en”>wine</rdfs:label>
          <rdfs:label xml:lang=”fr”>vin</rdfs:label>
          ...
    </owl:Class>

    <owl:Class rdf:ID=”Pasta”>
          <rdfs:subClassOf rdf:resource=”#EdibleThing” />
          ...
    </owl:Class>
</rdf:RDF>
```

Classes

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- Classes are defined using **owl:Class**
  - **owl:Class** is a subclass of **rdfs:Class**
- Disjointness is defined using **owl:disjointWith**

```
<owl:Class rdf:about="#associateProfessor">
    <owl:disjointWith rdf:resource="#professor"/>
    <owl:disjointWith rdf:resource="#assistantProfessor"/>
</owl:Class>
```

Classes (2)

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- **owl:equivalentClass** defines equivalence of classes

```
<owl:Class rdf:ID="faculty">
    <owl:equivalentClass rdf:resource="#academicStaffMember"/>
</owl:Class>
```

  - **owl:Thing** is the most general class, which contains everything
  - **owl:Nothing** is the empty class

Properties

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- In OWL there are two kinds of properties
  - Object properties, which relate objects to other objects
    - E.g. is-TaughtBy, supervises
  - Data type properties, which relate objects to datatype values
    - E.g. phone, title, age, etc.

Datatype Properties

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- OWL makes use of XML Schema data types, using the layered architecture of the SW

```
<owl:DatatypeProperty rdf:ID="age">
   <rdfs:range rdf:resource= "http://www.w3.org/2001/XLMSchema
     #nonNegativeInteger"/>
</owl:DatatypeProperty>
```

Object Properties

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- User-defined data types

```
<owl:ObjectProperty rdf:ID="isTaughtBy">
    <owl:domain rdf:resource="#course"/>
    <owl:range rdf:resource= "#academicStaffMember"/>
    <rdfs:subPropertyOf rdf:resource="#involves"/>
</owl:ObjectProperty>
```

Inverse and Equivalent Properties

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```
<owl:ObjectProperty rdf:ID="teaches">
    <rdfs:range rdf:resource="#course"/>
    <rdfs:domain rdf:resource="#academicStaffMember"/>
    <owl:inverseOf rdf:resource="#isTaughtBy"/>
</owl:ObjectProperty>

<owl:ObjectProperty rdf:ID="lecturesIn">
    <owl:equivalentProperty rdf:resource="#teaches"/>
</owl:ObjectProperty>
```

Property Restrictions

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- In OWL we can declare that the class C satisfies certain conditions
  - All instances of C satisfy the conditions
- This is equivalent to saying that C is subclass of a class C', where C' collects all objects that satisfy the conditions
  - C' can remain anonymous

Property Restrictions (2)

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- A (restriction) class is achieved through an **owl:Restriction** element
- This element contains an **owl:onProperty** element and one or more restriction declarations
- One type defines cardinality restrictions (at least one, at most 3,…)

Property Restrictions (3)

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- The other type defines restrictions on the kinds of values the property may take
  - **owl:allValuesFrom** specifies universal quantification
  - **owl:hasValue** specifies a specific value
  - **owl:someValuesFrom** specifies existential quantification

owl:allValuesFrom

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```
<owl:Class rdf:about="#firstYearCourse">
    <rdfs:subClassOf>
      <owl:Restriction>
          <owl:onProperty rdf:resource="#isTaughtBy"/>
          <owl:allValuesFrom rdf:resource="#Professor"/>
      </owl:Restriction>
    </rdfs:subClassOf>
</owl:Class>
```

owl:hasValue

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```
<owl:Class rdf:about="#mathCourse">
        <rdfs:subClassOf>
                <owl:Restriction>
                        <owl:onProperty rdf:resource= #isTaughtBy"/>
                        <owl:hasValue rdf:resource= "#949352"/>
                </owl:Restriction>
        </rdfs:subClassOf>
</owl:Class>
```

owl:someValuesFrom

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```
<owl:Class rdf:about="#academicStaffMember">
    <rdfs:subClassOf>
      <owl:Restriction>
          <owl:onProperty rdf:resource="#teaches"/>
          <owl:someValuesFrom rdf:resource=
          "#undergraduateCourse"/>
      </owl:Restriction>
    </rdfs:subClassOf>
</owl:Class>
```

Cardinality Restrictions

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- We can specify minimum and maximum number using **owl:minCardinality** and **owl:maxCardinality**
- It is possible to specify a precise number by using the same minimum and maximum number
- For convenience, OWL offers also **owl:cardinality**

Cardinality Restrictions (2)

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```
<owl:Class rdf:about="#course">
    <rdfs:subClassOf>
        <owl:Restriction>
            <owl:onProperty rdf:resource="#isTaughtBy"/>
            <owl:minCardinality rdf:datatype=
            "&xsd;nonNegativeInteger">
            1
            </owl:minCardinality>
        </owl:Restriction>
    </rdfs:subClassOf>
</owl:Class>
```

Special Properties

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- **owl:TransitiveProperty (**transitive property)
  - E.g. “has better grade than”, “is ancestor of”
- **owl:SymmetricProperty** (symmetry)
  - E.g. “has same grade as”, “is sibling of”
- **owl:FunctionalProperty** defines a property that has at most one value for each object
  - E.g. “age”, “height”, “directSupervisor”
- **owl:InverseFunctionalProperty** defines a property for which two different objects cannot have the same value

Special Properties (2)

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```
<owl:ObjectProperty rdf:ID="hasSameGradeAs">
        <rdf:type rdf:resource="&owl;TransitiveProperty"/>
        <rdf:type rdf:resource="&owl;SymmetricProperty"/>
        <rdfs:domain rdf:resource="#student"/>
        <rdfs:range rdf:resource="#student"/>
</owl:ObjectProperty>
```

Boolean Combinations

STI · INNSBRUCK

- We can combine classes using Boolean operations (union, intersection, complement)

```
<owl:Class rdf:about="#course">
    <rdfs:subClassOf>
        <owl:Restriction>
            <owl:complementOf rdf:resource= "#staffMember"/>
        </owl:Restriction>
    </rdfs:subClassOf>
</owl:Class>
```

Boolean Combinations (2)

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```
<owl:Class rdf:ID="peopleAtUni">
    <owl:unionOf rdf:parseType="Collection">
        <owl:Class rdf:about="#staffMember"/>
        <owl:Class rdf:about="#student"/>
    </owl:unionOf>
</owl:Class>
```

Boolean Combinations (3)

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```
<owl:Class rdf:ID="facultyInCS">
    <owl:intersectionOf rdf:parseType="Collection">
        <owl:Class rdf:about="#faculty"/>
        <owl:Restriction>
            <owl:onProperty rdf:resource="#belongsTo"/>
            <owl:hasValue rdf:resource= "#CSDepartment"/>
        </owl:Restriction>
    </owl:intersectionOf>
</owl:Class>
```

Nesting of Boolean Operators

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```
<owl:Class rdf:ID="adminStaff">
        <owl:intersectionOf rdf:parseType="Collection">
            <owl:Class rdf:about="#staffMember"/>
            <owl:complementOf>
                    <owl:unionOf rdf:parseType="Collection">
                            <owl:Class rdf:about="#faculty"/>
                            <owl:Class rdf:about="#techSupportStaff"/>
                    </owl:unionOf>
            </owl:complementOf>
        </owl:intersectionOf>
</owl:Class>
```

Enumerations with owl:oneOf

STI · INNSBRUCK

```
<owl:oneOf rdf:parseType="Collection">
        <owl:Thing rdf:about="#Monday"/>
        <owl:Thing rdf:about="#Tuesday"/>
        <owl:Thing rdf:about="#Wednesday"/>
        <owl:Thing rdf:about="#Thursday"/>
        <owl:Thing rdf:about="#Friday"/>
        <owl:Thing rdf:about="#Saturday"/>
        <owl:Thing rdf:about="#Sunday"/>
</owl:oneOf>
```

Declaring Instances

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- Instances of classes are declared as in RDF:

```
<rdf:Description rdf:ID="949352">
      <rdf:type rdf:resource= "#academicStaffMember"/>
</rdf:Description>
<academicStaffMember rdf:ID="949352">
      <uni:age rdf:datatype="&xsd;integer"> 39<uni:age>
</academicStaffMember>
```

No Unique-Names Assumption

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- OWL does not adopt the unique-names assumption of database systems
  - If two instances have a different name or ID does not imply that they are different individuals
- Suppose we state that each course is taught by at most one staff member, and that a given course is taught by two staff members
  - An OWL reasoner does not flag an error
  - Instead it infers that the two resources are equal

Distinct Objects

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- To ensure that different individuals are indeed recognized as such, we must explicitly assert their inequality:

```
<lecturer rdf:about="949318">
    <owl:differentFrom rdf:resource="949352"/>
</lecturer>
```

Distinct Objects (2)

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- OWL provides a shorthand notation to assert the pairwise inequality of all individuals in a given list

```
<owl:allDifferent>
    <owl:distinctMembers rdf:parseType="Collection">
        <lecturer rdf:about="949318"/>
        <lecturer rdf:about="949352"/>
        <lecturer rdf:about="949111"/>
    </owl:distinctMembers>
</owl:allDifferent>
```

Versioning Information

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- **owl:priorVersion** indicates earlier versions of the current ontology
  - No formal meaning, can be exploited for ontology management
- **owl:versionInfo** generally contains a string giving information about the current version, e.g. keywords

OWL Abstract syntax

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```
Class(professor partial)
Class(associateProfessor partial academicStaffMember)

DisjointClasses(associateProfessor assistantProfessor)
DisjointClasses(professor associateProfessor)

Class(faculty complete academicStaffMember)
```

OWL Abstract syntax

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- In DL syntax:

$$\mathbf{associateProfessor \sqsubseteq academicStaffMember}$$
$$\mathbf{associateProfessor \sqsubseteq \neg assistantProfessor}$$
$$\mathbf{professor \sqsubseteq \neg associateProfessor}$$
$$\mathbf{faculty \equiv academicStaffMember}$$

Class(professor **partial** **)**
Class(associateProfessor **partial** academicStaffMember**)**

DisjointClasses(associateProfessor assistantProfessor**)**
DisjointClasses(professor associateProfessor**)**

Class(faculty **complete** academicStaffMember**)**

More examples

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```
DatatypeProperty(age range(xsd:nonNegativeInteger))
ObjectProperty(lecturesIn)

ObjectProperty(isTaughtBy domain(course)
                          range(academicStaffMember))
SubPropertyOf(isTaughtBy involves)

ObjectProperty(teaches inverseOf(isTaughtBy)
                       domain(academicStaffMember)
                       range(course))

EquivalentProperties(lecturesIn teaches)

ObjectProperty(hasSameGradeAs Transitive Symmetric
                       domain(student)
                       range(student))
```

More Examples

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```
Individual(949318 type(lecturer))

Individual(949352 type(academicStaffMember)
                  value(age "39"^^&xsd;integer))

ObjectProperty(isTaughtBy Functional)

Individual(CIT1111 type(course)
                   value(isTaughtBy 949352)
                   value(isTaughtBy 949318))

DifferentIndividuals(949318 949352)
DifferentIndividuals(949352 949111 949318)
```

More Examples

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```
Class(firstYearCourse partial
      restriction(isTaughtBy allValuesFrom (Professor)))

Class(mathCourse partial
      restriction(isTaughtBy hasValue (949352)))

Class(academicStaffMember partial
      restriction (teaches someValuesFrom
                                  (undergraduateCourse)))

Class(course partial
      restriction (isTaughtBy minCardinality (1)))

Class(department partial
      restriction (hasMember minCardinality(10))
      restriction (hasMember maxCardinality(30)))
```

More Examples

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```
Class(course partial complementOf(staffMember))

Class(peopleAtUni complete unionOf(staffMember student))

Class(facultyInCS complete
   intersectionOf(faculty
       restriction (belongsTo hasValue (CSDepartment))))

Class(adminStaff complete
   intersectionOf(staffMember
       complementOf(unionOf(faculty techSupportStaff))))
```

That’s almost all for day…

WRAP-UP

Things to keep in mind (or summary)

STI · INNSBRUCK

- RDF
  - Reuse existing standards/tools
  - Standard format
  - Verbose

Things to keep in mind (or summary)

STI · INNSBRUCK

- RDF Schema
  - Advantages
    - A primitive ontology language
    - Offers certain modeling primitives with fixed meaning
    - Key concepts of RDF Schema
      - subclass relations, property, subproperty relations, domain and range restrictions
    - There exist query languages for RDF and RDFS
    - Allows metamodeling
  - Disadvantages
    - A quite primitive as a modeling language for the Web
    - Many desirable modeling primitives are missing
      - An ontology layer on top of RDF/RDFS is needed

Things to keep in mind (or summary)

STI · INNSBRUCK

- Web Ontology Language OWL
  - OWL Layering
  - OWL and Description Logics
  - OWL Syntaxes

New languages underway

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- RDFa
  - Integration of HTML world and Semantic Web
    - Means for "embedding" RDF-based annotation on traditional Web pages
    - Means for generating RDF triple stores from (annotated) Web pages
- RIF
  - Rules interchange format
    - Representing rules on the Web
    - Linking rule-based systems together
- And more
  - Multimedia annotation, Web-page Metadata annotation, Health Care and Life Science, Privacy

Semantic Web Bus

http://www.w3.org/2006/Talks/0718-aaai-tbl/

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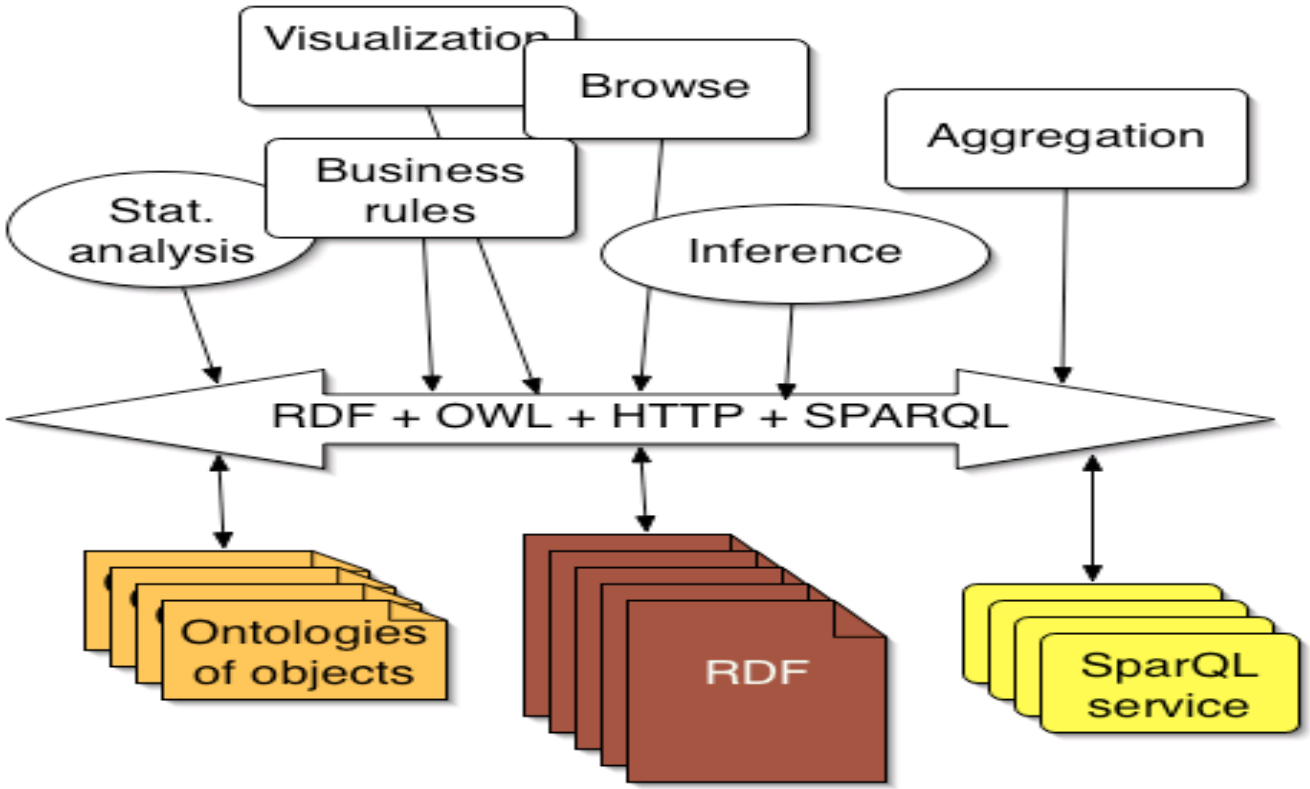

Semantic Web Tools

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- Browsers
  - mSpace, Longwell, OINK, BrownSauce, Piggy Bank, Tabulator, etc
- Annotators
  - Annotea, Clipmarks, PhotoStuff, M-OntoMat-Annotizer, KIM, WSMT
- Storages
  - Oracle Spatial 10g, Kowari, Jena, Yars, 3Store, AllegroGraph, Joseki, ARC RDF Store
- Ontology Mappers
  - OntoMerge, HMARFA, CMS
- Reasoners
  - BOR, Bossam, FaCT++, Jess, OWLJessKB, RacerPro
- Composite Applications/Frameworks
  - Cerbera, Corse, IODT, Jena, TopBraid Composer, KAON

Bibliography

STI · INNSBRUCK

- Mandatory reading
  - Semantic Web Primer
    - Chapter 3 (only Sections 3.1 to 3.6)
- Further reading
  - RDF Primer
    - http://www.w3.org/TR/REC-rdf-syntax/
  - RDF Vocabulary Description Language 1.0: RDF Schema
    - http://www.w3.org/TR/rdf-schema/

Further Reading

STI · INNSBRUCK

- Mandatory reading
  - Semantic Web Primer
    - Chapters 4
  - [OWL Guide]
    - http://www.w3.org/TR/owl-guide/
  - Ian Horrocks, Peter F. Patel-Schneider, and Frank van Harmelen. *From SHIQ and RDF to OWL: The making of a web ontology language. Journal of Web Semantics*, 1(1):7, 2003.
    - http://www.cs.vu.nl/%7Efrankh/abstracts/JWS03.html

- Further reading
  - [OWL Reference]
    - http://www.w3.org/TR/owl-ref/
  - [OWL Abstract syntax and Semantics]
    - http://www.w3.org/TR/owl-semantics