Organization of the Labs

Labs **weekly** (mandated by faculty)

- Wednesdays 17:00 – 18:00
- Exception: April 25
- Grading
  - Labs are **required** to be completed to get a grade
  - Grade: $max\{exam, 0.66 \times exam + 0.34 \times lab\}$
- All labs to be completed by May 30
- Beneficial to complete as soon as possible

Semantic Web Technologies

Advanced RDF and RDF Schema

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Outline

RDF Vocabulary Description Language

- 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 (cont'd)

- 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 (a):
  "The type of the property #hasName is # xsd:string:"
  ⟨#hasName,rdfs:range,xsd:string⟩

Recap: RDF Vocabulary

- RDF defines a number of resources and properties
- We have already seen: rdf:XMLLiteral, rdf:type, ...
- RDF vocabulary is defined in the namespace:
  `http://www.w3.org/1999/02/22-rdf-syntax-ns#`

- 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

RDFS **Extends** the RDF Vocabulary:

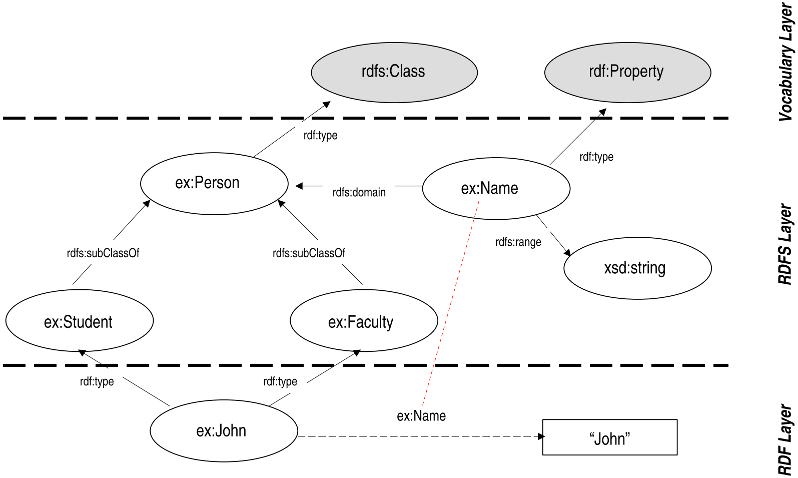
RDFS vocabulary is defined in the namespace:
`http://www.w3.org/2000/01/rdf-schema#`

- 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

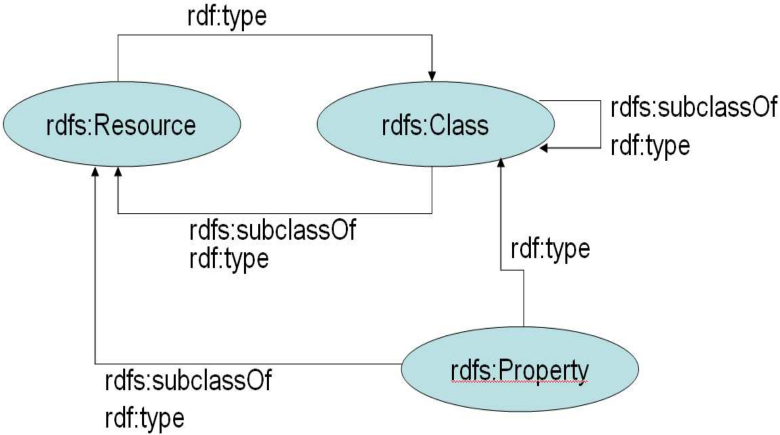
RDFS Principles

- **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

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>⟩

Recap: Literals

- Plain literals
  - E.g. "blabla"
  - 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
  - Datatype mechanism extensible
  - Type checking not in RDF
- Literals may only occur as objects of a triple
- Each literal is an rdfs:Literal
- Each datatype is an rdfs:Datatype

Literals in RDFS

- 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

- 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

E is a subgraph of *S* if and only if it is a subset

⟨<#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

- S entails E if E logically follows from S
  - Written: $S \models E$
- A graph entails all it subgraphs
  - If S' is a subgraph of S: $S \models S'$
- All instances of a graph S entail S
  - If S'' is an instance of S: $S'' \models S$

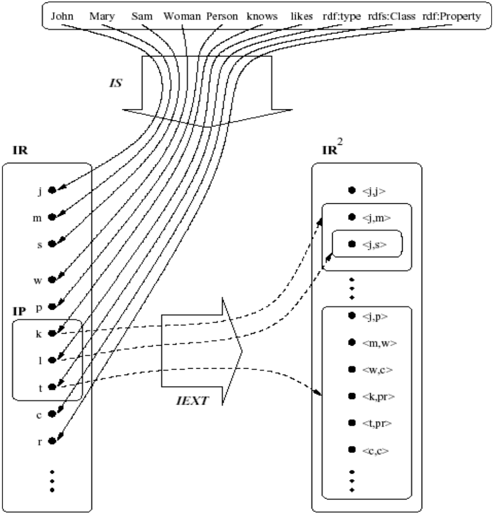
Side-step: model-theoretic semantics

- Semantics of a language is defined using a model theory
- **Interpretation**:
  - Domain D
  - Interpretation function $\cdot^I$
    - Maps symbols in the language to values in D
    - Maps statements in the language to truth values in $(D \times \ldots \times D)$
- The model theory describes conditions under which:
  - The interpretation is model for a theory
- A model theory provides a **declarative** semantics for a language
  - Two important semantic notions:
    - **Entailment**: a theory S entails S' iff every model of S is a model of S'
    - **Satisfiability**: a theory S is satisfiable iff S has a model

Basic RDF Interpretation

- Interpretation domain for resources IR
- Interpretation domain for properties $IP \subseteq IR$
- Interpretation function IS which maps URIs and blank nodes to elements of IR
- Extension function $IEXT$ which maps between IP and $IR \times IR$

Basic RDF Interpretation (cont'd)



RDF Satisfiability

- An RDF graph S is satisfiable iff S has a model

Do the following RDF graphs have a model?

<http://.../#john>	<http://.../#hasName>	"John Smith"
<http://.../#mary>	<http://.../#hasName>	"Mary Jane"

<http://.../#john>	<http://.../#marriedTo>	<http://.../#john>

In fact, **every RDF graph is satisfiable!**

RDF Entailment

- "S **rdf-entails** E if every rdf-interpretation which satisfies every member of S also satisfies E."
- Any subgraph S' of an RDF graph S **is entailed by** S
- Any instance E of an RDF graph S **entails** S
- Entailment is **transitive**

<http://.../#john>	<http://.../#hasName>	_:x
<http://.../#mary>	<http://.../#hasName>	"Mary Jane"

instance

entails

<http://.../#john>	<http://.../#hasName>	"John Smith"
<http://.../#mary>	<http://.../#hasName>	"Mary Jane"

entails

<http://.../#mary>	<http://.../#hasName>	"Mary Jane"

subgraph

Adding Literals

- Interpretation domain for resources IR
- Interpretation domain for properties $IP \subseteq IR$
- Interpretation function IS which maps URIs to elements of IR
- Extension function $IEXT$ which maps between IP and $IR \times IR$
- Interpretation domain for plain literals $LV \subseteq IR$
- Interpretation function IL which maps typed literals to elements of IR

RDF Semantic Conditions

Every RDF interpretation must satisfy these conditions:

1. x is in IP if and only if $\langle x, I(rdf : Property)\rangle$ is in $IEXT(I(rdf : type))$
   Informally: ⟨x,rdf:type,rdf:Property⟩
2. If "*xxx*"^^rdf:XMLLiteral is in the vocabulary and *xxx* is a **well-typed** XML literal string, then
   $IL("xxx"\hat{}\hat{}rdf : XMLLiteral)$ is the XML value of *xxx*;
   $IL("xxx"\hat{}\hat{}rdf : XMLLiteral)$ is in LV;
   $IEXT(I(rdf : type))$ contains $\langle IL("xxx"\hat{}\hat{}rdf : XMLLiteral),$
   $I(rdf : XMLLiteral)\rangle$
   Informally: ⟨"*xxx*"^^rdf:XMLLiteral,rdf:type,rdf:XMLLiteral⟩
3. If "*xxx*"^^rdf:XMLLiteral is in the vocabulary and *xxx* is an **ill-typed** XML literal string, then
   $IL("xxx"\hat{}\hat{}rdf : XMLLiteral)$ is not in LV;
   $IEXT(I(rdf : type))$ does not contain $\langle IL("xxx"\hat{}\hat{}rdf : XMLLiteral),$
   $I(rdf : XMLLiteral)\rangle$
   Informally: ~~⟨"*xxx*"^^rdf:XMLLiteral,rdf:type,rdf:XMLLiteral⟩~~

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>

Entailment rules

- Semantics defined through **entailment rules**
- IF S contains <**triple pattern**> then add <**triple pattern**>
- Executing all entailment rules yields **realization** of S
- S entails E if E is a subgraph of the realization of S (modulo blank node renaming)
- Axiomatic triple are always added

RDF Axiomatic triples

⟨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 I

⟨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:label, rdfs:domain, rdfs:Resource⟩

RDFS Axiomatic triples II

⟨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:isDefinedBy, rdfs:range, rdfs:Resource⟩
⟨rdfs:comment, rdfs:range, rdfs:Literal⟩

RDFS Axiomatic triples III

⟨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⟩
⟨rdf:_1, rdfs:domain, rdfs:Resource⟩
⟨rdf:_1, rdfs:range, rdfs:Resource⟩

RDFS Axiomatic triples IV

⟨rdf:_2, rdf:type, rdfs:ContainerMembershipProperty⟩

⟨rdf:_2, rdfs:domain, rdfs:Resource⟩

⟨rdf:_2, rdfs:range, rdfs:Resource⟩

...

RDF Entailment

if E **contains** $\langle A, B, C \rangle$ **then add** ⟨B,rdf:type,rdf:Property⟩

if E **contains** $\langle A, B, l \rangle$ (l is a valid XML literal) **then add** ⟨_:X,rdf:type,rdf:XMLLiteral⟩

RDFS Entailment I

everything in the subject is a resource:
if E **contains** $\langle A, B, C\rangle$ **then add** $\langle A,$rdf:type,rdfs:Resource$\rangle$

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

every class is subclass of rdfs:Resource:
if E **contains** $\langle A,$rdf:type,rdfs:Class$\rangle$ **then add** $\langle A,$rdfs:subClassOf,rdfs:Resource$\rangle$

inheritance: **if** E **contains** $\langle A,$rdf:type,$B\rangle$, $\langle B,$rdfs:subClassOf,$C\rangle$ **then add** $\langle A,$rdf:type,$C\rangle$

rdfs:subClassOf is transitive:
if E **contains** $\langle A,$rdfs:subClassOf,$B\rangle$, $\langle B,$rdfs:subClassOf,$C\rangle$ **then add** $\langle A,$rdfs:subClassOf,$C\rangle$

RDFS Entailment II

rdfs:subClassOf is reflexive:
if E **contains** $\langle A$,rdf:type,rdfs:Class$\rangle$ **then add** $\langle A$,rdfs:subClassOf,$A\rangle$

rdfs:subPropertyOf is transitive:
if E **contains** $\langle A$,rdfs:subPropertyOf,$B\rangle$, $\langle B$,rdfs:subPropertyOf,$C\rangle$ **then add** $\langle A$,rdfs:subPropertyOf,$C\rangle$

rdfs:subPropertyOf is reflexive:
if E **contains** $\langle P$,rdf:type,rdf:Property$\rangle$ **then add** $\langle P$,rdfs:subPropertyOf,$P\rangle$

domain of properties:
if E **contains** $\langle P$,rdfs:domain,$C\rangle$, $\langle A,P,B\rangle$ **then add** $\langle A$,rdf:type,$C\rangle$

range of properties:
if E **contains** $\langle P$,rdfs:range,$C\rangle$, $\langle A,P,B\rangle$ **then add** $\langle B$,rdf:type,$C\rangle$

RDFS Entailment III

every literal is a member of rdfs:Literal:
if E **contains** $\langle A,B,l\rangle$ (l is a plain literal) **then add**
$\langle$_:X,rdf:type,rdfs:Literal$\rangle$

every datatype is subclass of rdfs:Literal:
if E **contains** $\langle A$,rdf:type,rdfs:Datatype$\rangle$ **then add**
$\langle A$,rdfs:subClassOf,rdfs:Literal$\rangle$

More on literals

Recall:

if E **contains** $\langle A, B, l \rangle$ (l is a valid XML literal) **then add** $\langle$_:X,rdf:type,rdf:XMLLiteral$\rangle$

every literal is a member of rdfs:Literal:
if E **contains** $\langle A, B, l \rangle$ (l is a plain literal) **then add** $\langle$_:X,rdf:type,rdfs:Literal$\rangle$

allocating blank nodes to literals:
if E **contains** $\langle A, B, l \rangle$ (l is a literal) **then add** $\langle A, B,$_:n$\rangle$
_:n is **allocated to** l

"dereferencing" blank nodes:
if E **contains** $\langle A, B, \_ : n \rangle$ ($\_ : n$ is allocated to a literal l) **then add** $\langle A, B, l \rangle$

Summary

Required reading

- RDF Primer: http://www.w3.org/TR/rdf-primer/, Chapters 5–7
- RDF Semantics, Chapter 7: http://www.w3.org/TR/rdf-mt/

Further reading

- H. J. ter Horst. Completeness, decidability and complexity of entailment for rdf schema and a semantic extension involving the owl vocabulary. *Journal of Web Semantics*, 3(23):79115, 2005.
- J. de Bruijn, E. Franconi, and S. Tessaris. Logical reconstruction of normative RDF. In *OWL: Experiences and Directions Workshop (OWLED-2005)*, Galway, Ireland, November 2005.
- RDF Vocabulary Description Language 1.0: RDF Schema: http://www.w3.org/TR/rdf-schema/
- RDF Semantics: http://www.w3.org/TR/rdf-mt/
- (Semantic Web Primer, Sections 3.4–3.6)