INF3580 – Semantic Technologies – Spring 2011

Lecture 6: Introduction to Reasoning with RDF

Martin Giese

1st March 2010

Department of Informatics

University of Oslo

Today's Plan

1. Inference rules
2. RDFS Basics
3. Domains, ranges and open worlds

Outline

Model-theoretic semantics, a quick recap

The previous lecture introduced a “model-theoretic” semantics for Propositional Logic:

Model-theoretic semantics, a quick recap

The previous lecture introduced a “model-theoretic” semantics for Propositional Logic:

- we specified in a mathematically precise way

Model-theoretic semantics, a quick recap

The previous lecture introduced a "model-theoretic" semantics for Propositional Logic:

- we specified in a mathematically precise way
  - when a formula is true in an interpretation,

Model-theoretic semantics, a quick recap

The previous lecture introduced a “model-theoretic” semantics for Propositional Logic:

- we specified in a mathematically precise way
    - when a formula is true in an interpretation,
    - when a formula is a “tautology” (true in all interps.)

Model-theoretic semantics, a quick recap

The previous lecture introduced a “model-theoretic” semantics for Propositional Logic:

- we specified in a mathematically precise way
  - when a formula is true in an interpretation,
  - when a formula is a “tautology” (true in all interps.)
  - and when one formula entails another

Model-theoretic semantics, a quick recap

The previous lecture introduced a "model-theoretic" semantics for Propositional Logic:

- we specified in a mathematically precise way
  - when a formula is true in an interpretation,
  - when a formula is a "tautology" (true in all interps.)
  - and when one formula entails another

Model-theoretic semantics is well-suited for

Model-theoretic semantics, a quick recap

The previous lecture introduced a "model-theoretic" semantics for Propositional Logic:

- we specified in a mathematically precise way
  - when a formula is true in an interpretation,
  - when a formula is a "tautology" (true in all interps.)
  - and when one formula entails another

Model-theoretic semantics is well-suited for

- studying the behaviour of a logic, since

Model-theoretic semantics, a quick recap

The previous lecture introduced a "model-theoretic" semantics for Propositional Logic:

- we specified in a mathematically precise way
  - when a formula is true in an interpretation,
  - when a formula is a "tautology" (true in all interps.)
  - and when one formula entails another

Model-theoretic semantics is well-suited for

- studying the behaviour of a logic, since
- it is specified in terms of familiar mathematical objects, such as

Model-theoretic semantics, a quick recap

The previous lecture introduced a "model-theoretic" semantics for Propositional Logic:

- we specified in a mathematically precise way
  - when a formula is true in an interpretation,
  - when a formula is a "tautology" (true in all interps.)
  - and when one formula entails another

Model-theoretic semantics is well-suited for

- studying the behaviour of a logic, since
- it is specified in terms of familiar mathematical objects, such as
  - sets of letters

Preview: Model Semantics for RDF

- We will look at semantics for RDF in two weeks

Preview: Model Semantics for RDF

- We will look at semantics for RDF in two weeks
- Interpretations will consist of

Preview: Model Semantics for RDF

- We will look at semantics for RDF in two weeks
- Interpretations will consist of
  - A set $\mathcal{D}$ of resources (possibly infinite)

Preview: Model Semantics for RDF

- We will look at semantics for RDF in two weeks
- Interpretations will consist of
  - A set $\mathcal{D}$ of resources (possibly infinite)
  - A function mapping each URI to an object in $\mathcal{D}$

Preview: Model Semantics for RDF

- We will look at semantics for RDF in two weeks
- Interpretations will consist of
  - A set $\mathcal{D}$ of resources (possibly infinite)
  - A function mapping each URI to an object in $\mathcal{D}$
  - relations on $\mathcal{D}$ giving meaning for each property

Preview: Model Semantics for RDF

- We will look at semantics for RDF in two weeks
- Interpretations will consist of
  - A set $\mathcal{D}$ of resources (possibly infinite)
  - A function mapping each URI to an object in $\mathcal{D}$
  - relations on $\mathcal{D}$ giving meaning for each property
- Everything else will be defined in terms of these interpretations.

Preview: Model Semantics for RDF

- We will look at semantics for RDF in two weeks
- Interpretations will consist of
  - A set $\mathcal{D}$ of resources (possibly infinite)
  - A function mapping each URI to an object in $\mathcal{D}$
  - relations on $\mathcal{D}$ giving meaning for each property
- Everything else will be defined in terms of these interpretations.
- Entailment of RDF graphs, etc.

Preview: Model Semantics for RDF

- We will look at semantics for RDF in two weeks
- Interpretations will consist of
  - A set $\mathcal{D}$ of resources (possibly infinite)
  - A function mapping each URI to an object in $\mathcal{D}$
  - relations on $\mathcal{D}$ giving meaning for each property
- Everything else will be defined in terms of these interpretations.
- Entailment of RDF graphs, etc.
- Remember: interpretations for Propositional Logic could be listed in truth tables.

Preview: Model Semantics for RDF

- We will look at semantics for RDF in two weeks
- Interpretations will consist of
  - A set $\mathcal{D}$ of resources (possibly infinite)
  - A function mapping each URI to an object in $\mathcal{D}$
  - relations on $\mathcal{D}$ giving meaning for each property
- Everything else will be defined in terms of these interpretations.
- Entailment of RDF graphs, etc.
- Remember: interpretations for Propositional Logic could be listed in truth tables.
  - Only 2^n possibilities for n letters.

Preview: Model Semantics for RDF

- We will look at semantics for RDF in two weeks
- Interpretations will consist of
  - A set $\mathcal{D}$ of resources (possibly infinite)
  - A function mapping each URI to an object in $\mathcal{D}$
  - relations on $\mathcal{D}$ giving meaning for each property
- Everything else will be defined in terms of these interpretations.
- Entailment of RDF graphs, etc.
- Remember: interpretations for Propositional Logic could be listed in truth tables.
  - Only 2^n possibilities for n letters.
- Not possible for RDF:

Preview: Model Semantics for RDF

- We will look at semantics for RDF in two weeks
- Interpretations will consist of
  - A set $\mathcal{D}$ of resources (possibly infinite)
  - A function mapping each URI to an object in $\mathcal{D}$
  - relations on $\mathcal{D}$ giving meaning for each property
- Everything else will be defined in terms of these interpretations.
- Entailment of RDF graphs, etc.
- Remember: interpretations for Propositional Logic could be listed in truth tables.
  - Only 2^n possibilities for n letters.
- Not possible for RDF:
  - ∞ many different interpretations

Implementational disadvantages of model semantics

Model-theoretic semantics yields an unambigous notion of entailment,

Implementational disadvantages of model semantics

Model-theoretic semantics yields an unambigous notion of entailment,

- But it isn't easy to read off from it what exactly is to be implemented.

Implementational disadvantages of model semantics

Model-theoretic semantics yields an unambigous notion of entailment,

- But it isn't easy to read off from it what exactly is to be implemented.
- Much less does it provide an algorithmic means for computing it, that is

Implementational disadvantages of model semantics

Model-theoretic semantics yields an unambigous notion of entailment,

- But it isn't easy to read off from it what exactly is to be implemented.
- Much less does it provide an algorithmic means for computing it, that is
  - for actually doing the reasoning,

Implementational disadvantages of model semantics

Model-theoretic semantics yields an unambigous notion of entailment,

- But it isn't easy to read off from it what exactly is to be implemented.
- Much less does it provide an algorithmic means for computing it, that is
  - for actually doing the reasoning,
- In order to directly use the model-theoretic semantics,

Implementational disadvantages of model semantics

Model-theoretic semantics yields an unambigous notion of entailment,

- But it isn't easy to read off from it what exactly is to be implemented.
- Much less does it provide an algorithmic means for computing it, that is
  - for actually doing the reasoning,
- In order to directly use the model-theoretic semantics,
  - in principle all interpretations would have to be considered.

Implementational disadvantages of model semantics

Model-theoretic semantics yields an unambigous notion of entailment,

- But it isn't easy to read off from it what exactly is to be implemented.
- Much less does it provide an algorithmic means for computing it, that is
  - for actually doing the reasoning,
- In order to directly use the model-theoretic semantics,
  - in principle all interpretations would have to be considered.
  - But as there are always infinitely many such interpretations,

Implementational disadvantages of model semantics

Model-theoretic semantics yields an unambigous notion of entailment,

- But it isn't easy to read off from it what exactly is to be implemented.
- Much less does it provide an algorithmic means for computing it, that is
  - for actually doing the reasoning,
- In order to directly use the model-theoretic semantics,
  - in principle all interpretations would have to be considered.
  - But as there are always infinitely many such interpretations,
  - and an algorithm must terminate in finite time

Implementational disadvantages of model semantics

Model-theoretic semantics yields an unambigous notion of entailment,

- But it isn't easy to read off from it what exactly is to be implemented.
- Much less does it provide an algorithmic means for computing it, that is
  - for actually doing the reasoning,
- In order to directly use the model-theoretic semantics,
  - in principle all interpretations would have to be considered.
  - But as there are always infinitely many such interpretations,
  - and an algorithm must terminate in finite time
  - this is impossible.

Syntactic reasoning

We therefore need means to decide entailment syntactically:

Syntactic reasoning

We therefore need means to decide entailment syntactically:

- Syntactic methods operate only on the form of a statement, that is

Syntactic reasoning

We therefore need means to decide entailment syntactically:

- Syntactic methods operate only on the form of a statement, that is
- on its concrete grammatical structure,

Syntactic reasoning

We therefore need means to decide entailment syntactically:

- Syntactic methods operate only on the form of a statement, that is
- on its concrete grammatical structure,
- without recurring to interpretations,

Syntactic reasoning

We therefore need means to decide entailment syntactically:

- Syntactic methods operate only on the form of a statement, that is
- on its concrete grammatical structure,
- without recurring to interpretations,
- syntactic reasoning is, in other words, calculation.

Syntactic reasoning

We therefore need means to decide entailment syntactically:

- Syntactic methods operate only on the form of a statement, that is
- on its concrete grammatical structure,
- without recurring to interpretations,
- syntactic reasoning is, in other words, calculation.

Interpretations still figure as the theoretical backdrop, as one typically

Syntactic reasoning

We therefore need means to decide entailment syntactically:

- Syntactic methods operate only on the form of a statement, that is
- on its concrete grammatical structure,
- without recurring to interpretations,
- syntactic reasoning is, in other words, calculation.

Interpretations still figure as the theoretical backdrop, as one typically

- strives to define syntactical methods that are provably equivalent to checking *all* interpretations

Syntactic reasoning

We therefore need means to decide entailment syntactically:

- Syntactic methods operate only on the form of a statement, that is
- on its concrete grammatical structure,
- without recurring to interpretations,
- syntactic reasoning is, in other words, calculation.

Interpretations still figure as the theoretical backdrop, as one typically

- strives to define syntactical methods that are provably equivalent to checking *all* interpretations

Syntactic reasoning easier to understand and use than model semantics

Syntactic reasoning

We therefore need means to decide entailment syntactically:

- Syntactic methods operate only on the form of a statement, that is
- on its concrete grammatical structure,
- without recurring to interpretations,
- syntactic reasoning is, in other words, calculation.

Interpretations still figure as the theoretical backdrop, as one typically

- strives to define syntactical methods that are provably equivalent to checking *all* interpretations

Syntactic reasoning easier to understand and use than model semantics

- we will show that first!

Soundness and completeness

Semantics and calculus are typically made to work like chopsticks:

Soundness and completeness

Semantics and calculus are typically made to work like chopsticks:

- One proves that,

Soundness and completeness

Semantics and calculus are typically made to work like chopsticks:

- One proves that,
  I. every conclusion derivable in the calculus from a set of premises A, is true in all interpretations that satisfy A

Soundness and completeness

Semantics and calculus are typically made to work like chopsticks:

- One proves that,
  - I. every conclusion derivable in the calculus from a set of premises A, is true in all interpretations that satisfy A
  - II. and conversely that every statement entailed by A-interpretations is derivable in the calculus when the elements of A are used as premises.

Soundness and completeness

Semantics and calculus are typically made to work like chopsticks:

- One proves that,
  I. every conclusion derivable in the calculus from a set of premises A, is true in all interpretations that satisfy A
  II. and conversely that every statement entailed by A-interpretations is derivable in the calculus when the elements of A are used as premises.

We say that the calculus is

Soundness and completeness

Semantics and calculus are typically made to work like chopsticks:

- One proves that,
  I. every conclusion derivable in the calculus from a set of premises A, is true in all interpretations that satisfy A
  II. and conversely that every statement entailed by A-interpretations is derivable in the calculus when the elements of A are used as premises.

We say that the calculus is

- sound wrt the semantics, if (I) holds, and

Soundness and completeness

Semantics and calculus are typically made to work like chopsticks:

- One proves that,
    I. every conclusion derivable in the calculus from a set of premises A, is true in all interpretations that satisfy A
    II. and conversely that every statement entailed by A-interpretations is derivable in the calculus when the elements of A are used as premises.

We say that the calculus is

- sound wrt the semantics, if (I) holds, and
- complete wrt the semantics, if (II) holds.

Inference rules

Inference rules

A calculus is usually formulated in terms of

Inference rules

A calculus is usually formulated in terms of

- a set of axioms which are tautologies,

Inference rules

A calculus is usually formulated in terms of

- a set of axioms which are tautologies,
- and a set of inference rules for generating new statements.

Inference rules

A calculus is usually formulated in terms of

- a set of axioms which are tautologies,
- and a set of inference rules for generating new statements.

The general form of an inference rule is:

Inference rules

A calculus is usually formulated in terms of

- a set of axioms which are tautologies,
- and a set of inference rules for generating new statements.

The general form of an inference rule is:

$$\frac{P_1, \ldots, P_n}{P}$$

Inference rules

A calculus is usually formulated in terms of

- a set of axioms which are tautologies,
- and a set of inference rules for generating new statements.

The general form of an inference rule is:

$$\frac{P_1, \ldots, P_n}{P}$$

- the P_i are premises

Inference rules

A calculus is usually formulated in terms of

- a set of axioms which are tautologies,
- and a set of inference rules for generating new statements.

The general form of an inference rule is:

$$\frac{P_1, \ldots, P_n}{P}$$

- the P_i are premises
- and P is the conclusion.

Inference rules

A calculus is usually formulated in terms of

- a set of axioms which are tautologies,
- and a set of inference rules for generating new statements.

The general form of an inference rule is:

$$\frac{P_1, \ldots, P_n}{P}$$

- the P_i are premises
- and P is the conclusion.

An inference rule may have,

Inference rules

A calculus is usually formulated in terms of

- a set of axioms which are tautologies,
- and a set of inference rules for generating new statements.

The general form of an inference rule is:

$$\frac{P_1, \ldots, P_n}{P}$$

- the P_i are premises
- and P is the conclusion.

An inference rule may have,

- any number of premises (typically one or two),

Inference rules

A calculus is usually formulated in terms of

- a set of axioms which are tautologies,
- and a set of inference rules for generating new statements.

The general form of an inference rule is:

$$\frac{P_1, \ldots, P_n}{P}$$

- the P_i are premises
- and P is the conclusion.

An inference rule may have,

- any number of premises (typically one or two),
- but only one conclusion (obviously).

Inference for RDF

Inference for RDF

In a Semantic Web context, inference always means,

Inference for RDF

In a Semantic Web context, inference always means,

- adding triples,

Inference for RDF

In a Semantic Web context, inference always means,

- adding triples,

More specifically it means,

Inference for RDF

In a Semantic Web context, inference always means,

- adding triples,

More specifically it means,

- adding new triples to an RDF store (broadly construed),

Inference for RDF

In a Semantic Web context, inference always means,

- adding triples,

More specifically it means,

- adding new triples to an RDF store (broadly construed),
- on the basis of the triples already in it.

Inference for RDF

In a Semantic Web context, inference always means,

- adding triples,

More specifically it means,

- adding new triples to an RDF store (broadly construed),
- on the basis of the triples already in it.

From this point of view a rule

Inference for RDF

In a Semantic Web context, inference always means,

- adding triples,

More specifically it means,

- adding new triples to an RDF store (broadly construed),
- on the basis of the triples already in it.

From this point of view a rule

$$\frac{P_1, \ldots, P_n}{P}$$

Inference for RDF

In a Semantic Web context, inference always means,

- adding triples,

More specifically it means,

- adding new triples to an RDF store (broadly construed),
- on the basis of the triples already in it.

From this point of view a rule

$$\frac{P_1, \ldots, P_n}{P}$$

may be read as an instruction;

Inference for RDF

In a Semantic Web context, inference always means,

- adding triples,

More specifically it means,

- adding new triples to an RDF store (broadly construed),
- on the basis of the triples already in it.

From this point of view a rule

$$\frac{P_1, \ldots, P_n}{P}$$

may be read as an instruction;

- "If $P_1, \ldots, P_n$ are all in the store, add P to the store"

Outline

RDF Schema

- RDF Schema is a vocabulary defined by W3C.

RDF Schema

- RDF Schema is a vocabulary defined by W3C.
- Namespace:
  `rdfs` $\equiv$ `http://www.w3.org/2000/01/rdf-schema#`

RDF Schema

- RDF Schema is a vocabulary defined by W3C.
- Namespace:
  `rdfs` $\equiv$ `http://www.w3.org/2000/01/rdf-schema#`
- Originally though of as a "schema language" like XML Schema

RDF Schema

- RDF Schema is a vocabulary defined by W3C.
- Namespace:
  `rdfs` $\equiv$ `http://www.w3.org/2000/01/rdf-schema#`
- Originally though of as a "schema language" like XML Schema
- Actually it isn't – doesn't describe "valid" RDF graphs

RDF Schema

- RDF Schema is a vocabulary defined by W3C.
- Namespace:
  `rdfs` $\equiv$ `http://www.w3.org/2000/01/rdf-schema#`
- Originally though of as a "schema language" like XML Schema
- Actually it isn't – doesn't describe "valid" RDF graphs
- Comes with some inference rules

RDF Schema

- RDF Schema is a vocabulary defined by W3C.
- Namespace:
  `rdfs` $\equiv$ `http://www.w3.org/2000/01/rdf-schema#`
- Originally though of as a “schema language” like XML Schema
- Actually it isn’t – doesn’t describe “valid” RDF graphs
- Comes with some inference rules
  - Allows to derive new triples mechanically!

RDF Schema

- RDF Schema is a vocabulary defined by W3C.
- Namespace:
  `rdfs` $\equiv$ `http://www.w3.org/2000/01/rdf-schema#`
- Originally though of as a “schema language” like XML Schema
- Actually it isn’t – doesn’t describe “valid” RDF graphs
- Comes with some inference rules
  - Allows to derive new triples mechanically!
- A very simple *modeling language*

RDF Schema

- RDF Schema is a vocabulary defined by W3C.
- Namespace:
  `rdfs` $\equiv$ `http://www.w3.org/2000/01/rdf-schema#`
- Originally though of as a "schema language" like XML Schema
- Actually it isn't – doesn't describe "valid" RDF graphs
- Comes with some inference rules
  - Allows to derive new triples mechanically!
- A very simple *modeling language*
- (for our purposes) a subset of OWL

RDF Schema concepts

- RDFS adds the concept of “classes” which are like *types* or *sets* of resources

RDF Schema concepts

- RDFS adds the concept of “classes” which are like *types* or *sets* of resources
- The RDFS vocabulary allows statements about classes

RDF Schema concepts

- RDFS adds the concept of “classes” which are like *types* or *sets* of resources
- The RDFS vocabulary allows statements about classes
- Defined resources:

RDF Schema concepts

- RDFS adds the concept of “classes” which are like *types* or *sets* of resources
- The RDFS vocabulary allows statements about classes
- Defined resources:
  - `rdfs:Resource`: The class of resources, everything.

RDF Schema concepts

- RDFS adds the concept of "classes" which are like *types* or *sets* of resources
- The RDFS vocabulary allows statements about classes
- Defined resources:
  - `rdfs:Resource`: The class of resources, everything.
  - `rdfs:Class`: The class of classes.

RDF Schema concepts

- RDFS adds the concept of "classes" which are like *types* or *sets* of resources
- The RDFS vocabulary allows statements about classes
- Defined resources:
  - `rdfs:Resource`: The class of resources, everything.
  - `rdfs:Class`: The class of classes.
  - `rdf:Property`: The class of properties (from `rdf`)

RDF Schema concepts

- RDFS adds the concept of “classes” which are like *types* or *sets* of resources
- The RDFS vocabulary allows statements about classes
- Defined resources:
  - `rdfs:Resource`: The class of resources, everything.
  - `rdfs:Class`: The class of classes.
  - `rdf:Property`: The class of properties (from `rdf`)
- Defined properties:

RDF Schema concepts

- RDFS adds the concept of "classes" which are like *types* or *sets* of resources
- The RDFS vocabulary allows statements about classes
- Defined resources:
  - `rdfs:Resource`: The class of resources, everything.
  - `rdfs:Class`: The class of classes.
  - `rdf:Property`: The class of properties (from `rdf`)
- Defined properties:
  - `rdf:type`: relate resources to classes they are members of

RDF Schema concepts

- RDFS adds the concept of “classes” which are like *types* or *sets* of resources
- The RDFS vocabulary allows statements about classes
- Defined resources:
    - `rdfs:Resource`: The class of resources, everything.
    - `rdfs:Class`: The class of classes.
    - `rdf:Property`: The class of properties (from `rdf`)
- Defined properties:
    - `rdf:type`: relate resources to classes they are members of
    - `rdfs:domain`: The domain of a relation.

RDF Schema concepts

- RDFS adds the concept of “classes” which are like *types* or *sets* of resources
- The RDFS vocabulary allows statements about classes
- Defined resources:
  - `rdfs:Resource`: The class of resources, everything.
  - `rdfs:Class`: The class of classes.
  - `rdf:Property`: The class of properties (from `rdf`)
- Defined properties:
  - `rdf:type`: relate resources to classes they are members of
  - `rdfs:domain`: The domain of a relation.
  - `rdfs:range`: The range of a relation.

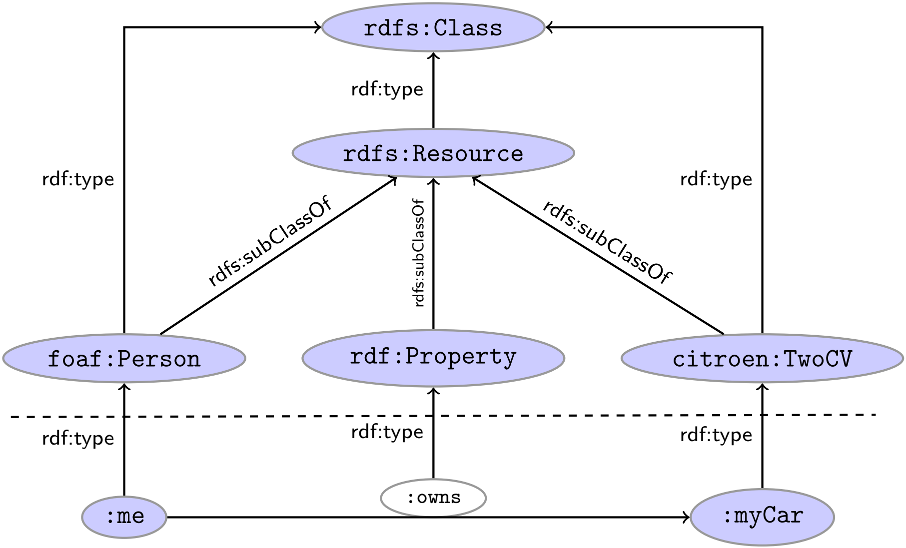
RDF Schema concepts

- RDFS adds the concept of "classes" which are like *types* or *sets* of resources
- The RDFS vocabulary allows statements about classes
- Defined resources:
  - `rdfs:Resource`: The class of resources, everything.
  - `rdfs:Class`: The class of classes.
  - `rdf:Property`: The class of properties (from `rdf`)
- Defined properties:
  - `rdf:type`: relate resources to classes they are members of
  - `rdfs:domain`: The domain of a relation.
  - `rdfs:range`: The range of a relation.
  - `rdfs:subClassOf`: Concept inclusion.

RDF Schema concepts

- RDFS adds the concept of “classes” which are like *types* or *sets* of resources
- The RDFS vocabulary allows statements about classes
- Defined resources:
  - `rdfs:Resource`: The class of resources, everything.
  - `rdfs:Class`: The class of classes.
  - `rdf:Property`: The class of properties (from `rdf`)
- Defined properties:
  - `rdf:type`: relate resources to classes they are members of
  - `rdfs:domain`: The domain of a relation.
  - `rdfs:range`: The range of a relation.
  - `rdfs:subClassOf`: Concept inclusion.
  - `rdfs:subPropertyOf`: Property inclusion.

Example


rdfs:Class
rdf:type
rdfs:Resource
rdf:type
rdf:type
rdfs:subClassOf
rdfs:subClassOf
rdfs:subClassOf
foaf:Person
rdf:Property
citroen:TwoCV
rdf:type
rdf:type
rdf:type
:owns
:me
:myCar

Intuition: Classes as Sets

- We can think of an `rdfs:Class` as denoting a set of Resources

Intuition: Classes as Sets

- We can think of an `rdfs:Class` as denoting a set of Resources
- Not quite correct, but OK for intuition

Intuition: Classes as Sets

- We can think of an `rdfs:Class` as denoting a set of Resources
- Not quite correct, but OK for intuition

RDFS	Set Theory
A `rdf:type rdfs:Class`	A is a set of resources
x `rdf:type` A	$x \in A$
A `rdfs:subClassOf` B	$A \subseteq B$

RDFS reasoning

RDFS supports three principal kinds of reasoning pattern:

RDFS reasoning

RDFS supports three principal kinds of reasoning pattern:

I. Type propagation:

RDFS reasoning

RDFS supports three principal kinds of reasoning pattern:

I. Type propagation:
   - “The 2CV is a car, and a car is a motorised vehicle, so. . . ”

RDFS reasoning

RDFS supports three principal kinds of reasoning pattern:

I. Type propagation:
   - "The 2CV is a car, and a car is a motorised vehicle, so. . ."

II. Property inheritance:

RDFS reasoning

RDFS supports three principal kinds of reasoning pattern:

I. Type propagation:
   - "The 2CV is a car, and a car is a motorised vehicle, so..."

II. Property inheritance:
   - "Martin lectures at Ifi, and anyone who does so is employed by Ifi, so..."

RDFS reasoning

RDFS supports three principal kinds of reasoning pattern:

I. Type propagation:
   - "The 2CV is a car, and a car is a motorised vehicle, so. . ."

II. Property inheritance:
   - "Martin lectures at Ifi, and anyone who does so is employed by Ifi, so. . ."

III. Domain and range reasoning:

RDFS reasoning

RDFS supports three principal kinds of reasoning pattern:

I. Type propagation:
   - "The 2CV is a car, and a car is a motorised vehicle, so..."

II. Property inheritance:
   - "Martin lectures at Ifi, and anyone who does so is employed by Ifi, so..."

III. Domain and range reasoning:
   - "Everything someone has written is a document. Martin has written a PhD thesis, therefore..."

RDFS reasoning

RDFS supports three principal kinds of reasoning pattern:

I. Type propagation:
   - "The 2CV is a car, and a car is a motorised vehicle, so..."

II. Property inheritance:
   - "Martin lectures at Ifi, and anyone who does so is employed by Ifi, so..."

III. Domain and range reasoning:
   - "Everything someone has written is a document. Martin has written a PhD thesis, therefore..."
   - "All fathers of people are males. Martin is the father of Karl, therefore..."

Type propagation with `rdfs:subClassOf`

Type propagation with `rdfs:subClassOf`

The type propagation rules apply

Type propagation with `rdfs:subClassOf`

The type propagation rules apply

- to combinations of `rdf:type`, `rdfs:subClassOf` and `rdfs:Class`,

Type propagation with `rdfs:subClassOf`

The type propagation rules apply

- to combinations of `rdf:type`, `rdfs:subClassOf` and `rdfs:Class`,
- and trigger recursive inheritance in a class taxonomy.

Type propagation with `rdfs:subClassOf`

The type propagation rules apply

- to combinations of `rdf:type`, `rdfs:subClassOf` and `rdfs:Class`,
- and trigger recursive inheritance in a class taxonomy.

Type propagation rules:

Type propagation with rdfs:subClassOf

The type propagation rules apply

- to combinations of rdf:type, rdfs:subClassOf and rdfs:Class,
- and trigger recursive inheritance in a class taxonomy.

Type propagation rules:

- Members of subclasses

Type propagation with `rdfs:subClassOf`

The type propagation rules apply

- to combinations of `rdf:type`, `rdfs:subClassOf` and `rdfs:Class`,
- and trigger recursive inheritance in a class taxonomy.

Type propagation rules:

- Members of subclasses

$$\frac{\texttt{A rdfs:subClassOf B .} \qquad \texttt{x rdf:type A .}}{\texttt{x rdf:type B .}}\ \text{rdfs9}$$

Type propagation with rdfs:subClassOf

The type propagation rules apply

- to combinations of `rdf:type`, `rdfs:subClassOf` and `rdfs:Class`,
- and trigger recursive inheritance in a class taxonomy.

Type propagation rules:

- Members of subclasses

$$\frac{\texttt{A rdfs:subClassOf B .} \qquad \texttt{x rdf:type A .}}{\texttt{x rdf:type B .}}\ \text{rdfs9}$$

- Reflexivity of sub-class relation

Type propagation with `rdfs:subClassOf`

The type propagation rules apply

- to combinations of `rdf:type`, `rdfs:subClassOf` and `rdfs:Class`,
- and trigger recursive inheritance in a class taxonomy.

Type propagation rules:

- Members of subclasses

$$\frac{\texttt{A rdfs:subClassOf B .} \qquad \texttt{x rdf:type A .}}{\texttt{x rdf:type B .}}\ \text{rdfs9}$$

- Reflexivity of sub-class relation

$$\frac{\texttt{A rdf:type rdfs:Class .}}{\texttt{A rdfs:subClassOf A .}}\ \text{rdfs10}$$

Type propagation with `rdfs:subClassOf`

The type propagation rules apply

- to combinations of `rdf:type`, `rdfs:subClassOf` and `rdfs:Class`,
- and trigger recursive inheritance in a class taxonomy.

Type propagation rules:

- Members of subclasses

$$\frac{\texttt{A rdfs:subClassOf B .} \qquad \texttt{x rdf:type A .}}{\texttt{x rdf:type B .}}\ \text{rdfs9}$$

- Reflexivity of sub-class relation

$$\frac{\texttt{A rdf:type rdfs:Class .}}{\texttt{A rdfs:subClassOf A .}}\ \text{rdfs10}$$

- Transitivity of sub-class relation

Type propagation with `rdfs:subClassOf`

The type propagation rules apply

- to combinations of `rdf:type`, `rdfs:subClassOf` and `rdfs:Class`,
- and trigger recursive inheritance in a class taxonomy.

Type propagation rules:

- Members of subclasses

$$\frac{\texttt{A rdfs:subClassOf B .} \qquad \texttt{x rdf:type A .}}{\texttt{x rdf:type B .}}\ \text{rdfs9}$$

- Reflexivity of sub-class relation

$$\frac{\texttt{A rdf:type rdfs:Class .}}{\texttt{A rdfs:subClassOf A .}}\ \text{rdfs10}$$

- Transitivity of sub-class relation

$$\frac{\texttt{A rdfs:subClassOf B .} \qquad \texttt{B rdfs:subClassOf C .}}{\texttt{A rdfs:subClassOf C .}}\ \text{rdfs11}$$

Example

RDFS/RDF knowledge base:

Example

RDFS/RDF knowledge base:

```
ex:KillerWhale rdf:type rdfs:Class .
```

Example

RDFS/RDF knowledge base:

```
ex:KillerWhale rdf:type rdfs:Class .
ex:Mammal rdf:type rdfs:Class .
```

Example

RDFS/RDF knowledge base:

```
ex:KillerWhale rdf:type rdfs:Class .
ex:Mammal rdf:type rdfs:Class .
ex:Vertebrate rdf:type rdfs:Class .
```

Example

RDFS/RDF knowledge base:

```
ex:KillerWhale rdf:type rdfs:Class .
ex:Mammal rdf:type rdfs:Class .
ex:Vertebrate rdf:type rdfs:Class .

ex:KillerWhale rdfs:subClassOf ex:Mammal .
```

Example

RDFS/RDF knowledge base:

```
ex:KillerWhale rdf:type rdfs:Class .
ex:Mammal rdf:type rdfs:Class .
ex:Vertebrate rdf:type rdfs:Class .

ex:KillerWhale rdfs:subClassOf ex:Mammal .
ex:Mammal rdfs:subClassOf ex:Vertebrate .
```

Example

RDFS/RDF knowledge base:

```
ex:KillerWhale rdf:type rdfs:Class .
ex:Mammal rdf:type rdfs:Class .
ex:Vertebrate rdf:type rdfs:Class .

ex:KillerWhale rdfs:subClassOf ex:Mammal .
ex:Mammal rdfs:subClassOf ex:Vertebrate .

ex:Keiko rdf:type ex:KillerWhale .
```

Example

RDFS/RDF knowledge base:

```
ex:KillerWhale rdf:type rdfs:Class .
ex:Mammal rdf:type rdfs:Class .
ex:Vertebrate rdf:type rdfs:Class .

ex:KillerWhale rdfs:subClassOf ex:Mammal .
ex:Mammal rdfs:subClassOf ex:Vertebrate .

ex:Keiko rdf:type ex:KillerWhale .
```

Example

RDFS/RDF knowledge base:

```
ex:KillerWhale rdf:type rdfs:Class .
ex:Mammal rdf:type rdfs:Class .
ex:Vertebrate rdf:type rdfs:Class .

ex:KillerWhale rdfs:subClassOf ex:Mammal .
ex:Mammal rdfs:subClassOf ex:Vertebrate .

ex:Keiko rdf:type ex:KillerWhale .
```

Inferred triples:

Example

RDFS/RDF knowledge base:

```
ex:KillerWhale rdf:type rdfs:Class .
ex:Mammal rdf:type rdfs:Class .
ex:Vertebrate rdf:type rdfs:Class .

ex:KillerWhale rdfs:subClassOf ex:Mammal .
ex:Mammal rdfs:subClassOf ex:Vertebrate .

ex:Keiko rdf:type ex:KillerWhale .
```

Inferred triples:

`ex:Keiko rdf:type ex:Mammal .` (rdfs9)

Example

RDFS/RDF knowledge base:

```
ex:KillerWhale rdf:type rdfs:Class .
ex:Mammal rdf:type rdfs:Class .
ex:Vertebrate rdf:type rdfs:Class .

ex:KillerWhale rdfs:subClassOf ex:Mammal .
ex:Mammal rdfs:subClassOf ex:Vertebrate .

ex:Keiko rdf:type ex:KillerWhale .
```

Inferred triples:

`ex:Keiko rdf:type ex:Mammal .` (rdfs9)

`ex:Keiko rdf:type ex:Vertebrate .` (rdfs9)

Example

RDFS/RDF knowledge base:

```
ex:KillerWhale rdf:type rdfs:Class .
ex:Mammal rdf:type rdfs:Class .
ex:Vertebrate rdf:type rdfs:Class .

ex:KillerWhale rdfs:subClassOf ex:Mammal .
ex:Mammal rdfs:subClassOf ex:Vertebrate .

ex:Keiko rdf:type ex:KillerWhale .
```

Inferred triples:

`ex:Keiko rdf:type ex:Mammal .` (rdfs9)

`ex:Keiko rdf:type ex:Vertebrate .` (rdfs9)

`ex:KillerWhale rdfs:subClassOf ex:Mammal .` (rdfs11)

Example

RDFS/RDF knowledge base:

```
ex:KillerWhale rdf:type rdfs:Class .
ex:Mammal rdf:type rdfs:Class .
ex:Vertebrate rdf:type rdfs:Class .

ex:KillerWhale rdfs:subClassOf ex:Mammal .
ex:Mammal rdfs:subClassOf ex:Vertebrate .

ex:Keiko rdf:type ex:KillerWhale .
```

Inferred triples:

`ex:Keiko rdf:type ex:Mammal .` (rdfs9)

`ex:Keiko rdf:type ex:Vertebrate .` (rdfs9)

`ex:KillerWhale rdfs:subClassOf ex:Mammal .` (rdfs11)

`ex:Mammal rdfs:subClassOf ex:Mammal .` (rdfs10)

Set Theory Analogy

- Members of subclasses

$$\frac{\texttt{A rdfs:subClassOf B .} \qquad \texttt{x rdf:type A .}}{\texttt{x rdf:type B .}}$$

$$\frac{A \subseteq B \qquad x \in A}{x \in B}$$

Set Theory Analogy

- Members of subclasses

$$\frac{\texttt{A rdfs:subClassOf B .} \qquad \texttt{x rdf:type A .}}{\texttt{x rdf:type B .}}$$

$$\frac{A \subseteq B \qquad x \in A}{x \in B}$$

- Reflexivity of sub-class relation

$$\frac{\texttt{A rdf:type rdfs:Class .}}{\texttt{A rdfs:subClassOf A .}} \qquad \frac{A \text{ is a set}}{A \subseteq A}$$

Set Theory Analogy

- Members of subclasses

$$\frac{\texttt{A rdfs:subClassOf B .} \qquad \texttt{x rdf:type A .}}{\texttt{x rdf:type B .}}$$

$$\frac{A \subseteq B \qquad x \in A}{x \in B}$$

- Reflexivity of sub-class relation

$$\frac{\texttt{A rdf:type rdfs:Class .}}{\texttt{A rdfs:subClassOf A .}} \qquad \frac{A \text{ is a set}}{A \subseteq A}$$

- Transitivity of sub-class relation

$$\frac{\texttt{A rdfs:subClassOf B .} \qquad \texttt{B rdfs:subClassOf C .}}{\texttt{A rdfs:subClassOf C .}}$$

$$\frac{A \subseteq B \qquad B \subseteq C}{A \subseteq C}$$

A typical taxonomy

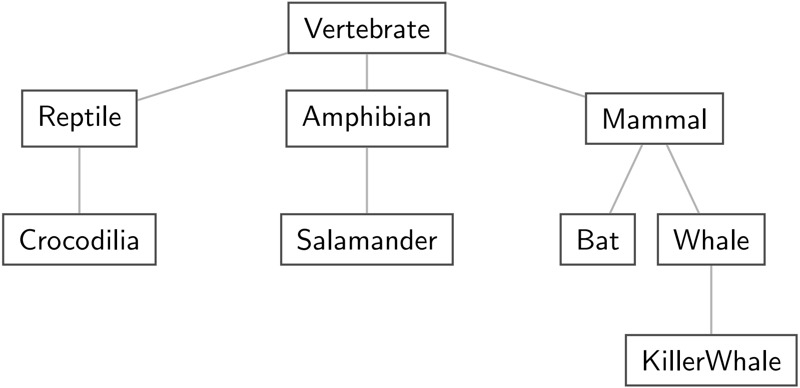


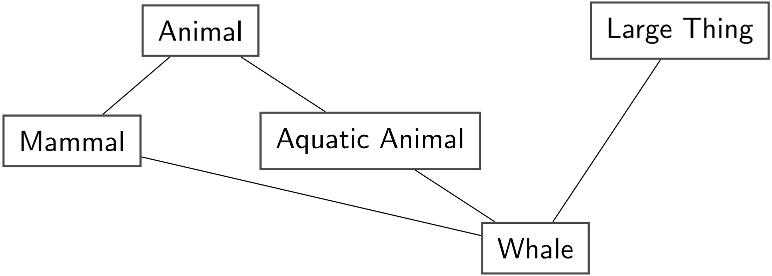
Figure: A typical taxonomy

Multiple Inheritance

- A set is a subset of many other sets:

$$\{2,3\} \subseteq \{1,2,2\} \quad \{2,3\} \subseteq \{2,3,4\} \quad \{2,3\} \subseteq \mathbb{N} \quad \{2,3\} \subseteq \mathbb{P}$$

- Similarly, a class is usually a subclass of many other classes.



- This is usually not called a *taxonomy*, but it's no problem for RDFS!

Second: Property transfer with `rdfs:subPropertyOf`

Second: Property transfer with `rdfs:subPropertyOf`

Reasoning with properties depends on certain combinations of

Second: Property transfer with `rdfs:subPropertyOf`

Reasoning with properties depends on certain combinations of

- `rdfs:subPropertyOf`,

Second: Property transfer with `rdfs:subPropertyOf`

Reasoning with properties depends on certain combinations of

- `rdfs:subPropertyOf`,
- `rdf:type`, and

Second: Property transfer with `rdfs:subPropertyOf`

Reasoning with properties depends on certain combinations of

- `rdfs:subPropertyOf`,
- `rdf:type`, and
- `rdf:Property`

Second: Property transfer with `rdfs:subPropertyOf`

Reasoning with properties depends on certain combinations of

- `rdfs:subPropertyOf`,
- `rdf:type`, and
- `rdf:Property`

Rules for property reasoning:

Second: Property transfer with `rdfs:subPropertyOf`

Reasoning with properties depends on certain combinations of

- `rdfs:subPropertyOf`,
- `rdf:type`, and
- `rdf:Property`

Rules for property reasoning:

- Transitivity:

Second: Property transfer with `rdfs:subPropertyOf`

Reasoning with properties depends on certain combinations of

- `rdfs:subPropertyOf`,
- `rdf:type`, and
- `rdf:Property`

Rules for property reasoning:

- Transitivity:

$$\frac{\texttt{p rdfs:subPropertyOf q .} \qquad \texttt{q rdfs:subPropertyOf r .}}{\texttt{p rdfs:subPropertyOf r .}}\ \text{rdfs5}$$

Second: Property transfer with `rdfs:subPropertyOf`

Reasoning with properties depends on certain combinations of

- `rdfs:subPropertyOf`,
- `rdf:type`, and
- `rdf:Property`

Rules for property reasoning:

- Transitivity:

$$\frac{\texttt{p rdfs:subPropertyOf q .} \qquad \texttt{q rdfs:subPropertyOf r .}}{\texttt{p rdfs:subPropertyOf r .}} \text{rdfs5}$$

- Reflexivity:

Second: Property transfer with `rdfs:subPropertyOf`

Reasoning with properties depends on certain combinations of

- `rdfs:subPropertyOf`,
- `rdf:type`, and
- `rdf:Property`

Rules for property reasoning:

- Transitivity:

$$\frac{\texttt{p rdfs:subPropertyOf q .} \quad \texttt{q rdfs:subPropertyOf r .}}{\texttt{p rdfs:subPropertyOf r .}}\ \text{rdfs5}$$

- Reflexivity:

$$\frac{\texttt{p rdf:type rdf:Property .}}{\texttt{p rdfs:subPropertyOf p .}}\ \text{rdfs6}$$

Second: Property transfer with `rdfs:subPropertyOf`

Reasoning with properties depends on certain combinations of

- `rdfs:subPropertyOf`,
- `rdf:type`, and
- `rdf:Property`

Rules for property reasoning:

- Transitivity:

$$\frac{\texttt{p rdfs:subPropertyOf q .} \qquad \texttt{q rdfs:subPropertyOf r .}}{\texttt{p rdfs:subPropertyOf r .}}\ \text{rdfs5}$$

- Reflexivity:

$$\frac{\texttt{p rdf:type rdf:Property .}}{\texttt{p rdfs:subPropertyOf p .}}\ \text{rdfs6}$$

- Property transfer:

Second: Property transfer with `rdfs:subPropertyOf`

Reasoning with properties depends on certain combinations of

- `rdfs:subPropertyOf`,
- `rdf:type`, and
- `rdf:Property`

Rules for property reasoning:

- Transitivity:

$$\frac{\texttt{p rdfs:subPropertyOf q .} \qquad \texttt{q rdfs:subPropertyOf r .}}{\texttt{p rdfs:subPropertyOf r .}}\ \text{rdfs5}$$

- Reflexivity:

$$\frac{\texttt{p rdf:type rdf:Property .}}{\texttt{p rdfs:subPropertyOf p .}}\ \text{rdfs6}$$

- Property transfer:

$$\frac{\texttt{p rdfs:subPropertyOf q .} \qquad \texttt{u p v .}}{\texttt{u q v .}}\ \text{rdfs7}$$

Intuition: Properties as Relations

- If an `rdfs:Class` is like a set of resources...

Intuition: Properties as Relations

- If an `rdfs:Class` is like a set of resources. . .
- . . . then an `rdf:Property` is like a relation on resources.

Intuition: Properties as Relations

- If an `rdfs:Class` is like a set of resources. . .
- . . . then an `rdf:Property` is like a relation on resources.
- Remember: not quite correct, but OK for intuition

Intuition: Properties as Relations

- If an `rdfs:Class` is like a set of resources...
- ...then an `rdf:Property` is like a relation on resources.
- Remember: not quite correct, but OK for intuition

RDFS	Set Theory
r `rdf:type rdf:Property`	r is a relation on resources
$x\ r\ y$	$\langle x, y \rangle \in r$
r `rdfs:subPropertyOf` s	$r \subseteq s$

Intuition: Properties as Relations

- If an `rdfs:Class` is like a set of resources…
- …then an `rdf:Property` is like a relation on resources.
- Remember: not quite correct, but OK for intuition

RDFS	Set Theory
r `rdf:type rdf:Property`	r is a relation on resources
$x\ \ r\ \ y$	$\langle x, y\rangle \in r$
r `rdfs:subPropertyOf` s	$r \subseteq s$

- Rules:

$$\frac{p \subseteq q \qquad q \subseteq r}{p \subseteq r} \qquad \frac{p \text{ a relation}}{p \subseteq p} \qquad \frac{p \subseteq q \qquad \langle u, v\rangle \in p}{\langle u, v\rangle \in q}$$

Example I: Harmonizing terminology

Example I: Harmonizing terminology

Integrating data from multiple sources in general requires:

Example I: Harmonizing terminology

Integrating data from multiple sources in general requires:

- Harmonisation of the data under a common vocabulary.

Example I: Harmonizing terminology

Integrating data from multiple sources in general requires:

- Harmonisation of the data under a common vocabulary.

The aim is to

Example I: Harmonizing terminology

Integrating data from multiple sources in general requires:

- Harmonisation of the data under a common vocabulary.

The aim is to

- make similar data answer to the same standardised queries,

Example I: Harmonizing terminology

Integrating data from multiple sources in general requires:

- Harmonisation of the data under a common vocabulary.

The aim is to

- make similar data answer to the same standardised queries,
- thus making queries independent of the terminology of the sources

Example I: Harmonizing terminology

Integrating data from multiple sources in general requires:

- Harmonisation of the data under a common vocabulary.

The aim is to

- make similar data answer to the same standardised queries,
- thus making queries independent of the terminology of the sources

For instance:

Example I: Harmonizing terminology

Integrating data from multiple sources in general requires:

- Harmonisation of the data under a common vocabulary.

The aim is to

- make similar data answer to the same standardised queries,
- thus making queries independent of the terminology of the sources

For instance:

- Suppose that a legacy bibliography system S uses `:author`, where

Example I: Harmonizing terminology

Integrating data from multiple sources in general requires:

- Harmonisation of the data under a common vocabulary.

The aim is to

- make similar data answer to the same standardised queries,
- thus making queries independent of the terminology of the sources

For instance:

- Suppose that a legacy bibliography system S uses `:author`, where
- another system T uses `:writer`

Example I: Harmonizing terminology

Integrating data from multiple sources in general requires:

- Harmonisation of the data under a common vocabulary.

The aim is to

- make similar data answer to the same standardised queries,
- thus making queries independent of the terminology of the sources

For instance:

- Suppose that a legacy bibliography system S uses `:author`, where
- another system T uses `:writer`

And suppose we wish to integrate S and T under a common scheme,

Example I: Harmonizing terminology

Integrating data from multiple sources in general requires:

- Harmonisation of the data under a common vocabulary.

The aim is to

- make similar data answer to the same standardised queries,
- thus making queries independent of the terminology of the sources

For instance:

- Suppose that a legacy bibliography system S uses `:author`, where
- another system T uses `:writer`

And suppose we wish to integrate S and T under a common scheme,

- For instance Dublin Core

Solution

Solution

From Ontology:

Solution

From Ontology:

```
:writer rdf:type rdf:Property .
```

Solution

From Ontology:

```
:writer rdf:type rdf:Property .
:author rdf:type rdf:Property .
```

Solution

From Ontology:

```
:writer rdf:type rdf:Property .
:author rdf:type rdf:Property .
:author rdfs:subPropertyOf dcterms:creator .
```

Solution

From Ontology:

```
:writer rdf:type rdf:Property .
:author rdf:type rdf:Property .
:author rdfs:subPropertyOf dcterms:creator .
:writer rdfs:subPropertyOf dcterms:creator .
```

Solution

From Ontology:

```
:writer rdf:type rdf:Property .
:author rdf:type rdf:Property .
:author rdfs:subPropertyOf dcterms:creator .
:writer rdfs:subPropertyOf dcterms:creator .
```

And Facts:

Solution

From Ontology:

```
:writer rdf:type rdf:Property .
:author rdf:type rdf:Property .
:author rdfs:subPropertyOf dcterms:creator .
:writer rdfs:subPropertyOf dcterms:creator .
```

And Facts:

```
ex:knausgård :writer ex:minKamp
```

Solution

From Ontology:

```
:writer rdf:type rdf:Property .
:author rdf:type rdf:Property .
:author rdfs:subPropertyOf dcterms:creator .
:writer rdfs:subPropertyOf dcterms:creator .
```

And Facts:

```
ex:knausgård :writer ex:minKamp
ex:hamsun :author ex:sult
```

Solution

From Ontology:

```
:writer rdf:type rdf:Property .
:author rdf:type rdf:Property .
:author rdfs:subPropertyOf dcterms:creator .
:writer rdfs:subPropertyOf dcterms:creator .
```

And Facts:

```
ex:knausgård :writer ex:minKamp
ex:hamsun :author ex:sult
```

Infer:

Solution

From Ontology:

```
:writer rdf:type rdf:Property .
:author rdf:type rdf:Property .
:author rdfs:subPropertyOf dcterms:creator .
:writer rdfs:subPropertyOf dcterms:creator .
```

And Facts:

```
ex:knausgård :writer ex:minKamp
ex:hamsun :author ex:sult
```

Infer:

```
ex:knausgård dcterms:creator ex:minKamp
```

Solution

From Ontology:

```
:writer rdf:type rdf:Property .
:author rdf:type rdf:Property .
:author rdfs:subPropertyOf dcterms:creator .
:writer rdfs:subPropertyOf dcterms:creator .
```

And Facts:

```
ex:knausgård :writer ex:minKamp
ex:hamsun :author ex:sult
```

Infer:

```
ex:knausgård dcterms:creator ex:minKamp
ex:hamsun dcterms:creator ex:sult
```

Consequences

- Any individual for which `:author` or `:writer` is defined,

Consequences

- Any individual for which `:author` or `:writer` is defined,
- will have the same value for the `dcterms:creator` property.

Consequences

- Any individual for which `:author` or `:writer` is defined,
- will have the same value for the `dcterms:creator` property.
- The work of integrating the data is thus done by the reasoning engine,

Consequences

- Any individual for which `:author` or `:writer` is defined,
- will have the same value for the `dcterms:creator` property.
- The work of integrating the data is thus done by the reasoning engine,
- instead of by a manual editing process.

Consequences

- Any individual for which `:author` or `:writer` is defined,
- will have the same value for the `dcterms:creator` property.
- The work of integrating the data is thus done by the reasoning engine,
- instead of by a manual editing process.
- Legacy applications that use e.g. `author` can operate unmodified.

Example II: Keeping track of employees

Example II: Keeping track of employees

Large organizations (e.g. universities) offer different kinds of contracts;

Example II: Keeping track of employees

Large organizations (e.g. universities) offer different kinds of contracts;

- for tenured positions (professors, assisting professors, lecturers),

Example II: Keeping track of employees

Large organizations (e.g. universities) offer different kinds of contracts;

- for tenured positions (professors, assisting professors, lecturers),
- for research associates (Post Docs),

Example II: Keeping track of employees

Large organizations (e.g. universities) offer different kinds of contracts;

- for tenured positions (professors, assisting professors, lecturers),
- for research associates (Post Docs),
- for PhD students,

Example II: Keeping track of employees

Large organizations (e.g. universities) offer different kinds of contracts;

- for tenured positions (professors, assisting professors, lecturers),
- for research associates (Post Docs),
- for PhD students,
- for subcontracting.

Example II: Keeping track of employees

Large organizations (e.g. universities) offer different kinds of contracts;

- for tenured positions (professors, assisting professors, lecturers),
- for research associates (Post Docs),
- for PhD students,
- for subcontracting.

Example II: Keeping track of employees

Large organizations (e.g. universities) offer different kinds of contracts;

- for tenured positions (professors, assisting professors, lecturers),
- for research associates (Post Docs),
- for PhD students,
- for subcontracting.

Employer/employee information can be read off from properties such as:

Example II: Keeping track of employees

Large organizations (e.g. universities) offer different kinds of contracts;

- for tenured positions (professors, assisting professors, lecturers),
- for research associates (Post Docs),
- for PhD students,
- for subcontracting.

Employer/employee information can be read off from properties such as:

- `:profAt` (*professorship at*),

Example II: Keeping track of employees

Large organizations (e.g. universities) offer different kinds of contracts;

- for tenured positions (professors, assisting professors, lecturers),
- for research associates (Post Docs),
- for PhD students,
- for subcontracting.

Employer/employee information can be read off from properties such as:

- `:profAt` (*professorship at*),
- `:tenAt` (*tenure at*),

Example II: Keeping track of employees

Large organizations (e.g. universities) offer different kinds of contracts;

- for tenured positions (professors, assisting professors, lecturers),
- for research associates (Post Docs),
- for PhD students,
- for subcontracting.

Employer/employee information can be read off from properties such as:

- `:profAt` (*professorship at*),
- `:tenAt` (*tenure at*),
- `:conTo` (*contracts to*),

Example II: Keeping track of employees

Large organizations (e.g. universities) offer different kinds of contracts;

- for tenured positions (professors, assisting professors, lecturers),
- for research associates (Post Docs),
- for PhD students,
- for subcontracting.

Employer/employee information can be read off from properties such as:

- `:profAt` (*professorship at*),
- `:tenAt` (*tenure at*),
- `:conTo` (*contracts to*),
- `:funBy` (*is funded by*) ,

Example II: Keeping track of employees

Large organizations (e.g. universities) offer different kinds of contracts;

- for tenured positions (professors, assisting professors, lecturers),
- for research associates (Post Docs),
- for PhD students,
- for subcontracting.

Employer/employee information can be read off from properties such as:

- `:profAt` (*professorship at*),
- `:tenAt` (*tenure at*),
- `:conTo` (*contracts to*),
- `:funBy` (*is funded by*) ,
- `:recSchol` (*receives scholarship from*).

Organising the properties

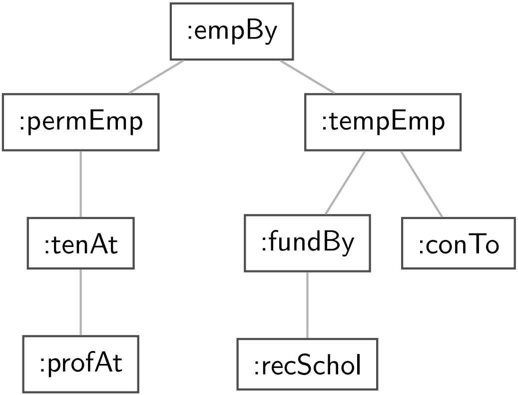


Figure: A hierarchy of employment relations

Organising the properties

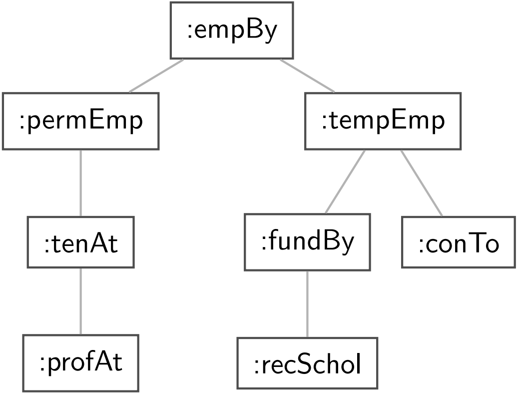


Figure: A hierarchy of employment relations

- Note: doesn't have to be tree-shaped!

Querying the inferred model

Formalising the tree:

Querying the inferred model

Formalising the tree:

```
:profAt rdf:type rdfs:Property .
```

Querying the inferred model

Formalising the tree:

```
:profAt rdf:type rdfs:Property .
:tenAt rdf:type rdfs:Property .
```

Querying the inferred model

Formalising the tree:

```
:profAt rdf:type rdfs:Property .
:tenAt rdf:type rdfs:Property .
:profAt rdfs:subPropertyOf :tenAt
```

Querying the inferred model

Formalising the tree:

```
:profAt rdf:type rdfs:Property .
:tenAt rdf:type rdfs:Property .
:profAt rdfs:subPropertyOf :tenAt
```

..... and so forth.

Querying the inferred model

Formalising the tree:

```
:profAt rdf:type rdfs:Property .
:tenAt rdf:type rdfs:Property .
:profAt rdfs:subPropertyOf :tenAt
```

..... and so forth.

Querying the inferred model

Formalising the tree:

```
:profAt rdf:type rdfs:Property .
:tenAt rdf:type rdfs:Property .
:profAt rdfs:subPropertyOf :tenAt
```

..... and so forth.

Given a data set such as:

Querying the inferred model

Formalising the tree:

```
:profAt rdf:type rdfs:Property .
:tenAt rdf:type rdfs:Property .
:profAt rdfs:subPropertyOf :tenAt
```

..... and so forth.

Given a data set such as:

```
:Arild :profAt :UiO .
```

Querying the inferred model

Formalising the tree:

```
:profAt rdf:type rdfs:Property .
:tenAt rdf:type rdfs:Property .
:profAt rdfs:subPropertyOf :tenAt
```

..... and so forth.

Given a data set such as:

```
:Arild :profAt :UiO .
:Audun :fundBy :UiO .
```

Querying the inferred model

Formalising the tree:

```
:profAt rdf:type rdfs:Property .
:tenAt rdf:type rdfs:Property .
:profAt rdfs:subPropertyOf :tenAt
```

..... and so forth.

Given a data set such as:

```
:Arild :profAt :UiO .
:Audun :fundBy :UiO .
:Martin :conTo :OLF .
```

Querying the inferred model

Formalising the tree:

```
:profAt rdf:type rdfs:Property .
:tenAt rdf:type rdfs:Property .
:profAt rdfs:subPropertyOf :tenAt
```

..... and so forth.

Given a data set such as:

```
:Arild :profAt :UiO .
:Audun :fundBy :UiO .
:Martin :conTo :OLF .
:Trond :recSchol :BI .
```

Querying the inferred model

Formalising the tree:

```
:profAt rdf:type rdfs:Property .
:tenAt rdf:type rdfs:Property .
:profAt rdfs:subPropertyOf :tenAt
```

..... and so forth.

Given a data set such as:

```
:Arild :profAt :UiO .
:Audun :fundBy :UiO .
:Martin :conTo :OLF .
:Trond :recSchol :BI .
:Jenny :tenAt :SSB .
```

cont.

We may now query on different levels of abstraction :

cont.

We may now query on different levels of abstraction :

Temporary employees

```
SELECT ?emp WHERE {?emp :tempEmp _:x .}
```

→ *Audun, Martin, Trond*

cont.

We may now query on different levels of abstraction :

Temporary employees

```
SELECT ?emp WHERE {?emp :tempEmp _:x .}
```

→ *Audun, Martin, Trond*

Permanent employees

```
SELECT ?emp WHERE {?emp :permEmp _:x .}
```

→ *Arild, Jenny*

cont.

We may now query on different levels of abstraction :

Temporary employees

```
SELECT ?emp WHERE {?emp :tempEmp _:x .}
```

→ *Audun, Martin, Trond*

Permanent employees

```
SELECT ?emp WHERE {?emp :permEmp _:x .}
```

→ *Arild, Jenny*

All employees

```
SELECT ?emp WHERE {?emp :empBy _:x .}
```

→ *Arild, Jenny, Audun, Martin, Trond*

Third pattern: Typing data based on their use

Third pattern: Typing data based on their use

Triggered by combinations of

Third pattern: Typing data based on their use

Triggered by combinations of

- `rdfs:range`

Third pattern: Typing data based on their use

Triggered by combinations of

- `rdfs:range`
- `rdfs:domain`

Third pattern: Typing data based on their use

Triggered by combinations of

- `rdfs:range`
- `rdfs:domain`
- `rdf:type`

Third pattern: Typing data based on their use

Triggered by combinations of

- `rdfs:range`
- `rdfs:domain`
- `rdf:type`

Rules for damain and range reasoning :

Third pattern: Typing data based on their use

Triggered by combinations of

- `rdfs:range`
- `rdfs:domain`
- `rdf:type`

Rules for damain and range reasoning :

- Typing first coordinates:

Third pattern: Typing data based on their use

Triggered by combinations of

- `rdfs:range`
- `rdfs:domain`
- `rdf:type`

Rules for damain and range reasoning :

- Typing first coordinates:

$$\frac{\texttt{p rdfs:domain A .} \qquad \texttt{x p y .}}{\texttt{x rdf:type A .}}\ \text{rdfs2}$$

Third pattern: Typing data based on their use

Triggered by combinations of

- `rdfs:range`
- `rdfs:domain`
- `rdf:type`

Rules for damain and range reasoning :

- Typing first coordinates:

$$\frac{\texttt{p rdfs:domain A .} \qquad \texttt{x p y .}}{\texttt{x rdf:type A .}}\ \text{rdfs2}$$

- Typing second coordinates:

Third pattern: Typing data based on their use

Triggered by combinations of

- `rdfs:range`
- `rdfs:domain`
- `rdf:type`

Rules for damain and range reasoning :

- Typing first coordinates:

$$\frac{\texttt{p rdfs:domain A .} \qquad \texttt{x p y .}}{\texttt{x rdf:type A .}}\ \text{rdfs2}$$

- Typing second coordinates:

$$\frac{\texttt{p rdfs:range B .} \qquad \texttt{x p y .}}{\texttt{y rdf:type B .}}\ \text{rdfs2}$$

Domain and range contd.

- `rdfs:domain` and `rdfs:range` tell us how a property is used.

Domain and range contd.

- `rdfs:domain` and `rdfs:range` tell us how a property is used.
- `rdfs:domain` types the possible possible subjects of these triples,

Domain and range contd.

- rdfs:domain and rdfs:range tell us how a property is used.
- rdfs:domain types the possible possible subjects of these triples,
- whereas rdfs:range types the possible objects,

Domain and range contd.

- `rdfs:domain` and `rdfs:range` tell us how a property is used.
- `rdfs:domain` types the possible possible subjects of these triples,
- whereas `rdfs:range` types the possible objects,
- When we assert that property `p has domain C`, we are saying

Domain and range contd.

- `rdfs:domain` and `rdfs:range` tell us how a property is used.
- `rdfs:domain` types the possible possible subjects of these triples,
- whereas `rdfs:range` types the possible objects,
- When we assert that property `p has domain C`, we are saying
  - that whatever is linked to anything by `p`

Domain and range contd.

- `rdfs:domain` and `rdfs:range` tell us how a property is used.
- `rdfs:domain` types the possible possible subjects of these triples,
- whereas `rdfs:range` types the possible objects,
- When we assert that property `p` has `domain` `C`, we are saying
  - that whatever is linked to anything by `p`
  - must be an object of type `C`,

Domain and range contd.

- `rdfs:domain` and `rdfs:range` tell us how a property is used.
- `rdfs:domain` types the possible possible subjects of these triples,
- whereas `rdfs:range` types the possible objects,
- When we assert that property `p` has `domain` `C`, we are saying
  - that whatever is linked to anything by `p`
  - must be an object of type `C`,
  - wherefore an application of `p` suffices to type that resource.

Domain and Range of Relations

- Given a relation R from A to B ($R \subseteq A \times B$)

Domain and Range of Relations

- Given a relation R from A to B ($R \subseteq A \times B$)
- The *domain* of R is the set of all x with $x\,R \cdots$:

$$\mathrm{d}om\, R = \{x \in A \mid xRy \text{ for some } y \in B\}$$

Domain and Range of Relations

- Given a relation R from A to B ($R \subseteq A \times B$)
- The *domain* of R is the set of all x with $x\,R\cdots$:

$$\mathrm{d}om\,R = \{x \in A \mid xRy \text{ for some } y \in B\}$$

- The *range* of R is the set of all y with $\cdots R\,y$:

$$\mathrm{r}g\,R = \{y \in B \mid xRy \text{ for some } x \in A\}$$

Domain and Range of Relations

- Given a relation R from A to B ($R \subseteq A \times B$)
- The *domain* of R is the set of all x with $x\,R \cdots$:

$$\mathrm{d}om\,R = \{x \in A \mid xRy \text{ for some } y \in B\}$$

- The *range* of R is the set of all y with $\cdots R\,y$:

$$\mathrm{r}g\,R = \{y \in B \mid xRy \text{ for some } x \in A\}$$

- Example:

Domain and Range of Relations

- Given a relation R from A to B ($R \subseteq A \times B$)
- The *domain* of R is the set of all x with $x\,R \cdots$:

$$\mathrm{d}om\, R = \{x \in A \mid xRy \text{ for some } y \in B\}$$

- The *range* of R is the set of all y with $\cdots R\, y$:

$$\mathrm{r}g\, R = \{y \in B \mid xRy \text{ for some } x \in A\}$$

- Example:
  - $R = \{\langle 1, \triangle\rangle, \langle 1, \Box\rangle, \langle 2, \Diamond\rangle\}$

Domain and Range of Relations

- Given a relation R from A to B ($R \subseteq A \times B$)
- The *domain* of R is the set of all x with $x\,R \cdots$:

$$\mathrm{d}om\, R = \{x \in A \mid xRy \text{ for some } y \in B\}$$

- The *range* of R is the set of all y with $\cdots R\, y$:

$$\mathrm{r}g\, R = \{y \in B \mid xRy \text{ for some } x \in A\}$$

- Example:
  - $R = \{\langle 1, \triangle\rangle, \langle 1, \square\rangle, \langle 2, \lozenge\rangle\}$
  - $\mathrm{d}om\, R = \{1, 2\}$

Domain and Range of Relations

- Given a relation R from A to B ($R \subseteq A \times B$)
- The *domain* of R is the set of all x with $x\,R \cdots$:

$$\mathrm{d}om\, R = \{x \in A \mid xRy \text{ for some } y \in B\}$$

- The *range* of R is the set of all y with $\cdots R\, y$:

$$\mathrm{r}g\, R = \{y \in B \mid xRy \text{ for some } x \in A\}$$

- Example:
  - $R = \{\langle 1, \triangle\rangle, \langle 1, \square\rangle, \langle 2, \lozenge\rangle\}$
  - $\mathrm{d}om\, R = \{1, 2\}$
  - $\mathrm{r}g\, R = \{\triangle, \square, \lozenge\}$

Set intuitions for `rdfs:domain` and `rdfs:range`

- If an `rdfs:Class` is like a set of resources and an `rdf:Property` is like a relation on resources. . .

Set intuitions for rdfs:domain and rdfs:range

- If an rdfs:Class is like a set of resources and an rdf:Property is like a relation on resources…

RDFS	Set Theory
r rdfs:domain A	$\mathrm{d}om\, r \subseteq A$
r rdfs:range B	$\mathrm{r}g\, r \subseteq B$

Set intuitions for `rdfs:domain` and `rdfs:range`

- If an `rdfs:Class` is like a set of resources and an `rdf:Property` is like a relation on resources...

RDFS	Set Theory
r `rdfs:domain` A	$\mathrm{dom}\, r \subseteq A$
r `rdfs:range` B	$\mathrm{rg}\, r \subseteq B$

- Rules:

$$\frac{\mathrm{dom}\, p \subseteq A \qquad \langle x, y\rangle \in p}{x \in A}$$

$$\frac{\mathrm{rg}\, p \subseteq B \qquad \langle x, y\rangle \in p}{y \in B}$$

Example I: Combining domain, range and subClassOf

Example I: Combining `domain`, `range` and `subClassOf`

Suppose we have a class tree that includes:

Example I: Combining domain, range and subClassOf

Suppose we have a class tree that includes:

```
:SymphonyOrchestra rdfs:subClassOf :Ensemble .
```

Example I: Combining domain, range and subClassOf

Suppose we have a class tree that includes:

```
:SymphonyOrchestra rdfs:subClassOf :Ensemble .
```

and a property `:conductor` whose domain and range are:

Example I: Combining `domain`, `range` and `subClassOf`

Suppose we have a class tree that includes:

```
:SymphonyOrchestra rdfs:subClassOf :Ensemble .
```

and a property `:conductor` whose domain and range are:

```
:conductor rdfs:domain :SymphonyOrchestra .
```

Example I: Combining `domain`, `range` and `subClassOf`

Suppose we have a class tree that includes:

```
:SymphonyOrchestra rdfs:subClassOf :Ensemble .
```

and a property `:conductor` whose domain and range are:

```
:conductor rdfs:domain :SymphonyOrchestra .
:conductor rdfs:range :Person .
```

Example I: Combining `domain`, `range` and `subClassOf`

Suppose we have a class tree that includes:

```
:SymphonyOrchestra rdfs:subClassOf :Ensemble .
```

and a property `:conductor` whose domain and range are:

```
:conductor rdfs:domain :SymphonyOrchestra .
:conductor rdfs:range :Person .
```

Now, if we assert

Example I: Combining `domain`, `range` and `subClassOf`

Suppose we have a class tree that includes:

```
:SymphonyOrchestra rdfs:subClassOf :Ensemble .
```

and a property `:conductor` whose domain and range are:

```
:conductor rdfs:domain :SymphonyOrchestra .
:conductor rdfs:range :Person .
```

Now, if we assert

```
:OsloPhilharmonic :conductor :Petrenko .
```

Example I: Combining `domain`, `range` and `subClassOf`

Suppose we have a class tree that includes:

```
:SymphonyOrchestra rdfs:subClassOf :Ensemble .
```

and a property `:conductor` whose domain and range are:

```
:conductor rdfs:domain :SymphonyOrchestra .
:conductor rdfs:range :Person .
```

Now, if we assert

```
:OsloPhilharmonic :conductor :Petrenko .
```

we may infer;

Example I: Combining domain, range and subClassOf

Suppose we have a class tree that includes:

```
:SymphonyOrchestra rdfs:subClassOf :Ensemble .
```

and a property `:conductor` whose domain and range are:

```
:conductor rdfs:domain :SymphonyOrchestra .
:conductor rdfs:range :Person .
```

Now, if we assert

```
:OsloPhilharmonic :conductor :Petrenko .
```

we may infer;

```
:OsloPhilharmonic rdf:type :SymphonyOrchestra .
```

Example I: Combining domain, range and subClassOf

Suppose we have a class tree that includes:

```
:SymphonyOrchestra rdfs:subClassOf :Ensemble .
```

and a property :conductor whose domain and range are:

```
:conductor rdfs:domain :SymphonyOrchestra .
:conductor rdfs:range :Person .
```

Now, if we assert

```
:OsloPhilharmonic :conductor :Petrenko .
```

we may infer;

```
:OsloPhilharmonic rdf:type :SymphonyOrchestra .
:OsloPhilharmonic rdf:type :Ensemble .
```

Example I: Combining domain, range and subClassOf

Suppose we have a class tree that includes:

```
:SymphonyOrchestra rdfs:subClassOf :Ensemble .
```

and a property :conductor whose domain and range are:

```
:conductor rdfs:domain :SymphonyOrchestra .
:conductor rdfs:range :Person .
```

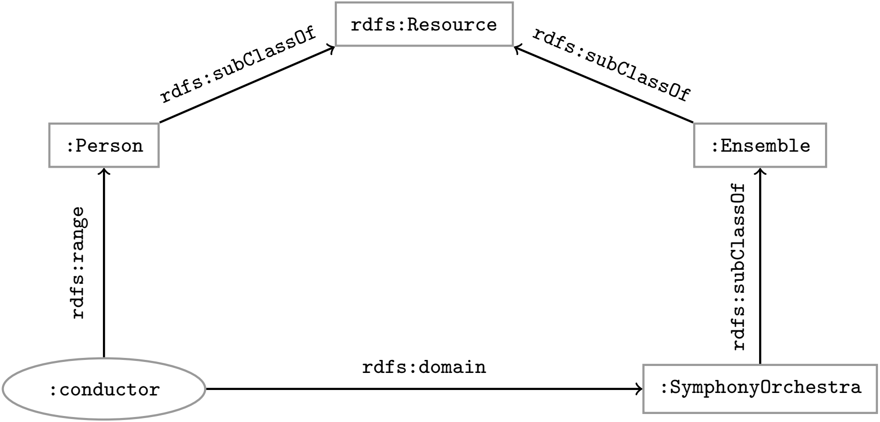
Now, if we assert

```
:OsloPhilharmonic :conductor :Petrenko .
```

we may infer;

```
:OsloPhilharmonic rdf:type :SymphonyOrchestra .
:OsloPhilharmonic rdf:type :Ensemble .
:Petrenko rdf:type :Person .
```

Conductors and ensembles



Example II: Filtering information based on use

Consider once more the dataset:

Example II: Filtering information based on use

Consider once more the dataset:

```
:Arild :profAt :UiO .
:Audun :fundBy :UiO .
:Martin :conTo :OLF .
:Trond :recSchol :BI .
:Jenny :tenAt :SSB .
```

Example II: Filtering information based on use

Consider once more the dataset:

```
:Arild :profAt :UiO .
:Audun :fundBy :UiO .
:Martin :conTo :OLF .
:Trond :recSchol :BI .
:Jenny :tenAt :SSB .
```

and suppose we wish to filter out everyone but the freelancers:

Example II: Filtering information based on use

Consider once more the dataset:

```
:Arild :profAt :UiO .
:Audun :fundBy :UiO .
:Martin :conTo :OLF .
:Trond :recSchol :BI .
:Jenny :tenAt :SSB .
```

and suppose we wish to filter out everyone but the freelancers:

- State that only freelancers `:conTo` an organisation,

Example II: Filtering information based on use

Consider once more the dataset:

```
:Arild :profAt :UiO .
:Audun :fundBy :UiO .
:Martin :conTo :OLF .
:Trond :recSchol :BI .
:Jenny :tenAt :SSB .
```

and suppose we wish to filter out everyone but the freelancers:

- State that only freelancers `:conTo` an organisation,
- i.e. introduce a class `:Freelancer`,

Example II: Filtering information based on use

Consider once more the dataset:

```
:Arild :profAt :UiO .
:Audun :fundBy :UiO .
:Martin :conTo :OLF .
:Trond :recSchol :BI .
:Jenny :tenAt :SSB .
```

and suppose we wish to filter out everyone but the freelancers:

- State that only freelancers `:conTo` an organisation,
- i.e. introduce a class `:Freelancer`,
- and declare it to be the domain of `:conTo`:

Example II: Filtering information based on use

Consider once more the dataset:

```
:Arild :profAt :UiO .
:Audun :fundBy :UiO .
:Martin :conTo :OLF .
:Trond :recSchol :BI .
:Jenny :tenAt :SSB .
```

and suppose we wish to filter out everyone but the freelancers:

- State that only freelancers `:conTo` an organisation,
- i.e. introduce a class `:Freelancer`,
- and declare it to be the domain of `:conTo`:

```
:freelancer rdf:type rdfs:Class .
```

Example II: Filtering information based on use

Consider once more the dataset:

```
:Arild :profAt :UiO .
:Audun :fundBy :UiO .
:Martin :conTo :OLF .
:Trond :recSchol :BI .
:Jenny :tenAt :SSB .
```

and suppose we wish to filter out everyone but the freelancers:

- State that only freelancers `:conTo` an organisation,
- i.e. introduce a class `:Freelancer`,
- and declare it to be the domain of `:conTo`:

```
:freelancer rdf:type rdfs:Class .
:conTo rdfs:domain :Freelancer .
```

Finding the freelancers

The class of freelancers is generated by the rdfs2 rule,

$$\frac{\text{:conTo rdfs:domain :Freelancer .} \qquad \text{:Martin :conTo :OLF .}}{\text{:Martin rdf:type :Freelancer}}\ \text{rdfs2}$$

Finding the freelancers

The class of freelancers is generated by the rdfs2 rule,

$$\frac{\text{:conTo rdfs:domain :Freelancer .} \qquad \text{:Martin :conTo :OLF .}}{\text{:Martin rdf:type :Freelancer}}\ \text{rdfs2}$$

and may be used as a type in SPARQL (reasoner presupposed):

Finding the freelancers

The class of freelancers is generated by the rdfs2 rule,

$$\frac{\text{:conTo rdfs:domain :Freelancer .} \qquad \text{:Martin :conTo :OLF .}}{\text{:Martin rdf:type :Freelancer}}\ \text{rdfs2}$$

and may be used as a type in SPARQL (reasoner presupposed):

Finding the freelancers

```
SELECT ?freelancer WHERE {
    ?freelancer rdf:type :Freelancer .
}
```

RDFS axiomatic triples (excerpt)

Some triples are axioms: they can always be added to the knowledge base.

RDFS axiomatic triples (excerpt)

Some triples are axioms: they can always be added to the knowledge base.

- Only resources have types:

RDFS axiomatic triples (excerpt)

Some triples are axioms: they can always be added to the knowledge base.

- Only resources have types:

```
rdf:type rdfs:domain rdfs:Resource .
```

RDFS axiomatic triples (excerpt)

Some triples are axioms: they can always be added to the knowledge base.

- Only resources have types:

```
rdf:type rdfs:domain rdfs:Resource .
```

- types are classes:

RDFS axiomatic triples (excerpt)

Some triples are axioms: they can always be added to the knowledge base.

- Only resources have types:

```
rdf:type rdfs:domain rdfs:Resource .
```

- types are classes:

```
rdf:type rdfs:range rdfs:Class .
```

RDFS axiomatic triples (excerpt)

Some triples are axioms: they can always be added to the knowledge base.

- Only resources have types:

```
rdf:type rdfs:domain rdfs:Resource .
```

- types are classes:

```
rdf:type rdfs:range rdfs:Class .
```

- Ranges apply only to properties:

RDFS axiomatic triples (excerpt)

Some triples are axioms: they can always be added to the knowledge base.

- Only resources have types:

```
rdf:type rdfs:domain rdfs:Resource .
```

- types are classes:

```
rdf:type rdfs:range rdfs:Class .
```

- Ranges apply only to properties:

```
rdfs:range rdfs:domain rdf:Property .
```

RDFS axiomatic triples (excerpt)

Some triples are axioms: they can always be added to the knowledge base.

- Only resources have types:

```
rdf:type rdfs:domain rdfs:Resource .
```

- types are classes:

```
rdf:type rdfs:range rdfs:Class .
```

- Ranges apply only to properties:

```
rdfs:range rdfs:domain rdf:Property .
```

- Ranges are classes:

RDFS axiomatic triples (excerpt)

Some triples are axioms: they can always be added to the knowledge base.

- Only resources have types:

```
rdf:type rdfs:domain rdfs:Resource .
```

- types are classes:

```
rdf:type rdfs:range rdfs:Class .
```

- Ranges apply only to properties:

```
rdfs:range rdfs:domain rdf:Property .
```

- Ranges are classes:

```
rdfs:range rdfs:range rdfs:Class .
```

RDFS axiomatic triples (excerpt)

Some triples are axioms: they can always be added to the knowledge base.

- Only resources have types:

  ```
  rdf:type rdfs:domain rdfs:Resource .
  ```

- types are classes:

  ```
  rdf:type rdfs:range rdfs:Class .
  ```

- Ranges apply only to properties:

  ```
  rdfs:range rdfs:domain rdf:Property .
  ```

- Ranges are classes:

  ```
  rdfs:range rdfs:range rdfs:Class .
  ```

- Only properties have subproperties:

RDFS axiomatic triples (excerpt)

Some triples are axioms: they can always be added to the knowledge base.

- Only resources have types:

  ```
  rdf:type rdfs:domain rdfs:Resource .
  ```

- types are classes:

  ```
  rdf:type rdfs:range rdfs:Class .
  ```

- Ranges apply only to properties:

  ```
  rdfs:range rdfs:domain rdf:Property .
  ```

- Ranges are classes:

  ```
  rdfs:range rdfs:range rdfs:Class .
  ```

- Only properties have subproperties:

  ```
  rdfs:subPropertyOf rdfs:domain rdf:Property .
  ```

RDFS axiomatic triples (excerpt)

Some triples are axioms: they can always be added to the knowledge base.

- Only resources have types:

  ```
  rdf:type rdfs:domain rdfs:Resource .
  ```

- types are classes:

  ```
  rdf:type rdfs:range rdfs:Class .
  ```

- Ranges apply only to properties:

  ```
  rdfs:range rdfs:domain rdf:Property .
  ```

- Ranges are classes:

  ```
  rdfs:range rdfs:range rdfs:Class .
  ```

- Only properties have subproperties:

  ```
  rdfs:subPropertyOf rdfs:domain rdf:Property .
  ```

- Only classes have subclasses:

RDFS axiomatic triples (excerpt)

Some triples are axioms: they can always be added to the knowledge base.

- Only resources have types:

  ```
  rdf:type rdfs:domain rdfs:Resource .
  ```

- types are classes:

  ```
  rdf:type rdfs:range rdfs:Class .
  ```

- Ranges apply only to properties:

  ```
  rdfs:range rdfs:domain rdf:Property .
  ```

- Ranges are classes:

  ```
  rdfs:range rdfs:range rdfs:Class .
  ```

- Only properties have subproperties:

  ```
  rdfs:subPropertyOf rdfs:domain rdf:Property .
  ```

- Only classes have subclasses:

  ```
  rdfs:subClassOf rdfs:domain rdfs:Class .
  ```

RDFS axiomatic triples (excerpt)

Some triples are axioms: they can always be added to the knowledge base.

- Only resources have types:

  ```
  rdf:type rdfs:domain rdfs:Resource .
  ```
- types are classes:

  ```
  rdf:type rdfs:range rdfs:Class .
  ```
- Ranges apply only to properties:

  ```
  rdfs:range rdfs:domain rdf:Property .
  ```
- Ranges are classes:

  ```
  rdfs:range rdfs:range rdfs:Class .
  ```
- Only properties have subproperties:

  ```
  rdfs:subPropertyOf rdfs:domain rdf:Property .
  ```
- Only classes have subclasses:

  ```
  rdfs:subClassOf rdfs:domain rdfs:Class .
  ```
- ... (another 30 or so)

Using the Axiomatic Triples

- From the statement
  `:conductor rdfs:range :Person`

Using the Axiomatic Triples

- From the statement
  `:conductor rdfs:range :Person`
- We can derive:

Using the Axiomatic Triples

- From the statement
  `:conductor rdfs:range :Person`
- We can derive:
  - `:conductor rdf:type rdf:Property`

Using the Axiomatic Triples

- From the statement
  `:conductor rdfs:range :Person`
- We can derive:
  - `:conductor rdf:type rdf:Property`
  - `:Person rdf:type rdfs:Class`

Using the Axiomatic Triples

- From the statement
  `:conductor rdfs:range :Person`
- We can derive:
  - `:conductor rdf:type rdf:Property`
  - `:Person rdf:type rdfs:Class`
  - `:conductor rdf:type rdfs:Resource`

Using the Axiomatic Triples

- From the statement
  `:conductor rdfs:range :Person`
- We can derive:
  - `:conductor rdf:type rdf:Property`
  - `:Person rdf:type rdfs:Class`
  - `:conductor rdf:type rdfs:Resource`
  - `rdf:Property rdf:type rdfs:Class`

Using the Axiomatic Triples

- From the statement

  `:conductor rdfs:range :Person`
- We can derive:
  - `:conductor rdf:type rdf:Property`
  - `:Person rdf:type rdfs:Class`
  - `:conductor rdf:type rdfs:Resource`
  - `rdf:Property rdf:type rdfs:Class`
  - `:Person rdfs:type rdfs:Resource`

Using the Axiomatic Triples

- From the statement
  `:conductor rdfs:range :Person`
- We can derive:
  - `:conductor rdf:type rdf:Property`
  - `:Person rdf:type rdfs:Class`
  - `:conductor rdf:type rdfs:Resource`
  - `rdf:Property rdf:type rdfs:Class`
  - `:Person rdfs:type rdfs:Resource`
  - `rdfs:Class rdfs:type rdfs:Class`

Using the Axiomatic Triples

- From the statement
  `:conductor rdfs:range :Person`
- We can derive:
  - `:conductor rdf:type rdf:Property`
  - `:Person rdf:type rdfs:Class`
  - `:conductor rdf:type rdfs:Resource`
  - `rdf:Property rdf:type rdfs:Class`
  - `:Person rdfs:type rdfs:Resource`
  - `rdfs:Class rdfs:type rdfs:Class`
  - ...

Using the Axiomatic Triples

- From the statement
  `:conductor rdfs:range :Person`
- We can derive:
  - `:conductor rdf:type rdf:Property`
  - `:Person rdf:type rdfs:Class`
  - `:conductor rdf:type rdfs:Resource`
  - `rdf:Property rdf:type rdfs:Class`
  - `:Person rdfs:type rdfs:Resource`
  - `rdfs:Class rdfs:type rdfs:Class`
  - ...
- In OWL, there are some simplification which make this superfluous!

Outline

Gentle RDFS

Recall that RDF *Schema* was conceived of as a schema language for RDF.

Gentle RDFS

Recall that RDF *Schema* was conceived of as a schema language for RDF.

- However, the statements in an RDFS ontology never trigger inconsistencies.

Gentle RDFS

Recall that RDF *Schema* was conceived of as a schema language for RDF.

- However, the statements in an RDFS ontology never trigger inconsistencies.
- I.e. no amount of reasoning will lead to a "contradiction", "error", "non-valid document"

Gentle RDFS

Recall that RDF *Schema* was conceived of as a schema language for RDF.

- However, the statements in an RDFS ontology never trigger inconsistencies.
- I.e. no amount of reasoning will lead to a "contradiction", "error", "non-valid document"
- Example: Say we have the following triples;

Gentle RDFS

Recall that RDF *Schema* was conceived of as a schema language for RDF.

- However, the statements in an RDFS ontology never trigger inconsistencies.
- I.e. no amount of reasoning will lead to a "contradiction", "error", "non-valid document"
- Example: Say we have the following triples;

```
:isRecordedBy rdfs:range :Orchestra .
```

Gentle RDFS

Recall that RDF *Schema* was conceived of as a schema language for RDF.

- However, the statements in an RDFS ontology never trigger inconsistencies.
- I.e. no amount of reasoning will lead to a "contradiction", "error", "non-valid document"
- Example: Say we have the following triples;

```
:isRecordedBy rdfs:range :Orchestra .
:Turangalîla :isRecordedBy :Boston .
```

Gentle RDFS

Recall that RDF *Schema* was conceived of as a schema language for RDF.

- However, the statements in an RDFS ontology never trigger inconsistencies.
- I.e. no amount of reasoning will lead to a "contradiction", "error", "non-valid document"
- Example: Say we have the following triples;

```
:isRecordedBy rdfs:range :Orchestra .
:Turangalîla :isRecordedBy :Boston .
```

- Suppose now that `Boston` is not defined to be an `Orchestra`:

Gentle RDFS

Recall that RDF *Schema* was conceived of as a schema language for RDF.

- However, the statements in an RDFS ontology never trigger inconsistencies.
- I.e. no amount of reasoning will lead to a "contradiction", "error", "non-valid document"
- Example: Say we have the following triples;

```
:isRecordedBy rdfs:range :Orchestra .
:Turangalîla :isRecordedBy :Boston .
```

- Suppose now that `Boston` is not defined to be an `Orchestra`:
    - i.e., there is no triple `:Boston rdf:type :Orchestra .` in the data.

Gentle RDFS

Recall that RDF *Schema* was conceived of as a schema language for RDF.

- However, the statements in an RDFS ontology never trigger inconsistencies.
- I.e. no amount of reasoning will lead to a "contradiction", "error", "non-valid document"
- Example: Say we have the following triples;

```
:isRecordedBy rdfs:range :Orchestra .
:Turangalîla :isRecordedBy :Boston .
```

- Suppose now that `Boston` is not defined to be an `Orchestra`:
  - i.e., there is no triple `:Boston rdf:type :Orchestra .` in the data.
- in a standard relational database,

Gentle RDFS

Recall that RDF *Schema* was conceived of as a schema language for RDF.

- However, the statements in an RDFS ontology never trigger inconsistencies.
- I.e. no amount of reasoning will lead to a "contradiction", "error", "non-valid document"
- Example: Say we have the following triples;

```
:isRecordedBy rdfs:range :Orchestra .
:Turangalîla :isRecordedBy :Boston .
```

- Suppose now that `Boston` is not defined to be an `Orchestra`:
  - i.e., there is no triple `:Boston rdf:type :Orchestra .` in the data.
- in a standard relational database,
- it would follow that `:Boston` is not an `:Orchestra`,

Gentle RDFS

Recall that RDF *Schema* was conceived of as a schema language for RDF.

- However, the statements in an RDFS ontology never trigger inconsistencies.
- I.e. no amount of reasoning will lead to a "contradiction", "error", "non-valid document"
- Example: Say we have the following triples;

```
:isRecordedBy rdfs:range :Orchestra .
:Turangalîla :isRecordedBy :Boston .
```

- Suppose now that `Boston` is not defined to be an `Orchestra`:
  - i.e., there is no triple `:Boston rdf:type :Orchestra .` in the data.
- in a standard relational database,
- it would follow that `:Boston` is not an `:Orchestra`,
- which contradicts the rule `rdfs7`:

Gentle RDFS

Recall that RDF *Schema* was conceived of as a schema language for RDF.

- However, the statements in an RDFS ontology never trigger inconsistencies.
- I.e. no amount of reasoning will lead to a “contradiction”, “error”, “non-valid document”
- Example: Say we have the following triples;

```
:isRecordedBy rdfs:range :Orchestra .
:Turangalîla :isRecordedBy :Boston .
```

- Suppose now that `Boston` is not defined to be an `Orchestra`:
  - i.e., there is no triple `:Boston rdf:type :Orchestra .` in the data.
- in a standard relational database,
- it would follow that `:Boston` is not an `:Orchestra`,
- which contradicts the rule `rdfs7`:

Gentle RDFS

Recall that RDF *Schema* was conceived of as a schema language for RDF.

- However, the statements in an RDFS ontology never trigger inconsistencies.
- I.e. no amount of reasoning will lead to a “contradiction”, “error”, “non-valid document”
- Example: Say we have the following triples;

```
:isRecordedBy rdfs:range :Orchestra .
:Turangalîla :isRecordedBy :Boston .
```

- Suppose now that `Boston` is not defined to be an `Orchestra`:
  - i.e., there is no triple `:Boston rdf:type :Orchestra .` in the data.
- in a standard relational database,
- it would follow that `:Boston` is not an `:Orchestra`,
- which contradicts the rule `rdfs7`:

$$\frac{\texttt{:isRecordedBy rdfs:range :Orchestra .} \qquad \texttt{:Turangal\^{i}la :isRecordedBy :Boston .}}{\texttt{:Boston rdf:type :Orchestra .}}\ \text{rdfs7}$$

Contd.

Instead;

Contd.

Instead;

- RDFS infers a new triple.

Contd.

Instead;

- RDFS infers a new triple.
- More specifically it adds `:Boston rdf:type :Orchestra .`

Contd.

Instead;

- RDFS infers a new triple.
- More specifically it adds `:Boston rdf:type :Orchestra .`
- which is precisely what `rdfs7` is designed to do.

Contd.

Instead;

- RDFS infers a new triple.
- More specifically it adds `:Boston rdf:type :Orchestra .`
- which is precisely what `rdfs7` is designed to do.

Contd.

Instead;

- RDFS infers a new triple.
- More specifically it adds `:Boston rdf:type :Orchestra .`
- which is precisely what `rdfs7` is designed to do.

This is open world reasoning in action:

Contd.

Instead;

- RDFS infers a new triple.
- More specifically it adds `:Boston rdf:type :Orchestra .`
- which is precisely what `rdfs7` is designed to do.

This is open world reasoning in action:

- Instead of saying "I know that `:Boston` is not an `:Orchestra`",

Contd.

Instead;

- RDFS infers a new triple.
- More specifically it adds `:Boston rdf:type :Orchestra .`
- which is precisely what `rdfs7` is designed to do.

This is open world reasoning in action:

- Instead of saying "I know that `:Boston` is not an `:Orchestra`",
- RDFS says "`:Boston` *is* an `:Orchestra`, I just didn't know it."

Contd.

Instead;

- RDFS infers a new triple.
- More specifically it adds `:Boston rdf:type :Orchestra .`
- which is precisely what `rdfs7` is designed to do.

This is open world reasoning in action:

- Instead of saying "I know that `:Boston` is not an `:Orchestra`",
- RDFS says "`:Boston` *is* an `:Orchestra`, I just didn't know it."
- RDFS will not signal an inconsistency, therefore

Contd.

Instead;

- RDFS infers a new triple.
- More specifically it adds `:Boston rdf:type :Orchestra .`
- which is precisely what `rdfs7` is designed to do.

This is open world reasoning in action:

- Instead of saying "I know that `:Boston` is not an `:Orchestra`",
- RDFS says "`:Boston` *is* an `:Orchestra`, I just didn't know it."
- RDFS will not signal an inconsistency, therefore
- but rather just add the missing information

Contd.

Instead;

- RDFS infers a new triple.
- More specifically it adds `:Boston rdf:type :Orchestra .`
- which is precisely what `rdfs7` is designed to do.

This is open world reasoning in action:

- Instead of saying "I know that `:Boston` is not an `:Orchestra`",
- RDFS says "`:Boston` *is* an `:Orchestra`, I just didn't know it."
- RDFS will not signal an inconsistency, therefore
- but rather just add the missing information

This is *the* most important difference between relational DBs and RDF!

Ramifications

This fact has two important consequences:

Ramifications

This fact has two important consequences:

1. RDFS is useless for validation,

Ramifications

This fact has two important consequences:

1. RDFS is useless for validation,
   - ... understood as sorting conformant from non-conformant documents,

Ramifications

This fact has two important consequences:

1. RDFS is useless for validation,
   - ... understood as sorting conformant from non-conformant documents,
   - since it never signals an inconsistency in the data,

Ramifications

This fact has two important consequences:

1. RDFS is useless for validation,
    - ... understood as sorting conformant from non-conformant documents,
    - since it never signals an inconsistency in the data,
    - it just goes along with anything,

Ramifications

This fact has two important consequences:

1. RDFS is useless for validation,
    - ... understood as sorting conformant from non-conformant documents,
    - since it never signals an inconsistency in the data,
    - it just goes along with anything,
    - and adds triples whenever they are inferred,

Ramifications

This fact has two important consequences:

1. RDFS is useless for validation,
    - ... understood as sorting conformant from non-conformant documents,
    - since it never signals an inconsistency in the data,
    - it just goes along with anything,
    - and adds triples whenever they are inferred,
    - It is *in this respect* more like a database schema,

Ramifications

This fact has two important consequences:

1. RDFS is useless for validation,
    - ... understood as sorting conformant from non-conformant documents,
    - since it never signals an inconsistency in the data,
    - it just goes along with anything,
    - and adds triples whenever they are inferred,
    - It is *in this respect* more like a database schema,
    - which declares what joins are possible,

Ramifications

This fact has two important consequences:

1. RDFS is useless for validation,
    - ... understood as sorting conformant from non-conformant documents,
    - since it never signals an inconsistency in the data,
    - it just goes along with anything,
    - and adds triples whenever they are inferred,
    - It is *in this respect* more like a database schema,
    - which declares what joins are possible,
    - but makes no statement about the validity of the joined data.

Ramifications

This fact has two important consequences:

1. RDFS is useless for validation,
   - ... understood as sorting conformant from non-conformant documents,
   - since it never signals an inconsistency in the data,
   - it just goes along with anything,
   - and adds triples whenever they are inferred,
   - It is *in this respect* more like a database schema,
   - which declares what joins are possible,
   - but makes no statement about the validity of the joined data.
   - Note though, that validation functionality beyond RDFS is often implemented in RDFS reasoners.

Ramifications

This fact has two important consequences:

1. RDFS is useless for validation,
   - ... understood as sorting conformant from non-conformant documents,
   - since it never signals an inconsistency in the data,
   - it just goes along with anything,
   - and adds triples whenever they are inferred,
   - It is *in this respect* more like a database schema,
   - which declares what joins are possible,
   - but makes no statement about the validity of the joined data.
   - Note though, that validation functionality beyond RDFS is often implemented in RDFS reasoners.
2. RDFS has no notion of negation at all

Ramifications

This fact has two important consequences:

1. RDFS is useless for validation,
   - ... understood as sorting conformant from non-conformant documents,
   - since it never signals an inconsistency in the data,
   - it just goes along with anything,
   - and adds triples whenever they are inferred,
   - It is *in this respect* more like a database schema,
   - which declares what joins are possible,
   - but makes no statement about the validity of the joined data.
   - Note though, that validation functionality beyond RDFS is often implemented in RDFS reasoners.
2. RDFS has no notion of negation at all
   - For instance, the two triples

Ramifications

This fact has two important consequences:

1. RDFS is useless for validation,
   - ... understood as sorting conformant from non-conformant documents,
   - since it never signals an inconsistency in the data,
   - it just goes along with anything,
   - and adds triples whenever they are inferred,
   - It is *in this respect* more like a database schema,
   - which declares what joins are possible,
   - but makes no statement about the validity of the joined data.
   - Note though, that validation functionality beyond RDFS is often implemented in RDFS reasoners.
2. RDFS has no notion of negation at all
   - For instance, the two triples

```
ex:Martin rdf:type ex:Smoker .,
```

Ramifications

This fact has two important consequences:

1. RDFS is useless for validation,
   - ... understood as sorting conformant from non-conformant documents,
   - since it never signals an inconsistency in the data,
   - it just goes along with anything,
   - and adds triples whenever they are inferred,
   - It is *in this respect* more like a database schema,
   - which declares what joins are possible,
   - but makes no statement about the validity of the joined data.
   - Note though, that validation functionality beyond RDFS is often implemented in RDFS reasoners.
2. RDFS has no notion of negation at all
   - For instance, the two triples

```
ex:Martin rdf:type ex:Smoker .,
ex:Martin rdf:type ex:NonSmoker .
```

Ramifications

This fact has two important consequences:

1. RDFS is useless for validation,
   - ... understood as sorting conformant from non-conformant documents,
   - since it never signals an inconsistency in the data,
   - it just goes along with anything,
   - and adds triples whenever they are inferred,
   - It is *in this respect* more like a database schema,
   - which declares what joins are possible,
   - but makes no statement about the validity of the joined data.
   - Note though, that validation functionality beyond RDFS is often implemented in RDFS reasoners.
2. RDFS has no notion of negation at all
   - For instance, the two triples

     ```
     ex:Martin rdf:type ex:Smoker .,
     ex:Martin rdf:type ex:NonSmoker .
     ```

     are not inconsistent.

Ramifications

This fact has two important consequences:

1. RDFS is useless for validation,
    - ... understood as sorting conformant from non-conformant documents,
    - since it never signals an inconsistency in the data,
    - it just goes along with anything,
    - and adds triples whenever they are inferred,
    - It is *in this respect* more like a database schema,
    - which declares what joins are possible,
    - but makes no statement about the validity of the joined data.
    - Note though, that validation functionality beyond RDFS is often implemented in RDFS reasoners.
2. RDFS has no notion of negation at all
    - For instance, the two triples

      ```
      ex:Martin rdf:type ex:Smoker .,
      ex:Martin rdf:type ex:NonSmoker .
      ```

      are not inconsistent.
        - (It is not possible to in RDFS to say that `ex:Smoker` and `ex:nonSmoker` are disjoint).

Expressive limitations of RDFS

Hence,

Expressive limitations of RDFS

Hence,

- RDFS cannot express inconsistencies,

Expressive limitations of RDFS

Hence,

- RDFS cannot express inconsistencies,
- so any RDFS graph is consistent.

Expressive limitations of RDFS

Hence,

- RDFS cannot express inconsistencies,
- so any RDFS graph is consistent.

Therefore,

Expressive limitations of RDFS

Hence,

- RDFS cannot express inconsistencies,
- so any RDFS graph is consistent.

Therefore,

- RDFS supports no reasoning services that require consistency-checking.

Expressive limitations of RDFS

Hence,

- RDFS cannot express inconsistencies,
- so any RDFS graph is consistent.

Therefore,

- RDFS supports no reasoning services that require consistency-checking.
- If consistency-checks are needed, one must turn to OWL.

Expressive limitations of RDFS

Hence,

- RDFS cannot express inconsistencies,
- so any RDFS graph is consistent.

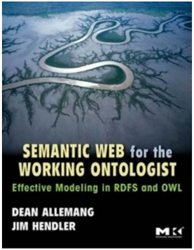
Therefore,

- RDFS supports no reasoning services that require consistency-checking.
- If consistency-checks are needed, one must turn to OWL.
- More about that in a few weeks.

Supplementary reading

- For RDFS design patterns:

  Semantic Web for the Working Ontologist.
  Allemang, Hendler.
  Morgan Kaufmann 2008
  Read chapter 6.



Supplementary reading

- For RDFS design patterns:

  Semantic Web for the Working Ontologist.
  Allemang, Hendler.
  Morgan Kaufmann 2008
  Read chapter 6.

- For RDFS semantics:

  Read chapter 3.