Knowledge Graphs: RDFS

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RDF Schema (RDFS)

- Constraints on RDF statements must be stated in RDFS or OWL
- RDFS allows to specify constraints on individual and relationships. More specifically:
  - Declare objects and subjects as instances of certain classes
    - E.g., *Oscar isa lecturer*
  - Inclusion statements between classes and between properties
    - E.g., lecturer *isa* human **TAXONOMIES!**
  - Relate the domain and the range of a property to some classes
    - E.g., the predicate fatherOf relates a subject and an object that must be instances of the class human
- RDFS extends RDF not only to consider *instances* but schema
  - The schema can be described with the same description
  - rdfs: A namespace for RDFS
    - The URI is: http://www.w3.org/2000/01/rdf-schema#

RDFS Example

- Instances:
  - :Oscar rdf:type :Lecturer
- Taxonomies:
  - (classes) :Lecturer rdfs:subclassOf :Human
  - (rels) :ResponsibleFor rdfs:subpropertyOf :Lectures
- Domain and Range:
  - :Lectures rdfs:domain :Human
  - :Lectures rdfs:range :Course

Some controversy here:
Some consider rdf:type to be part of RDF, some of RDFS

Reasoning (Inference)

- Non-explicit knowledge inferred from explicitly asserted knowledge
- A knowledge-base consists of schema and instances
  - Schema:
    - :Lecturer rdfs:subclassOf :Human
    - :ResponsibleFor rdfs:subpropertyOf :Lectures
    - :Lectures rdfs:domain :Human
    - :Lectures rdfs:range :Course
  - Instances (explicit facts asserted):
    - :Oscar rdf:type :Lecturer
    - :OpenData rdf:type :Course
    - :Oscar :ResponsibleFor :OpenData
  - Inferred knowledge (logical consequence):
    - :Oscar rdf:type :Human
    - :Oscar :Lectures :OpenData

RDFS

- RDFS was created with two objectives:
  - Express constraints on data (~ schema)
    - Core classes
    - Core properties
  - Enable reasoning on data based on the asserted constraints
    - Rule-based reasoning
    - Two kinds of reasoning:
      - **Core type inference**: it infers the **type** (any of the core classes) of an asserted resource R (i.e., *R* rdf:type *coreClass*)
      - **Domain-specific inference**:
        - **Inclusion dependencies** (taxonomies)
        - **Type inference**: it infers the type of an asserted resource R wrt a user-created class

RDFS Core Classes

- *rdfs:Resource*, the class of all resources (**everything** is a resource)
- *rdfs:Class*, the class of all classes
- *rdfs:Literal*, the class of all literals
- *rdf:Property*, the class of all properties
- *rdf:Statement*, the class of all statements

RDFS Core Properties (I)

- *rdf:type*, which relates a resource to its class

  `:oscar rdf:type :lecturer`

  - **Meaning**: the subject resource (i.e., :*oscar*) is declared to be an instance of the object class (i.e., *:lecturer*)
  - **Inferred knowledge**:
    - Core type inference: the object is inferred as a Class

    I.e.,: lecturer is a Class (*:lecturer rdf:type rdfs:Class*)

RDFS Core Properties (II)

- *rdfs:subClassOf*, which relates a class to **one** of its superclasses

  `:lecturer rdfs:subClassOf :human`

  `:oscar rdf:type :lecturer`

  - **Meaning**: the subject and object resources are declared to be classes AND any instance of the subject is automatically declared as an instance of the object
  - **Inferred knowledge**:
    - Core type inference: the subject and object are inferred as classes

    I.e.,: `:lecturer rdf:type rdfs:Class` *and*

    `:human rdf:type rdfs:Class`

    - Domain-specific inference (inclusion dependency): if *x* rdf:type *subject* then *x* rdf:type *object*

    I.e.,: `:oscar rdf:type :human`

RDFS Core Properties (III)

- rdfs:subPropertyOf, which relates a property to **one** of its superproperties

  `:responsibleFor rdfs:subpropertyOf :lectures`

  `:oscar :responsibleFor :OD`

  - **Meaning**: the subject and object resources are declared to be properties AND any subject, object related by subject predicate are automatically declared as to be related by the object predicate
  - **Inferred knowledge**:
    - Core type inference: the subject and object are inferred as properties

    I.e.,: `:responsibleFor rdf:type rdf:Property and :lectures rdf:type rdf:Property`

    - Additional inference (inclusion dependency): *x subject y* then *x object y*

    I.e.,: `:oscar :lectures :OD`

RDFS Core Properties (IV)

- rdfs:domain, which specifies the domain of a property

```
:lectures rdfs:domain :lecturer
:oscar :lectures :OD
```

  - **Meaning**: Whenever :*lectures* is used in a triple as predicate, the class of the resource used as subject of that triple must be :*lecturer*
  - **Inferred knowledge**:
    - Core type inference: the subject is declared to be a property and the object is declared to be a class

    I.e.,: `:lectures rdf:type rdf:Property and`
    `:lecturer rdf:type rdfs:Class`
    - Domain-specific inference (type inference): if *x subject y* then *x rdf:type object*

    I.e., `:oscar rdf:type :lecturer`

RDFS Core Properties (V)

- rdfs:range, which specifies the range of a property

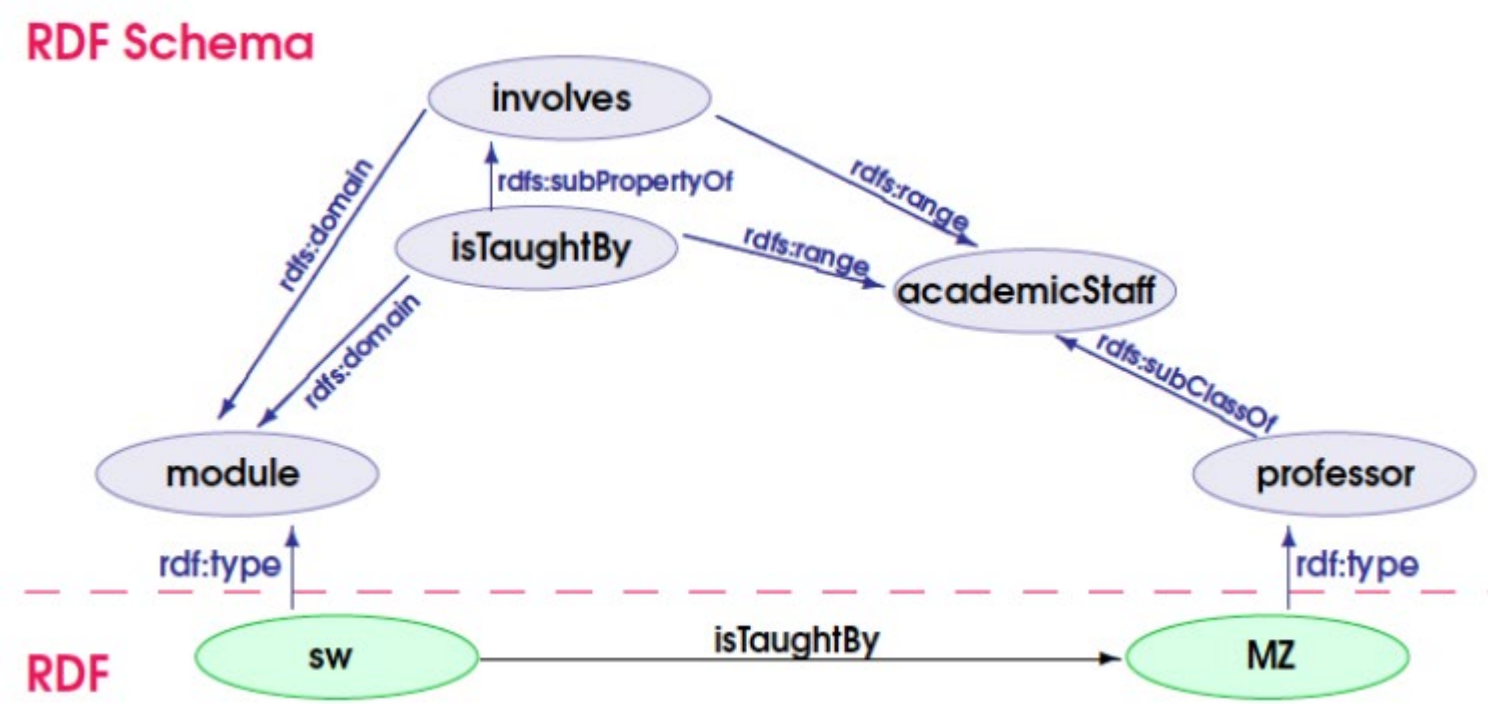
```
:lectures rdfs:range :course
:oscar :lectures :OD
```

  - **Meaning**: Whenever :*lectures* is used in a triple as predicate, the class of the resource used as object of that triple must be :*course*
  - **Inferred knowledge**:
    - Core type inference: the subject is declared to be a property and the object is declared to be a class

    I.e.,: `:lectures rdf:type rdf:Property and`
    `:course rdf:type rdfs:Class`
    - Domain-specific inference (type inference): if *x subject y* then *y rdf:type object*

    I.e., `:OD rdf:type :course`

RDFS Semantics



Inference?

The RDFS Paradox

- Russel's Paradox was ennounced as:

$$\text{Consider the set } A = \{B \mid B \notin B\}$$

- Popular version, the barber paradox

Suppose there is a town with just one male barber. According to law in this town, the barber shaves all and only those men in town who do not shave themselves.
Who shaves the barber?
- if the barber does shave himself, then the barber (himself) must not shave himself
- if the barber does not shave himself, then the barber (himself) must shave himself

- It is a set-theoretical paradox that arises within naïve set theory by considering the set of all sets that are not members of themselves.
  - It does happen in RDFS

http://plato.stanford.edu/entries/russell-paradox/

Beware of the RDFS Paradox!

- The RDF metamodel is flawed
- Problems of RDFS
  - *rdfs:Class* is an instance of itself
    - In RDFS all clases are instances of rdfs:Class, including rdfs:Class (Russel's paradox)
    - Thus, it presents a possibly infinite layer of classes
  - *rdfs:Resource* is a superclass and an instance of *rdfs:Class*
  - *rdfs:subClassOf, rdf:type, rdfs:Range* and *rdfs:Domain* are both used to define the other RDFS primitives and the ontology
    - Metamodel and model mixed
    - Is *rdfs:subClassOf* a relationship between sets or between sets of sets?!

RDFS Flawed Reasoning

- Due to the Russel's paradox, reasoning in RDFS (as originally defined) is flawed
- As consequence, the SPARQL community rethought the RDFS metamodel to introduce fix-point reasoning
  - Modified RDFS Entailment Regime

RDFS Inference Rules

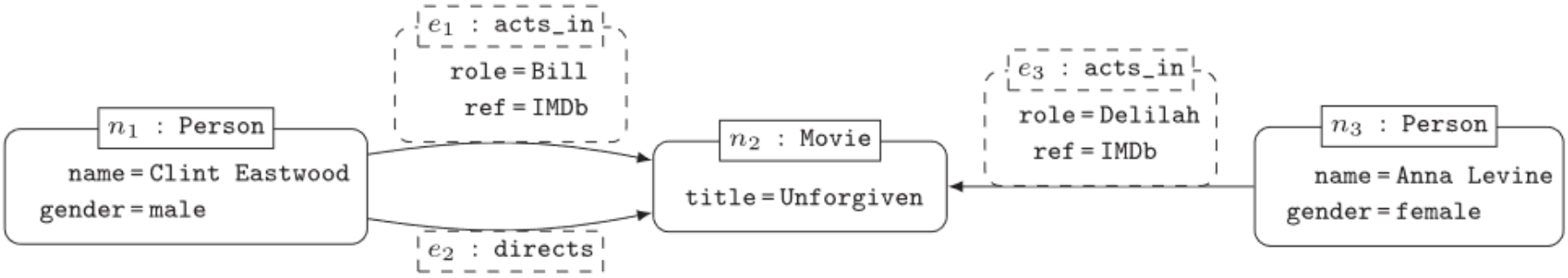
RDFS entailment patterns.

	If S contains:	then S RDFS entails recognizing D:
rdfs1	xxx aaa yyy.	aaa rdf:type rdf:Property .
rdfs2	aaa rdfs:domain xxx . yyy aaa zzz .	yyy rdf:type xxx .
rdfs3	aaa rdfs:range xxx . yyy aaa zzz .	zzz rdf:type xxx .
rdfs4a	xxx aaa yyy .	xxx rdf:type rdfs:Resource .
rdfs4b	xxx aaa yyy.	yyy rdf:type rdfs:Resource .
rdfs5	xxx rdfs:subPropertyOf yyy . yyy rdfs:subPropertyOf zzz .	xxx rdfs:subPropertyOf zzz .
~~***rdfs6***~~	~~xxx rdf:type rdf:Property .~~	~~xxx rdfs:subPropertyOf xxx .~~
rdfs7	aaa rdfs:subPropertyOf bbb . xxx aaa yyy .	xxx bbb yyy .
~~***rdfs8***~~	~~xxx rdf:type rdfs:Class .~~	~~xxx rdfs:subClassOf rdfs:Resource .~~
rdfs9	xxx rdfs:subClassOf yyy . zzz rdf:type xxx .	zzz rdf:type yyy .
~~***rdfs10***~~	~~xxx rdf:type rdfs:Class .~~	~~xxx rdfs:subClassOf xxx .~~
rdfs11	xxx rdfs:subClassOf yyy . yyy rdfs:subClassOf zzz .	xxx rdfs:subClassOf zzz .
~~***rdfs12***~~	~~xxx rdf:type rdfs:ContainerMembershipProperty .~~	~~xxx rdfs:subPropertyOf rdfs:member .~~
rdfs13	xxx rdf:type rdfs:Datatype .	xxx rdfs:subClassOf rdfs:Literal .

+ core class inference rules (check the RDF core properties slides)

RDFS Exercise

- Create a correct RDFS graph capturing as much constraints as possible from the following graph:



- What triples may you infer from the asserted RDFS graph?

Summary

- RDFS
  - RDFS Core Components
  - RDFS Semantics
  - RDFS Metamodel

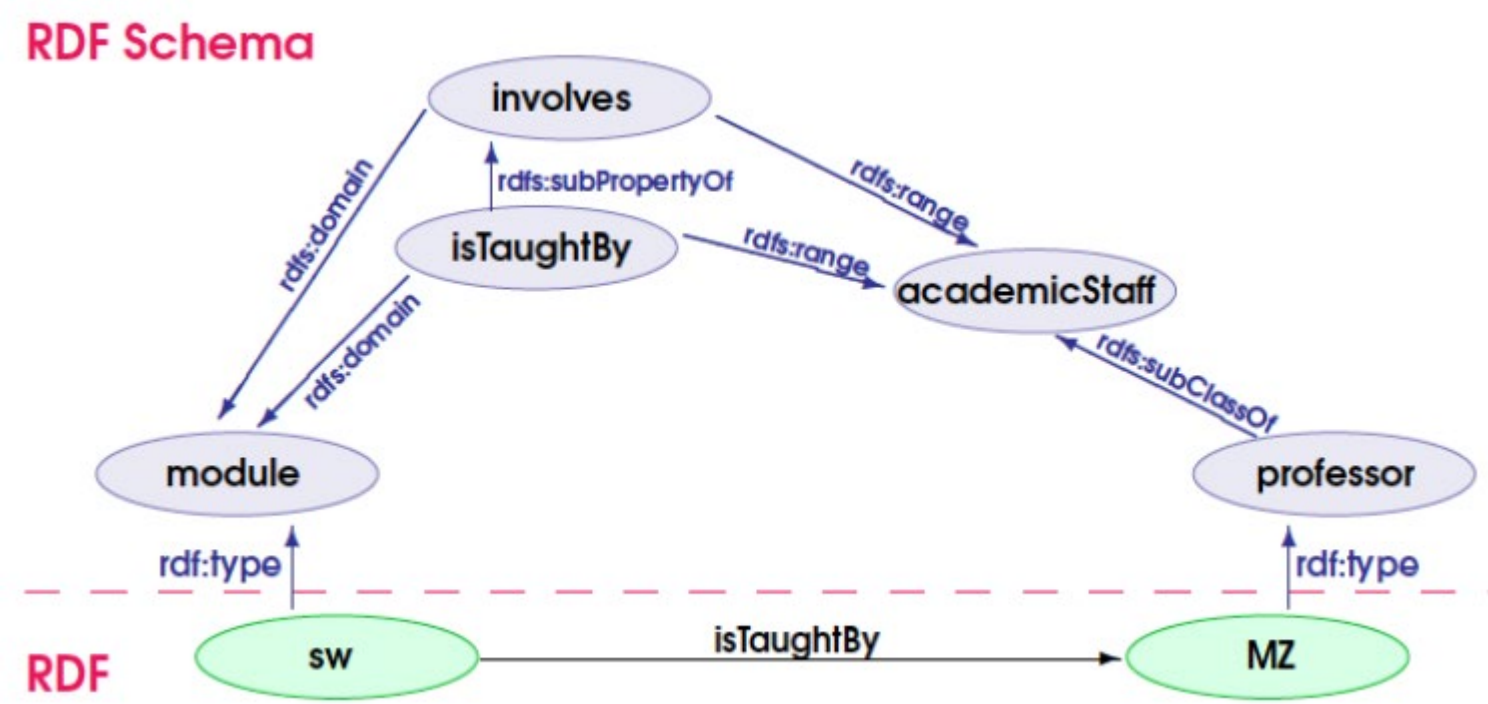
Bibliography

- RDFS. W3C Recommendation. Latest version at http://www.w3.org/TR/rdf-schema/

APPENDIX

- Here, we showcase why RDFS reasoning is flawed. In this appendix, we will blindly follow the inference rules presented in this chapter for a toy example.
- Considering the example in the next slide, the subsequent slides apply certain inference rules (the rules stated in the title).

RDFS Semantics

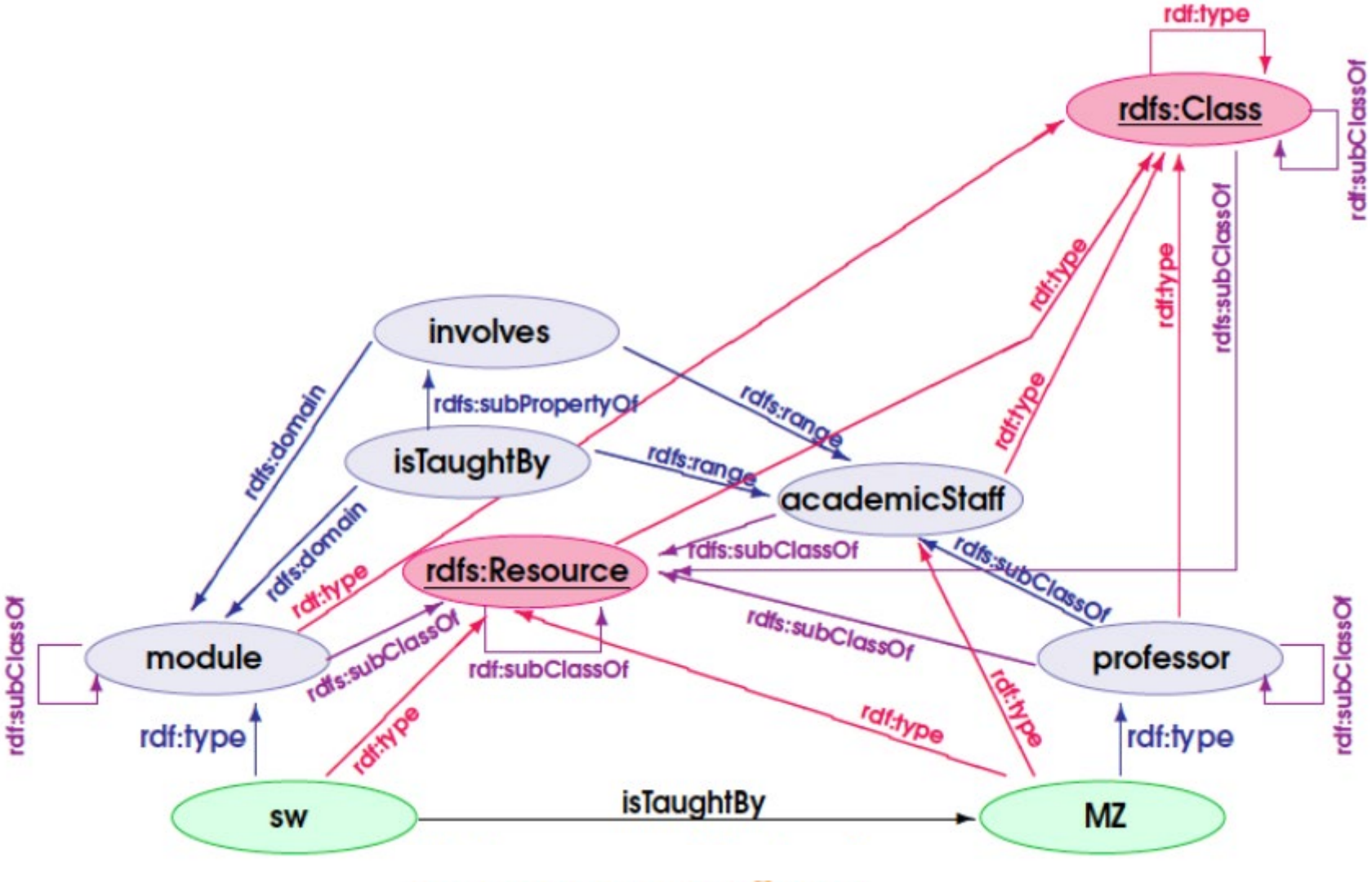


Inference?

RDF Semantics: Class and Subclass

- Consider the following inferred knowledge:
  - The object of *rdf:type* is a class
  - Every class is a subclass of *rdfs:Resource*
  - If C_1 is *rdfs:subClassOf* of C_2 then, both C_1 and C_2 are classes. Also:
    - *rdfs:subClassOf* is reflexive on classes
    - *rdfs:subClassOf* is transitive

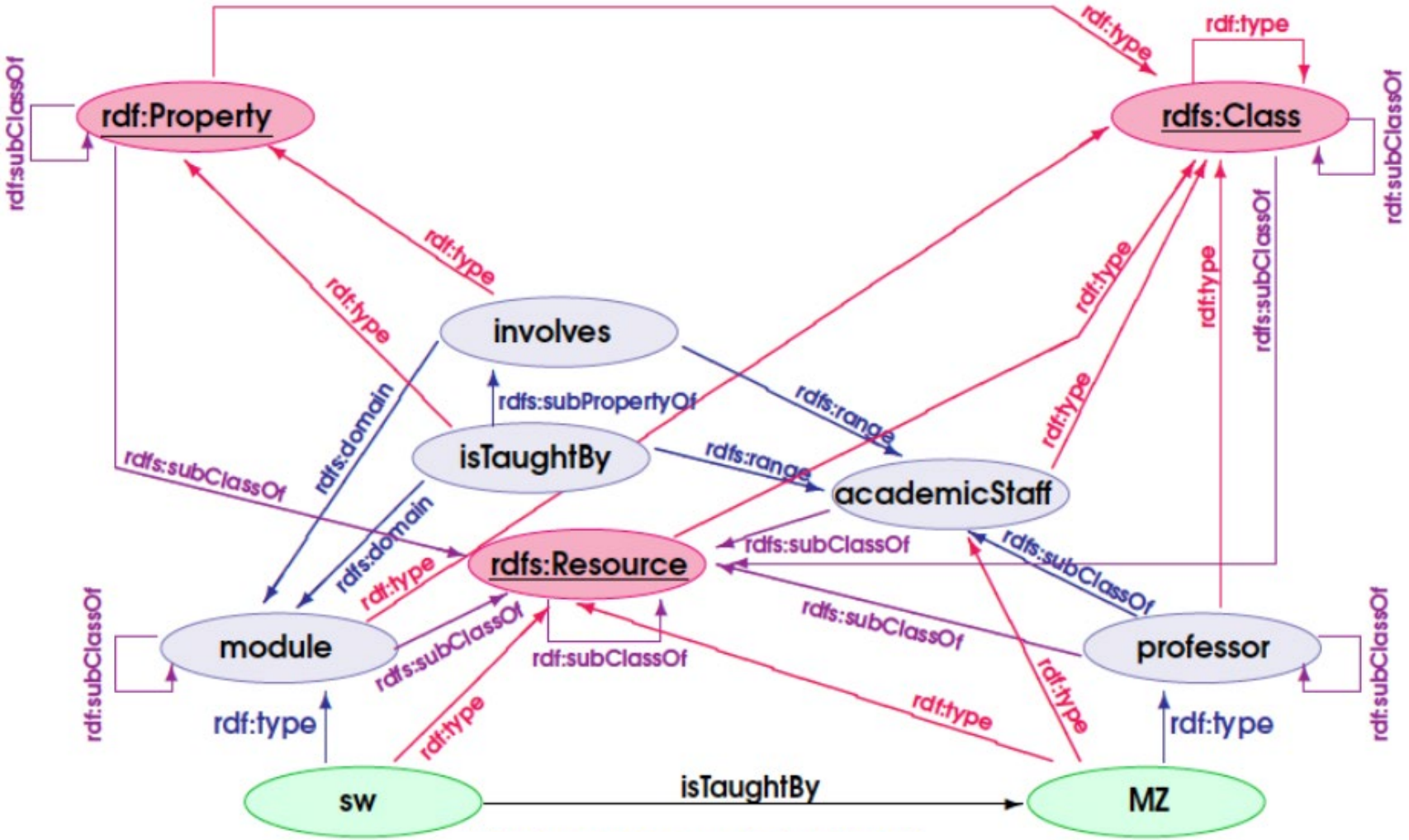
RDF Semantics: Class and Subclass



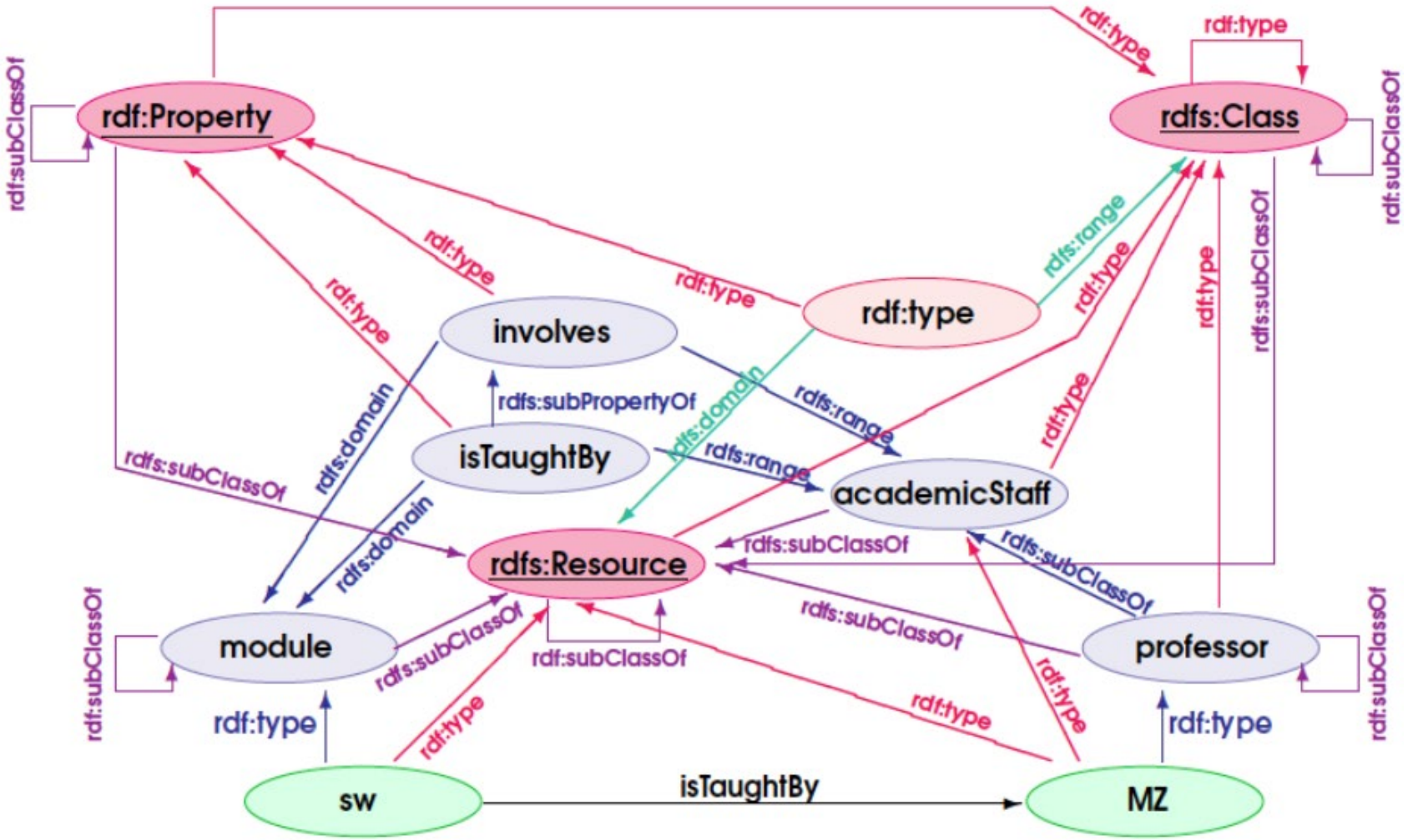
RDFS Semantics: Property and SubProperty

- Consider the following inferred knowledge:
  - If P_1 is *rdfs:subPropertyOf* of P_2 then, both P_1 and P_2 are properties. Also:
    - *rdfs:subPropertyOf* is reflexive on properties
    - *rdfs:subPropertyOf* is transitive

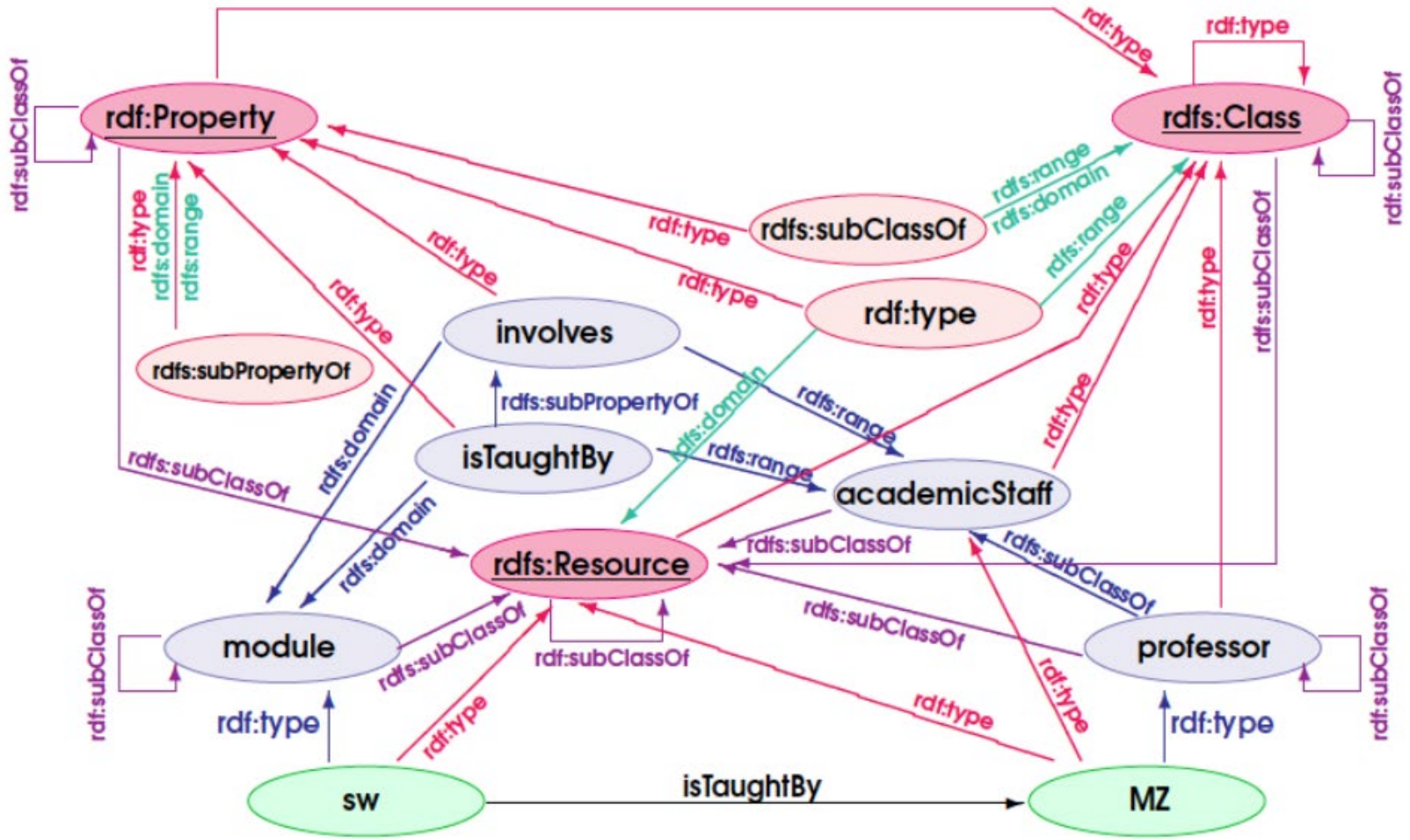
RDFS Semantics: Property and Subproperty



RDFS Semantics: Property and Subproperty



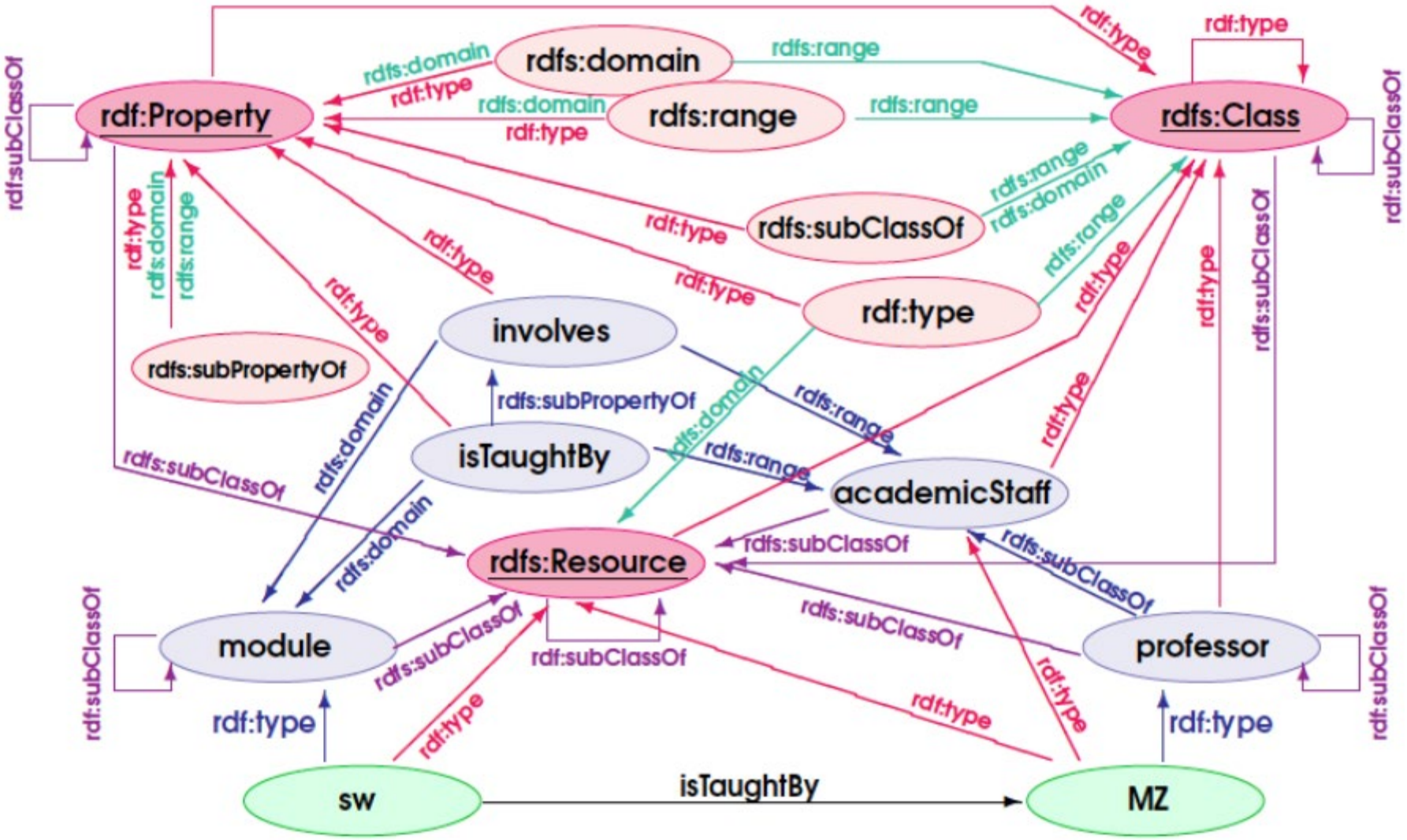
RDFS Semantics: Property and Subproperty



RDFS Semantics: Domain and Range

- These are **axiomatic** triples
  - Core knowledge to be assumed to be true for any for any profile (reasoning)
  - If P *rdfs:domain* C then C is a class
  - If P *rdfs:range* C then C is a class

RDFS Semantics: Domain and Range



RDFS Semantics: Conclusions

- If you carefully check the graph from the previous slide, you will realize it does not make any sense and, indeed, it falls into the Russell's Paradox.