Knowledge Graphs

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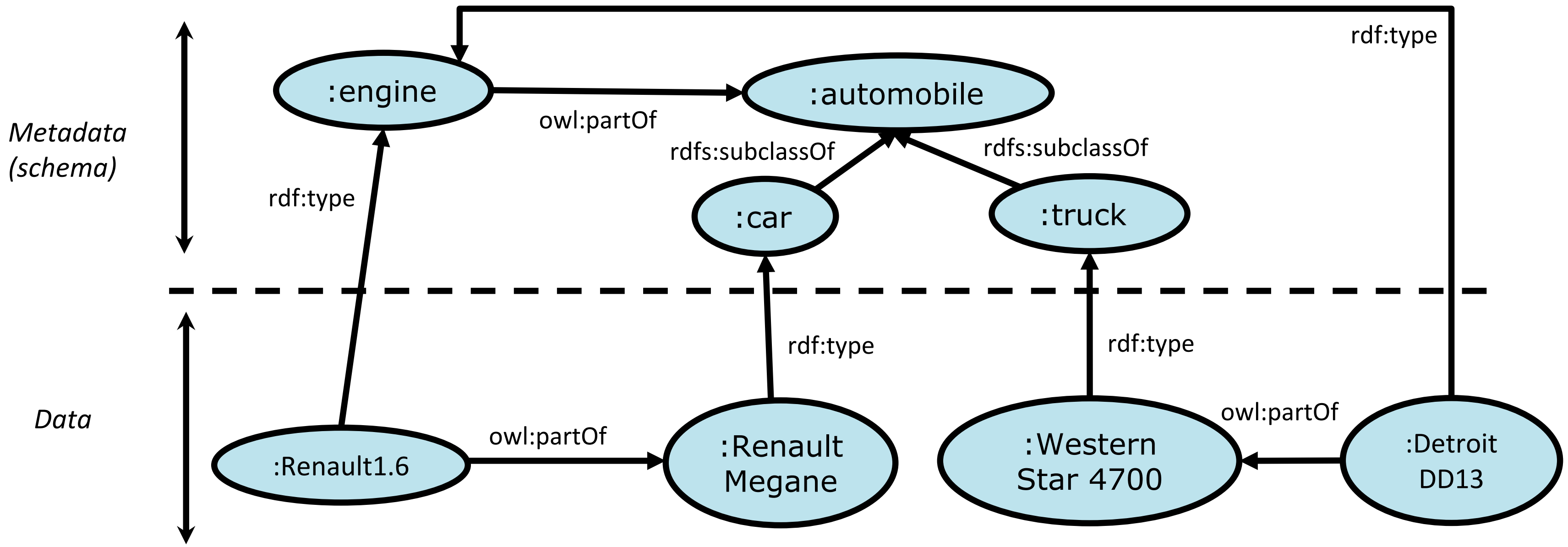
The Overall Idea

It is a graph! But…

- Every node is represented with a unique identifier and can be **universally** referred
- *Metadata* is represented as nodes and edges (no special construct such as labels or attributes)
  - Pre-defined identifiers (i.e., nodes and edges) set semantics: pre-defined vocabularies (e.g., to distinguish data and metadata)

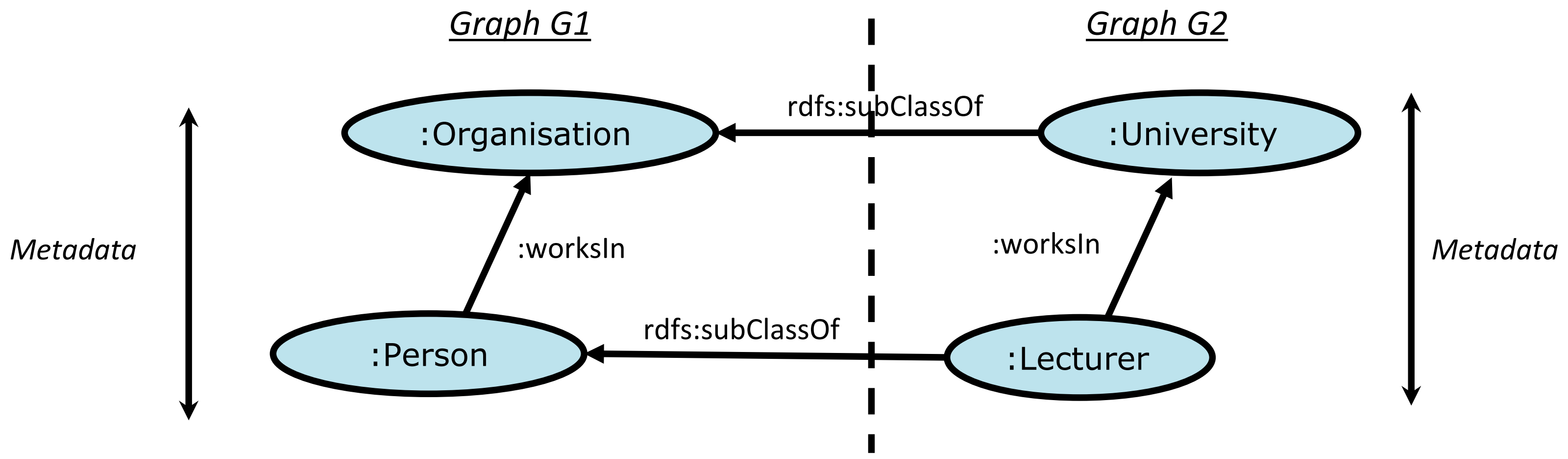


Can you think of any data model allowing you to model data and metadata (schema) with the same constructs?

The Power of Knowledge Graphs

Knowledge graphs facilitate **relating** (*linking, crossing, integrating*) data

- Linking metadata is way more powerful than linking data: a unique feature of their own



How to do this in a property graph?

The Power of Knowledge Graphs

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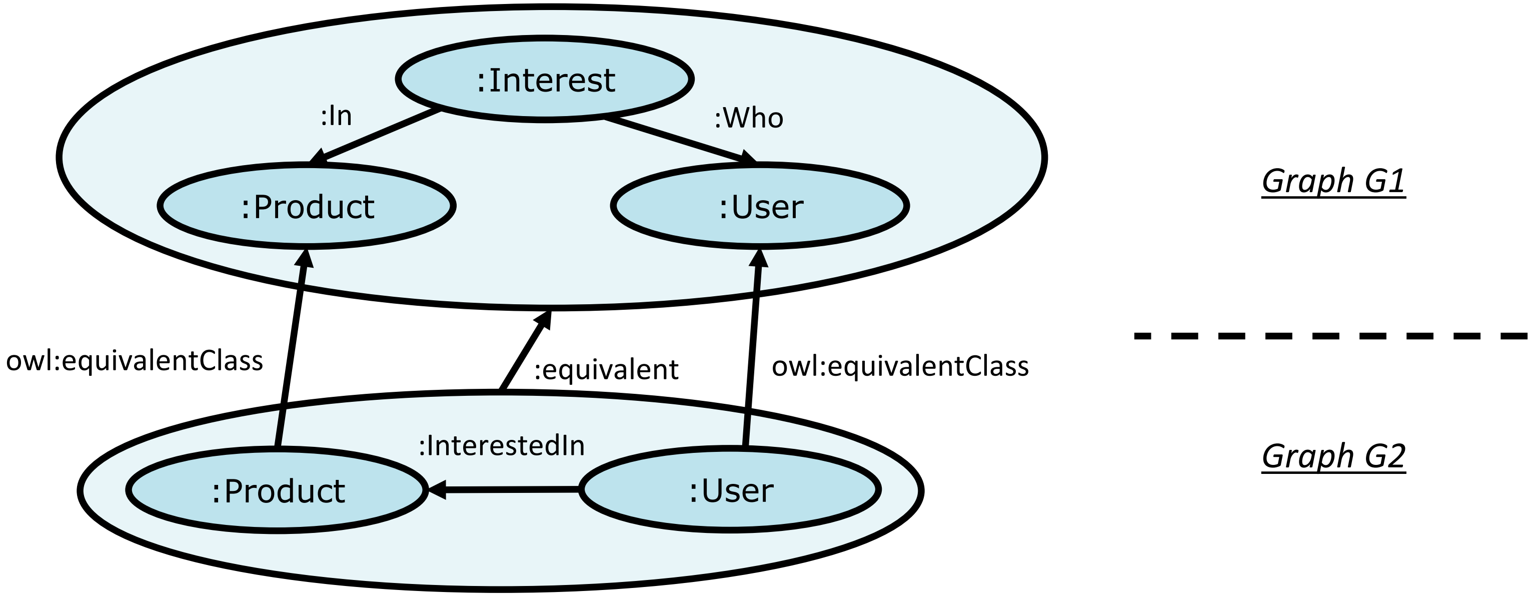
But KGs are even more flexible than that…



Activity: Using KGs to Integrate Data

Objective: Understand the knowledge graph data model

Tasks:

1. *With a teammate think of the following:*
   - I. *Assume KGs as canonical data model*
   - II. *First, model as graphs each source (separately):*
     - I. *Model schema (metadata) and some instances for each source*

- User
- Tweet
- Date
- Location

- Product
- Product features

- User
- Product
- time

   - I. *Now, relate the metadata from each graph with new edges generating a unique connected graph*
     - I. *Look for similar or identical concepts*
     - II. *Think of **interesting relationships** you could exploit later*

***Note**: assume the following pre-defined edges: owl:equivalentClass, rdf:type and rdfs:subClassOf, which embed the semantics already discussed. Anyhow, feel free to create new ones if required (justify their need)*

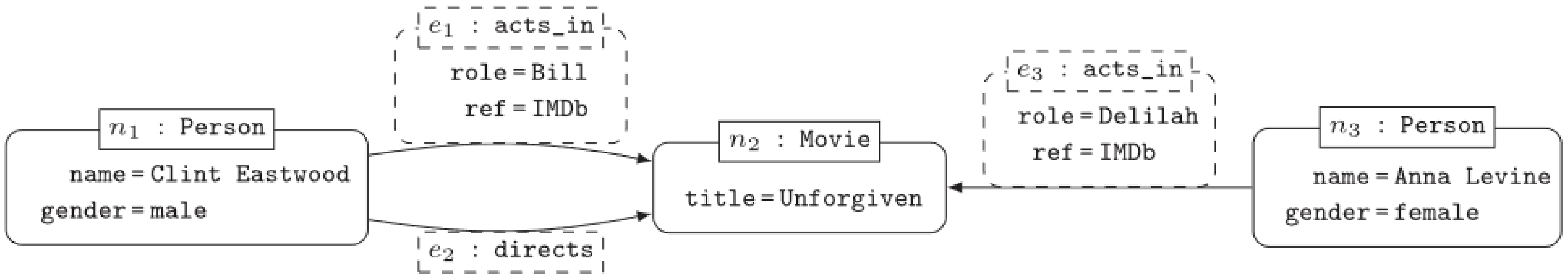
Activity: Property Vs. Knowledge Graphs

Objective: understand the differences between both graph data models

Tasks:

I. *Consider the property graph below*
II. *Represent it in the form of a knowledge graph*
    I. *What are the main differences between both formalisms?*
    II. *What are the similarities?*

<u>An example of Property Graph:</u>



Knowledge Graph Families

W3C Standards for *sharing meaning (things, not strings)*

- RDF (Resource Description Framework)
  - Introduces the basic data structure: <subject predicate object>
- RDFS (RDF Schema)
  - Predefined vocabulary to assert basic schema information and distinguish it from instances
- OWL / Ontologies
  - Richer conceptualizations (i.e., richer schema-related information)

RDF

THE FOUNDATIONS OF KNOWLEDGE GRAPHS

Disclaimer

Even if knowledge graphs were born in the Semantic Web (c.f., to fulfill the concept of Linked Data) we are going to use them for a broader range of purposes

DO NOT UNDERSTAND RDF AS SYNONYM OF THE SEMANTIC WEB

RDF: Resource Description Format

The basic RDF block is the ***RDF statement****:*

It is a ***triple*** representing: a *binary relationship* between two *resources* **or** between a *resource* and a *literal*

<subject predicate object>

- *Subject* S has value *object* O for *predicate* P
- *Subject* and *predicate* are resources and must be **URIs**
- *Object* can be a *resource* (URI) or a *literal* (i.e., a constant value)

Resources (or objects) are identified by URIs (*global identifiers*): *URL+URN*

- URN (Universal Resource Name) ~ id
- URL (Universal Resource Location) ~ *where* to locate it
- Many times, we omit the URL for simplicity and refer to the URI as ***:URN***
- Blank nodes are resources without a defined URL (i.e., _)

- Literals are atomic values such as string, dates, numbers, etc.

A set of triples form an RDF graph

- RDF graphs are also known as *semantic graphs*

RDF: Resource Description Format

The basic RDF block is the ***RDF statement***:

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It is a simple language for describing *annotations* (facts) about resources

- The most basic **ontology** language
  - Triples map to First Order Logic as grounded atomic formulas (subject and object are constants)
  - Blank nodes map to existential variables

Later in the course we will formally define ontologies and their relationship with logics

Querying:

- **SPARQL** is the de facto language to query RDF
  - It is also the standard to query RDF variants / extensions
- Inspired in SQL but oriented to express graph operations (*hello pattern matching!*)

RDF: The Big Picture

Semantics: http://www.w3.org/TR/rdf11-primer/

- **Triples** (i.e., RDF statements),
- To create **semantic graphs** (aka RDF graphs)

Syntax

- **XML-based serialization** (aka RDF syntax)
  - The way to express RDF triples in a machine-processable format

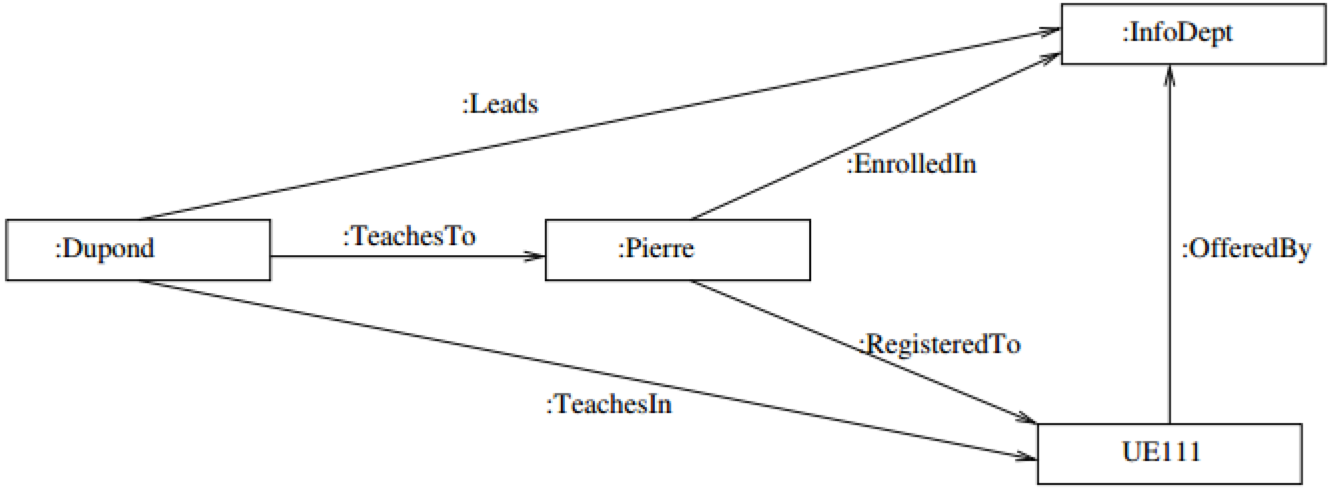
RDF Example: Semantics

RDF triplets or statements:

⟨ :Dupond :Leads :CSDept ⟩
⟨ :Dupond :TeachesIn :UE111 ⟩
⟨ :Dupond :TeachesTo :Pierre ⟩
⟨ :Pierre :EnrolledIn :CSDept ⟩
⟨ :Pierre :RegisteredTo :UE111 ⟩
⟨ :UE111 :OfferedBy :CSDept ⟩

Subject	Predicate	Object
:Dupond	:Leads	:CSDept
:Dupond	:TeachesIn	:UE111
:Dupond	:TeachesTo	:Pierre
:Pierre	:EnrolledIn	:CSDept
:Pierre	:RegisteredTo	:UE111
:UE111	:OfferedBy	:CSDept

RDF graph:



Extracted from Web Data Management (Abiteboul et al.)

RDF Example: Syntax

RDF was originally serialized as XML (syntax)

The rdf URL is the namespace for RDF (http://www.w3.org/1999/02/22-rdf-syntax-ns#)

Example:

```
<?xml version="1.0"?>

<rdf:RDF
xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
xmlns:cd="http://www.recshop.fake/cd#">

<rdf:Description
rdf:about="http://www.recshop.fake/cd/Empire Burlesque">
  <cd:artist>Bob Dylan</cd:artist>
  <cd:country>USA</cd:country>
  <cd:company>Columbia</cd:company>
  <cd:price>10.90</cd:price>
  <cd:year>1985</cd:year>
</rdf:Description>
```

Other RDF Syntaxes:

- **Turtle** (human-readable)
- N-triples
- Notation 3
- …

Turtle :

```
(…)
<#empire-burlesque>
    cd:artist    <#Bob-Dylan>  ;
    cd:country   <#USA>        ;
    cd:price     10.90         ;
    cd:year      1985          .
(…)
```

https://www.w3.org/TR/turtle/

Extracted from W3C School

Activity: Modeling in RDF

Objective: Grasp the main idea behing RDF modeling

Model a RDF Graph about lecturers, courses and students:

A student enrolls several courses from her faculty per semester. He is forced to enroll, at least, one course per semester. Each course has one responsible lecturer but potentially, it might have several lecturers

Your graph must be a correct RDF graph and therefore defining the namespaces used

Afterwards, write the triples you created in Turtle syntax

Basics on RDF Modeling

RDF modeling is based on binary relationships

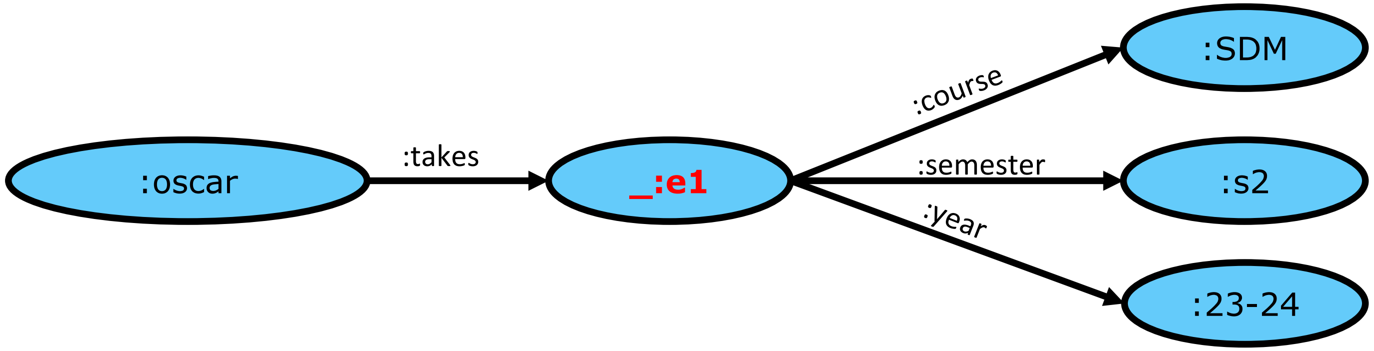
- Since n-ary relationships may be needed, blank nodes were presented as solution

We cannot express neither schema (not even the concept of label) nor additional constraints

- Example: *at least one, at most three, the domain of a property must be of type X*, a node is of type lecturer, etc.
- RDFS and OWL are languages that build on top of RDF to express schema and constraints

Blank Nodes: Reification

Example of use:



Statements involving blank nodes can be written as:

- [*property object*] (meaning the subject of this triple is a blank node)
    - e.g., :oscar :takes [:course :SDM]

Blank Nodes

Blank nodes do **<u>not</u>** have a URI and cannot be referenced

- They can only be subjects or objects

Its semantics are yet not clear, though

- De facto use (i.e., most spread use, also in SPARQL): An **<u>identifier</u>** without a URI
- W3C position: Incomplete data (potentially two blank nodes might be the same resource)
  - An unknown value,
  - A value that does not apply / anonymized value

The de facto use is a pragmatic use

- Facilitates reasoning when translating KGs to logics (CWA)

Good practices discourage their use

- All resources should have a proper URI (!)

RDF-star

RDF-star is an RDF extension

- Systematizes the use of blank nodes
- Compact and precise syntax for reification

  https://w3c.github.io/rdf-star/cg-spec/2021-02-18.html

Example:

```
@prefix :   <http://www.example.org/> .

:employee38 :familyName "Smith" .

:employee22 :claims << :employee38 :jobTitle "Assistant Designer" >> .
```

Embedded triple

SPARQL-star is an extension of SPARQL to query RDF-star

Summary

Sharing data for integration or data exchange purposes require new modeling standards

RDF represents resources by means of identifiers (URIs) that can be universally located

RDF, however, does not provide means to annotate the resources with types and rich annotations (e.g., constraints)

- We need RDFS and OWL (other KG language families) for that purpose

Modeling in RDF

- Very similar to property graphs
  - IRIs are mandatory
  - Property graph attributes do not exist in RDF
  - We may use blank nodes (although not advisable!)

Bibliography

RDF. W3C Recommendation. Latest version at http://www.w3.org/TR/rdf-concepts/

S. Abiteboul et al. Web Data Management, 2012 (chapter 7, until section 7.3.3)

Ian Robinson et al. Graph Databases. O'Reilly. 2013 (http://graphdatabases.com/)