Ontologies and Semantic Web

Semantic Web:
standards and languages for knowledge representation

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http://www.irit.fr/-Equipe-MELODI-

Further readings

- **Foundations of Semantic Web Technologies**
  Pascal Hitzler, Sebastian Rudolph, Markus Kroetzsch
  Coll. : Textbooks in Computing. Chapman & Hall/CRC (2009)

- More tutorials and slides
  - http://www.semantic-web-book.org/page/Slides
  - http://www-sop.inria.fr/acacia/cours/iut2007/sparql-rule.pdf

En attendant les TP

- Survey récents
  - https://arxiv.org/pdf/2002.00388v2.pdf

    A Survey on Knowledge Graphs: Representation, Acquisition and Applications
  - https://arxiv.org/pdf/2003.02320.pdf

    Knowledge Graphs (132 pages)

- Dbpedia http://es.dbpedia.org/
- Installer le logiciel Protégé : http://protege.stanford.edu/

Motivations for a new web

- A vision: the www
- New needs: towards a semantic web
- New means: the semantic web program

Semantic
Web

A semantic web: foundational acts

- From Tim Beners-Lee’s vision at the 1994 WWW conference
  - http://www.w3.org/Talks/WWW94Tim
- The Semantic Web by Tim Berners-Lee, James Hendler and Ora Lassila, Scientific American, may 2001
  - http://websemantique.org/ScientificAmericanMai2001

The semantic web statement

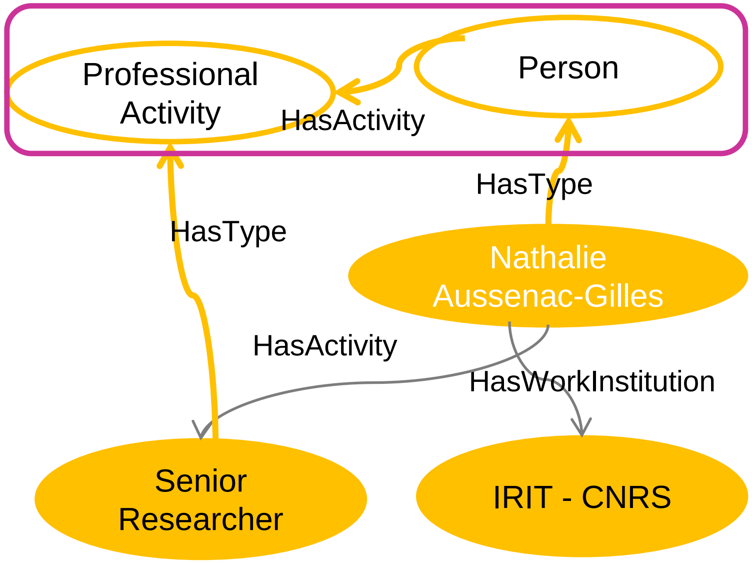
“The Semantic Web is an extension of the current web in which information is given well-defined meaning, better enabling computers and people to work in cooperation. The mix of content on the web has been shifting from exclusively human-oriented content to more and more data content.

The Semantic Web brings to the web the idea of having data defined and linked in a way that it can be used for more effective discovery, automation, integration, and reuse across various applications. For the web to reach its full potential, it must evolve into a Semantic Web, providing a universally accessible platform that allows data to be shared and processed by automated tools as well as by people.”

W3C Semantic Web Activity Statement

The semantic web program

- Continuity with the www
  - Semantics for computers
  - Open and decentralised
  - Extension of the existing web
- Knowledge representation
  - AI and logic based languages
  - Open world hypothesis
  - Flexibility and decentralisation
- Ontologies and knowledge graphs
  - Shared and consensual formal vocabularies
  - Public on the web
  - Axioms and inferences



The semantic web program

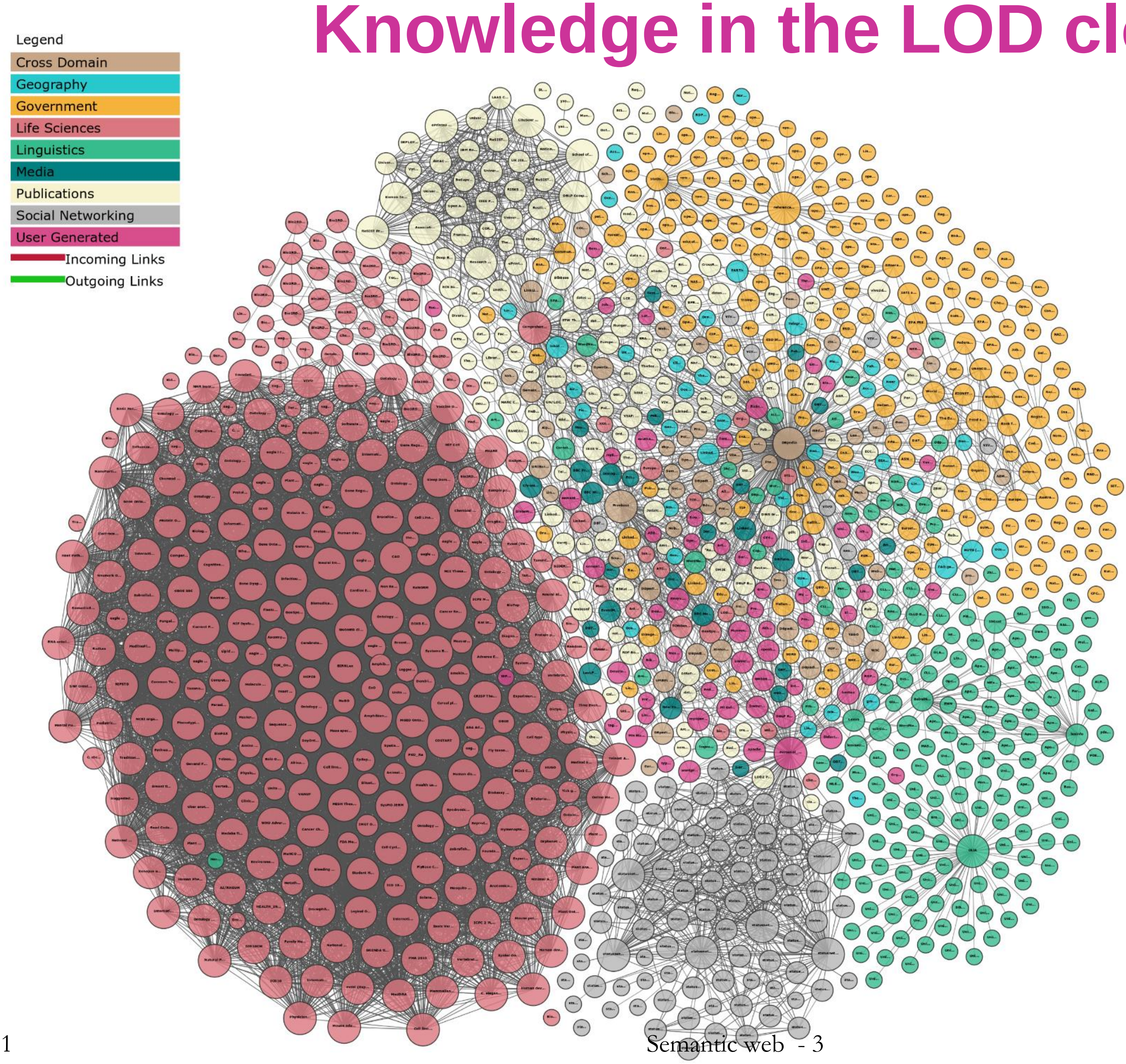
- Formal Agents
  - Web programs that combine, aggregate, share data and make decisions
  - Even “things” can become nodes of the web and behave like agents - > IoT

- Dynamicity, knowledge evolution
  - Anyone can feed the semantic web
  - Redundant information may appear
  - Need for identifying relations between similar entities (data mapping, ontology alignment)

The semantic web program: how?

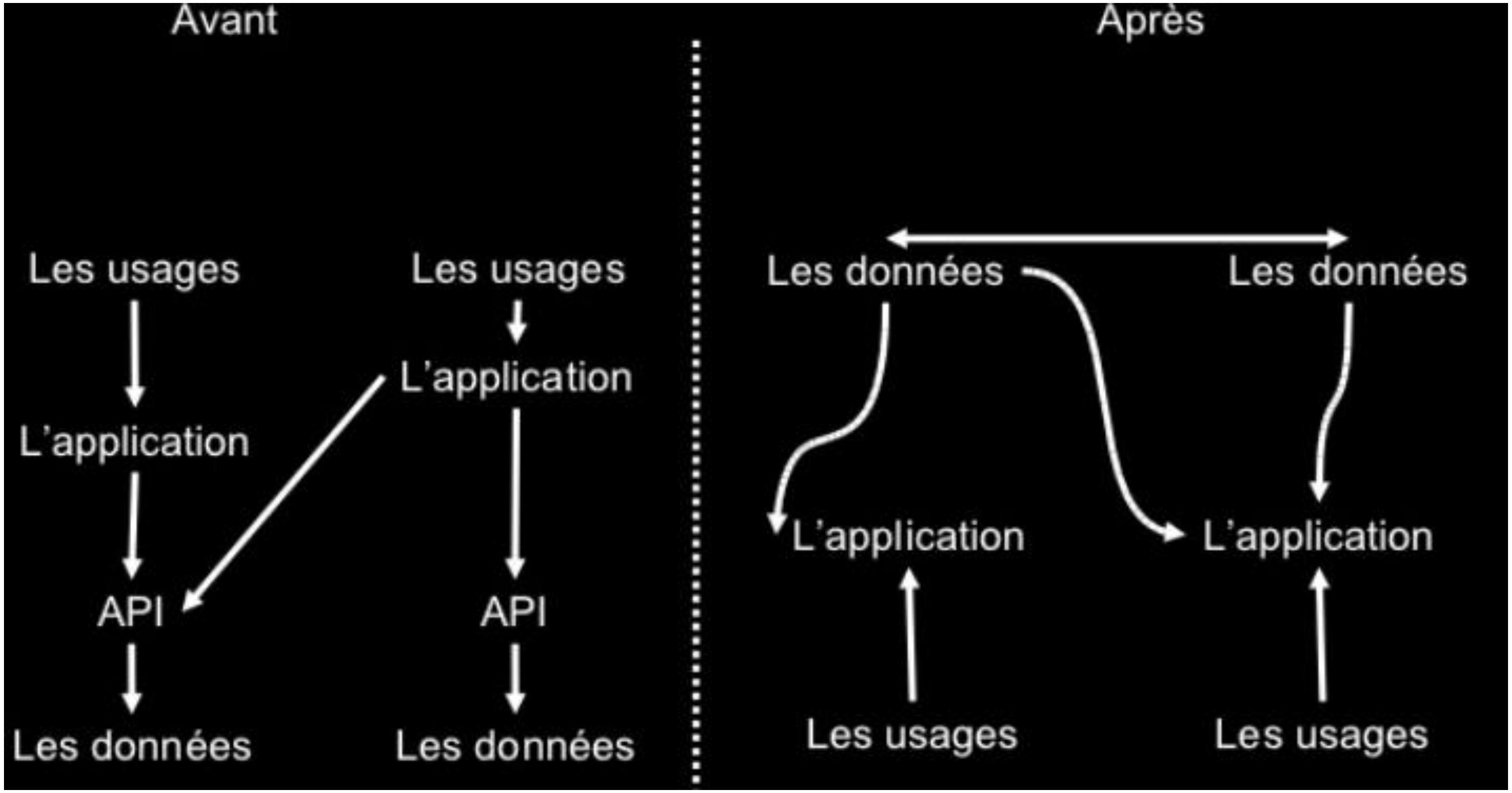
- Add knowledge to the web
  - Propose new standards for web knowledge representations
  - Collect structured data
- New applications
  - Semantic web services
  - New communication protocoles, trust management
- Facilitate interoperability
  - Of heterogeneous data and vocabularies

Knowledge in the LOD cloud



The semantic web program: how?

- A new paradigm for web applications



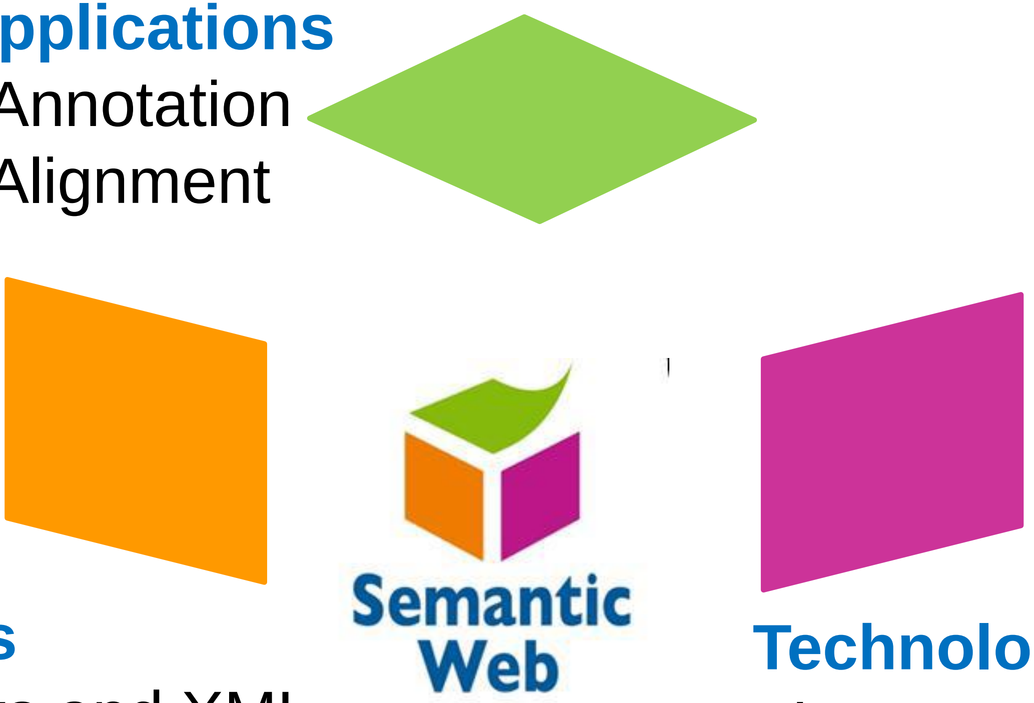
The semantic web: who will do it? (2020)

- Adding knowledge has a cost
  - Build ontologies
  - Annotate pages
  - Identify user’s needs
- Who will pay for it?
  - Authors
  - Users
  - Web managers
  - Developers of innovating applications

The semantic web: who will do it? (2020)

- Adding knowledge has a cost
  - Build ontologies: ML + human
  - Browse the web, collect pages with search engines
  - Information extraction, entity linking and NLP > automatic and usage oriented semantic annotation
- Who will pay for it?
  - Scientific community and standardization groups build resources
  - Developers of innovating applications use them

Building blocs of the semantic web

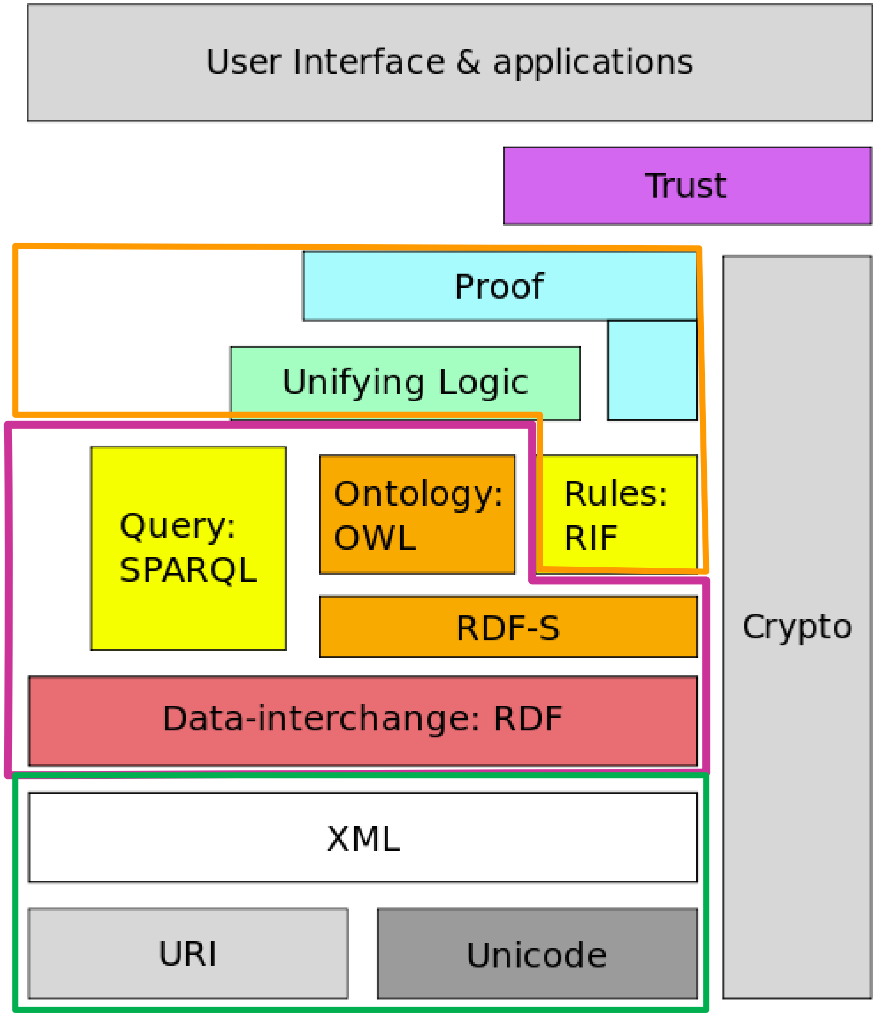


Applications
- Annotation
- Alignment

Groudings
- Hypertexts and XML
- Description logic
- Formal ontology

Technologies
- Languages
- Models: ontologies, vocabularies, Linked Data

The semantic web layer cake (2006)



Semantic web specific blocs

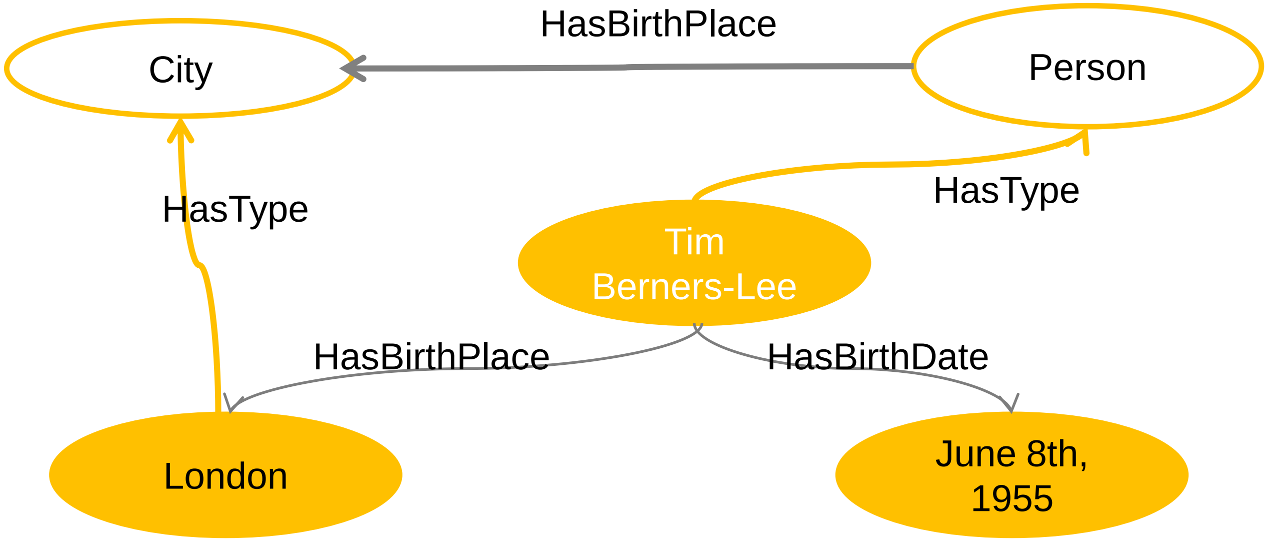
Reasoning with knowledge graphs

Query and search for data, generate graphs

Agree on share vocabularies

Motivations and design options

- A web linked resources -> uniform handling of resources, URI
- Sharing data and “meaning” -> type definitions
- Connecting data to documents -> XML compliant
- AAA -> open representation, modularity

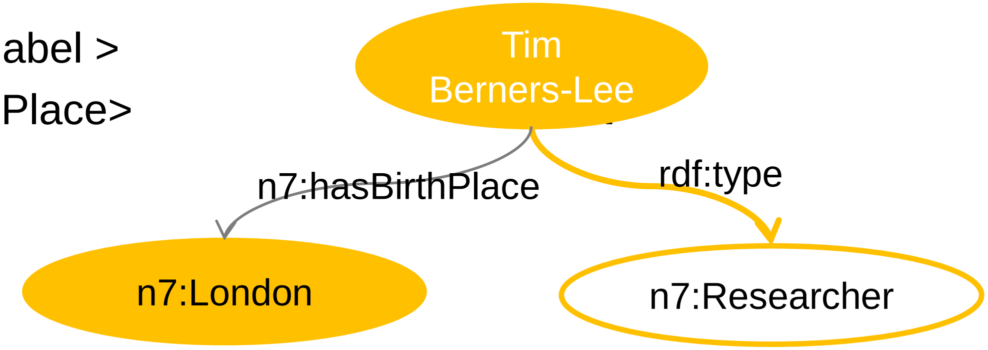


Motivation: semantic search on the web

n7 = namespace

“Tim Berners Lee is a researcher”

```
<rdf:Description id=n7:Tb>
    <rdfs:label> “Tim Berners Lee” </ rdfs:label >
    <hasBirthPlace> n7:London </hasBirthPlace>
</rdf:Description >
n7:Tb rdf:type n7:Researcher
```



“I am looking for persons born in London”

```
SELECT ?x WHERE {
    ?x rdf:type n7:Person .
    ?x n7:hasBirthPlace #London ..
}
```

Motivation: semantic search on the web

"Tim Berners Lee is a researcher"

n7 = namespace

```
<rdf:Description id=n7:Tb>
    < rdfs:label > "Tim Berners Lee" </ rdfs:label >
    <birthPlace> n7:London </birthPlace>
</rdf:Description >
```

RDF

n7:Tb rdf:type n7:Researcher

"I am looking for persons"

SELECT ?x WHERE {?x rdf:type n7:Person. }

SPARQL

n7:Tb rdf:type n7:Person

Ou

n7:Researcher rdfs:subClassof n7:Person

RDFs

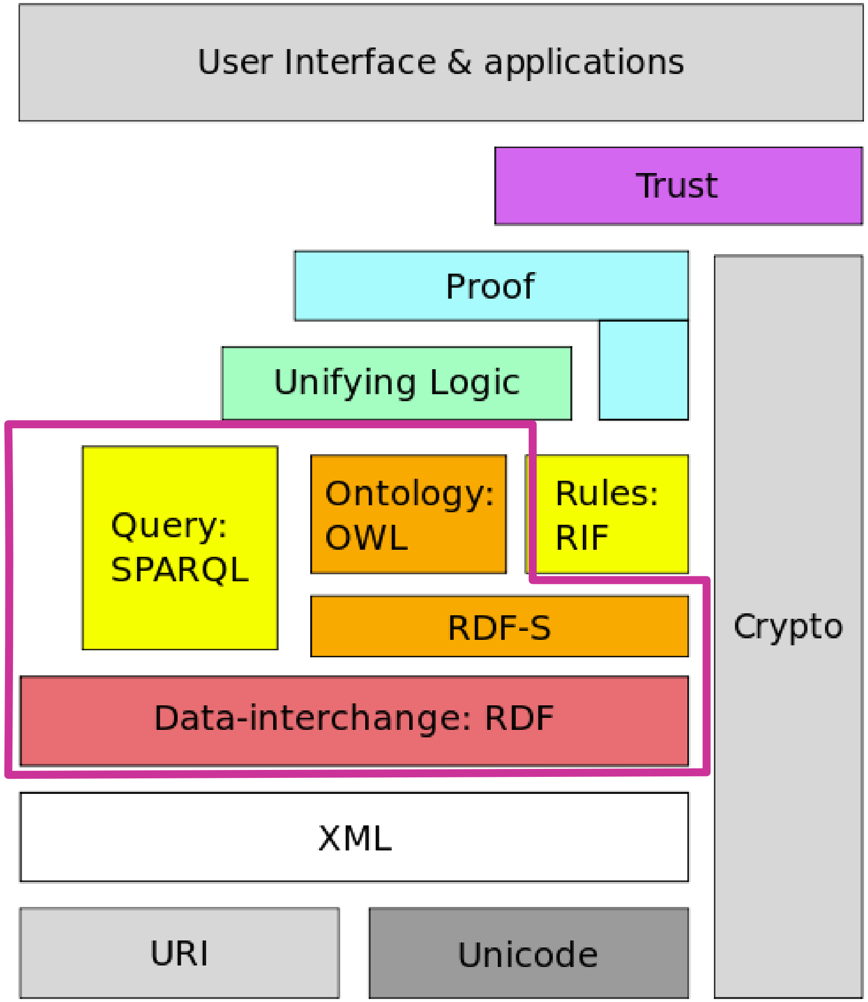
∀?x ?y (?x rdf:type ?y and ?y rdfs:subClassof ?z)
→ ?x rdf:type ?z

Semantics of subsumption

n7:Tb rdf:type n7:Person

The Semantic Web layer cake (2006)

Semantic web specific blocks



Semantic

Syntax

naming

RDF

- RDF Building Blocks and Turtle Syntax
- Model Theory For RDF
- RDF Schema
- RDFS Entailment
- Shortcomings of RDF

RDF: Resource Description Framework

- A meta-data model
  - A descriptive model (1999)
  - A W3C standard (2004)

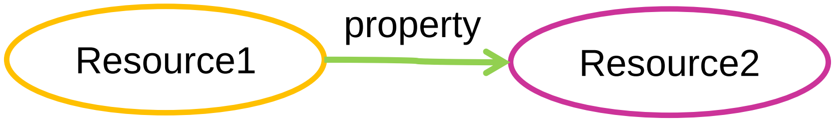
  http://www.w3.org/RDF/ http://www.w3.org/TR/rdf-concepts/

- Universal machine readable data format
- Resources identified by URIs
  - Uniform Resource Identifier
  - URIs identify on the web any Resource (on or outside the web)
    - on the www
    - any object with a clear identity (within the context of a given application)
    - examples: books, cities, humans, publishers, but also
    - relations between those, abstract concepts, etc.

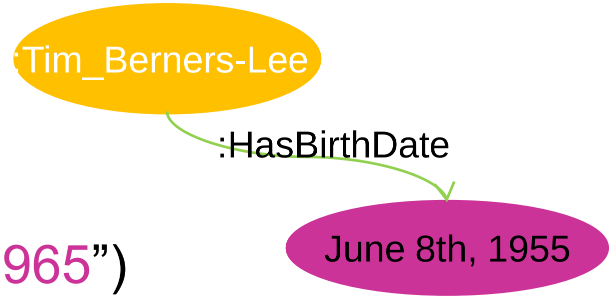
- RDF models refer to namespaces using prefixes
  - URIs that identify sets of resource, schemas, (formal) vocabularies
  - Prefixes: `xmlns:rdf = http://www.w3.org:1999/02/22-rdf-syntax-ns#`

RDF

- A model made of triples
  (resource1, property, resource2)



- Analogy: simple sentence
  (subject, predicate, object)
  (:Tim Berners Lee, :hasBirthDate, “June 8th, 1965”)



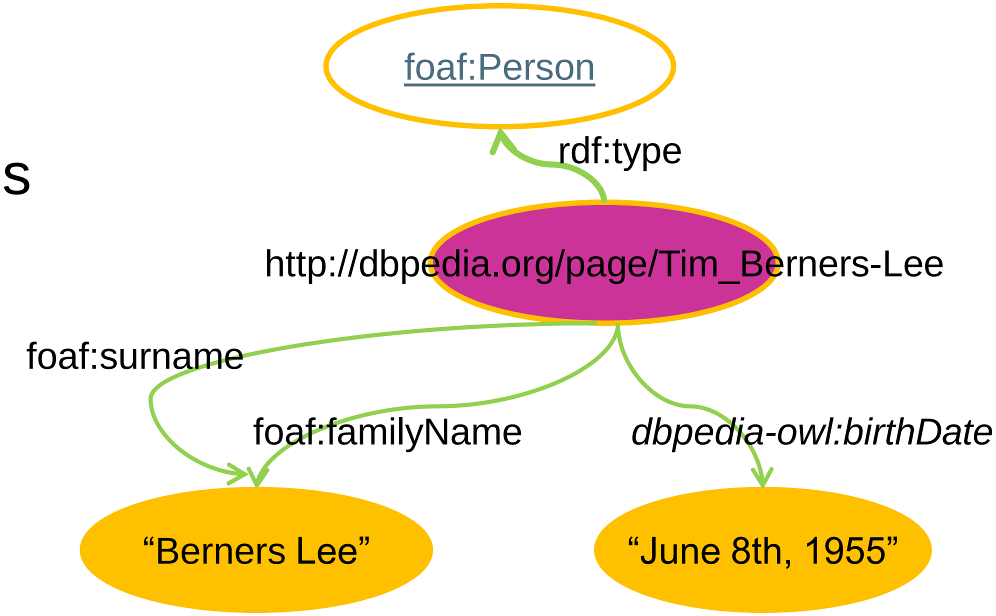
- Building blocks
  - Resources
  - Properties
  - Triples
  - Graphs

RDF: a graph model

- A triple is an edge and 2 nodes

(Node1, edgeLabel, Node2)

- The RDF graph is
  - a set of triples
  - multigraph
  - directed
  - labelled

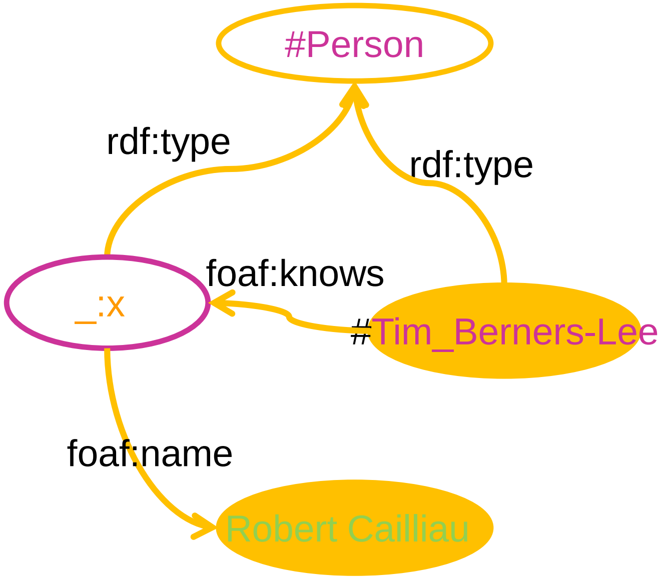


- Each resource may come from a different set / web site / with its own XML namespace

```
xmlns:foaf=http://xmlns.com/foaf/0.1/
foaf:person=http://xmlns.com/foaf/0.1/person

xmlns:dbpedia-owl=http://dbpedia.org/resource/classes#
```

RDF: nodes

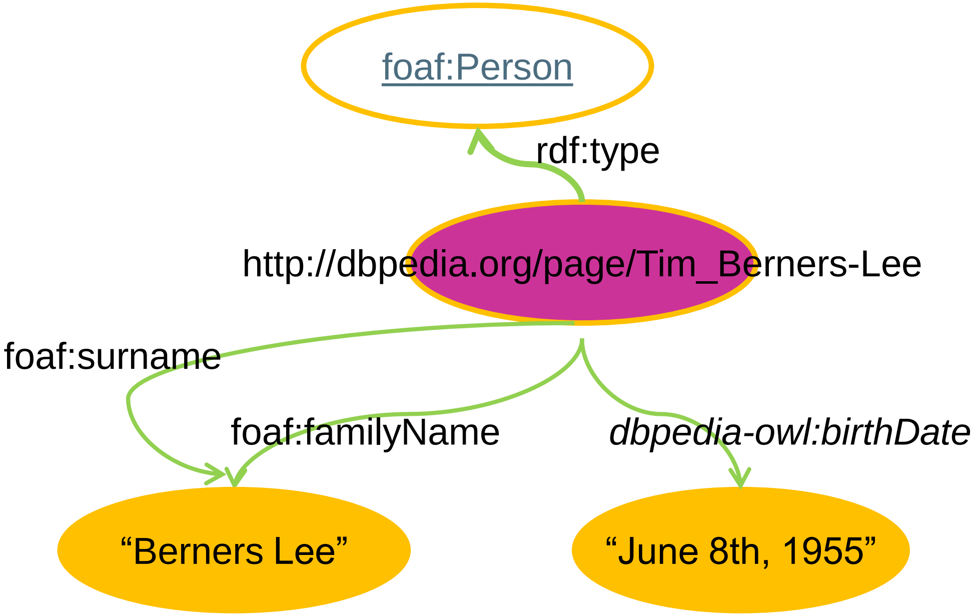


- URI
  - Define your own http URI
  - Use http URIs of web spaces you control
  - A URI ***denotes*** a Resource in the world
- Literals
  - Represent data values of a datatype
  - Written as strings
  - Interpreted as strings if no datatype is given
- Blank nodes
  - Refer to the existence of an unknown entity
    - `_:x  rdf:type  #Person`

RDF: edges

- properties
  - directed
  - Labelled (strings)
  - Defined in a namespace
  - W3C standard (rdf:type) or specific (foaf:name)

RDF XML syntax: graphs in XML trees



- Ressources

  http://dbpedia.org/page/Tim_Berners-Lee
  `foaf:Person`

- Litterals

  “Berners Lee”
  “June 8th, 1955”

- Predicates

  rdf:type, foaf:surname
  foaf:familyName, dbpedia-owl:birthdate

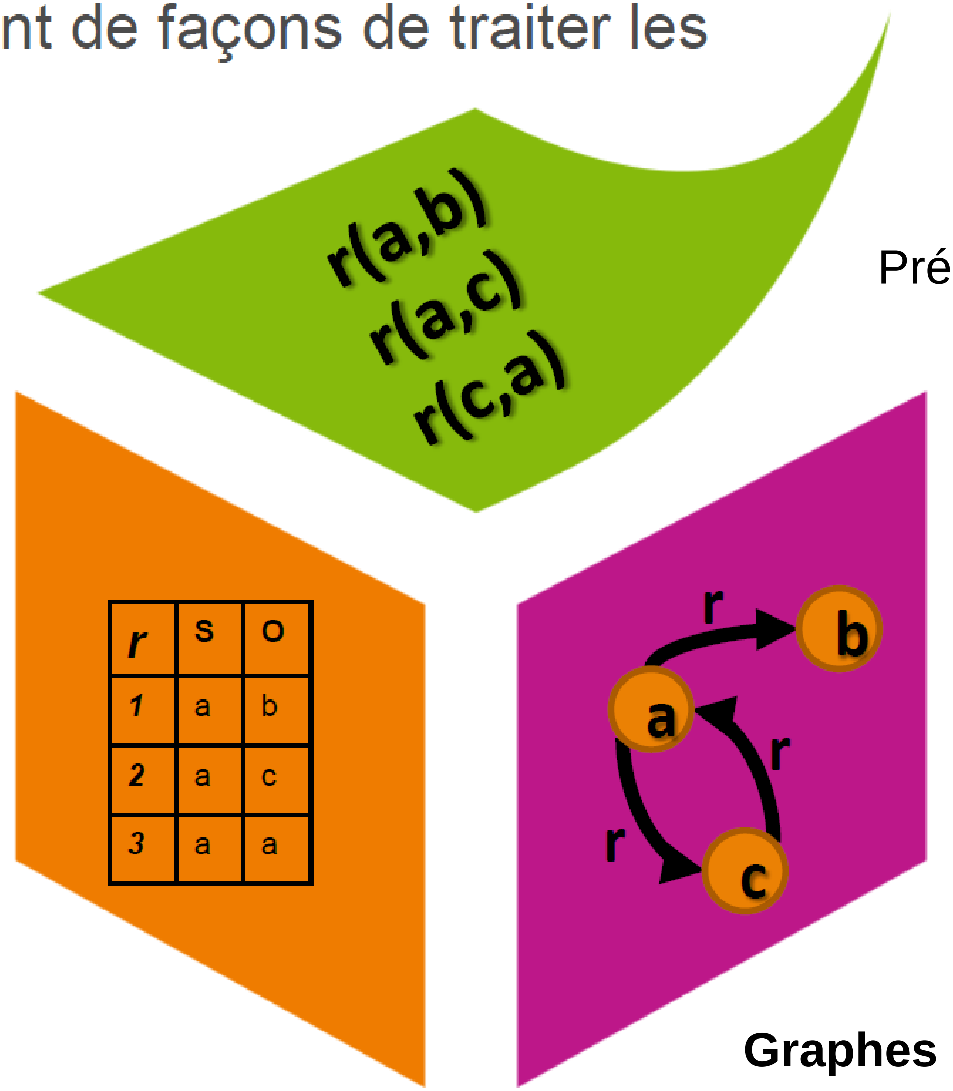
- Triples

  (subject, predicate, object)
  Resource-URI Predicate-URI Resource or Literal

  (http://dbpedia.org/page/Tim_Berners-Lee, foaf:surname, “Berners Lee”)
  (http://dbpedia.org/page/Tim_Berners-Lee, foaf:familyName, “Berners Lee”)
  (http://dbpedia.org/page/Tim_Berners-Lee, rdf:type, foaf:Person)
  (http://dbpedia.org/page/Tim_Berners-Lee, dbpedia-owl:birthdate, “June 8th, 1955”)

plusieurs vues sur un graphe

il y a énormément de façons de traiter les données RDF



Prédicats logiques

r(a,b)
r(a,c)
r(c,a)

Table de BDI

r	s	o
1	a	b
2	a	c
3	a	a

Graphes étiquetés

RDF XML syntax: root of the XML tree

namespaces

```
<rdf:RDF
xmlns:rdf=http://www.w3.org:1999/02/22-rdf-syntax-ns#
xmlns:foaf= http://xmlns.com/foaf/0.1/
xmlns:dbpedia-owl= http://dbpedia.org/resource/classes#
xmlns:n7=http://www.irit.fr/ontologies/n7# >

<rdf:Description
rdf:about=‘’http://dbpedia.org/page/Tim_Berners-Lee’’>
   <foaf:surname>  Berners Lee </foaf:surname>
   <foaf:familyname> Berners Lee </foaf:familyname>
   <n7:worksWith
rdf:resource=‘’http://fr.dbpedia.org/resource/Vint_Cerf’’ />
</rdf:Description>

</rdf:RDF>
```

RDF vocabulary

- Resource description

```
<rdf:Description rdf:about= "http://dbpedia.org/page/Tim_Berners-Lee">
…
</rdf:Description>

<rdf:Description rdf:ID= « TB" />
```

- Absolute or relative URI identifier
  - **http://dbpedia.org/page/Tim_Berners-Lee (absolute)**
  - **xmlns:n7= http://www.irit.fr/ontologies/n7#**
  - **n7:TB (relative)**
  - **http://www.irit.fr/ontologies/n7#TB (absolute)**
  - **TB(local)**
- Give the description an identifier
  - **rdf:about : the resource needs to have a global identifier**
  - **rdf:ID : the resource has a local identifier**

RDF vocabulary : triples

```
<rdf:Description
rdf:about=‘’http://dbpedia.org/page/Tim_Berners-Lee’’>
   <foaf:surname> Berners Lee </foaf:surname>
   <foaf:familyname> Berners Lee </foaf:familyname>
   <n7:worksWith
   rdf:resource=‘’http://fr.dbpedia.org/resource/Vint_Cerf’’
/>
</rdf:Description>
```

RDF –XML: syntactic variation

- Resource reference: `rdf:resource`

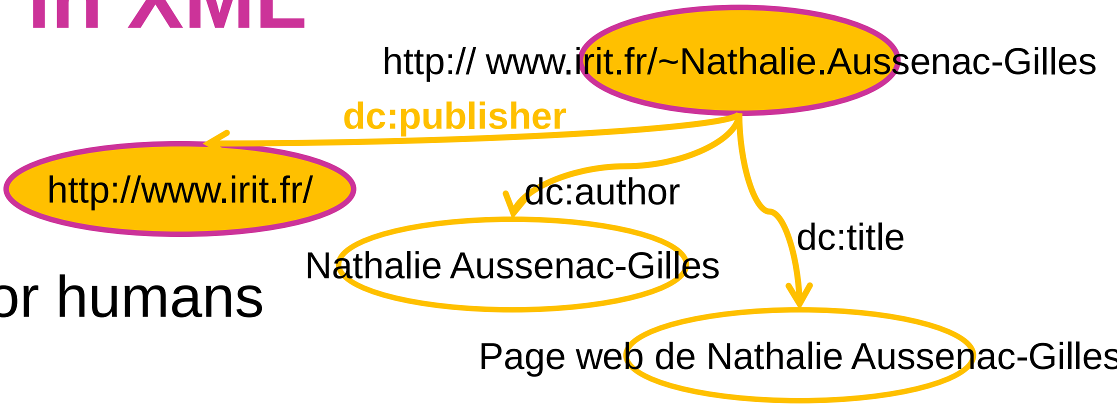
```
<rdf:Description rdf:about="http://www.irit.fr/~Nathalie.Aussenac-Gilles ">
   <dc:title> Page web de Nathalie Aussenac-Gilles</dc:title>
   <dc:author rdf:resource=‘’n7:Nathalie’’ />
</rdf:Description>
```

- Description imbrication

```
<rdf:Description rdf:about="http://www.irit.fr/~Nathalie.Aussenac-Gilles ">
   <dc:title> Page web de Nathalie Aussenac-Gilles</dc:title>
   <dc:author>  <rdf:Description rdf:about=‘’n7:Nathalie’’>
                 <foaf:name> Nathalie </foaf:name>
                 </rdf:Description>
   </dc:author>
</rdf:Description>
```

RDF serialization in XML

- RDF/XML
  - Widely used
  - But not easily readable for humans

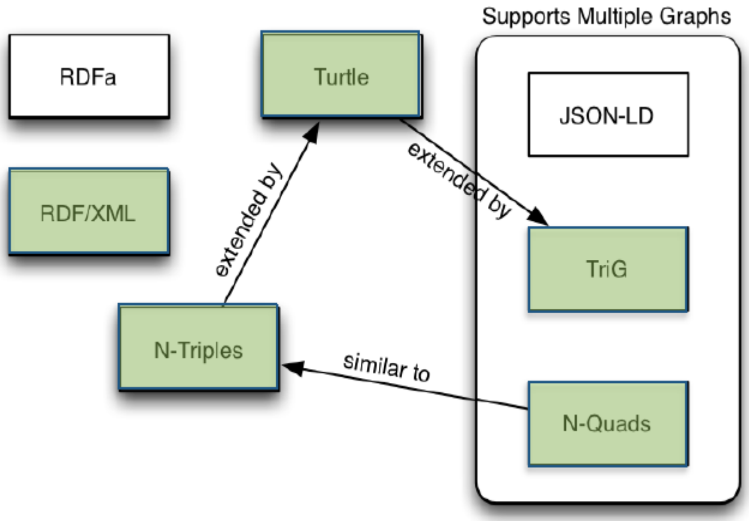


http:// www.irit.fr/~Nathalie.Aussenac-Gilles
dc:publisher
http://www.irit.fr/
dc:author
dc:title
Nathalie Aussenac-Gilles
Page web de Nathalie Aussenac-Gilles

```
<?xml version="1.0"?>
<rdf:RDF xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
        xmlns:dc=“http://purl.org/elements/1.1/”
        xml:base=http://www.irit.fr/exemple
        xmlns:n7=“http://www.irit.fr/exemple#>

<rdf:Description rdf:about="http://www.irit.fr/exemple#WebPageAussenac">
        <dc:title>Page web de Nathalie Aussenac-Gilles</dc:title>
        <dc:author>Nathalie Aussenac-Gilles</dc:author>
        <dc:publisher rdf:resource="http://www.irit.fr/"/>
        <n7:URI> http://www.irit.fr/~Nathalie.Aussenac-Gilles />
</rdf:Description>
<rdf:Description rdf:about="http://www.irit.fr/exemple#WebPageIRIT">
        <dc:title>Institut de Recherche en Informatique de Toulouse</dc:title>
        <n7:URI> http://www.irit.fr/~Nathalie.Aussenac-Gilles />
</rdf:Description>
</rdf:RDF>
```

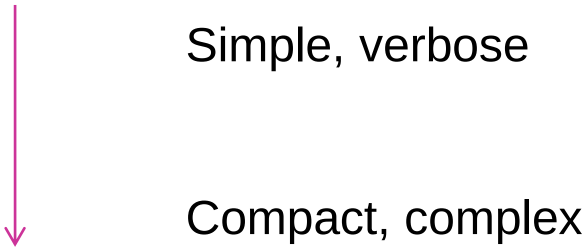
RDF a une syntaxe historique en XML et d'autres syntaxes : Turtle, TriG, JSON-LD, N-Triples, N-Quads



W3C ©

RDF: various possible notations

- RDF/XML syntax
- Easy syntaxes
  - N-Triples
  - TURTLE
  - N3



Simple, verbose

Compact, complex

RDF: N3 or N-Triple notation

- Simple representation
- Easier to read by humans

Subject predicate object .

- Easily uploaded and read by programs

```
<http://www.irit.fr/exemple#WebPageAussenac>
        dc:title “Page web de Nathalie Aussenac-Gilles”.

<http://www.irit.fr/exemple#WebPageIRIT> dc:title “Institut de
Recherche en Informatique de Toulouse” .
```

URI

Literal

End of Triple

RDF: Turtle notation

- Simple and **compact** representation
- Easier to read by humans

Subject predicate object .   or   Subject predicate object ,
predicate object1, object2 .

- Name spaces are declared as @prefix

```
@prefix rdf: http://www.w3.org/1999/02/22-rdf-syntax-ns#.
@prefix  dc: http://purl.org/elements/1.1/>.

<http://www.irit.fr/exemple#WebPageAussenac>
         dc:title “Page web de Nathalie Aussenac-Gilles” ;
         dc:author “Nathalie Aussenac-Gilles”, n7:webmasterIrit ;
         dc:publisher <http://www.irit.fr/> .
<http://www.irit.fr> dc:title ‟ Institut de Recherche en Informatique de
Toulouse ” .
```

Name space

URI

List of predicates -properties

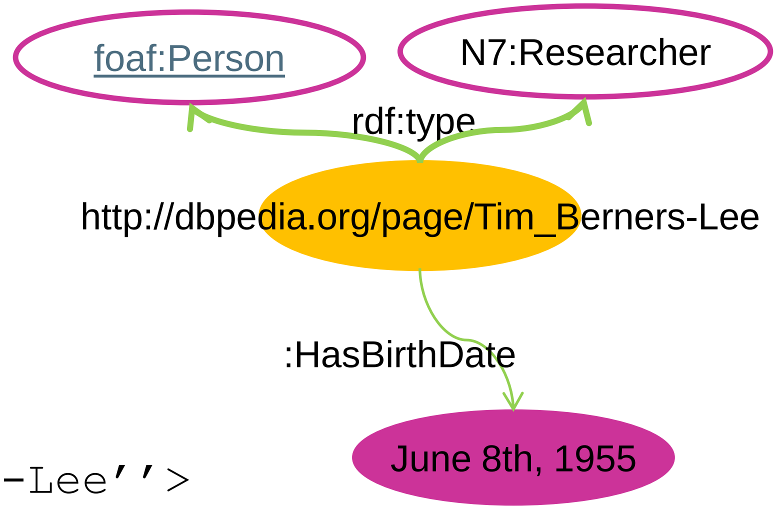
Literal

End of Triple

List of values-objects

URI

RDF:type, un prédicat particulier



- rdf:type

  prédicat réservé en RDF

  définit une ressource comme type d’une autre

- Syntaxe RDF- XML

```
<rdf:Description rdf:about=
‘’http://dbpedia.org/page/Tim_Berners-Lee’’>
     <rdf:type foaf:Person>
     <rdf:type n7:Researcher>
     <n7:hasBirthDate> ”June 8th, 1965” </n7:hasBirthdate>
</rdf:Description>
```

- RDF Turtle : `rdf:type` `devient` `a`

```
<http://dbpedia.org/page/Tim_Berners-Lee> a foaf:Person,
n7:Researcher .
```

RDF: types for literals

- Literals can have a datatype

(#Tim Berners Lee, n7:hasBirthDate, “June 8th, 1965”)

```
<foaf:Person  rdf:about="http://dbpedia.org/page/Tim_Berners-Lee">
<ex:hasBirthYear rdf:datatype="&xsd;gYear">  1965</ex:hasBirthYear>
</foaf:Person>

<http://dbpedia.org/page/Tim_Berners-Lee> ex:hasBirthDate “1965-06-
   08”^^xsd:date
```

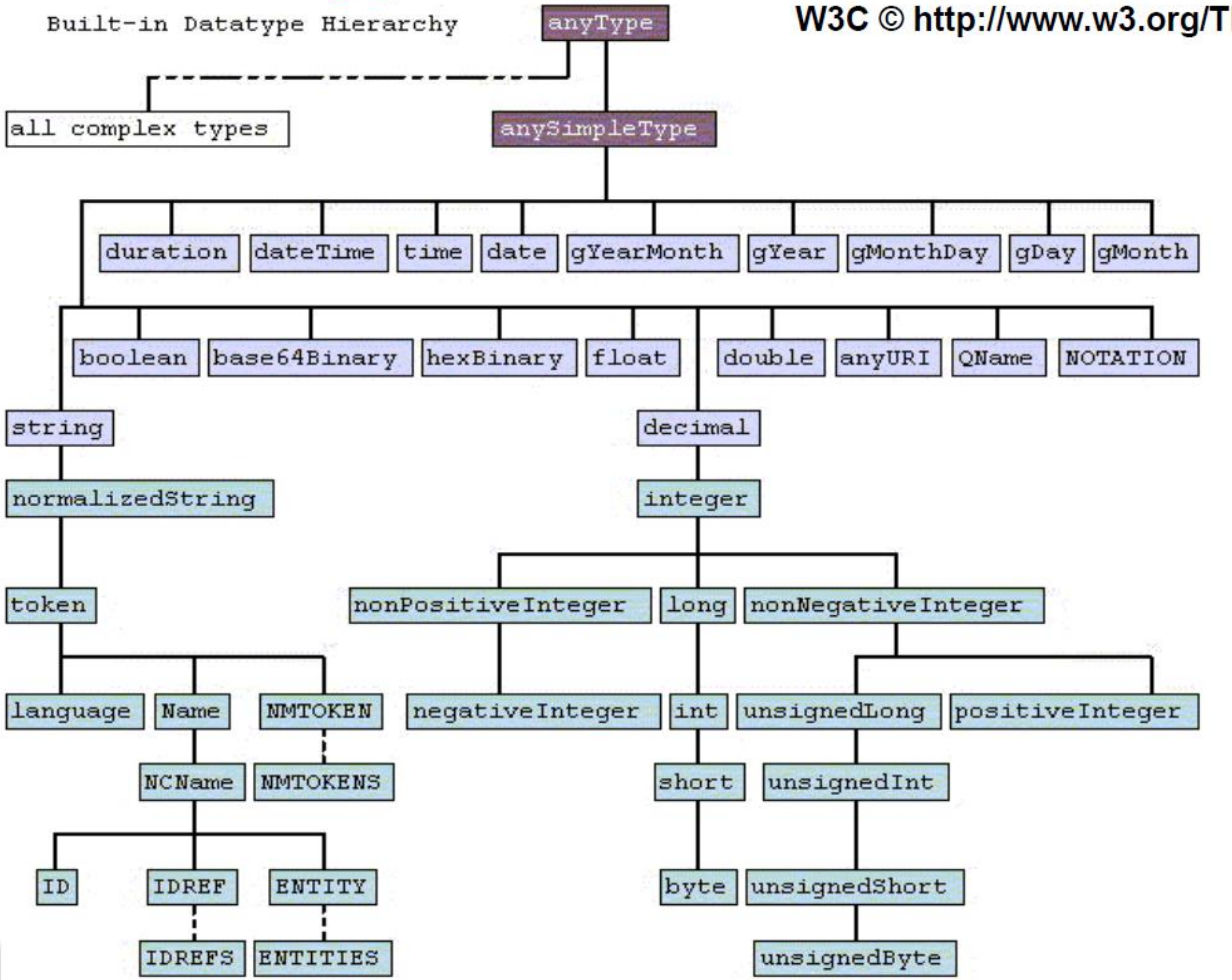
- Datatypes
  - denoted by URIs
  - can be freely chosen
  - frequently: xsd datatypes from XML
  - syntax of typed literal: “datavalue"^^datatype-URI

- Literals can have several datatypes

```
<http://crcpress.com/uri> http://example.org/Name "CRC Press",
                                                   "CRC Press"@en ,
                                                   "CRC Press"^^xsd:string
```

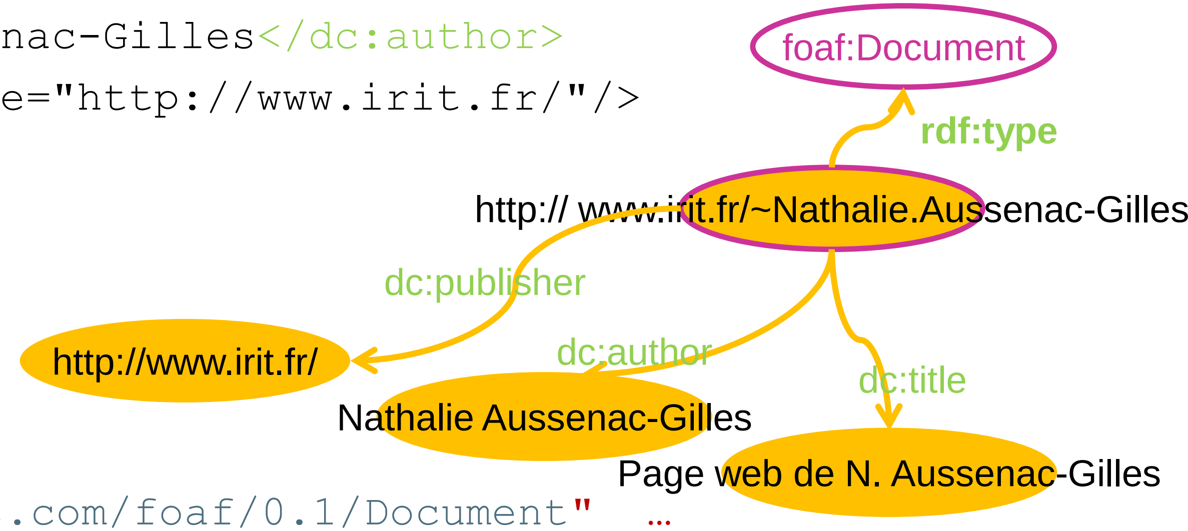
tous les types de données des schémas

W3C © http://www.w3.org/TR/xmlschema-2/



RDF/XML: variants to express types

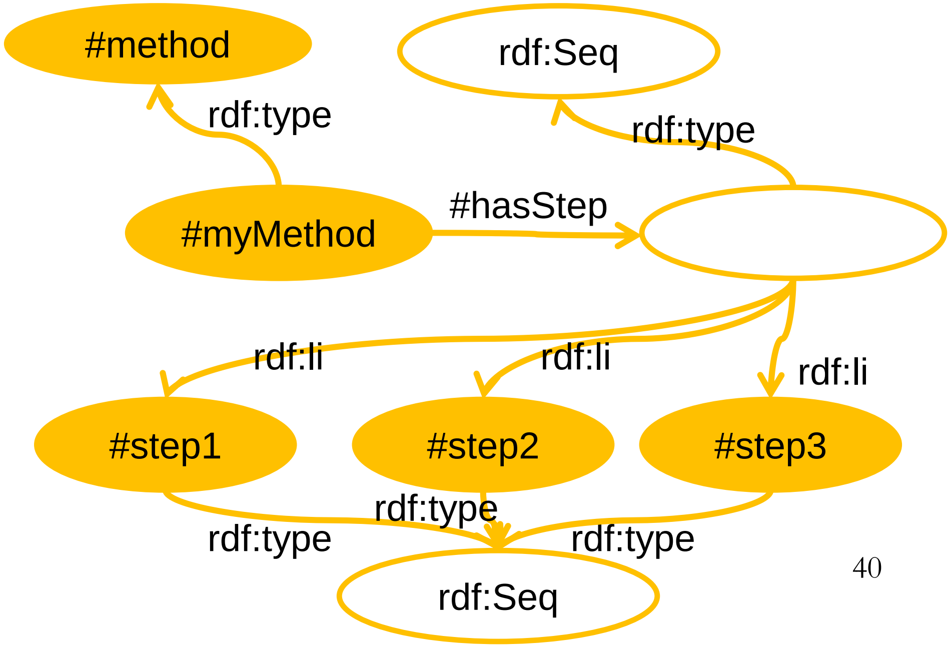
```
<rdf:Description rdf:about="http://www.irit.fr/~Nathalie.Aussenac-
   Gilles">
   <rdf:type rdf:resource="http://xmlns.com/foaf/0.1/Document" />
   <dc:title>Page web de Nathalie Aussenac-Gilles</dc:title>
   <dc:author>Nathalie Aussenac-Gilles</dc:author>
   <dc:publisher rdf:resource="http://www.irit.fr/"/>
</rdf:Description>
```



```
… xmlns: foaf ="http://xmlns.com/foaf/0.1/Document"_ …
<foaf:Document  rdf:about="http://www.irit.fr/~Nathalie.Aussenac-Gilles">
   <dc:title>Page web de Nathalie Aussenac-Gilles</dc:title>
   <dc:author>Nathalie Aussenac-Gilles</dc:author>
   <dc:publisher> <rdf:Description rdf:resource="http://www.irit.fr/"/>
   </dc:publisher>
</foaf:Document>
```

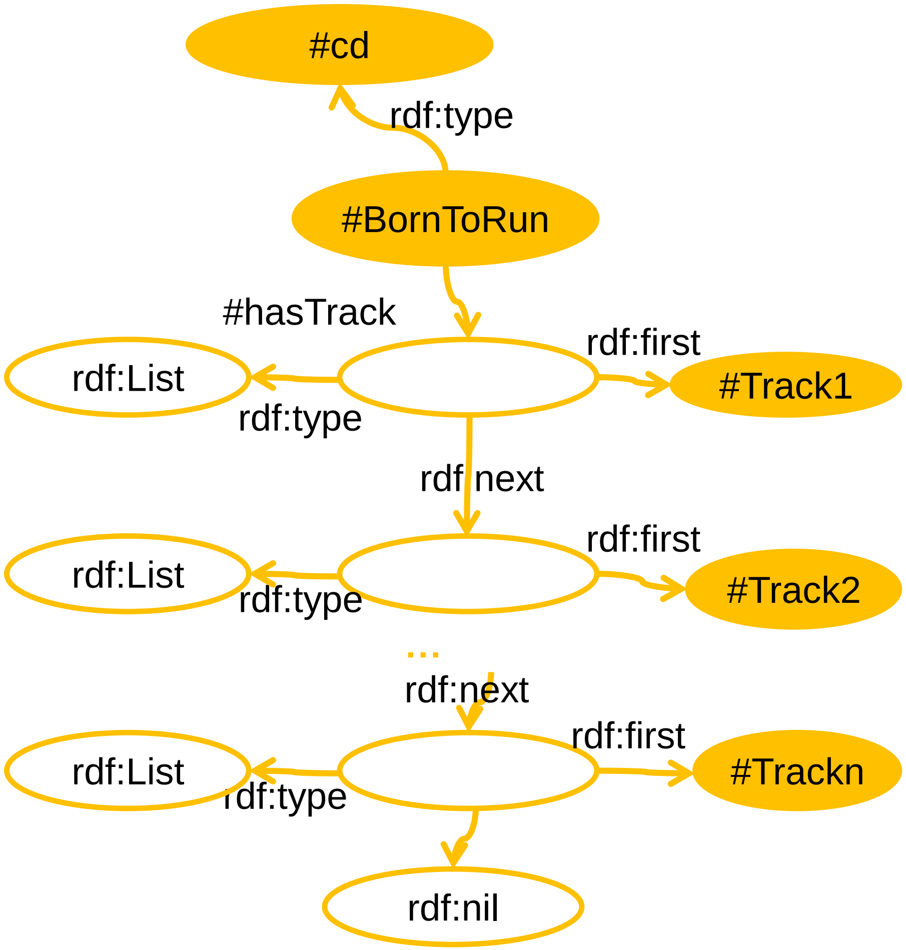
RDF syntax: complex data structures

- Containers (open lists)
  - rdf:Bag non ordered group
  - rdf:Seq ordered list
  - rdf:Alt set of alternatives or choices (select ONE)
  - rdf:li = is member of a container
  - The list of members can be extended



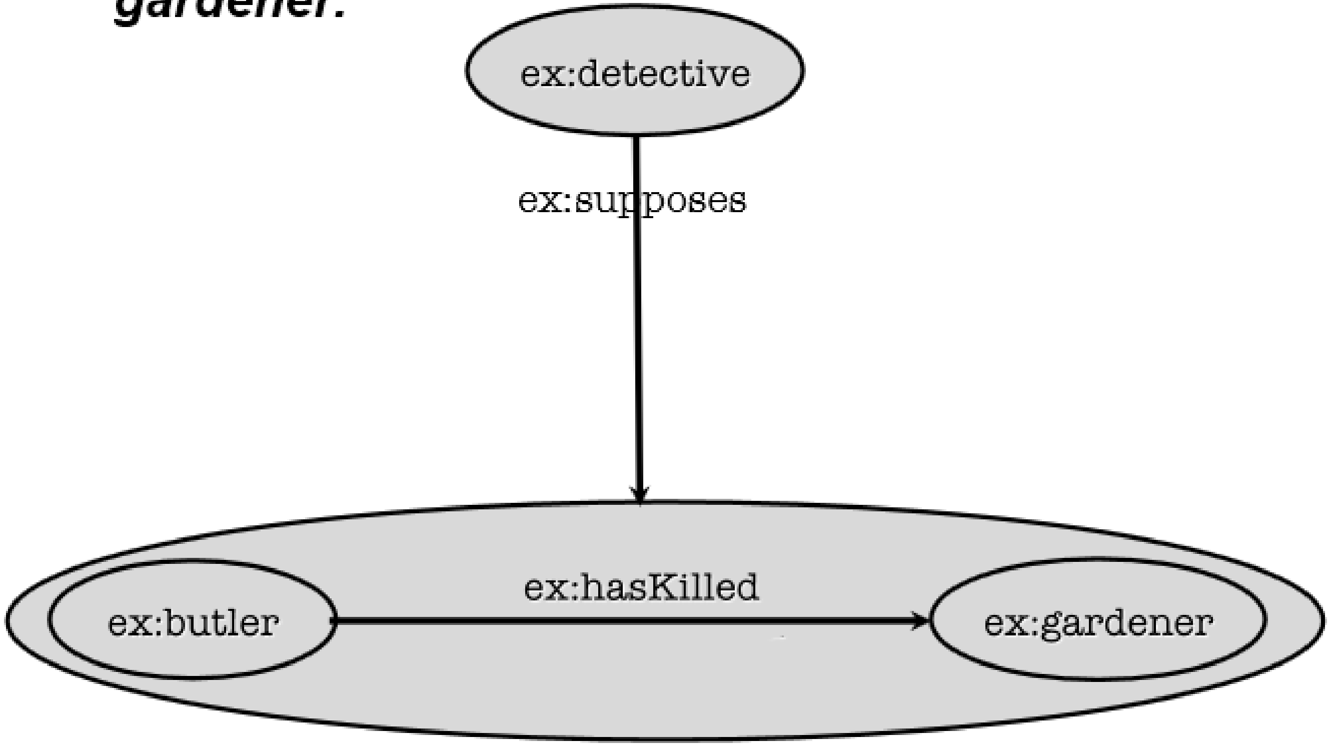
RDF: data structures

- Collections (closed lists)
  - rdf:list
  - rdf:first, rdf:rest, rdf:nil
  - The collection is closed to the members listed in the definition



RDF data structures

- Reified triples
  - **How to model propositions about propositions such as: *„The Detective supposes that the butler killed the gardener.“***



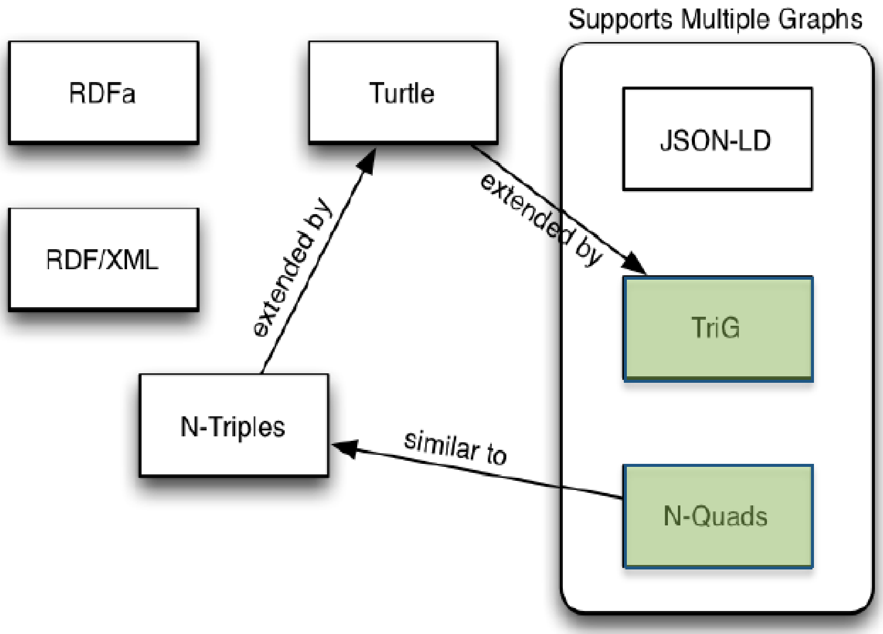
http://www.semantic-web-book.org/w/images/4/40/SWeMoL-Part-1-IJCAI-09.pdf

RDF data structures

- **Solution: auxiliary node for nested proposition**

```
<?xml version="1.0"?>
<rdf:RDF xmlns:rdf=http://www.w3.org/1999/02/22-rdf-syntax-ns#
  xmlns:ex="http://www.irit.fr /exemple/ex#“ >
<rdf:Description rdf:about=#detective>
              <supposes>
              <rdf:Statement rdf:about=#theory>
                            <rdf:subject rdf:resource=“ex:butler”/>
                            <rdf:predicate rdf:resource=“ex:hasKilled"/>
                            <rdf:object rdf:resource=“ex:gardener"/>
              </rdf:Statement>
              </supposes>
</rdf:Description>
</rdf:RDF>
```

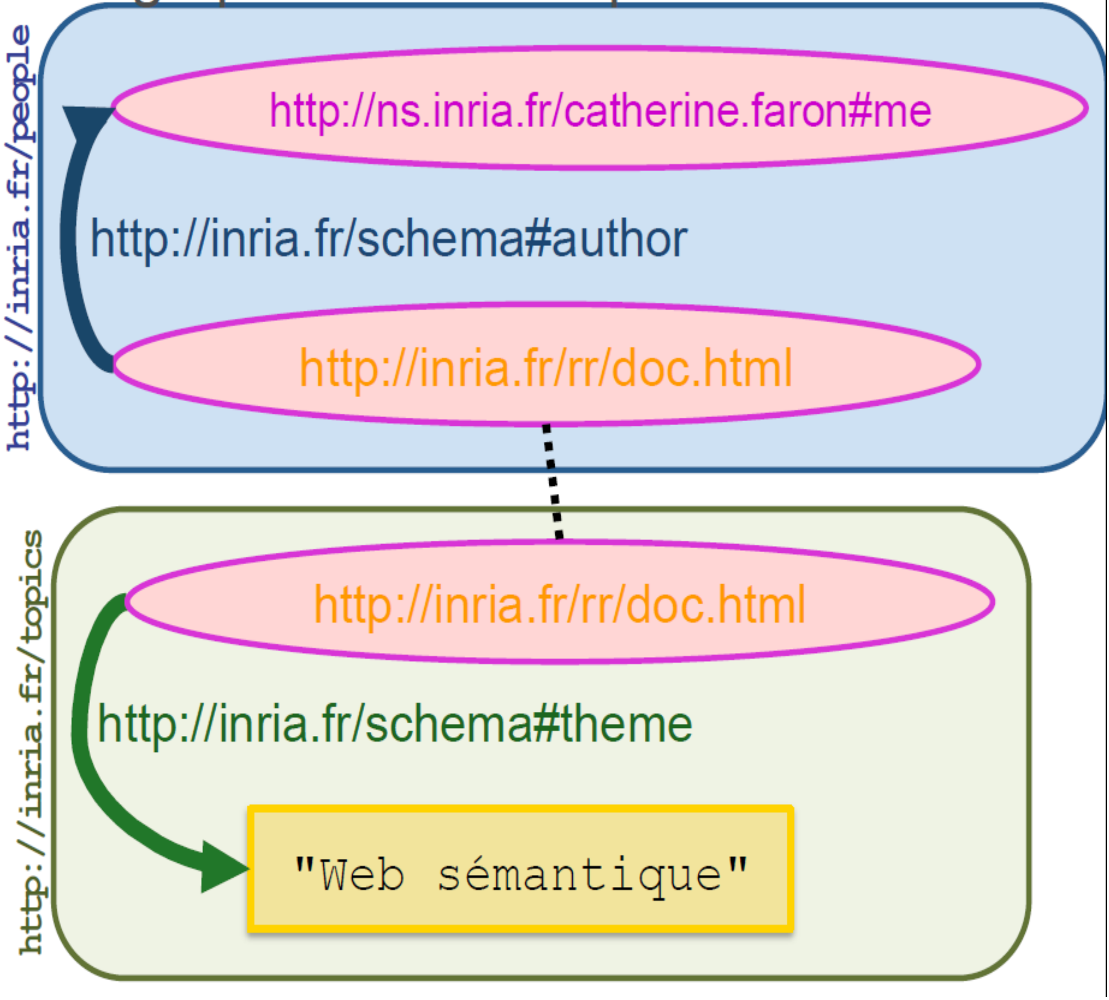
RDF a une syntaxe TriG et une syntaxe N-Quads permettant d'exprimer des contextes



W3C ©

les graphes nommés

grouper des triplets dans des sous-graphes identifiés par des URI


http://inria.fr/people
http://ns.inria.fr/catherine.faron#me
http://inria.fr/schema#author
http://inria.fr/rr/doc.html
http://inria.fr/topics
http://inria.fr/rr/doc.html
http://inria.fr/schema#theme
"Web sémantique"

RDF vocabulary

- **Classes**

  rdf:Description – triple description

  rdf:Resource - the class resource, everything

  rdf:XMLLiteral - the class of XML literal values

  rdf:Property - the class of properties

  rdf:Statement - the class of RDF statements

  rdf:Alt, rdf:Bag, rdf:Seq - containers of alternatives, unordered containers, and ordered containers

  rdf:List - the class of RDF Lists

  rdf:nil - an instance of rdf:List representing the empty list

- **Properties**

  rdf:type - an instance of rdf:Property used to state that a resource is an instance of a class

  rdf:first - the first item in the subject RDF list

  rdf:rest - the rest of the subject RDF list after the first item

  rdf:value - idiomatic property used for structured values

  rdf:subject - the subject of the subject RDF statement

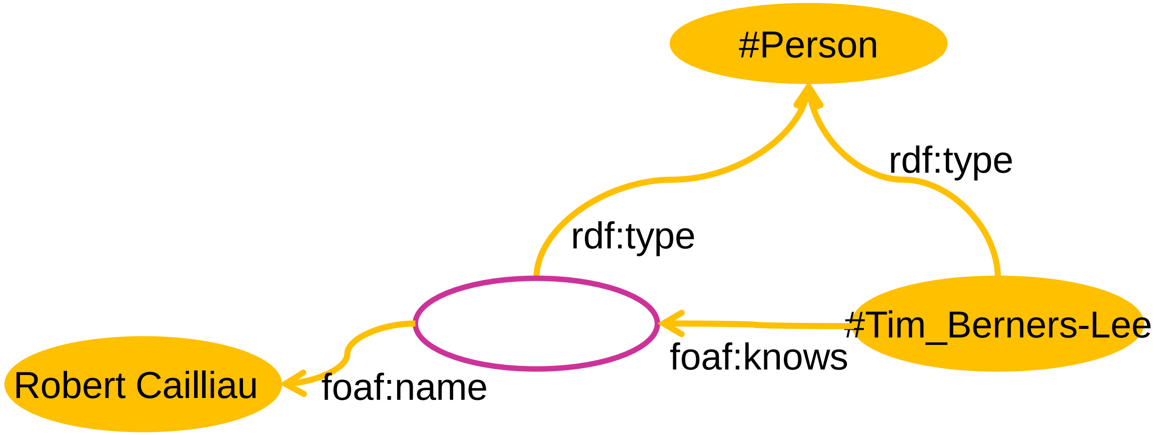
  rdf:predicate - the predicate of the subject RDF statement

  rdf:object - the object of the subject RDF statement

RDF semantics

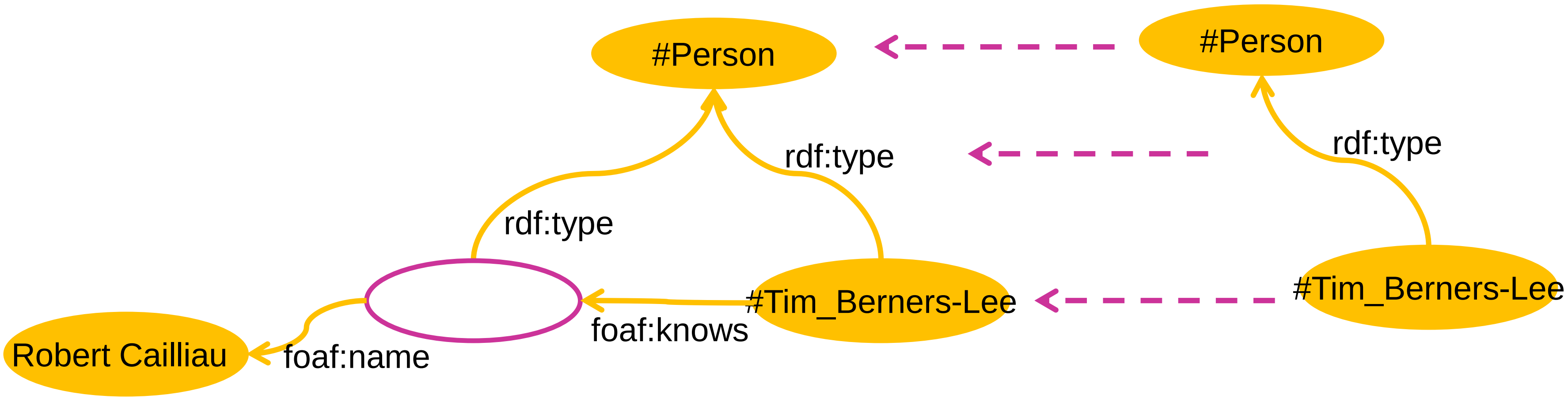
- Semantics in model theory
  - Triple: <s,p,o> is associated an atomic formula p(o,s)
  - Document: existential closure of the conjunction of atomic formulas
- Interpretation in predicate logic

$\exists$x, (rdf:type(#Tim_Berners-Lee, #Person) $\wedge$ rdf:type(x, #Person) $\wedge$ foaf:knows(#Tim_Berners-Lee, x) $\wedge$ faof:name(x, “Robert Cailliau”))



RDF semantics

- Reasoning mechanism
  - An RDF document is the consequence of another RDF document iff there is a graph homomorphisme between them
  - Goal = identify all the consequences of a set of predicates



RDF: strengths and limitations

- compared with DB
  - better manages semi-structured data
  - “universal”
  - Adapted to the web
  - But very verbose, little efficiency for storage and querrying
- Semantics
  - Logical model / model theory

RDF and the semantic web

- Difficulties with meta-data
  - May be missing
  - May be conflicting or erroneous
  - Reflect a point of view
  - Refer to local / specific types

- Difficulties to query different structural options

```
<foaf:Person  rdf:about="http://dbpedia.org/page/Tim_Berners-Lee">
<ex:hasActivity rdf:resource=#researcher”/>
</foaf:Person>

<foaf:Person  rdf:about="http://dbpedia.org/page/Marie_Curie">
rdf:type rdf:resource=#researcher”
</foaf:Person>

<ex:researcher rdf:about=“http://dbpedia.org/page/Albert_Einstein” />
```

which persons are researchers ?

From RDF to RDFS

- **Need** to define properties for generic groups of individuals, such as the class of publishers, of organizations, or of persons
- **Solution**:
  - (XML) schema knowledge
  - RDF Schema (RDFS): part of the RDF W3C recommendation
  - Adequate for simple models, hierarchies of classes and instances