Welcome to INFO216:
Knowledge Graphs
Spring 2023

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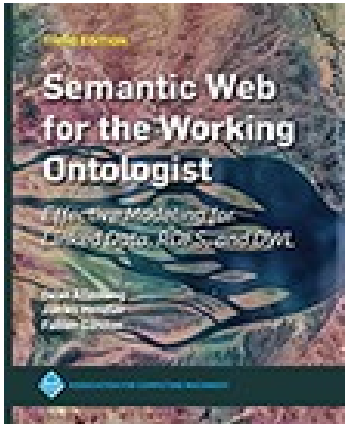
Session 2: Representing KGs (RDF)

- Themes:
  - *Resource Description Framework (RDF)*
    - a normal form for semantic data
    - a central semantic standard
  - *RDFLib's basic API*
    - creating and deleting graphs, input/output, listing statements, managing literals, type mappings
  - about INFO216
  - a little more *background*
    - what are the *semantic web*, *semantic technologies*, *and linked data*?

Reading

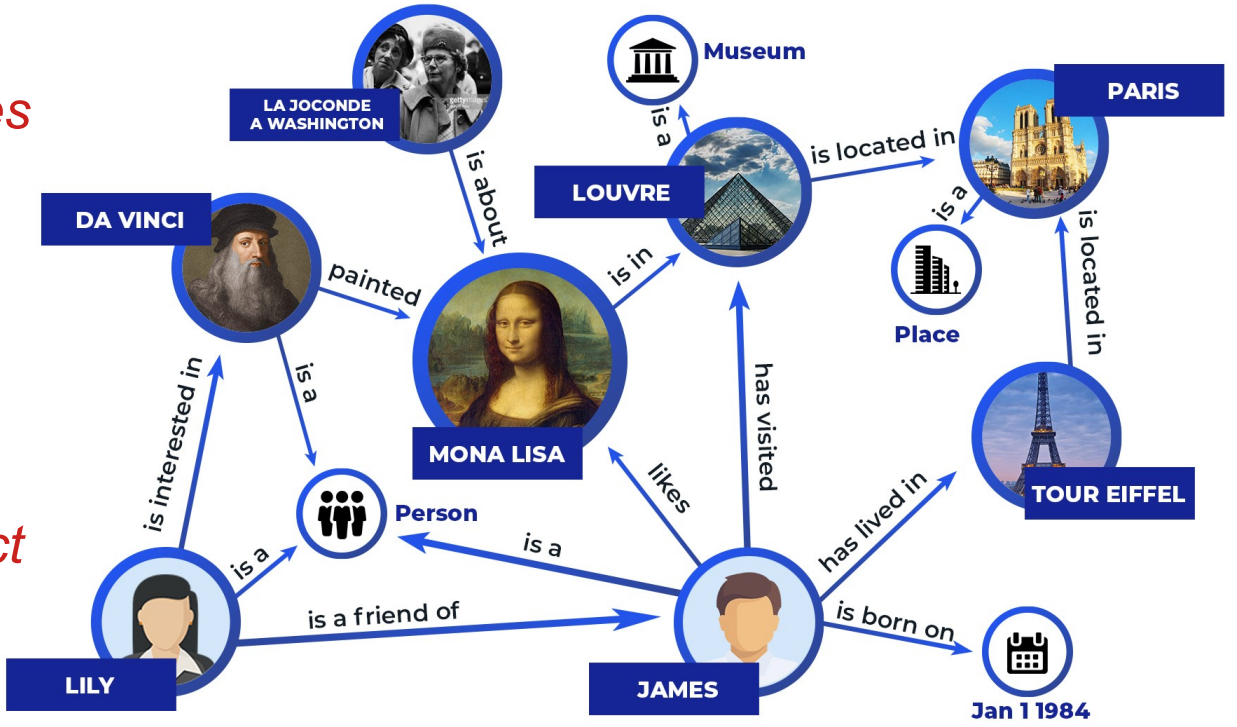
- Sources:
  - Allemang, Hendler & Gandon (2020):
    Semantic Web for the Working Ontologist, 3rd edition:
    chapter 3
  - Blumauer & Nagy (2020):
    Knowledge Graph Cookbook – Recipes that Work:
    for example pages 92-100, 125-128, 164-167 (*supplementary)*
- Materials in the wiki <http://wiki.uib.no/info216>:
  - RDF Primer
  - rdflib documentation



Resource Description Framework (RDF)

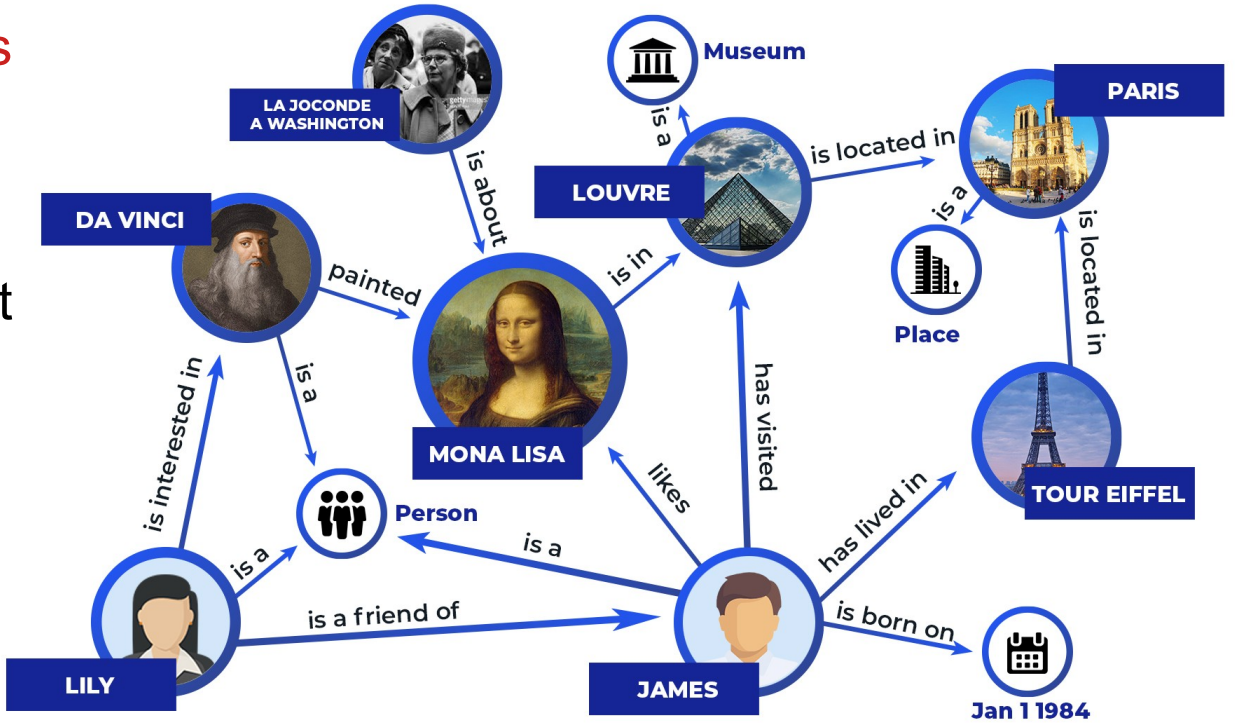
Knowledge graph

- A *graph* of *nodes* connected by directed *edges*
- Nodes can represent *resources* or *values*
- Edges represent *relations*
- Each node–edge–node *triple* represents a *fact*
  - *subject–predicate–object*
  - *head–relation–tail*
- A *knowledge graph* represents *knowledge* as *triples* connected by *nodes*



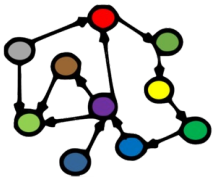
Knowledge graph → semantic knowledge graph

- Through standard identifiers for resources, relations, and types supported by formal definitions, inference and reasoning, KGs attempt to capture (some of) the meaning of data
- The result is semantic knowledge graphs
- In addition to the primary data, semantic KGs contain semantic metadata



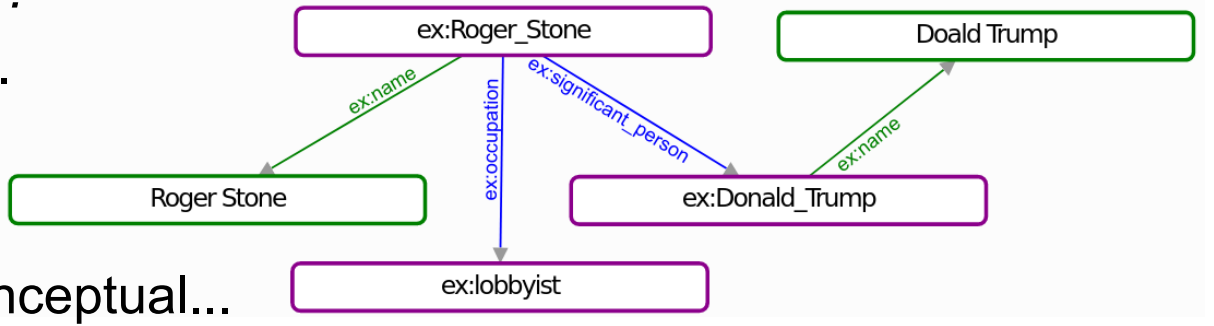
How can we represent semantic KGs?

- Semantic knowledge graphs rely heavily on the *Resource Description Framework (RDF)*
  - a normal form for semantic data (data with associated metadata about its meaning)
  - usable both for the data and their metadata
  - both are represented as KGs
  - either *native/reified*, *embedded, or virtual*
- More expressive vocabularies are available as KGs
  - more types and relations and more formal definitions
  - *RDF Schema (RDFS), "RDFS Plus"*
  - *Web Ontology Language (OWL)*
  - *they all* (can be said to) *build on RDF*



How can we represent semantic KGs?

- Resource Description Framework (RDF)
- RDF models (KGs) consist of statements (triples)
  - of *subject predicate object* .
  - or *subject predicate literal* .
- The subject:
  - must be a *resource*
  - physical, informational, conceptual...
- The predicate:
  - must be a *property* (subtype of *resource*)
- The object:
  - is either a *resource*
  - or a *literal* (or a *value*: string, number... – *not* a *resource*)



How can we represent semantic KGs?

- Resource Description Framework (RDF → S02)
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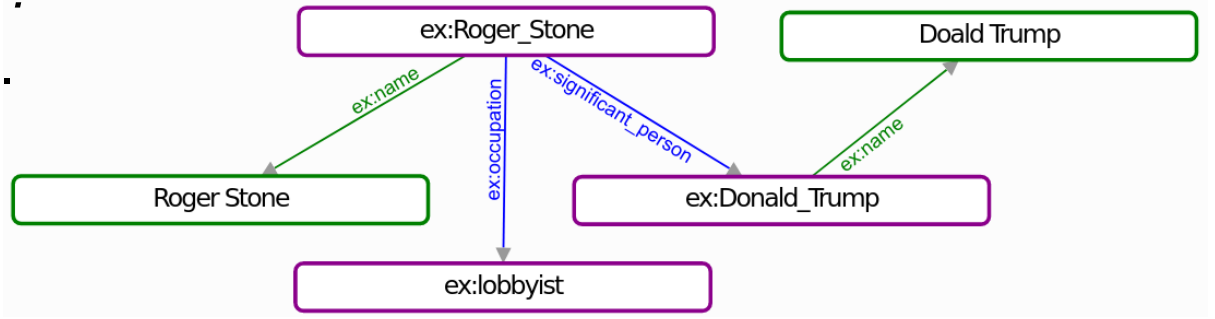
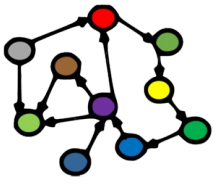
- Serialisations, e.g., in *Turtle*:




```
ex:Roger_Stone ex:name "Roger Stone" .
ex:Roger_Stone ex:occupation ex:lobbyist .
ex:Roger_Stone ex:significant_person ex:Donald_Trump .

ex:Donald_Trump ex:name "Doald Trump" .
```

Uniform Resource Identifiers (URIs) identify resources, including types and relations



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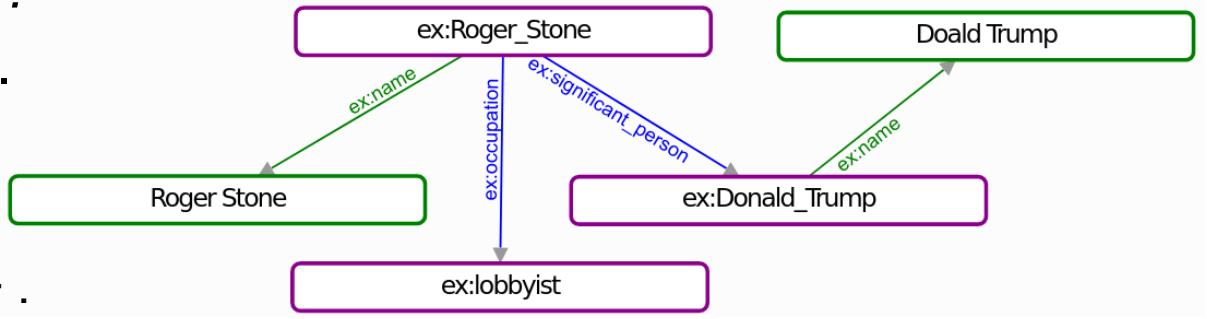


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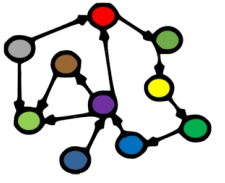

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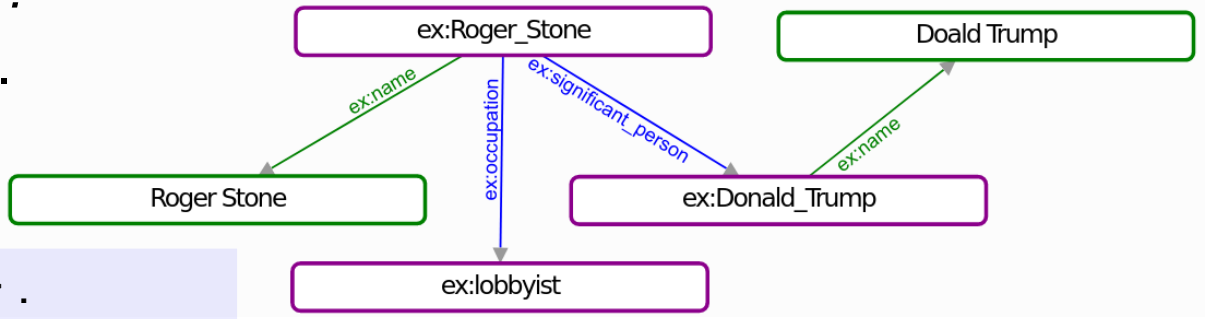


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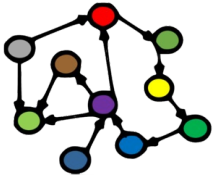
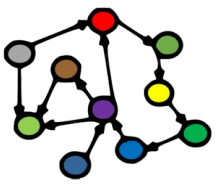


Prefixing

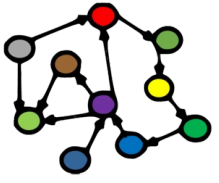
- XML Qualified Name (QName):
  - from “eXtensible Markup Language” (XML)
  - provides short forms for much used URI bases
- Much used prefixes (here in Turtle syntax):

```
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
@prefix dc: <http://purl.org/dc/elements/1.1/> .
@prefix owl: <http://www.w3.org/2002/07/owl#> .
@prefix ex: <http://www.example.org/> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .
```

  - ...or self-defined prefixes
  - see http://*prefix.cc*
- Example: *http://www.w3.org/2001/XMLSchema#string* can be written with a prefix as: *xsd:string*

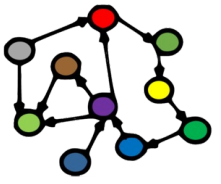


Programming RDF
(and RDFS, SPARQL...)
with Python



RDFLib (→S01)

- RDFLib:
  - an API for programming RDF and SPARQL in Python
  - simple, powerful and *pythonic*
  - parsers and serialisers for most RDF formats
  - a *Graph* interface
  - with multiple alternative *Stores*
  - supports SPARQL 1.1 Query and Update



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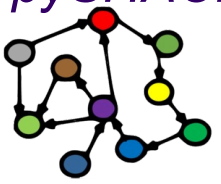
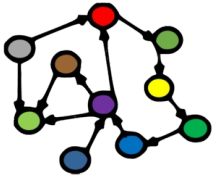
  - parsers and serialisers for most RDF formats
  - a *Graph* interface
  - with multiple alternative *Stores*
  - supports SPARQL 1.1 Query and Update
- More APIs and tools later:
  - a triple store (RDF database): *Blazegraph*
  - APIs for queries and rules: *SPARQLWrapper*, *OWL-RL* and *pySHACL*
  - a tool for OWL ontologies: *Protegé-OWL*
  - an OWL library for Python: most likely *owlready2*



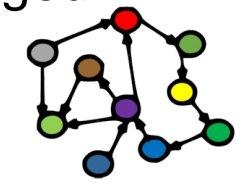
RDFLib graphs (→S01)

- Graph:
  - a graph holds an RDF model
  - is a Python collection (set) of triples
  - supports adding, removing, listing, and searching for triples
  - supports writing to and reading from RDF files
  - responds to SPARQL queries and updates
  - backed by an in-memory or persistent *Store*
  - can be combined with other graphs

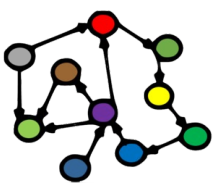


RDFLib resources (→S01)

- URIRef: a node with a URI (represents resources, types, relations)
- Namespace: a more compact way to create resources, types, and properties
  - predefined:
    - RDF, RDFS, OWL, XSD, FOAF, SKOS, DC, DCTERMS
    - >>> from rdflib import RDF
    - >>> from rdflib.namespace import ...
  - add prefix to graph:
    - >>> g.bind('i2s', i2s)
- Triples / statements: ordinary 3-item Python tuples
- Literals: a typed or untyped value; strings can be language-tagged
- BNode:
  - a blank node (a resource without a URI)



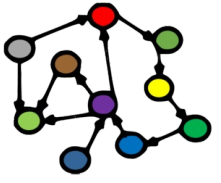
Resources, properties, and literals



Resources

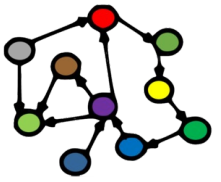
- RDF resources represent be physical phenomena (including people and artefacts), information resources, concepts, constructs...
  - the nodes in knowledge graphs
  - can represent most things, really, as well as information about them
  - can be the *subject* or *object* in a statement
    - can also be *predicates*, but then we call them properties
  - can be *named* by an URI or *anonymous* (a blank *node*)
- A resources can have one or more *rdf:type*-s
  - ex:Robert_Mueller rdf:type ex:Human .
  - ex:Robert_Mueller **a** ex:Human **,** ex:Omnivore **,** rdfs:Resource .
- Every resource has the rdf:type *rdfs:Resource*
- *Convention: resource names start with a capital letter*

More Turtle shorthands!



Anonymous resources (blank nodes)

- Some resources (nodes) do not need URIs
- When to use?
  - when you do not (yet) know the right URI
  - when you do not want to reveal the URI (sensitive, business critical...)
  - when you need to group properties that are related
- Advantage:
  - no need to invent (“mint”) unnecessary URIs
- Disadvantages:
  - not supported by all RDF technologies
  - cannot be referenced from the outside
    - but can still have a local (non-URI) identifier *inside the graph*



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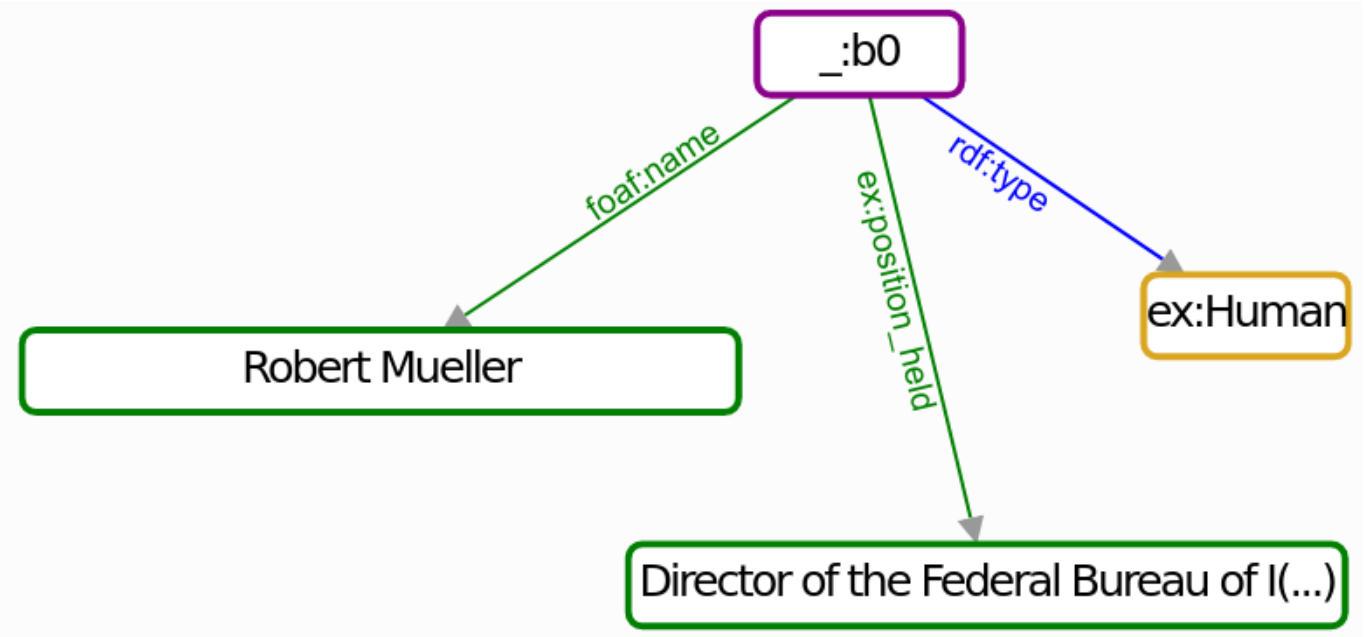
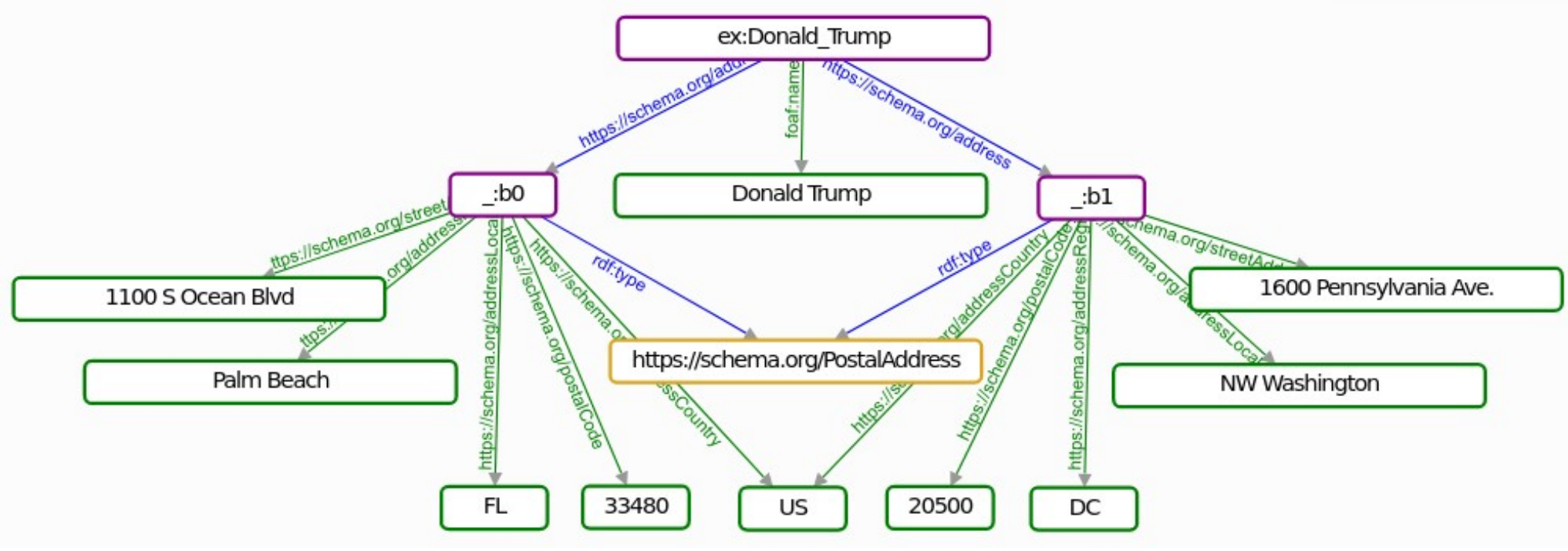



```
g = Graph()
g.bind('ex', EX)

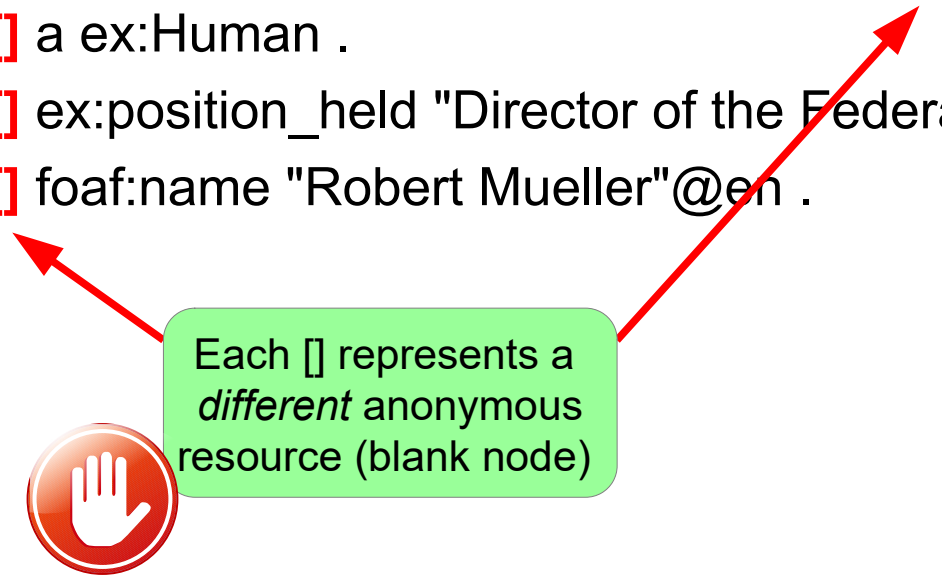
robertMueller = BNode()
g.add((robertMueller, RDF.type, EX.Human))
g.add((robertMueller, FOAF.name, Literal('Robert Mueller', lang='en')))
g.add((robertMueller, EX.position_held, Literal('Director of the Federal Bureau of Investigation', lang='en')))
```

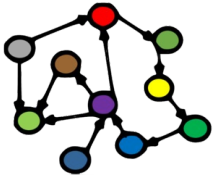
Anonymous resources (blank nodes)



Turtle syntax for blank nodes

```
ex:Mueller_Investigation ex:chairperson [] .
[] a ex:Human .
[] ex:position_held "Director of the Federal Bureau of Investigation"@en .
[] foaf:name "Robert Mueller"@en .
```





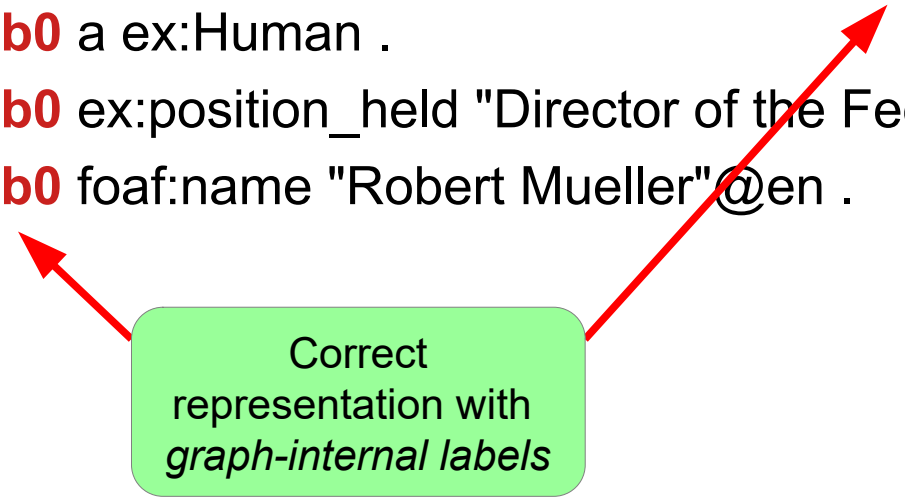
Turtle syntax for blank nodes

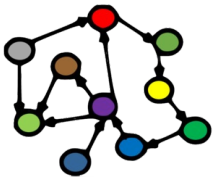
ex:Mueller_Investigation ex:chairperson **_:b0** .

_:b0 a ex:Human .

_:b0 ex:position_held "Director of the Federal Bureau of Investigation"@en .

_:b0 foaf:name "Robert Mueller"@en .





Turtle syntax for blank nodes

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ex:Mueller_Investigation ex:chairperson _:b0 .
_:b0 a ex:Human ;
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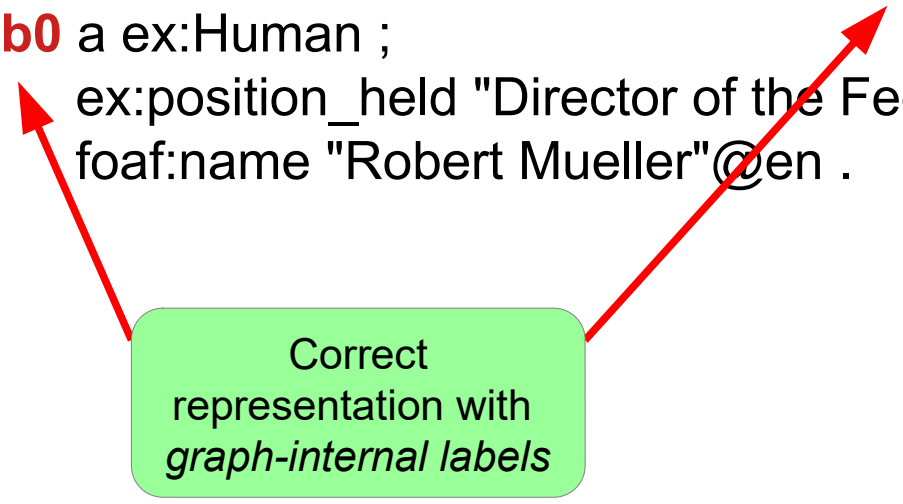
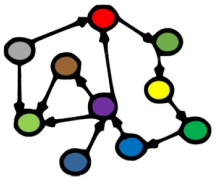
     foaf:name "Robert Mueller"@en .
```





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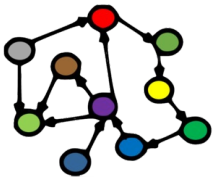
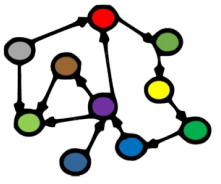
Predicate-object pairs embedded in the anonymous-node bracket.



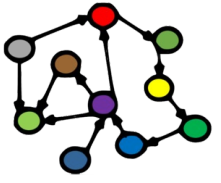
Properties

- RDF properties are (a subtype of) resources that *either*
  - represent a relation from one resource to another *or*
  - represent a relation from a resource to a literal value
- Mostly used as a *predicate* in triples (statements)
  - examples:
    - rdf:type is a property defined by the (very small) RDF vocabulary
    - dc:title is a property in the Dublin Core (DC) vocabulary
    - foaf:name is a property in the Friend-of-a-Friend (FOAF) vocabulary
- Can *sometimes* be a subject or object in triples (statements)
    - dc:name rdf:type rdf:Property .
- *Convention: property names start with lower-case letters*



Resource types

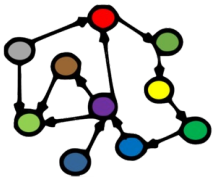
- RDFS classes are resources that represent the types of other resources
  - also nodes in knowledge graphs
  - usually with one or more rdf:type arrows pointing to them
  - often the *object* in a statement (but can sometimes be *subjects*)
- Examples:
  - ex:Human, ex:Omnivore, rdfs:Resource .
  - rdf:Property, rdfs:Resource, rdfs:Class .
- Every resource type itself has the rdf:type *rdfs:Class*
- *Convention: resource type names start with a capital letter (because they are resources)*



Literals

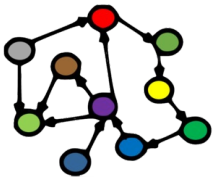
- RDF literals are used to represent values that describe resources (features)
  - always the *object* in a statement (triple)
- Untyped (simple) literals:
  - just a character string: “2001”, ““““sixth director of the FBI”””” *or*
  - a character string with a language code (ISO 639-1):
    “ Robert Mueller”@”en”, “رابرتمولر”@”fa”
- Typed literals:
  - a character string with *a URI that represents a literal type:*
    "2001"^^<http://www.w3.org/2001/XMLSchema#integer>
    "2001"^^<xsd:integer>
- Every literal itself has the rdf:type *rdfs:Literal*

The examples are written in Turtle!



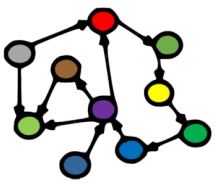
Literal types

- RDFS literal types are resources that represent the types of literals
  - also nodes in knowledge graphs
  - usually with one or more rdf:type arrows pointing to them
  - often the *object* in a statement (but can sometimes be *subjects*)
- XML Schema Definition (XSD) language is most used to represent literal types, for example xsd:string, xsd:integer, xsd:decimal, xsd:double, xsd:date, xsd:dateTime, xsd:anyURI
- Built-in literal types defined by RDF: rdf:XMLLiteral, rdf:HTML
- Other literal types can also be used, even self-defined ones
- Every literal type itself has the rdf:type *rdfs:Datatype*



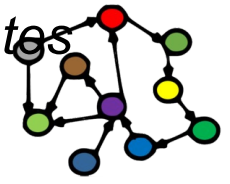
XML Schema Definition (XSD) types

- Most XSD types can be used in RDF:
  xsd:string, xsd:boolean, xsd:decimal, xsd:integer, xsd:float, xsd:double, xsd:dateTime, xsd:dateTimeStamp, xsd:time, xsd:date, xsd:gYearMonth, xsd:gYear, xsd:gMonthDay, xsd:gDay, xsd:gMonth, xsd:duration, xsd:yearMonthDuration, xsd:dayTimeDuration, xsd:hexBinary, xsd:base64Binary, xsd:anyURI, xsd:normalizedString, xsd:token, xsd:language, xsd:NMTOKEN, xsd:Name, xsd:NCName, xsd:positiveInteger, xsd:nonPositiveInteger, xsd:negativeInteger, xsd:long, xsd:int, xsd:short, xsd:byte, xsd:nonNegativeInteger, xsd:unsignedLong, xsd:unsignedInt, xsd:unsignedShort, xsd:unsignedByte
- Not all XML Schema types can be used in RDF:
  - *must be a set of string values*
  - *...that can be mapped into*
  - *...a well-defined value space*



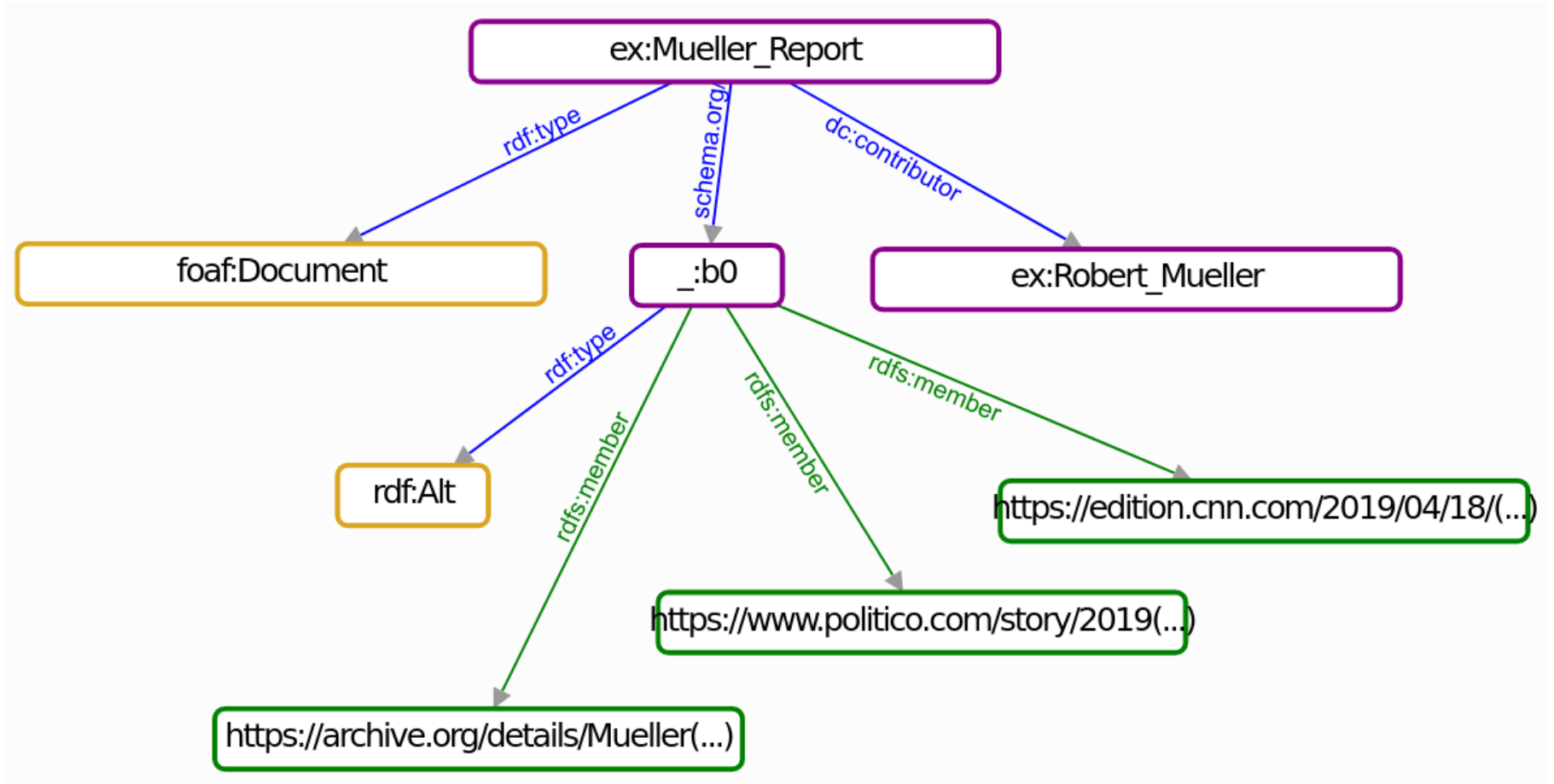
Containers

- An RDF container represents an *open* grouping of other resources
  - often the *subject* in a statement
  - usually with one or more rdfs:member arrows pointing from it
  - open: allows adding new members (without deleting triples)
  - often anonymous (blank), but not necessarily
- Every container has the rdf:type rdfs:Container
- Three subtypes:
  - rdf:type rdf:Alt – represents *alternative* resources
  - rdf:type rdf:Seq – represents resources that are *ordered*
    - special properties *rdf:_1, rdf:_2, ...* represent order of members
  - rdf:type rdf:Bag – represents resources that may be *duplicates*



Containers: alternatives

There are several *alternative* distribution sites.



Containers: alternatives

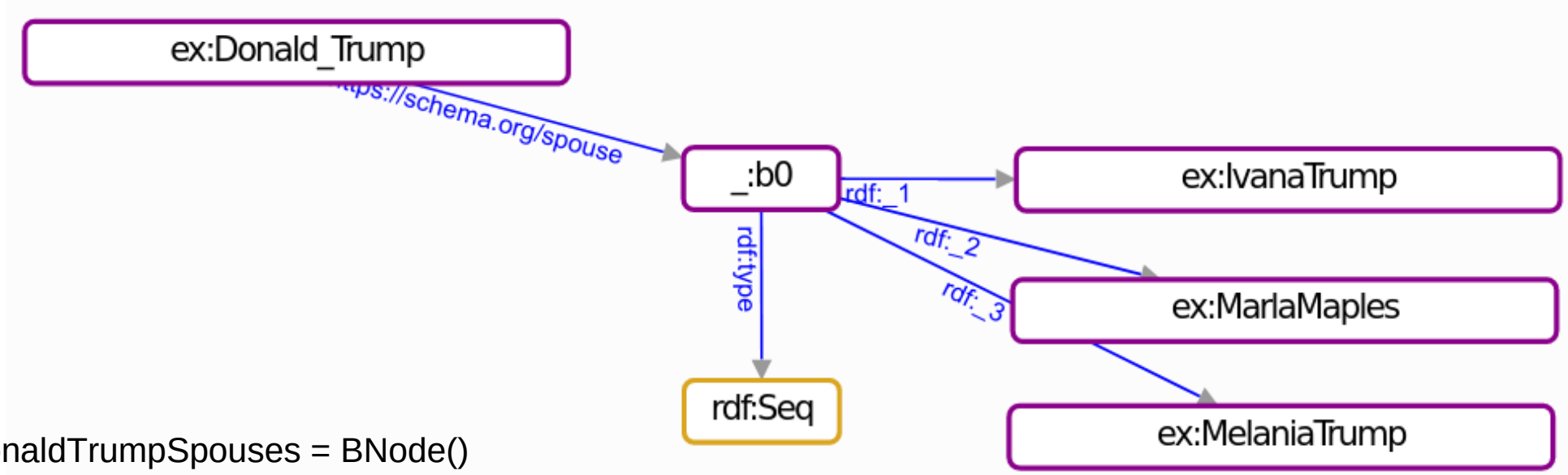
There are several *alternative* distribution sites.

```
muellerReportArchives = BNode()
g.add((muellerReportArchives, RDF.type, RDF.Alt))
archive1 = 'https://archive.org/details/MuellerReportVolume1Searchable/' \
                        'Mueller%20Report%20Volume%201%20Searchable/'
archive2 = 'https://edition.cnn.com/2019/04/18/politics/full-mueller-report-pdf/index.html'
archive3 = 'https://www.politico.com/story/2019/04/18/mueller-report-pdf-download-text-file-1280891'
g.add((muellerReportArchives, RDFS.member, Literal(archive1, datatype=XSD.anyURI)))
g.add((muellerReportArchives, RDFS.member, Literal(archive2, datatype=XSD.anyURI)))
g.add((muellerReportArchives, RDFS.member, Literal(archive3, datatype=XSD.anyURI)))

g.add((EX.Mueller_Report, RDF.type, FOAF.Document))
g.add((EX.Mueller_Report, DC.contributor, EX.Robert_Mueller))
g.add((EX.Mueller_Report, SCHEMA.archivedAt, muellerReportArchives))
```

Containers: sequences

The wives are *ordered* and we can *add more* without deleting triples.



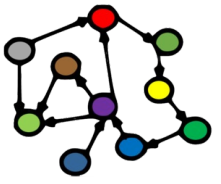

```
donaldTrumpSpouses = BNode()

g.add((donaldTrumpSpouses, RDF.type, RDF.Seq))
g.add((donaldTrumpSpouses, RDF._1, EX.IvanaTrump))
g.add((donaldTrumpSpouses, RDF._2, EX.MarlaMaples))
g.add((donaldTrumpSpouses, RDF._3, EX.MelaniaTrump))

g.add((EX.Donald_Trump, SCHEMA.spouse, donaldTrumpSpouses))
```

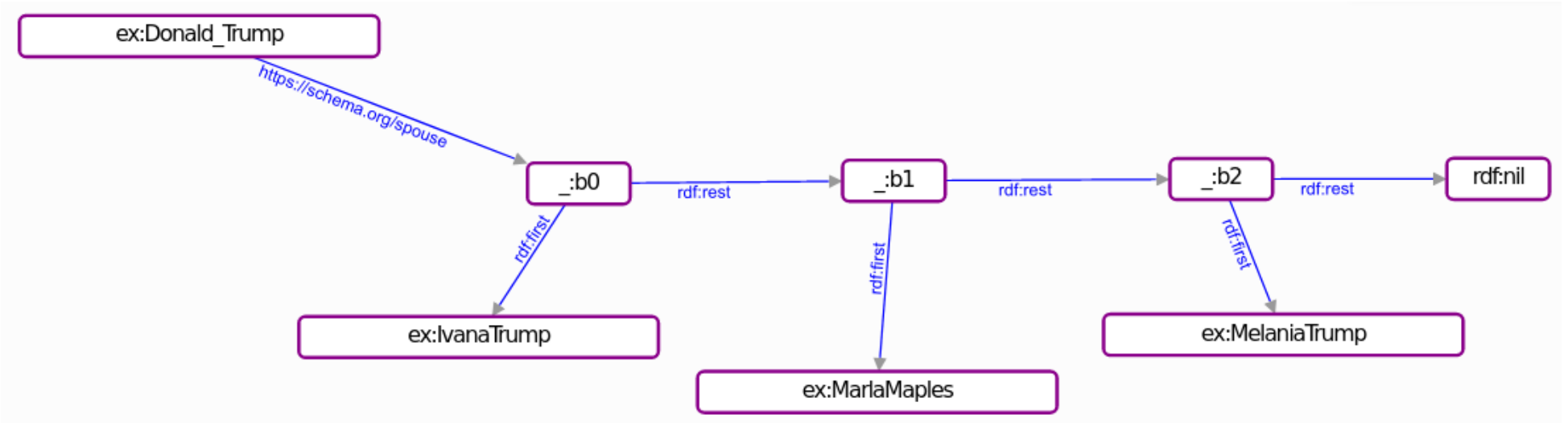
Collections

- An RDF container represents a *closed* grouping of other resources
  - often the *subject* in a statement
  - with one rdf:first and one rdf:first arrows pointing from it
  - closed: prohibits adding new members (without deleting triples)
  - often anonymous (blank), but not necessarily
- Every collection has the rdf:type rdf:List
  - rdf:first gives the first resource in the list (has rdf:type rdf:Property)
  - rdf:rest gives the rest of the list (has rdf:type rdf:Property)
  - rdf:nil represents an empty list (has rdf:type rdf:List)



Collections: lists

The wives remain *ordered* but we cannot *add more* wives without deleting triples.

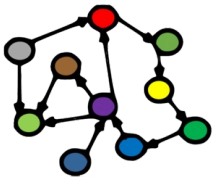



```
donaldTrumpSpouses = BNode()
Collection(g, donaldTrumpSpouses, [
    EX.IvanaTrump, EX.MarlaMaples, EX.MelaniaTrump
])
g.add((EX.Donald_Trump, SCHEMA.spouse, donaldTrumpSpouses))
```

Other knowledge graph formats

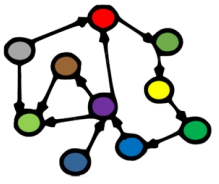
Other types of knowledge graphs

- *Labelled Property Graphs (LPG)*
  - becoming increasingly popular
  - not inherently semantic/linked
  - but can be used semantically, e.g., to store RDF
  - has so far not been standardised:
    - different tools use different query languages, exchange formats
    - standardisation is moving quickly forward
- Our focus remains on *RDF-based knowledge graphs*:
  - what we call *semantic knowledge graphs*

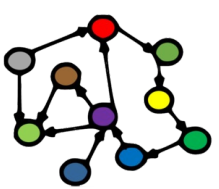


Other types of knowledge graphs

- *Non-semantic knowledge graphs*
  - many recent ML approaches use graph data
  - e.g., graph embeddings, link prediction
  - but the graphs are not necessarily *dereferenced*
    - they can use human-understandable labels
    - but they do not use standard URI
  - but can be used semantically too, e.g., on RDF data
- Our focus remains on *RDF-based knowledge graphs*:
  - what we call *semantic knowledge graphs*

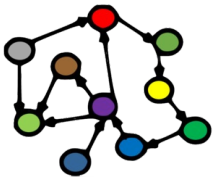


About INFO216



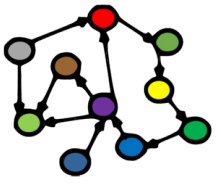
Purpose

- To learn theories, techniques, tools, and best practices for managing knowledge graphs.
- To acquire understanding and skills for programming applications that use and produce such data and metadata.
- To learn about existing sources of and standards for big, open, and semantic data.
- To gain practical experience in developing knowledge graph-based applications using technologies such as RDF, RDFS, OWL, SPARQL, and JSON-LD.



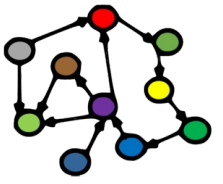
Curriculum

- Course book (*the whole book is mandatory*):
  - Allemang, Hendler & Gandon (2020).
    Semantic Web for the Working Ontologist,
    Effective Modeling for Linked Data, RDFS and OWL (Third Edition)
- Supplementary course book (*suggested, not mandatory*):
  - Blumauer & Nagy (2020).
    The Knowledge Graph Cookbook - Recipes that Work
- Additional readings (both *mandatory* and *suggested*) will be made available in the course wiki: https://wiki.uib.no/info216
- The lectures and lectures notes are also *mandatory* parts of the curriculum.



Practical

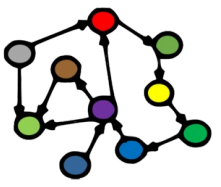
- 14 lectures:
  - Tuesdays 1215-1400
- 14 lab weeks:
  - 2 hours of weekly lab groups
  - starting this week, no labs week 10 and 14 (Easter)
  - seminar/lab leader: Robin Johansen Bøe <Robin.Boe@student.uib.no>
- Evaluation:
  - individual, written 4-hour exam
- Requirements:
  - participation in 75% of labs
- Course wiki:
  - http://wiki.uib.no/info216



Lecture plan (tentative)

1. Introduction to KGs
2. Representing KGs (RDF)
3. Querying and updating KGs (SPARQL)
4. Open KGs 1
5. Open KGs 2
6. Enterprise KGs
7. Rules (RDFS)
8. Ontologies (OWL)
9. Vocabularies
10. Reasoning about KGs (DL)
11. Formal ontologies (OWL-DL)
12. KG embeddings 1
13. KG embeddings 2
14. Knowledge engineering

You learn KGs best through practice: do the lab exercises thoroughly!



A brief history of KGs

Tim Berners-Lee's call for a transition

- From around 1990: creation of a *Web of Documents*
  - the "plain old web" (PoW)
  - document-centric
  - document-to-document links
  - for humans
- From around 2000: transition to a *Web of Data*
  - document- *and data-centric*
  - doc-to-doc *and data-to-data links*
  - for humans *and machines*
  - also called the *Semantic Web*, *Web 3.0*, the *Web of Knowledge,* the *Linked Open Data (LOD) cloud*, the *Giant Global Graph (GGG)*, ...

Tim Berners-Lee
Inventor of the
World Wide Web
(WWW, 1989)

Tim Berners-Lee's call for a transition

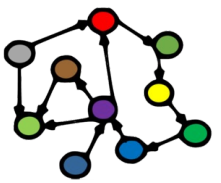
- There's an enormous amount of data on the web
  - ...but the data are mostly not linked
    (think of a world wide web without document links!)
  - availability, accessibility does not go all the way
  - *what if we had standard ways of representing data so that linkable data could always be automatically linked?*
  - *enormous potential to solve, simplify, speed up... many critical information handling problems*
- This is the purpose of *semantic technologies*
- This is the vision that led to today's *semantic knowledge graphs*

Tim Berners-Lee
Inventor of the
World Wide Web
(WWW, 1989)

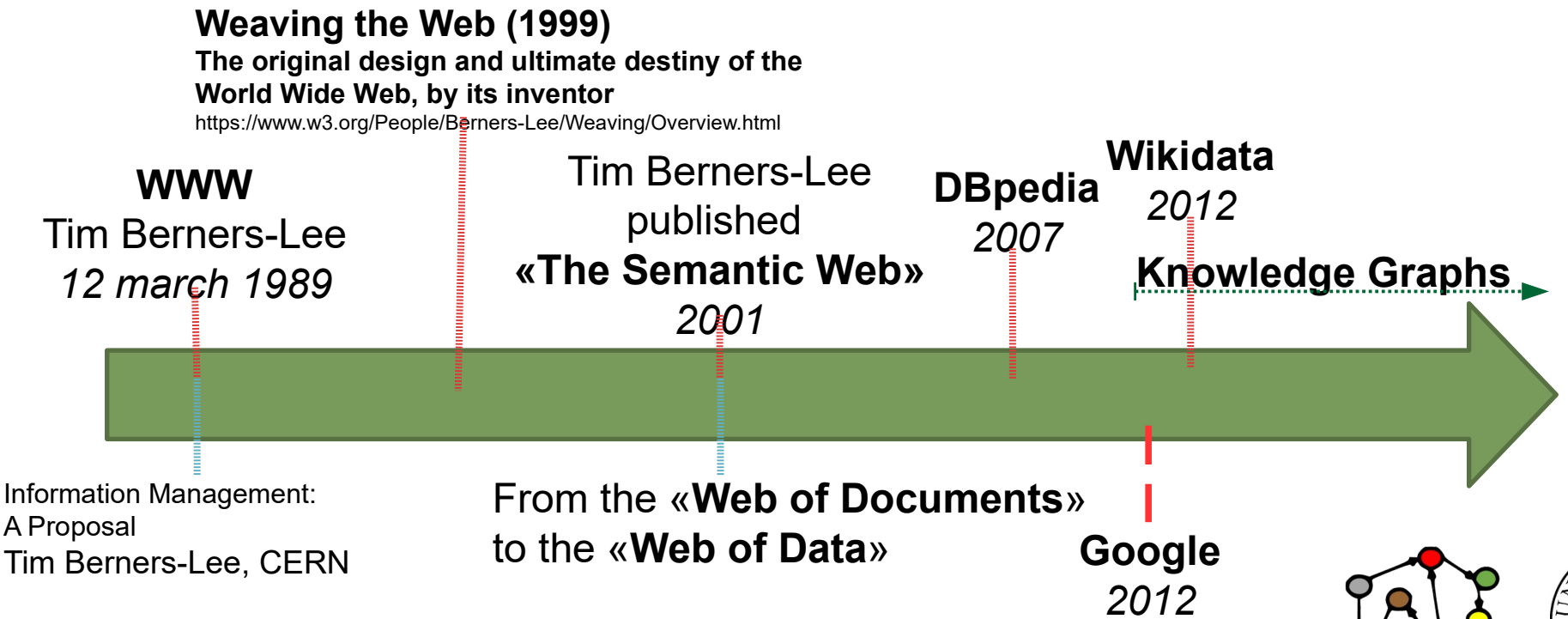
Tim Berners-Lee: <http://www.youtube.com/watch?v=HeUrEh-nqtU>

Many independent, but related developments

- The *Linked Open Data (LOD)* cloud:
  - interlinking semantic datasets, making them openly available: DBpedia (2007-), Wikidata (2012-), …
- *Knowledge graphs:*
  - currently popular term for semantic graph representations of (primarily) factual information (Google, 2012)
- *Enterprise knowledge graphs:*
  - company-internal semantic data
  - linked open data and semantic-web technologies used inside an enterprise or cluster



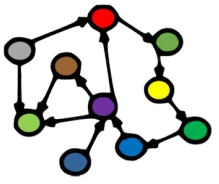
Semantic web and WWW history



Tim Berners-Lee: http://www.youtube.com/watch?v=HeUrEh-nqtU
Information Management: A Proposal: https://cds.cern.ch/record/369245/files/dd-89-001.pdf

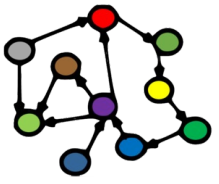
Common themes

- *Graph representations* of knowledge
  - RDF, RDFS, OWL, SPARQL
  - a recent alternative: Labelled-Property Graphs (LPGs)
- *Semantically tagged* data
  - well-defined tags (terms)
    - defined in standard vocabularies
    - formal ontologies, description logic
- *Global* and *interlinked*
  - standard formats, technologies, resource URIs, etc.
- From the start *open* and *community-based*



The LOD cloud

- *http://lod-cloud.net/*
  - which datasets mention resources in other datasets?
  - >1250 datasets with >15000 links between them
    - started in 2007
    - exponential-like growth for a few years
    - consolidating since ca 2017
- *How big is the LOD cloud?*
  - hard to measure exactly (old stats: http://*lodstats.aksw.org*)
  - approx. 150G (150 000M) triples from >3000 data sets (2020)
  - *Wikidata <http://wikidata.org>* is the largest general one:
    - >100M resources (items), >1,2G (1200M) triples



Next week:
Querying and updating KGs (SPARQL)