

Introduction to Linked Data

Understanding, creating, and querying

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About me

- Dr Xander Wilcke
- Research fellow at the Dept. of CS
at the *Vrije Universiteit Amsterdam*
- Research topics:
 - Machine Learning
 - Graph Neural Networks
 - Heterogeneous knowledge
 - Multimodal information
 - Knowledge Graphs (Linked Data)



Linked Data



Learning Goals

After this lecture, you will be able to

- explain the core idea behind Linked Data to your peers
- read, write, and understand Linked Data
- convert your tabular data to Linked Data
- browse through and query Linked Data

Outline

Understanding Linked Data

Creating Linked Data

Querying Linked Data

Wrap Up

Outline

Understanding Linked Data

Creating Linked Data

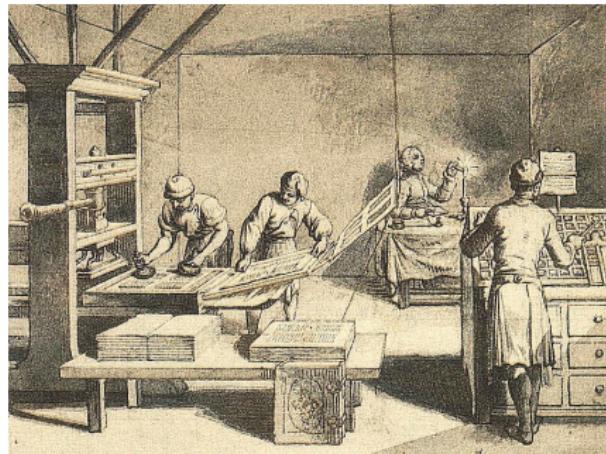
Querying Linked Data

Wrap Up

Unstructured Knowledge

The printing press

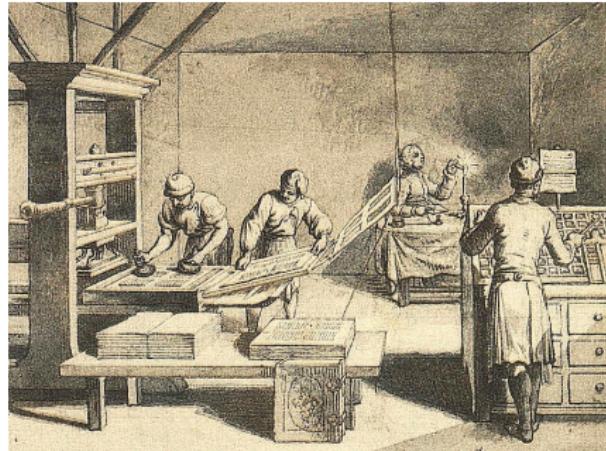
- Johannes Gutenberg, c 1440
- One of the most influential discoveries in human history
- Enables the sharing of knowledge on a grand scale



Unstructured Knowledge

The printing press

- Johannes Gutenberg, c 1440
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- Enables the sharing of knowledge on a grand scale



Unstructured Knowledge:

- No predefined structure
- Prone to different interpretations (ambiguity)
- Difficult to process by software agents

Processing human knowledge

Two broad approaches:

- Natural Language Processing (NLP)
- Adding structure to knowledge



Processing human knowledge

Two broad approaches:

- Natural Language Processing (NLP)
 - Requires a large number of steps
 - Difficult to get right
 - Never perfect
(colloquiums, language drift, etc)
- Adding structure to knowledge



Processing human knowledge

Two broad approaches:

- Natural Language Processing (NLP)
 - Requires a large number of steps
 - Difficult to get right
 - Never perfect
(colloquiums, language drift, etc)
- Adding structure to knowledge
 - Modelling knowledge according to schemas
 - Semantics conveyed using annotations
 - For example, as [Linked Data](#)



Expressing Knowledge as Statements

Example statements:

Frodo is a Hobbit .

Frodo likes Sam .

Sam is age 50 .

Sam fullname "Samwise Gamgee" .

Sam lives in The Shire .

The Shire has area 47,000m² .



Expressing Knowledge as Statements

Example statements:

Frodo	is a	Hobbit .
Frodo	likes	Sam .
Sam	is age	50 .
Sam	fullname	“Samwise Gamgee” .
Sam	lives in	The Shire .
The Shire	has area	47,000m ² .



Statements express **relationships** between *things*

Entities and Literals

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Things can be either

Entities everything unique, tangible or otherwise

e.g. people, objects, concepts, dreams, etc.

Literals non-unique property values, belong to entities

e.g. dates, strings, numbers, geometries, etc.

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The Resource Description Framework

The Resource Description Framework (RDF):

- a data model to encode (binary) statements with
- allows for unambiguous expressing of knowledge
- aims at making knowledge readable by machines

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A RDF statement takes the form of a **triple**:

<subject> <predicate> <object> .

where

subjects are entities

predicates are relationships

objects are either entities or literals

NB: this is a simplified view

The Resource Description Framework



RDF 1.1 Primer

W3C Working Group Note 24 June 2014

This version:

<http://www.w3.org/TR/2014/NOTE-rdf11-primer-20140624/>

Latest published version:

<http://www.w3.org/TR/rdf11-primer/>

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Please check the [errata](#) for any errors or issues reported since publication.

This document is also available in this non-normative format: [Japanese translation](#)

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Abstract

This primer is designed to provide the reader with the basic knowledge required to effectively use RDF. It introduces the basic concepts of RDF into the key elements of RDF. Changes between RDF 1.1 and RDF 1.0 (2004 version) are summarized in a separate document: "What's New

<https://www.w3.org/TR/rdf11-primer>

The Universal Resource Identifier

The Universal Resource Identifier (URI)

- uniquely identifies **resources**
resources include entities, literals, and predicates
- takes the form of a web address (`http://...`)
- foreign language support:
Internationalized Resource Identifier (IRI)

NB: literals are an exception and don't use URIs

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Examples:

`http://example.org/LOTR/character/Frodo`
`http://example.org/LOTR/realm/The_Shire`
`http://example.org/LOTR/race/Hobbit`
`http://example.org/schema/is_a`
`http://example.org/schema/lives_in`

NB: literals are an exception and don't use URIs

Namespaces and Prefixes

URIs are composed of a *namespace* and a resource identifier

A **namespace** is

- the location at which resources are defined
- typically context or domain specific
- often dereferenceable

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A **prefix** can be used to abbreviate a namespace

Namespaces and Prefixes

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A **namespace** is

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- often dereferenceable

Examples:

lotrhc:Frodo

lotrrl:The_Shire

lotrrc:Hobbit

schema:is_a

schema:lives_in

A **prefix** can be used to abbreviate a namespace

Expressing statements in RDF

Example statements:

```
@prefix lotrch: <http://example.org/LOTR/character> .  
@prefix lotrrl: <http://example.org/LOTR/realm> .  
@prefix lotrrc: <http://example.org/LOTR/race> .  
@prefix schema: <http://example.org/schema/> .  
  
lotrch:Frodo      schema:is_a          lotrrc:Hobbit .  
lotrch:Frodo      schema:likes         lotrch:Sam .  
lotrch:Sam        schema:age           50 .  
lotrch:Sam        schema:fullname      "Samwise Gamgee" .  
lotrch:Sam        schema:lives_in     lotrrl:The_Shire .  
lotrrl:The_Shire  schema:has_area     47,000 .
```

Vocabularies and Ontologies

Two kinds of knowledge:

Assertion knowledge: the knowledge that you want to state
≈ your dataset

Terminology knowledge: used to state assertion knowledge with
≈ the schema of your dataset

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Assertion knowledge: the knowledge that you want to state
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≈ the schema of your dataset

Vocabularies / Ontologies

- contain purely terminology knowledge
- are tailored to a specific domain, context, or purpose
- are published separately from datasets
- are intended for sharing and reuse

NB: the term vocabulary and ontology are sometimes used interchangeably

Dublin Core and FOAF

	<p>Class: foaf:Person</p> <p>Person - A person.</p> <p>Status: stable</p> <p>Properties include:</p> <p>Used with:</p> <p>Subclass Of: Agent Spatial Thing</p> <p>Disjoint With: Project Organization</p> <p>The Person class represents people. Sometimes it is a Person if it is a person. We don't mind about whether there's also dead, rest or inanimate.</p>
Term Name: creator	<p>Class: foaf:OnlineAccount</p> <p>Online Account - An online account.</p> <p>Status: testing</p> <p>Properties include: accountName account</p>
URI: http://purl.org/dc/terms/creator	
Label: Creator	
Definition: An entity responsible for making the resource.	
Comment: Recommended practice is to identify the creator with a URI. If this is not possible or feasible, a literal value is	
Type of Term: Property	
Range Includes:	<ul style="list-style-type: none">http://purl.org/dc/terms/Agent
Equivalent Property:	<ul style="list-style-type: none">http://xmlns.com/foaf/0.1/maker
Subproperty of:	<ul style="list-style-type: none">Creator (http://purl.org/dc/elements/1.1/creator)Contributor (http://purl.org/dc/elements/1.1/contributor)
Term Name: date	 <p>DublinCore Metadata Innovation</p>
URI: http://purl.org/dc/terms/date	
Label: Date	
Definition: A point or period of time asso	

<https://www.dublincore.org/>

<http://xmlns.com/foaf/spec/>

About: Gimli (Middle-earth)

An Entity of Type: [agent](#), from Named Graph: <http://dbpedia.org>, within Data Space: dbpedia.org

Gimli is a fictional character from J. R. R. Tolkien's Middle-earth legendarium, featured in The Lord of the Rings. A dwarf warrior, he is the son of Glóin, a member of Thorin's company in Tolkien's earlier book The Hobbit. Gimli is chosen to represent the race of Dwarves as part of the Fellowship of the Ring. As such, he is one of the primary characters of the novel. In the course of the adventure, Gimli aids the Ring-bearer Frodo Baggins, participates in the War of the Ring, and becomes close friends with Legolas, overcoming an ancient enmity of Dwarves and Elves.

[Thumbnail](#)

Property	Value
dbo:abstract	<ul style="list-style-type: none">Gimli is a fictional character from J. R. R. Tolkien's Middle-earth legendarium, featured in The Lord of the Rings. A dwarf warrior, he is the son of Glóin, a member of Thorin's company in Tolkien's earlier book The Hobbit. Gimli is chosen to represent the race of Dwarves as part of the Fellowship of the Ring. As such, he is one of the primary characters of the novel. In the course of the adventure, Gimli aids the Ring-bearer Frodo Baggins, participates in the War of the Ring, and becomes close friends with Legolas, overcoming an ancient enmity of Dwarves and Elves. (en)
dbo:series	<ul style="list-style-type: none">J. R. R. Tolkien
dbo:thumbnail	<ul style="list-style-type: none">wiki-commons:Special:FilePath/Bakshi_Gimli.jpg?width=300
dbo:wikiPageID	<ul style="list-style-type: none">20599055 (xsd:integer)
dbo:wikiPageLength	<ul style="list-style-type: none">17319 (xsd:nonNegativeInteger)
dbo:wikiPageRevisionID	<ul style="list-style-type: none">1049768332 (xsd:integer)
dbo:wikiPageWikiLink	<ul style="list-style-type: none">HobbitFile:Bakshi_Gimli.jpgJohn Rhys-DaviesThe History of The Lord of the RingsBattle of the Pelennor FieldsThe Book of Lost Tales

[https://dbpedia.org/page/Gimli_\(Middle-earth\)](https://dbpedia.org/page/Gimli_(Middle-earth))

DBpedia

Behind the scenes:

```
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .  
@prefix rdfs: <www.w3.org/2000/01/rdf-schema#> .  
@prefix dc: <http://purl.org/dc/> .  
@prefix dbo: <http://dbpedia.org/ontology/> .  
@prefix dbr: <http://dbpedia.org/resource/> .  
@prefix yago: <https://yago-knowledge.org/> .
```

dbr:Gimli_(Middle-earth)	rdf:type	yago:WikicatFictionalCharacters .
dbr:Gimli_(Middle-earth)	rdfs:label	"Gimli"@en .
dbr:Gimli_(Middle-earth)	dct:subject	dbc:Literary_characters_introduced_in_1954 .
dbr:Gimli_(Middle-earth)	dbo:race	dbr:Dwarf_(Middle-earth) .
dbr:Gimli_(Middle-earth)	dbo:affiliation	dbr:The_Fellowship_of_the_Ring .
dbr:The_Lord_of_the_Rings	dbo:wikiPageWikiLink	dbr:Gimli_(Middle-earth) .
...		

[https://dbpedia.org/page/Gimli_\(Middle-earth\)](https://dbpedia.org/page/Gimli_(Middle-earth))

Serialization Formats

A serialization format specifies how RDF data is encoded

Various choices:

- Turtle (ttl)
- N-Triples (nt)
- RDF/XML (xml)
- Header-Dictionary-Triples (hdt)

Which one works best depends on the purpose
e.g. human or machine consumption

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Turtle Syntax (ttl)

- very readable
- many syntactic shortcuts
- less suitable for machine processing

W3C Recommendation



RDF 1.1 Turtle

Terse RDF Triple Language

[W3C Recommendation 25 February 2014](#)

This version:

<http://www.w3.org/TR/2014/REC-turtle-20140225/>

Latest published version:

<http://www.w3.org/TR/turtle/>

Test suite:

<http://www.w3.org/TR/2014/NOTE-rdf11-testcases-20140225/>

Implementation report:

<http://www.w3.org/2013/TurtleReports/index.html>

Previous version:

<http://www.w3.org/TR/2014/PR-turtle-20140225/>

Editors:

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[Gavin Carothers, Lex Machina, Inc](#)

Authors:

[David Beckett](#)

[Tim Berners-Lee, W3C](#)

[Eric Prud'hommeaux, W3C](#)

[Gavin Carothers, Lex Machina, Inc](#)

Please check the [errata](#) for any errors or issues reported since publication.

The English version of this specification is the only normative version. Non-normative [translations](#) may also be available.

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

N-Triples Syntax (nt)

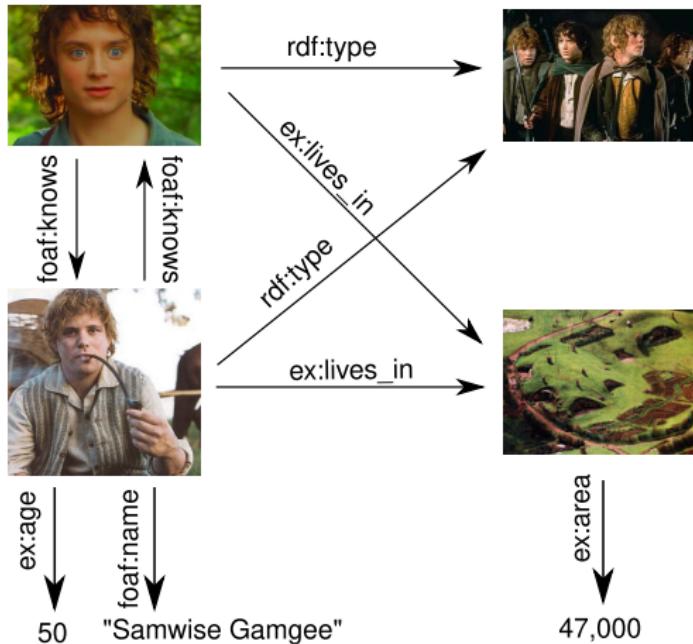
- very simply but verbose
- no syntactic shortcuts
- suitable for machine processing
- fairly readable by humans

```
<http://example.org/LOTR/character/Frodo>
<http://www.w3.org/1999/02/22-rdf-syntax-ns#>
<http://example.org/LOTR/race/Hobbit> .

<http://example.org/LOTR/character/Frodo>
<http://xmlns.com/foaf/spec/knows>
<http://example.org/LOTR/character/Sam> .
```

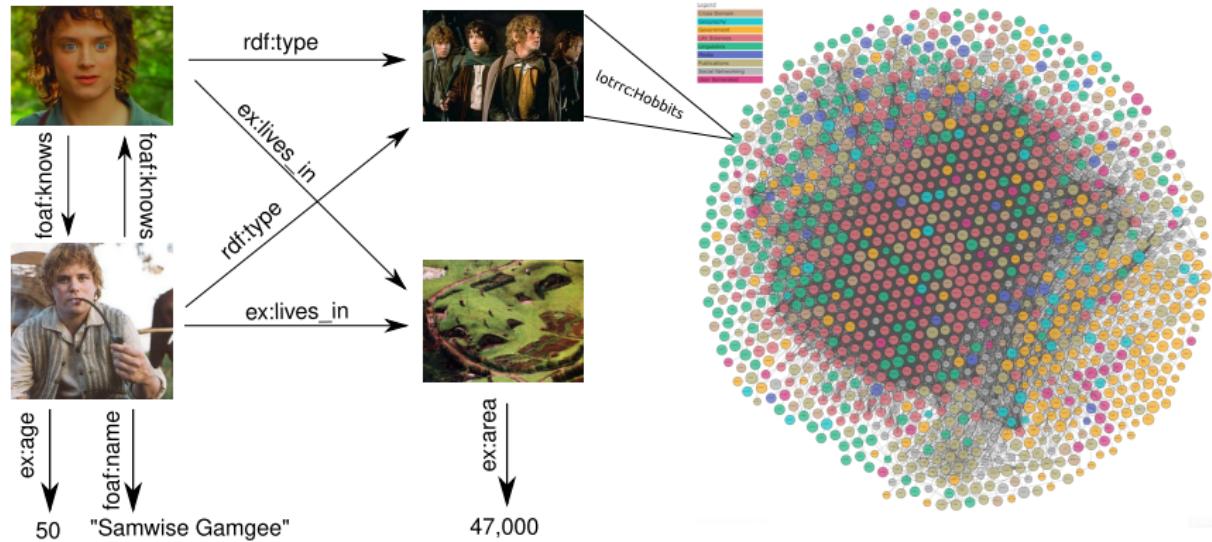
<https://www.w3.org/TR/n-triples/>

Visualizing Linked Data as a Graph



also known as a *knowledge graph*

Linking to the Linked Open Data Cloud



By reusing identifiers between graphs we implicitly merge datasets
(here, via `lotrrc:Hobbit`)

Outline

Understanding Linked Data

Creating Linked Data

Querying Linked Data

Wrap Up

Conversion from CSV

Various tools

- OpenRefine
 - Cow
 - LDWizard
 - Python
 - etc.

Using facets and filters

Show as: rows records Show: 5 to 25 50 rows < first | previous 1 - 25 next | last > last

All	Commodity_Cat	Commodity_Des	Country_Code	Country_Name	Market_Year
1.	8113300	Meat, Cofeined	BR	Brazil	1969
2.	8113300	Meat, Cofeined	BR	Brazil	1969
3.	8113300	Meat, Cofeined	BR	Brazil	1969
4.	8113300	Meat, Cofeined	BR	Brazil	1969
5.	8113300	Meat, Cofeined	BR	Brazil	1969
6.	8113300	Meat, Cofeined	BR	Brazil	1969
7.	8113300	Meat, Cofeined	BR	Brazil	1969
8.	8113300	Meat, Cofeined	BR	Brazil	1969
9.	8113300	Meat, Cofeined	BR	Brazil	1969
10.	8113300	Meat, Cofeined	BR	Brazil	1969
11.	8113300	Meat, Cofeined	BR	Brazil	1969
12.	8113300	Meat, Cofeined	BR	Brazil	1969
13.	8113300	Meat, Cofeined	BR	Brazil	1969
14.	8113300	Meat, Cofeined	BR	Brazil	1969



**CSVW
Converters**

Navigation

CoW: Converter for CSV on the Web

Quick search

Ge

CoW: Converter for CSV on the Web

This package is a comprehensive tool (CoW [\[1\]](#)) for batch conversion of multiple datasets expressed in CSV. It uses a JSON schema expressed using an extended version of the CSVW standard, to convert CSV files to RDF in scalable fashion.

Instead of using the command line tool there is also the webservice [cattle](#), providing the same functionality that CoW provides without having to install it. CSV files can be uploaded to the service and a JSON schema will be created, using that JSON schema cattle

Use Case

Characters of *The Lord of the Ring*

master IntroductionToLinkedData / data History Find file Download Clone

Name	Last commit	Last update
..		
LOTR_CSV_cleaning.ipynb	initial commit	1 day ago
LOTR_CSV_to_RDF.ipynb	initial commit	1 day ago
ldwizard_output.nt	initial commit	1 day ago
ldwizard_output.ttl	initial commit	1 day ago
lotr_characters.csv	initial commit	1 day ago
lotr_characters_cleaned.csv	initial commit	1 day ago
lotr_characters_cleaned.csv	initial commit	1 day ago

<https://tinyurl.com/posthumousIntroLD>

Use Case

Characters of *The Lord of the Ring*

master introductionToLinkedData / data / lotr_characters_cleaned.csv Find file Blame History Permalink

initial commit Xander Wilcke authored 1 day ago 0c8cc3b3 Download

lotr_characters_cleaned.csv 30.25 KiB Open in Web IDE

birth	death	gender	hair	name	race	realm	spouse
		Female		Adanel	Men		Belemir
2978		Male	Dark	Boromir	Men		
		Male		Lagduf	Orcs		
280	515	Male		Tarcl	Men	Arnor	

<https://tinyurl.com/posthumousIntroLD>

Conversion from CSV

Data cleaning is an important first step

```
for index, row in lotr_csv.iterrows():
    birth, death, gender, hair, name, race, realm, spouse = row

    birth_cleaned = np.nan
    birth_match = match(".*[A-Z]{2}\s([0-9]+)", str(birth).strip())
    if birth_match is not None:
        birth_cleaned = birth_match.groups()[0]

    death_cleaned = np.nan
    death_match = match(".*[A-Z]{2}\s([0-9]+)", str(death).strip())
    if death_match is not None:
        death_cleaned = death_match.groups()[0]

    if birth_cleaned is not np.nan and int(death_cleaned) < int(birth_cleaned):
        # ignore different calendars for simplicity
        death_cleaned = np.nan

    gender_cleaned = np.nan
    gender = str(gender)
    if 'female' in gender.strip().lower():
        gender_cleaned = "Female"
    elif 'male' in gender.strip().lower():
        gender_cleaned = "Male"
```

Notebook available at <https://tinyurl.com/posthumousIntroLD>

LDWizard

Task

- 1 go to <https://hulc.triplay.cc> (CLARIAH LDWizard instance)
- 2 load a (not too large) CSV file
- 3 set *key column* (identifiers used for the row entities)
- 4 set *resource class* (class used for the row entities)
- 5 for each column:
 - select or define predicate
 - in case of entities: select class (URI)
- 6 download converted file (N-Triples)

The screenshot shows the first step of the LDWizard process: 'Upload'. It features a horizontal navigation bar with three items: 'Upload' (selected), 'Configure', and 'Publish'. Below the bar, a message says 'No file selected'. A central button labeled 'LOAD YOUR CSV FILE' contains an upward arrow icon. At the bottom left are 'BACK' and 'NEXT' buttons.

Set *key column* and *resource class*

1 Upload 2 Configure 3 Publish

Key column
Row number

Resource class IRI
<http://xmlns.com/foaf/0.1/Person>

foaf:Agent
An agent (e.g. person, group, software or physical artifact).

foaf:Person
A person.

foaf:Document
A document.

foaf:Image
An image.

foaf:OnlineAccount
An online account.

foaf:Project
A project (a collective endeavour of some kind).

foaf:LabelProperty

	280	515	Male	Tarcil	Men	Armor
			Male	Fire-drake of Gondolin	Dragons	
2709	2962		Male	Ar-Adûnakhôr	Men	Númenor

LDWizard

Select column predicates for literal values (properties)

The screenshot shows the LDWizard interface with a tooltip overlay. The main interface includes buttons for Upload, Configure, and Publish, and fields for Key column (Row number), Resource class IRI (http://xmlns.com/foaf/0.1/Person), and a foaf:Person example. A link to Advanced settings is also present. A red arrow points to the 'birth' column in a table.

Column configuration (birth)

Property configuration

property URI
birt

foaf:birthday
The birthday of this Agent, represented in mm-dd string form, e.g. '12-31'.
http://www.cidoc-crm.org/cidoc-crm/P96i_gave_birth

sdo:birthDate
Date of birth.

sdo:birthPlace
The place where the person was born.

birth	2978	280	2709	296

look at schema.org and dbpedia.org/page/LOTR for more options

LDWizard

Select column predicates and classes for entities

1 Upload 2 Configure 3 Publish

Key column
Row number

Resource class IRI
<http://xmlns.com/foaf/0.1/Person>

foaf:Person

Advanced

↓ Scroll to bottom

birth	Property configuration	Column configuration (gender)	spouse		
sdo:birthDate	property URI				
	http://xmlns.com/foaf/0.1/gender				
	foaf:gender				
2978			Belemir		
Value configuration					
	<input checked="" type="checkbox"/> Convert to IRI				
	Prefix				
280		https://schema.org/			
2709	2962	Male	Ar-Adûnakhôr	Men	Númenor
		Male	Annael	Elves	
4EE	Male	Gold	Arvedui	Elves	Fëanore

CONFIRM CANCEL

look at schema.org and dbpedia.org/page/LOTR for more options

Download converted file

Upload

Configure

Publish

Download results

Download CSV

Your data has been enriched before being transformed, the CoW and RML transformation scripts expect to use this file. Download your tabular source data as standardized CSV.

[DOWNLOAD ENRICHED CSV](#) ▾

Download RDF

Download the transformed Linked Data (RDF) to your local machine.

[DOWNLOAD RDF](#)

Download script

Download a script that you can use to run the transformation yourself. The following script languages are supported: RATT, CoW, RML.

[DOWNLOAD RML](#) ▾

Publish results to TriplyDB

Token

Create a new token [here](#)

Remember

[LOAD TOKEN](#)

[PUBLISH](#)

LDWizard

Output of LDWizard

ldwizard_output.nt  499.30 kB

[Open in Web](#)

```
1 <http://example.org/LOTR/characters/1> <http://xmlns.com/foaf/0.1/gender> <https://schema.org/Female> .  
2 <http://example.org/LOTR/characters/1> <http://xmlns.com/foaf/0.1/name> "Adanel" .  
3 <http://example.org/LOTR/characters/1> <https://dbpedia.org/property/race> <http://example.org/LOTR/race/Men> .  
4 <http://example.org/LOTR/characters/1> <https://schema.org/spouse> <http://example.org/LOTR/character/Belemirs> .  
5 <http://example.org/LOTR/characters/1> <http://www.w3.org/1999/02/22-rdf-syntax-ns#type> <http://xmlns.com/foaf/0.1/Person> .  
6 <http://example.org/LOTR/characters/2> <https://schema.org/birthDate> "2978" .  
7 <http://example.org/LOTR/characters/2> <http://xmlns.com/foaf/0.1/gender> <https://schema.org/Male> .  
8 <http://example.org/LOTR/characters/2> <https://dbpedia.org/property/haircolour> "Dark" .  
9 <http://example.org/LOTR/characters/2> <http://xmlns.com/foaf/0.1/name> "Boromir" .  
10 <http://example.org/LOTR/characters/2> <https://dbpedia.org/property/race> <http://example.org/LOTR/race/Men> .  
11 <http://example.org/LOTR/characters/2> <http://www.w3.org/1999/02/22-rdf-syntax-ns#type> <http://xmlns.com/foaf/0.1/Person> .  
12 <http://example.org/LOTR/characters/3> <http://xmlns.com/foaf/0.1/gender> <https://schema.org/Male> .  
13 <http://example.org/LOTR/characters/3> <http://xmlns.com/foaf/0.1/name> "Lagduf" .  
14 <http://example.org/LOTR/characters/3> <https://dbpedia.org/property/race> <http://example.org/LOTR/race/Orcs> .  
15 <http://example.org/LOTR/characters/3> <http://www.w3.org/1999/02/22-rdf-syntax-ns#type> <http://xmlns.com/foaf/0.1/Person> .  
16 <http://example.org/LOTR/characters/4> <https://schema.org/birthDate> "280" .  
17 <http://example.org/LOTR/characters/4> <https://schema.org/deathDate> "515" .  
18 <http://example.org/LOTR/characters/4> <http://xmlns.com/foaf/0.1/gender> <https://schema.org/Male> .  
19 <http://example.org/LOTR/characters/4> <https://dbpedia.org/property/race> <http://example.org/LOTR/race/Hobbits> .  
20 <http://example.org/LOTR/characters/4> <http://www.w3.org/1999/02/22-rdf-syntax-ns#type> <http://xmlns.com/foaf/0.1/Person> .
```

NB: exact output may differ

LDWizard

Task

- 1 go to <https://hulc.triplay.cc> (CLARIAH LDWizard instance)
- 2 load a (not too large) CSV file
- 3 set *key column* (identifiers used for the row entities)
- 4 set *resource class* (class used for the row entities)
- 5 for each column:
 - select or define predicate
 - in case of entities: select class (URI)
- 6 download converted file (N-Triples)

Duration: 5 minutes

The Power of Python

More fine-grained control

```
from rdflib.namespace import FOAF, RDF, XSD # load predefined namespaces
DBP = rdflib.Namespace("https://dbpedia.org/property/") # add this namespace by hand
```

```
lotr_rdf = rdflib.Graph() # initialize empty RDF graph

character_list = list()

character_ns = rdflib.URIRef(base_ns + "character" + '/')
for index, row in lotr_csv.iterrows():
    birth, death, gender, hair, name, race, realm, spouse = row

    character_URI = makeURI(character_ns, name)
    suffix = 65 # corresponds to char 'A'; 66 = 'B', 67 = 'C', etc
    while character_URI in character_list: # if this name also exists in another row
        # add suffix to this name to make it unique
        character_URI = makeURI(character_ns, name + '_' + chr(suffix))
        suffix += 1

    character_list.append(character_URI)

    lotr_rdf.add((character_URI, RDF.type, FOAF.Person)) # define type of entity

    # add the entities we created earlier by retrieving their URIs and adding them using proper relations
    if race is not np.nan:
```

Notebook available at <https://tinyurl.com/posthumousIntroLD>

Outline

Understanding Linked Data

Creating Linked Data

Querying Linked Data

Wrap Up

Triple Stores

Triple stores are graph databases tailored to Linked Data

Many choices

- Ontotext GraphDB
- Stardog
- OpenLink Virtuoso
- ClioPatria
- TriplyDB
- etc.

The screenshot shows a user interface for managing RDF datasets. At the top, there are two tabs: "User data" and "Server files". Below the tabs are two buttons: "Upload RDF files" (with a file icon) and "Get RDF data from a URL" (with a link icon). There is also a "Reset status" button and a "Remove" button. A checkbox is present next to the "Import" button. The main area displays a list of imported datasets, each with a checkbox, a file icon, a dataset name, and a status message indicating successful importation in less than a second. The datasets listed are:

- graphdb-news-dataset.nt: Imported successfully in less than a second.
- pub-ontology-types.ttl: Imported successfully in less than a second.
- pub-ontology.ttl: Imported successfully in less than a second.
- pub-properties.ttl: Imported successfully in less than a second.
- publishing-ontology.ttl: Imported successfully in less than a second.

Druid

Druid: a TriplyDB instance running at the IISG

Subject	Predicate	Object	Graph
ltr:character/Adalbert_Bolger	rdf:type	foaf:Person	http://example.org/LOTR/
1 ltr:character/Adalbert_Bolger	foaf:name	Adalbert Bolger	http://example.org/LOTR/
1 ltr:character/Adamanta_Chubb	rdf:type	foaf:Person	http://example.org/LOTR/
1 ltr:character/Adamanta_Chubb	foaf:name	Adamanta Chubb	http://example.org/LOTR/
ltr:character/Almorian	rdf:type	foaf:Person	http://example.org/LOTR/
ltr:character/Almorian	foaf:gender	sdo:Female	http://example.org/LOTR/
ltr:character/Almorian	foaf:name	Almorian	http://example.org/LOTR/
ltr:character/Almorian	https://dbpedia.org/property/race	ltr:race/Men	http://example.org/LOTR/
ltr:character/Almorian	https://dbpedia.org/property/realm	ltr:realm/Númenor	http://example.org/LOTR/
ltr:character/Ar-Pharazón	rdf:type	foaf:Person	http://example.org/LOTR/
ltr:character/Ar-Pharazón	foaf:gender	sdo:Male	http://example.org/LOTR/
ltr:character/Ar-Pharazón	foaf:name	Ar-Pharazón	http://example.org/LOTR/
ltr:character/Ar-Pharazón	https://dbpedia.org/property/birthYear	3118	http://example.org/LOTR/

<https://druid.datalegend.net/wxwilcke/LOTR>

SPARQL

SPARQL Protocol and RDF Query Language (SPARQL)

- the SQL equivalent for LinkedData
- can be called using standard web protocols
- syntax similar to Turtle
- requires a triples store

The most basic query:

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
SELECT ?s ?p ?o WHERE {
  ?s ?p ?o .
} LIMIT 10
```

<https://www.w3.org/TR/sparql11-query/>

SPARQL Queries

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
SELECT ?s ?p ?o WHERE {
  ?s ?p ?o .
} LIMIT 10
```

- defines prefixes *rdf* and *rdfs*
- initialises three unbound variables: *s*, *p*, and *o*
- binds the variables to resources matching the pattern
- returns the first 10 matches

SPARQL Query: Simple matching

The first 10 characters named Gimli

```
1 . PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
2 . PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
3 . PREFIX foaf: <http://xmlns.com/foaf/0.1/>
4 . SELECT ?s ?p ?o WHERE {
5 .     ?s foaf:name "Gimli" .
6 . } LIMIT 10
```

Table

Response

Gallery

Chart

Geo

Geo-3D

s

- 1 <<http://example.org/LOTR/characters/489>>
- 2 <<http://example.org/LOTR/characters/490>>

Showing 1 to 2 of 2 entries

SPARQL Query: Type matching

The first 10 characters

```
1 PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
2 PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
3 PREFIX foaf: <http://xmlns.com/foaf/0.1/>
4 SELECT ?s WHERE {
5   ?s rdf:type foaf:Person .
6 } LIMIT 10
```

Table

Response

Gallery

Chart

Geo

Geo-3D

s

- 1 <<http://example.org/LOTR/characters/1>>
- 2 <<http://example.org/LOTR/characters/10>>
- 3 <<http://example.org/LOTR/characters/100>>
- 4 <<http://example.org/LOTR/characters/101>>
- 5 <<http://example.org/LOTR/characters/102>>
- 6 <<http://example.org/LOTR/characters/103>>
- 7 <<http://example.org/LOTR/characters/104>>
- 8 <<http://example.org/LOTR/characters/105>>
- 9 <<http://example.org/LOTR/characters/106>>
- 10 <<http://example.org/LOTR/characters/107>>

SPARQL Query: ORDER

All characters by their (ordered) name

```
1 . PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
2 . PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
3 . PREFIX foaf: <http://xmlns.com/foaf/0.1/>
4 . SELECT ?s ?name WHERE {
5 .     ?s rdf:type foaf:Person ;
6 .         foaf:name ?name .
7 . } ORDER by ?name
```

Table Response Gallery Chart Geo Geo-3D

s	name
1 < http://example.org/LOTR/characters/748 >	Adaldrida Brandybuck
2 < http://example.org/LOTR/characters/353 >	Adalgar Bolger
3 < http://example.org/LOTR/characters/777 >	Adalgrim Took
4 < http://example.org/LOTR/characters/775 >	Adamanta Took
5 < http://example.org/LOTR/characters/1 >	Adanel
6 < http://example.org/LOTR/characters/774 >	Adelard Took
7 < http://example.org/LOTR/characters/911 >	Adrahil I
8 < http://example.org/LOTR/characters/910 >	Adrahil II
9 < http://example.org/LOTR/characters/909 >	Aegnor
10 < http://example.org/LOTR/characters/908 >	Aerandir

SPARQL Query: FILTER

All Dwarves by their (ordered) name

```
1 . PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
2 . PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
3 . PREFIX foaf: <http://xmlns.com/foaf/0.1/>
4 . PREFIX dbp: <http://dbpedia.org/property/>
5 . SELECT ?s ?name WHERE {
6 .     ?s rdf:type foaf:Person ;
7 .         foaf:name ?name ;
8 .         dbp:race ?race .
9 .     FILTER (?race = <http://example.org/LOTR/race/Dwarves>)
10 . } ORDER by ?name
```

[Table](#) [Response](#) [Gallery](#) [Chart](#) [Geo](#) [Geo-3D](#) [?l](#)

	s	name
1	<http://example.org/LOTR/characters/833>	Azaghâl
2	<http://example.org/LOTR/characters/618>	Balin
3	<http://example.org/LOTR/characters/383>	Bifur
4	<http://example.org/LOTR/characters/356>	Bofur
5	<http://example.org/LOTR/characters/340>	Bombur
6	<http://example.org/LOTR/characters/339>	Borin
7	<http://example.org/LOTR/characters/306>	Dori
8	<http://example.org/LOTR/characters/300>	Durin VII
9	<http://example.org/LOTR/characters/298>	Dwalin
10	<http://example.org/LOTR/characters/297>	Dáin I

SPARQL Query: COUNT

The number of known Dwarves

```
1 . PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
2 . PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
3 . PREFIX foaf: <http://xmlns.com/foaf/0.1/>
4 . PREFIX dbp: <http://dbpedia.org/property/>
5 . SELECT (count(?race) as ?num_dwarves) WHERE {
6 .   ?s rdf:type foaf:Person ;
7 .     dbp:race ?race .
8 .   FILTER (?race = <http://example.org/LOTR/race/Dwarves>)
9 . } ORDER by ?name
```

Table

Response

Gallery

Chart

Geo

Geo-3D

num_dwarves

1 "44"^^xsd:integer

SPARQL Query: BIND and arithmetic

Which character lived the longest

```
1 . PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
2 PREFIX foaf: <http://xmlns.com/foaf/0.1/>
3 PREFIX schema: <http://schema.org/>
4 PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
5 PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
6 . SELECT ?name ?lived_for WHERE {
7     ?s rdf:type foaf:Person ;
8         foaf:name ?name ;
9         schema:birthDate ?bd ;
10        schema:deathDate ?dd .
11        BIND(xsd:int(?dd) - xsd:int(?bd) AS ?lived_for)
12 } ORDER BY DESC(?lived_for)
```

Table Response Gallery Chart Geo Geo-3D

	name	↳ lived_for
1	Gil-galad	"2991"^^xsd:integer
2	Celebrian	"2110"^^xsd:integer
3	Tar-Atanamir	"421"^^xsd:integer
4	Tar-Ancalimë	"412"^^xsd:integer
5	Isilmo	"411"^^xsd:integer

SPARQL Query: UNION

Characters from Gondor or The Shire born between the year 100 and 250

```
1 . PREFIX schema: <http://schema.org/>
2 . PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
3 . PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
4 . PREFIX foaf: <http://xmlns.com/foaf/0.1/>
5 . PREFIX dbp: <http://dbpedia.org/property/>
6 . PREFIX lotrll: <http://example.org/LOTR/realm/>
7 . PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
8 . SELECT ?name ?bd WHERE {
9 .     ?s rdf:type foaf:Person ;
10 .        foaf:name ?name ;
11 .        schema:birthDate ?bd .
12 .    { ?s dbp:realm lotrll:Gondor } UNION { ?s dbp:realm lotrll:Shire }
13 .    FILTER (xsd:int(?bd) > 100 && xsd:int(?bd) < 250)
14 . } ORDER by DESC(?bd)
```

Table Response Gallery Chart Geo Geo-3D Geo events

	name	bd
1	Ostoher	222
2	Anardil	136

Showing 1 to 2 of 2 entries

SPARQL Query: Federated queries

Ask DBpedia about Frodo

```
1 . PREFIX dbo: <http://dbpedia.org/ontology/>
2 . PREFIX dbp: <http://dbpedia.org/property/>
3 . PREFIX foaf: <http://xmlns.com/foaf/0.1/>
4 . PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
5 . PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
6 . SELECT ?name ?fa ?la ?rela_name WHERE {
7 .   <http://example.org/LOTR/characters/820> foaf:name ?name .
8 .   BIND(STRLANG(?name, "en") as ?name_en)
9 .   SERVICE <http://dbpedia.org/sparql> {
10 .     SELECT * WHERE {
11 .       ?s dbp:name ?name_en ;
12 .         dbo:firstAppearance ?fa ;
13 .         dbo:lastAppearance ?la ;
14 .         dbo:relative ?rela .
15 .       ?rela dbp:name ?rela_name .
16 .     }
17 .   }
18 . }
```

Table Response Gallery Chart Geo Geo-3D Geo events Markup Network

	name	fa	la	rela_name
1	Frodo Baggins	The Fellowship of the Ring (1954)	<http://dbpedia.org/resource/Bilbo's_Last_Song>	"Bilbo Baggins"

Showing 1 to 1 of 1 entries

SPARQL Task I

Task: list everything we know about “Frodo Baggins”

Duration: 2 minute

<https://druid.datalegend.net/wxwilcke/LOTR>

SPARQL Task 1

Task: list everything we know about “Frodo Baggins”

```
1 . PREFIX foaf: <http://xmlns.com/foaf/0.1/>
2 . PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
3 . PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
4 . SELECT ?p ?o WHERE {
5 .     ?s foaf:name "Frodo Baggins" ;
6 .     ?p ?o .
7 . }
```

Table

Response

Gallery

Chart

Geo

Geo-3D

	p	o
1	rdf:type	foaf:Person
2	foaf:gender	schema:Male
3	foaf:name	Frodo Baggins
4	dbp:race	lotrc:Hobbits
5	schema:birthDate	2968
6	dbp:haircolour	Brown

Showing 1 to 6 of 6 entries

SPARQL Task II

Task: count the number of women in Rohan

Duration: 2 minute

<https://druid.datalegend.net/wxwilcke/LOTR>

SPARQL Task II

Task: count the number of women in Rohan

```
1 . PREFIX lotrrl: <http://example.org/LOTR/realm/>
2 . PREFIX dbp: <http://dbpedia.org/property/>
3 . PREFIX schema: <http://schema.org/>
4 . PREFIX foaf: <http://xmlns.com/foaf/0.1/>
5 . PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
6 . PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
7 . SELECT (COUNT(?s) as ?num_women) WHERE {
8 .     ?s foaf:gender schema:Female ;
9 .         dbp:realm lotrrl:Rohan .
10 . }
```

Table

Response

Gallery

Chart

Geo

Geo-3D

num_women

1 "3"^^xsd:integer

SPARQL Task III

Task: list 10 Elves by name and ordered by their year of birth

Duration: 2 minute

<https://druid.datalegend.net/wxwilcke/LOTR>

SPARQL Task III

Task: list 10 Elves by name and ordered by their year of birth

```
1 . PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
2 . PREFIX foaf: <http://xmlns.com/foaf/0.1/>
3 . PREFIX lotrrc: <http://example.org/LOTR/race/>
4 . PREFIX dbp: <http://dbpedia.org/property/>
5 . PREFIX schema: <http://schema.org/>
6 . PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
7 . PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
8 . SELECT ?name ?bd WHERE {
9 .     ?s dbp:race lotrrc:Elves ;
10 .        foaf:name ?name ;
11 .        schema:birthDate ?bd .
12 . } ORDER BY xsd:int(?bd) LIMIT 10
```

[Table](#) [Response](#) [Gallery](#) [Chart](#) [Geo](#) [Geo-3D](#)

	name	bd
1	Círdan	121
2	Elladan and Elrohir	130
3	Maeglin	320
4	Celebrían	400
5	Gil-galad	450
6	Eluréd and Elurín	500
7	Thingol	1050
8	Fëanor	1169
9	Fingolfin	1190

Outline

Understanding Linked Data

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Wrap Up

Concluding Remarks

Linked Data

- is built on top of the RDF data model
- expresses knowledge as triples *subject, predicate, object*
- reuses common elements in *vocabularies* or *ontologies*
- can be created from scratch or by converting existing datasets
(e.g. using LDWizard)
- can be published as a file or via a triple store
- can be queried using SPARQL

Thank you for your attention!