

Lecture 2

Knowledge Graphs

COMP 474/6741, Winter 2024

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- Motivation
- Why Knowledge Graphs?

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- Knowledge Representation
- Semantic Web
- Knowledge Graphs

RDF

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- Blank Nodes
- Knowledge Bases: DBpedia, Wikidata
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- Architecture
- Examples
- KGs and LLMs

Notes and Further Reading

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Department of Computer Science
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Concordia University

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- 3 The Resource Description Framework (RDF)
- 4 Example: Data Integration with Knowledge Graphs
- 5 Conclusions
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Slides Credit

- Includes slides from Jay Pujara & Sameer Singh, *Mining Knowledge Graphs from Text*, <https://kgtutorial.github.io/>
- Includes slides by Ivan Herman, W3C [Her]
- Includes slides from Kristof Neys, Neo4j, *The perfect couple: Uniting Large Language Models and Knowledge Graphs for Enhanced Knowledge Representation*,
<https://www.slideshare.net/neo4j/the-perfect-couple-uniting-large-language-models-and-knowledge-graphs-for-enhanced-knowledge-representation>

Outline

René Witte



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doctor

File Edit Options Buffers Tools Text Help

I am the psychotherapist.

Please, describe your problems. Each time you are finished talking, type RET twice.

What is Concordia University?

Why do you say what is concordia university?

Just tell me what it is!

Is it because of your plans that you say just tell you what it is?

[]



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What is Concordia University?



Concordia University (French: Université **Concordia**; commonly referred to as **Concordia**) is a public comprehensive research **university** located in Montreal, Quebec, Canada. ... **Concordia** is a non-sectarian and coeducational institution, with more than 215,000 alumni worldwide.

Athletics brand: Concordia Stingers

Subsidiary or constituent schools: Loyola Campus, Faculty of Arts

Date founded: August 24, 1974

Geographic scope: Canada



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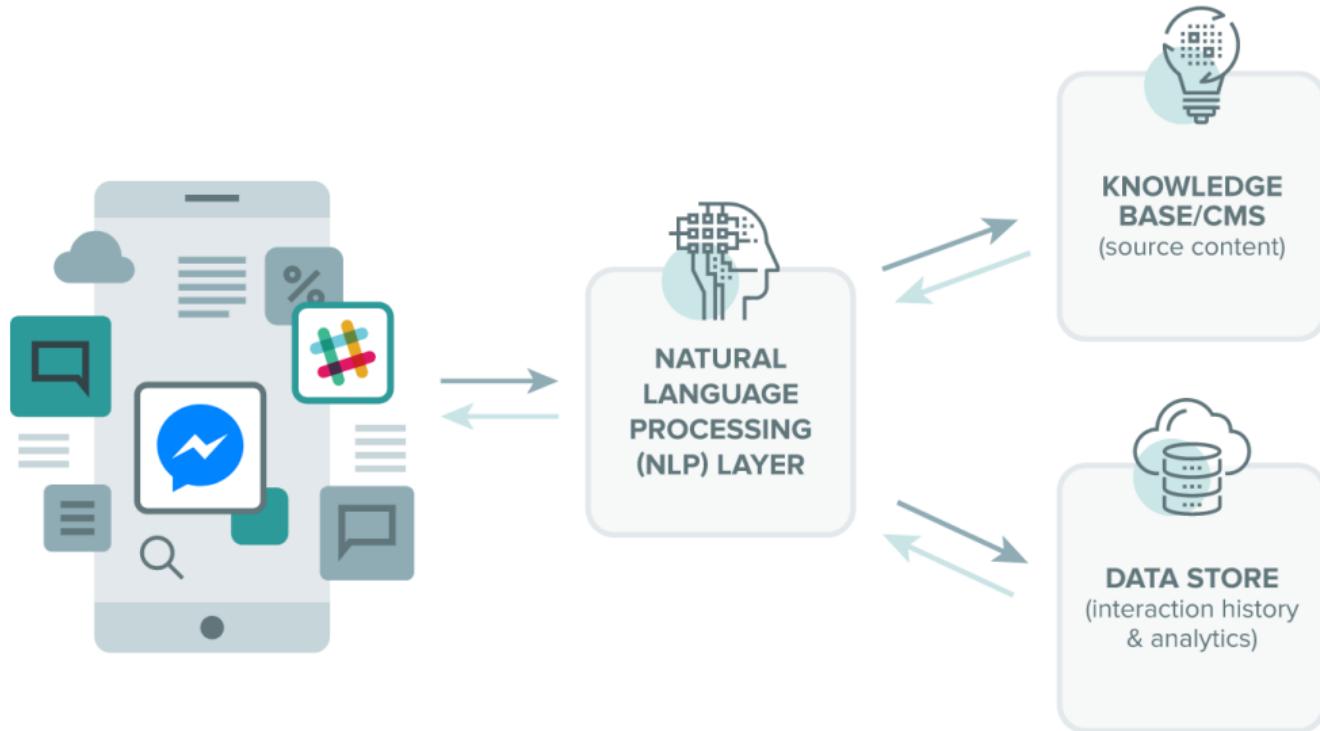
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Generic Assistant Architecture

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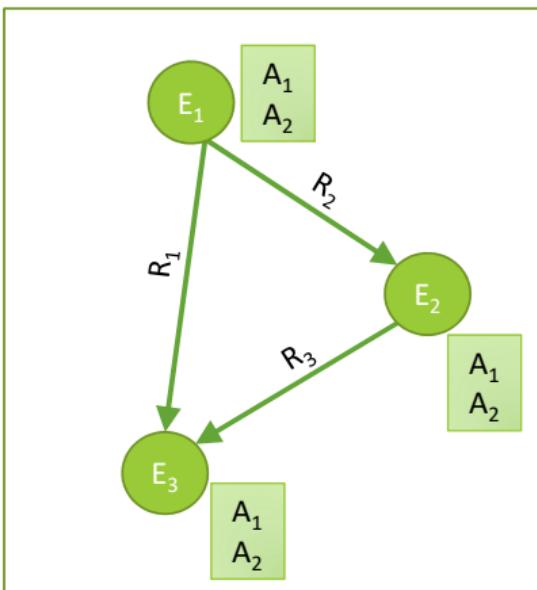
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What is a knowledge graph?

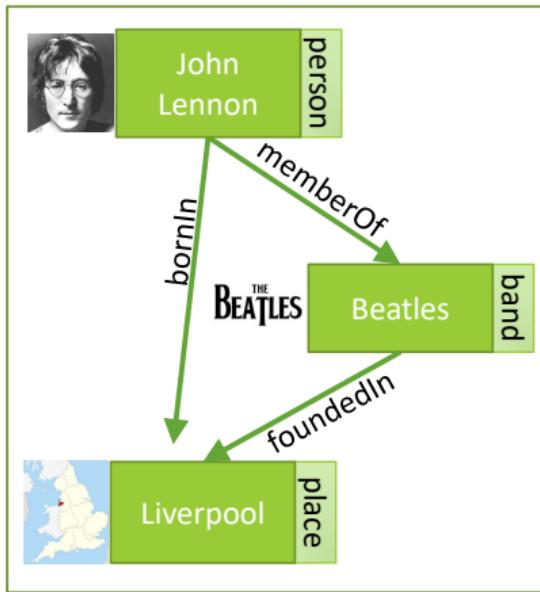
- Knowledge in graph form!
- Captures entities, attributes, and relationships
- Nodes are entities
- Nodes are labeled with attributes (e.g., types)
- Typed edges between two nodes capture a relationship between entities



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Example knowledge graph

- Knowledge in graph form!
- Captures entities, attributes, and relationships
- Nodes are entities
- Nodes are labeled with attributes (e.g., types)
- Typed edges between two nodes capture a relationship between entities



Why knowledge graphs?

- Humans:
 - Combat information overload
 - Explore via intuitive structure
 - Tool for supporting knowledge-driven tasks
- AIs:
 - Key ingredient for many AI tasks
 - Bridge from data to human semantics
 - Use decades of work on graph analysis

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Applications 1: QA/Agents



who is playing in this year's super bowl

All News Shopping Videos Maps More Settings Tools

About 4,350,000 results (0.46 seconds)

Super Bowl LII

NFL · Today, 3:30 PM

Philadelphia Eagles at New England Patriots
Super Bowl

Game preview

Watch on: NBC

All times are in Pacific Time

Feedback

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Applications 2: Decision Support

IBM Watson Knowledge Studio

View Details Attribute View View Guidelines Completed 5 X Close Alpha... 14pt 1 Entity Mention

2004-49-168A.txt

A Merlin

1 V1, a 1999 Toyota Camry, was traveling southbound in the second lane of a four-lane divided (seven lanes overall, divided by raised median), concrete roadway, approaching an intersection.

2 V2, a 2004 Mercedes S430, was northbound in the fourth lane of a four-lane, divided (seven lanes overall, divided by raised median), concrete roadway about to turn left into westbound traffic at the same intersection.

3 As both vehicles entered the intersection, the front of V1 impacted the front of V2.

4 V1 rotated clockwise as V2 rotated counter-clockwise, and the left side of V1 impacted the right side of V2 in a sideslip configuration.

5 Both vehicles moved southwest to final rest.

6 Both vehicles were towed due to damage.

7 The unrestrained driver of V1 was hospitalized with foot and rib fractures as well as a liver laceration.

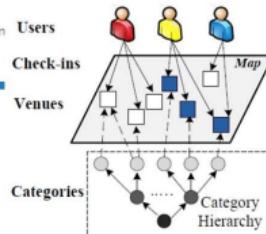
8 The restrained driver of V2 was treated and released with minor abrasion and contusion as well as a finger fracture.

9 The restrained male right passenger in V2 was pronounced brain dead two days later from brain injuries.

10 V1 was equipped with airbags and dual front airbags which deployed.

Type Subtype Role

- a ACCIDENT_CAUSE
- b ACCIDENT_OUTCOME
- c CONDITION
- d IMPACT
- e MANUFACTURER
- m MODEL
- y MODEL_YEAR
- f PART_OF_CAR
- p PERSON
- s STRUCTURE
- v VEHICLE


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Applications 3: Fueling Discovery

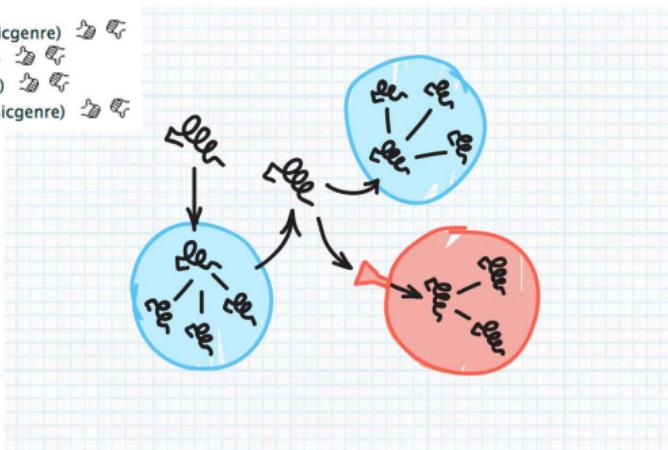
beatles (musicartist)

literal strings: BEATLES, Beatles, beatles

Help NELL Learn!

NELL wants to know if these be
If they are or ever were, click thumbs-up. Or

- beatles is a musical artist  
- beatles is a musician in the genre classic pop (musicgenre)  
- beatles is a musician in the genre pop (musicgenre)  
- beatles is a musician in the genre rock (musicgenre)  
- beatles is a musician in the genre classic rock (musicgenre)  



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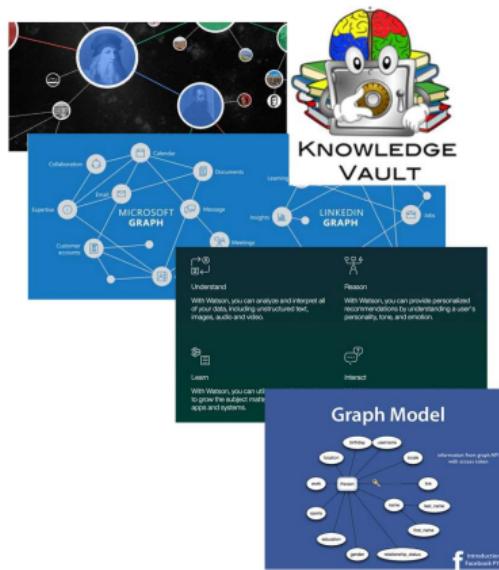
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Knowledge Graphs & Industry

- Google Knowledge Graph
 - Google Knowledge Vault
- Amazon Product Graph
- Facebook Graph API
- IBM Watson
- Microsoft Satori
 - Project Hanover/Literome
- LinkedIn Knowledge Graph
- Yandex Object Answer
- Diffbot, GraphIQ, Maana, ParseHub, Reactor Labs, SpazioDati



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Where do knowledge graphs come from?

- Structured Text
 - Wikipedia Infoboxes, tables, databases, social nets

The Beatles												
	Mon 30th	00:18	07:06	12:36	19:32							
	Jan 2017	9.15m H	1.34m L	9.50m H	1.20m L							
	Tue 31st	00:55	07:43	13:14	20:10							
		9.18m H	1.36m L	9.49m H	1.25m L							
	Wed 1st	01:33	08:21	13:53	20:47							
	Feb 2017	9.10m H	1.51m L	9.37m H	1.42m L							
	Thu 2nd	02:14	08:59	14:36	21:27							
		8.91m H	1.76m L	9.15m H	1.70m L							
	Fri 3rd	09:00	09:42	15:34	22:12							
		8.66m H	2.00m L	8.84m H	2.04m L							
	Sat 4th	03:52	10:34	18:21	23:09							
		8.27m H	2.43m L	8.45m H	2.39m L							
	Sun 5th	04:59	11:42	17:34								
		7.95m H	2.71m L	8.13m H								
	Mon 6th	00:24	06:20	13:09	18:57							
		7.63m L	7.82m L	7.23m L	8.06m H							
	Tue 7th	01:49	07:39	14:31	20:13							
		7.25m L	8.03m L	7.42m L	8.29m H							
	Wed 8th	03:03	08:49	15:43	21:18							
		6.88m L	8.46m L	7.93m L	8.66m H							
	Thu 9th	04:08	09:47	16:45	22:14							
		6.52m L	8.94m L	7.41m L	9.07m H							
	Fri 10th	05:03	10:36	17:38	23:01							
		6.14m L	9.34m L	8.98m L	9.35m H							
	Sat 11th	05:51	11:21	18:24	23:44							
		5.77m L	9.81m L	8.75m L	9.47m H							
<small>© National Oceanography Centre, Liverpool</small>												
Background information												
Origin	Liverpool, England, United Kingdom											
Genres	Rock · pop											
Years active	1960–1970											
Labels	EMI · Polydor Swan · Vertigo United Artists											
	<small>Total number of albums released</small>											
	7300,000,000											
	<small>Total albums sold in Tunes</small>											
	780,000											
	<small>Total singles sold on Tunes</small>											
	8,800,000											
Associated acts	The Quarrymen · Cavern Club · Preston · Patti Page · thebeatles.com · John Lennon · Paul McCartney · George Harrison · Ringo Starr · Brian Epstein · Freddie Starr · Arctic Monkeys · Bertrand											
	<small>Total Available Works</small>											
	206,100,000											
Website	thebeatles.com											
Past members	John Lennon · Paul McCartney · George Harrison · Ringo Starr · Brian Epstein · Freddie Starr · Arctic Monkeys · Bertrand											
	<small>Number of weeks on chart</small>											
	1,270 weeks											
	<small>Total weeks on chart</small>											
	16											
	<small>Total weeks at number one</small>											
	178 weeks											
	<small>Album with longest time spent at number one (Please Please Me)</small>											
	30 weeks											
<small>© BEATLES TOTAL ALBUMS COUNT STATISTICS</small>												
<small>© BEATLES WEEKS ON CHART STATISTICS</small>												
<small>© BEATLES DATA SET</small>												

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- Unstructured Text
 - WWW, news, social media, reference articles

Beatles last live performance

Published: Thursday, January 26th 2017, 5:24 am PST

Updated: Monday, January 30th 2017, 4:06 am PST

Written by Jim Eltink, Producer [CONNECT](#)



(Source: Stock Im) By ALLAN KOZINN DEC. 31, 2016

(KFVS) - How about a little Beatles history.

It was on this date in 1969, the band performed their last live public performance.

Allan Williams, First Manager of the Beatles, Dies at 86

du1 The Beatles
The Harrison family is proud to announce the release of George Harrison - 1
Ltd Ltd
WWD GEORGE HARRISON - THE JOHN COLLECTION

Released on 24th February, 2017, the vinyl box set includes all twelve of George's solo albums with each track of the original studio track listing and artwork. Pre-order now! The box set can be ordered via classicbox.com

George Harrison - The Vinyl Collection - Release February 2017
George Harrison - The Vinyl Collection, available to pre-order now with an exclusive & limited edition.

Like 0 Comment 0 Share

Like 1,000,000 Comment Top Comments

100 shares Write a comment...

Jeffrey Smith What I would really be interested in is an "All Things Must Go" book on the Beatles. I have a copy of the book "The Beatles" that I would sell if it would sound really good and I would buy it if it is interesting. Like 100 Share 1/17/17 10:10 AM Edited

Dave Branning I can just see the grannies from my family and the grandmas making little crafts like this. I am thinking of making them with glue since more often than not these methods to make things less than originally bought and paid for record collectors are not used. Like 100 Reply 1/17/17 10:10 AM Edited

View more comments

The Beatles - A Day In The Life

"Of very few individual songs can it be said, "This changed the course of popular music." "A Day In The Life" is such song." - Richard Havers

The Beatles - A Day In The Life Video Collection

A Day In The Life Beatles Video Collection

Or Now Get your own beatles



anager of the Beatles in 1964, he sent them on a stint in Germany

tagecraft. Press Association, via Associated Press

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- Images

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 - Wikipedia Infoboxes, tables, databases, social nets
- Unstructured Text
 - WWW, news, social media, reference articles
- Images
- Video
 - YouTube, video feeds

The Beatles - Topic

Home Videos Playlists Channels About

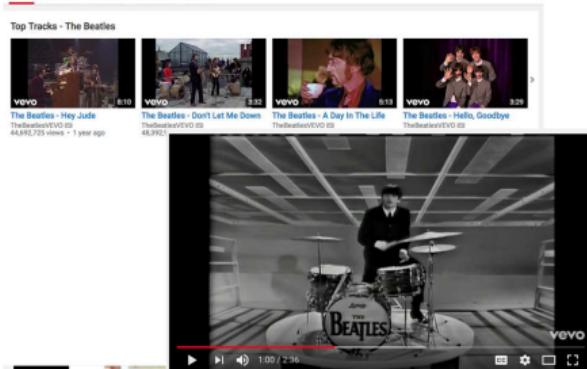
Top Tracks - The Beatles

The Beatles - Hey Jude TheBeatlesVEVO 816 44,692,723 views • 1 year ago

The Beatles - Don't Let Me Down TheBeatlesVEVO 832 48,751 views

The Beatles - A Day In The Life TheBeatlesVEVO 83 329

The Beatles - Hello, Goodbye TheBeatlesVEVO 83



The Beatles - I Want To Hold Your Hand - Performed Live On The Ed Sullivan Show 2/9/64



BED PEACE starring John Lennon & Yoko Ono

Yoko Ono 17,609 subscribers 852,022 views

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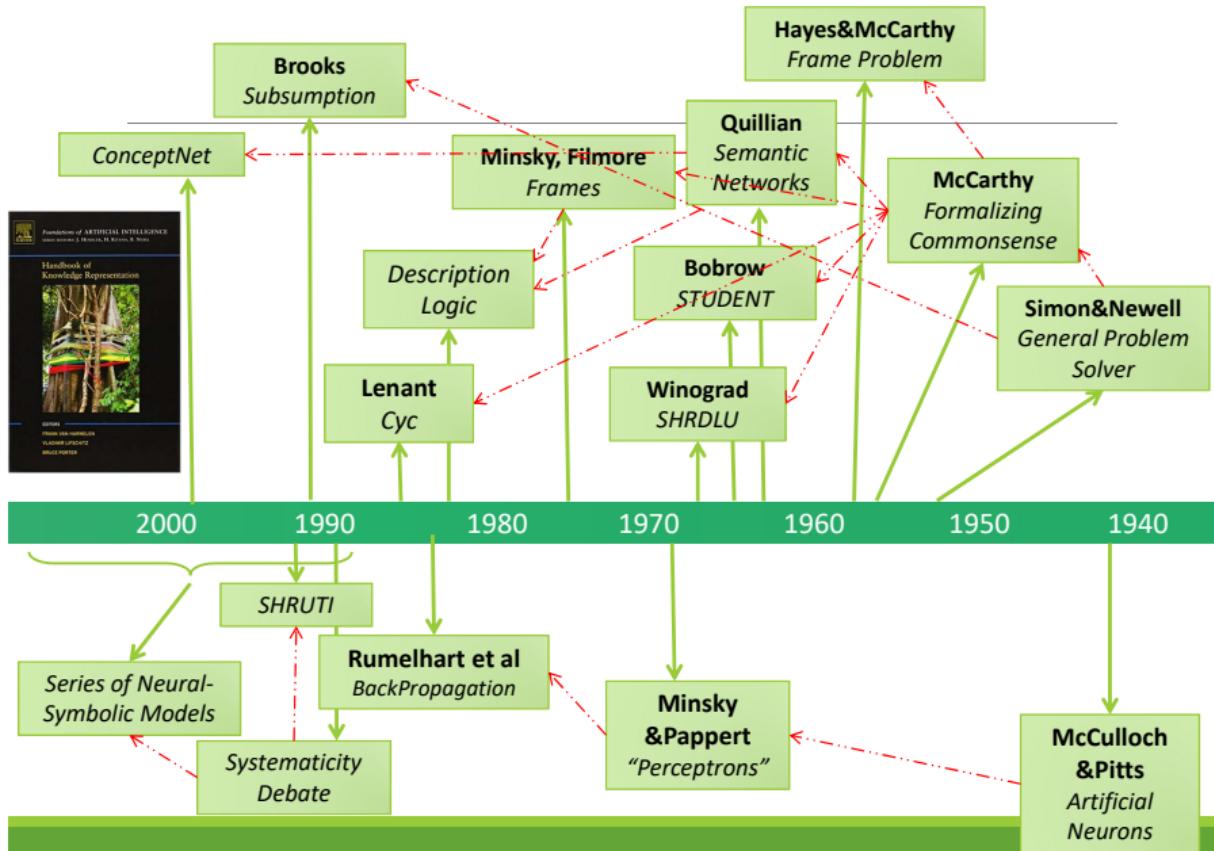
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History of Knowledge Representation (KR)

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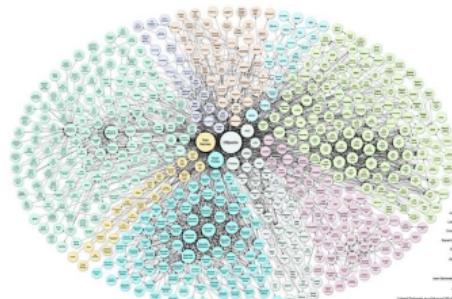
Knowledge Representation

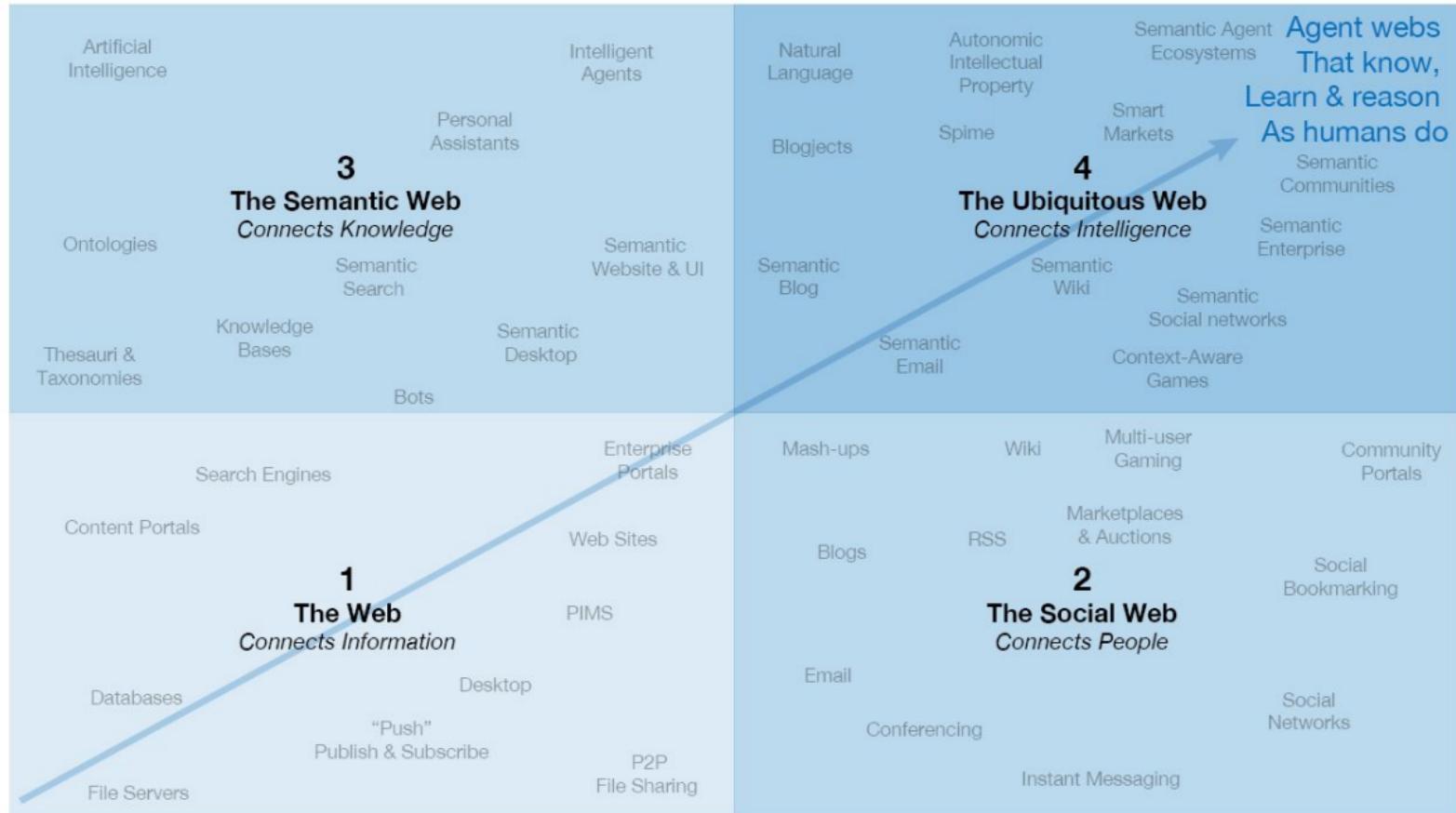
- Decades of research into knowledge representation
- Most knowledge graph implementations use RDF triples
 - <rdf:subject, rdf:predicate, rdf:object> : r(s,p,o)
 - Temporal scoping, reification, and skolemization...
- ABox (assertions) versus TBox (terminology)
- Common ontological primitives
 - rdfs:domain, rdfs:range, rdf:type, rdfs:subClassOf, rdfs:subPropertyOf, ...
 - owl:inverseOf, owl:TransitiveProperty, owl:FunctionalProperty, ...

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Semantic Web

- Standards for defining and exchanging knowledge
 - RDF, RDFa, JSON-LD, schema.org
 - RDFS, OWL, SKOS, FOAF
- Annotated data provide critical resource for automation
- Major weakness: annotate everything?

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Increasing Social Connectivity

From 1950–2020...

- Concepts have been around for a long time (Semantic Networks, Frames, Description Logic, ...)

1980s/90s

- AI/IS systems suffer from the *Knowledge Acquisition Bottleneck*
- One of the reasons for the *AI Winter* at that time

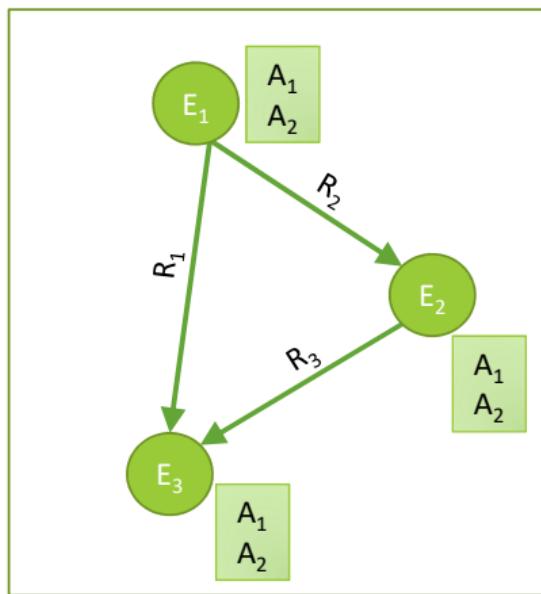
Technology

- Open standards, based on W3C recommendations, e.g., [RDF](#)
- Proprietary products, e.g., [Neo4J](#) or [Oracle Spatial and Graph](#)
- We now have substantial [knowledge bases](#) available, both proprietary (e.g., Facebook Graph Search, Google Knowledge Graph) and open access (e.g., Wikidata, DBpedia, YAGO)

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- Nodes are labeled with attributes (e.g., types)
- Typed edges between two nodes capture a relationship between entities

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TBL at TED on “The Next Web” (2009)

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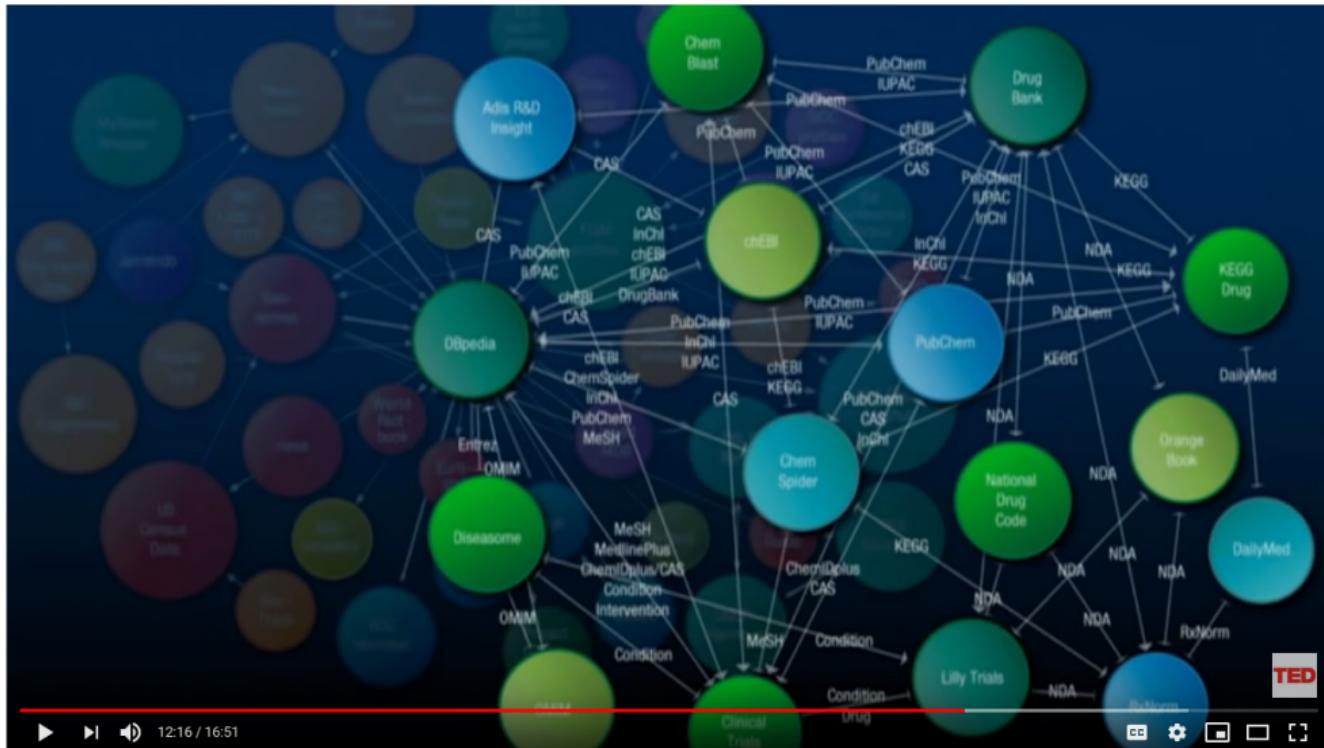
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Tim Berners-Lee: The next Web of open, linked data

https://www.youtube.com/watch?v=OM6XIIICm_qo

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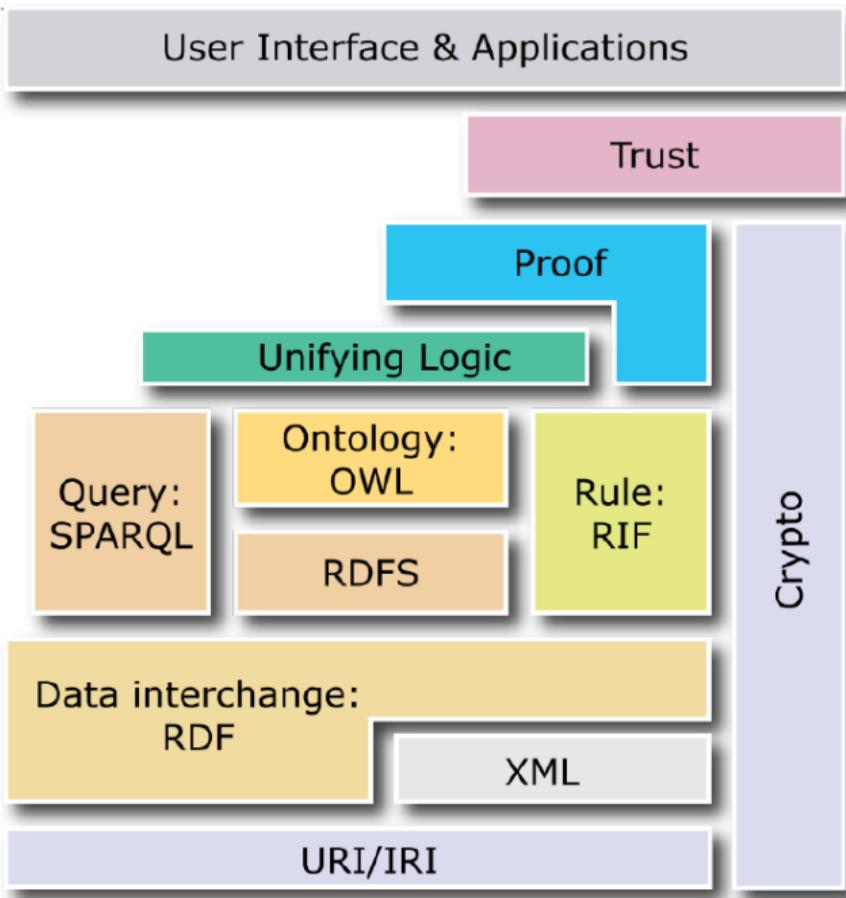
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Knowledge as Graphs

René Witte

Alice



is a friend of



BOB

is interested in



The Mona Lisa

is a

Person

is born on

14 July 1990

Leonardo Da Vinci



was created by



La Joconde à Washington



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Representation of Knowledge Graphs

In a system, we represent graphs in form of **triples**:

<subject> <predicate> <object>

(The *predicate* is sometimes called *property*.)

Examples

<Bob> <is a> <person>.

<Bob> <is a friend of> <Alice>.

<Bob> <is born on> <the 14th of July 1990>.

<Bob> <is interested in> <the Mona Lisa>.

<the Mona Lisa> <was created by> <Leonardo da Vinci>.

→ Worksheet #1: Tasks 3 & 4

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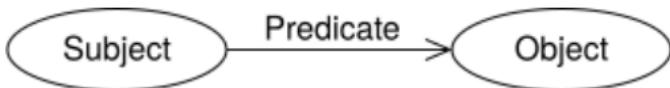
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<subject> <predicate> <object>



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The Resource Description Framework (RDF)

W3C (World Wide Web Consortium) standard (“recommendation”)

- first public draft 1997
- RDF 1.0 in 1999; revised in 2004
- RDF 1.1 in 2014 (current version)

Family of standards: RDF, RDFS, RDFa, Turtle, N3, SPARQL, ...

Format of triples

In RDF,

- Subject and predicate must be URIs (IRIs)
- Object can be IRI or literal

Examples

```
<http://www.wikidata.org/entity/Q12418>
    <http://purl.org/dc/terms/title>
    "Mona Lisa" .  
  
<http://www.wikidata.org/entity/Q12418>
    <http://purl.org/dc/terms/creator>
    <http://dbpedia.org/resource/Leonardo_da_Vinci> .
```

→ Worksheet #1: Tasks 5 & 6

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"Mona Lisa"

In this triple

```
<http://www.wikidata.org/entity/Q12418>
  <http://purl.org/dc/terms/title> "Mona Lisa" .
```

"Mona Lisa" is a string literal

Things to know about literals

- Literals have a datatype, e.g., string or int
- Strings can have a language tag, e.g.,

"Leonardo da Vinci"@en

"Léonard de Vinci"@fr

- Strings are often used to provide human-readable labels
"Hey, how did you like the movie Q168154?"

- For strings only, datatype can be omitted:
"Mona Lisa" is equivalent to "Mona Lisa"^^xsd:string
- Again, literals can only appear in the object position of a triple <s> <p> <o>

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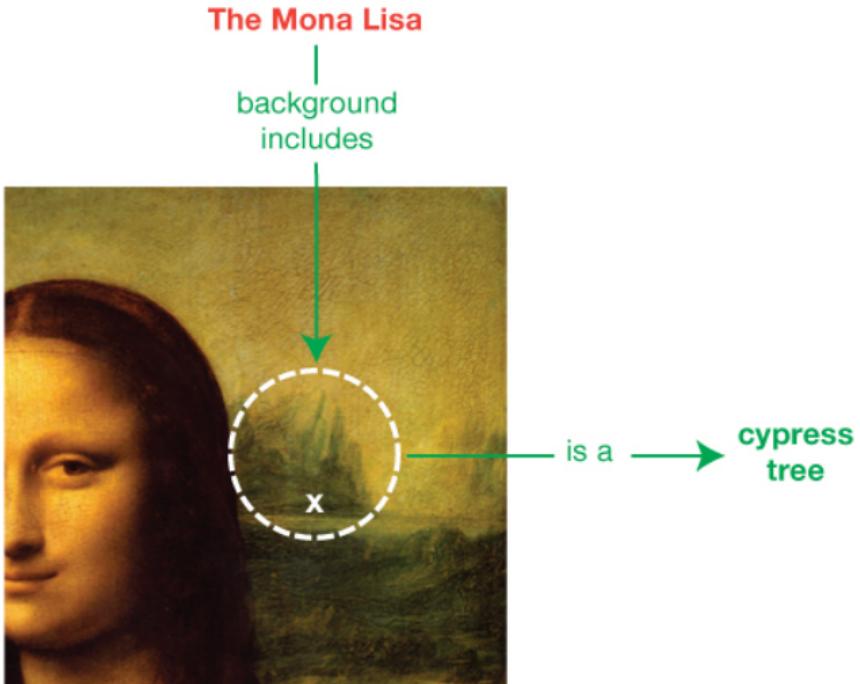
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```
<http://dbpedia.org/resource/Mona_Lisa> <lio:shows> _:x .  
_:x a <http://dbpedia.org/resource/Cypress> .
```

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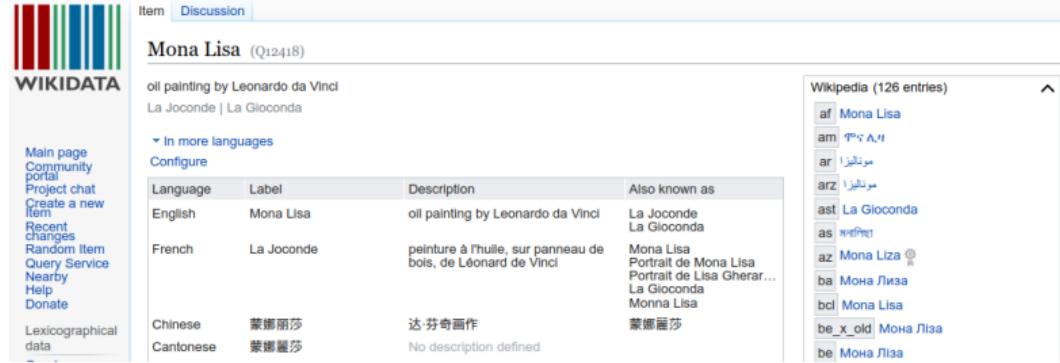
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Mona Lisa (Q12418)

oil painting by Leonardo da Vinci
La Joconde | La Gioconda

In more languages
Configure

Language	Label	Description	Also known as
English	Mona Lisa	oil painting by Leonardo da Vinci	La Joconde La Gioconda
French	La Joconde	peinture à l'huile, sur panneau de bois, de Léonard de Vinci	Mona Lisa Portrait de Mona Lisa Portrait of Lisa Gherar... La Gioconda Monna Lisa
Chinese	蒙娜丽莎	达·芬奇画作	蒙娜麗莎
Cantonese	蒙娜麗莎	No description defined	

Wikipedia (126 entries)

- af Mona Lisa
- am ማኖላሳ
- ar موناليزا
- arz موناليسا
- ast La Gioconda
- as ମୋନା ଲିସା
- az Mona Liza
- ba Мона Ліза
- bcl Mona Lisa
- be_x-old Мона Ліза
- be Мона Ліза

Wikidata URIs

Make sure you use the correct URI:

- `http://wikidata.org/entity/Q{id}` is the persistent URI
- Visited with a web browser, the Wikidata server redirects to
 - `http://wikidata.org/wiki/Q{id}` (HTML data, for a human)

→ Worksheet #1: Task 7

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Browse using ▾ Formats ▾

Faceted Browser Sparql Endpoint

About: Leonardo da Vinci

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

Leonardo di ser Piero da Vinci (Italian: [leo'nardo di ser 'pjero da (v)'intʃi] (); 14/15 April 1452 – 2 May 1519), known as Leonardo da Vinci (English: LEE-ə-NAR-doh də VIN-chee, LEE-oh-, LAY-oh-), was an Italian polymath of the Renaissance who is widely considered one of the greatest painters of all time (despite less than 25 of his paintings having survived). He is also known for his , in which he made drawings and notes on science and invention; these involve a variety of subjects including anatomy, cartography, and paleontology.

Property	Value
dbo:abstract	■ Leonardo di ser Piero da Vinci (Italian: [leo'nardo di ser 'pjero da (v)'intʃi] (); 14/15 April 1452 – 2 May 1519),

DBpedia URIs

Similarly, make sure you use the correct DBpedia URIs:

- [http://dbpedia.org/resource/...](http://dbpedia.org/resource/) is the canonical URI
- The DBpedia server returns either
 - [http://dbpedia.org/page/...](http://dbpedia.org/page/) (HTML data, for a human)
 - [http://dbpedia.org/data/...](http://dbpedia.org/data/) (RDF data, for an AI)

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Shortening URIs

Instead of always writing full URIs (IRIs), we can split them into a **prefix** and **suffix**,
e.g.: <http://dbpedia.org/resource/Leonardo_da_Vinci>

- We define a prefix **dbpedia**:

```
PREFIX dbpedia: <http://dbpedia.org/resource/>
```

- and now we can simple write:

```
dbpedia:Leonardo_da_Vinci
```

- Note: angle brackets <> only for full IRIs

→ reduces dataset sizes, easier to read

Conventions

Commonly used URLs use the same namespace prefix

- E.g., FOAF (friend-of-a-friend):

```
PREFIX foaf: <http://xmlns.com/foaf/0.1/>
```

- Lookup a prefix at <https://prefix.cc/>

→ Worksheet #1: Tasks 8 & 9

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Formats

There is no single format .rdf (like .xml), commonly used are:

RDF/XML for data exchange (somewhat deprecated)

RDFa for embedding RDF into web pages

N-Triples (N3) for streaming RDF data and bulk dataset up-/download

Turtle for human-readable files

JSON-LD for web applications

plus some variations/extensions.

N-Triples

So far, we've mostly used the N-Triples format:

```
<http://www.wikidata.org/entity/Q12418> ←  
<http://purl.org/dc/terms/title> "Mona Lisa" .
```

each line in a file is one triple, full IRIs only (no namespace prefixes) and ended by a period '.'

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```
BASE <http://example.org/>
PREFIX foaf: <http://xmlns.com/foaf/0.1/>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema>
PREFIX schema: <http://schema.org/>
PREFIX dcterms: <http://purl.org/dc/terms/>
PREFIX wd: <http://www.wikidata.org/entity/>
```

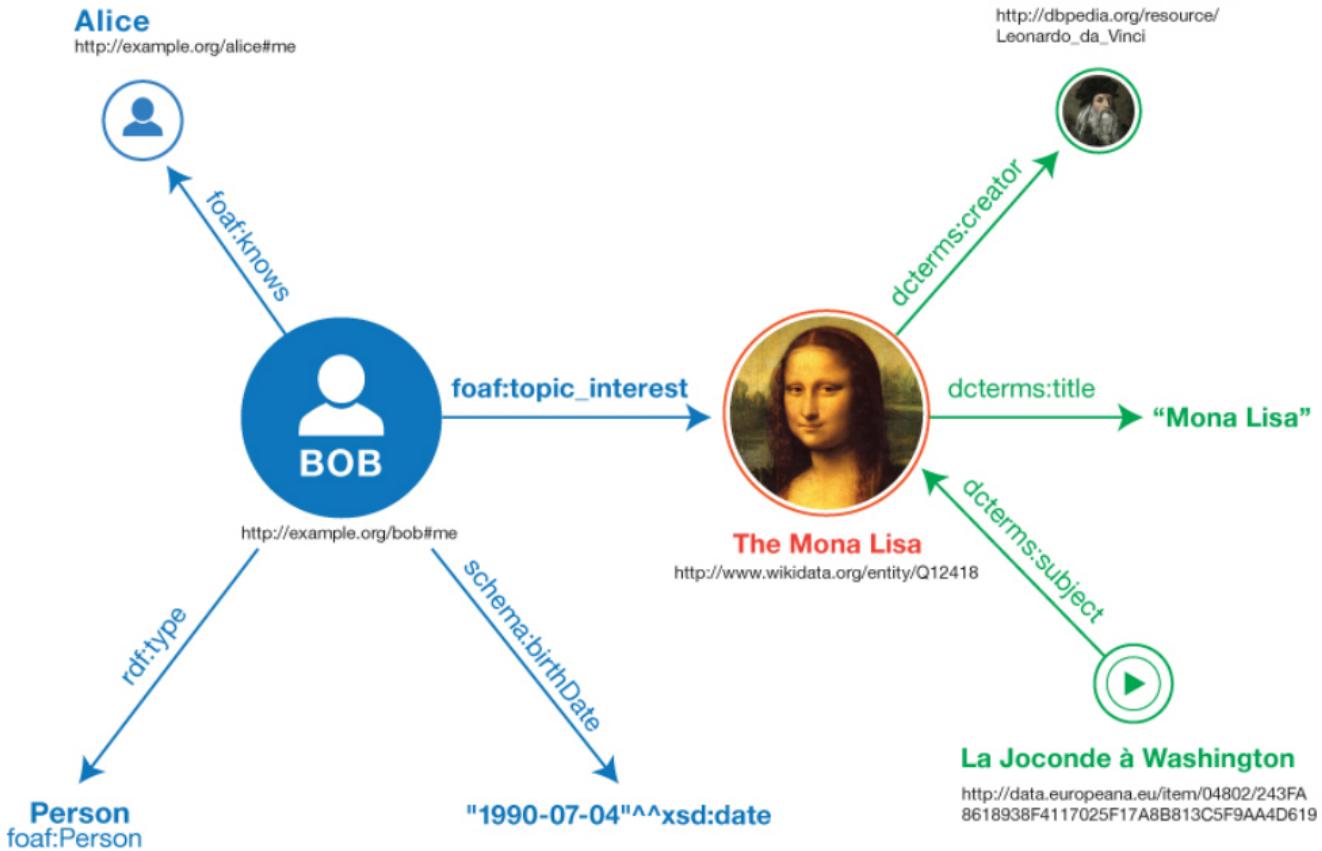
```
<bob#me>
  a foaf:Person ;
  foaf:knows <alice#me> ;
  schema:birthDate "1990-07-04"^^xsd:date ;
  foaf:topic_interest wd:Q12418 .
```

```
wd:Q12418
  dcterms:title "Mona_Lisa" ;
  dcterms:creator <http://dbpedia.org/resource/Leonardo_da_Vinci> .
<http://data.europeana.eu/item/04802/243FA8618938F4117025F17A8B813C5F9AA4D619>
  dcterms:subject wd:Q12418 .
```

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Graph corresponding to the Turtle example

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RDF in programming practice

- ▶ For example, using Python+RDFLib:
 - a “Graph” object is created
 - the RDF file is parsed and results stored in the Graph
 - the Graph offers methods to retrieve (or add):
 - triples
 - (property,object) pairs for a specific subject
 - (subject,property) pairs for specific object
 - etc.
 - the rest is conventional programming...
- ▶ Similar tools exist in Java, PHP, etc.

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Python example using RDFLib

```
# create a graph from a file
graph = rdflib.Graph()
graph.parse("filename.rdf", format="rdfformat")
# take subject with a known URI
subject = rdflib.URIRef("URI_of_Subject")
# process all properties and objects for this subject
for (s,p,o) in graph.triples((subject,None,None)) :
    do_something(p,o)
```

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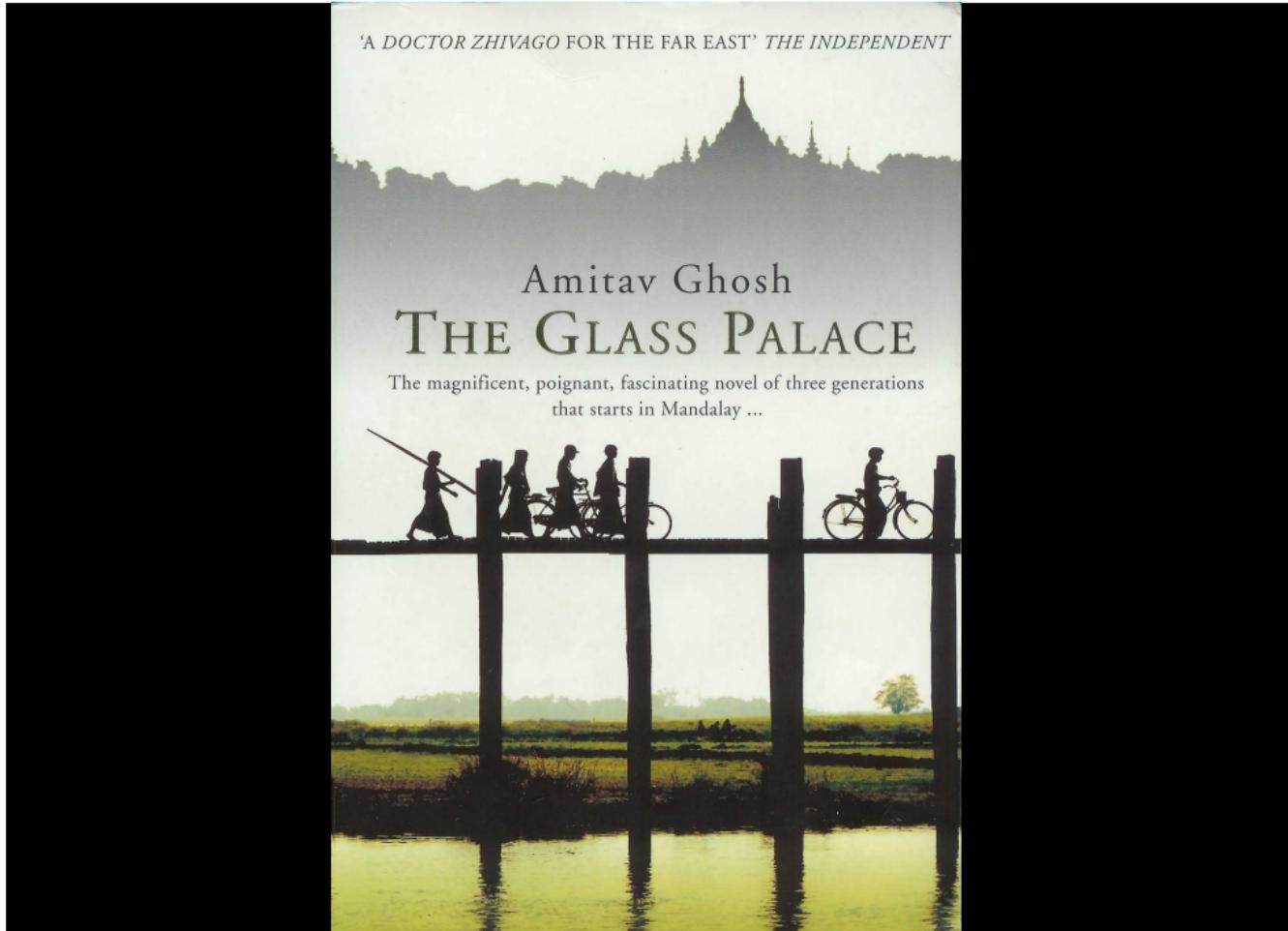
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Let's start with a Book...



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A simplified bookstore data (dataset “A”)

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ISBN	Author	Title	Publisher	Year
0006511409X	id_xyz	The Glass Palace	id_qpr	2000

ID	Name	Homepage
id_xyz	Ghosh, Amitav	http://www.amitavghosh.com

ID	Publisher's name	City
id_qpr	Harper Collins	London

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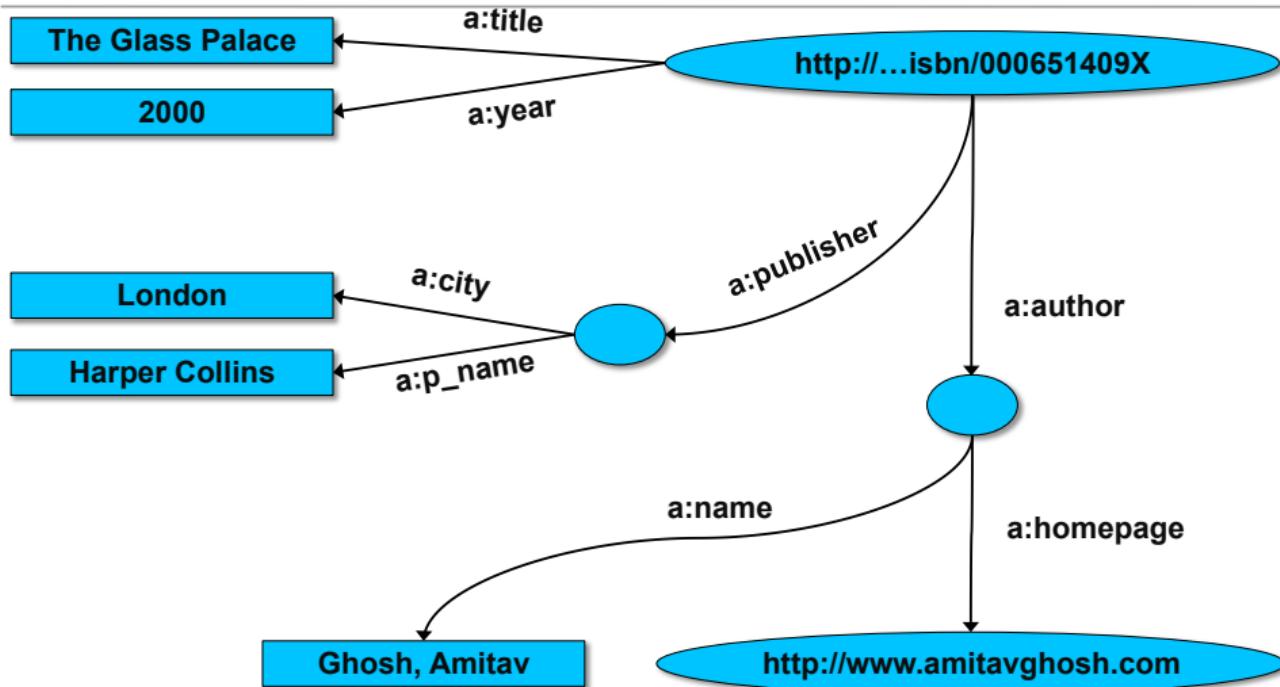
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1st: export your data as a set of relations


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Some notes on the exporting the data

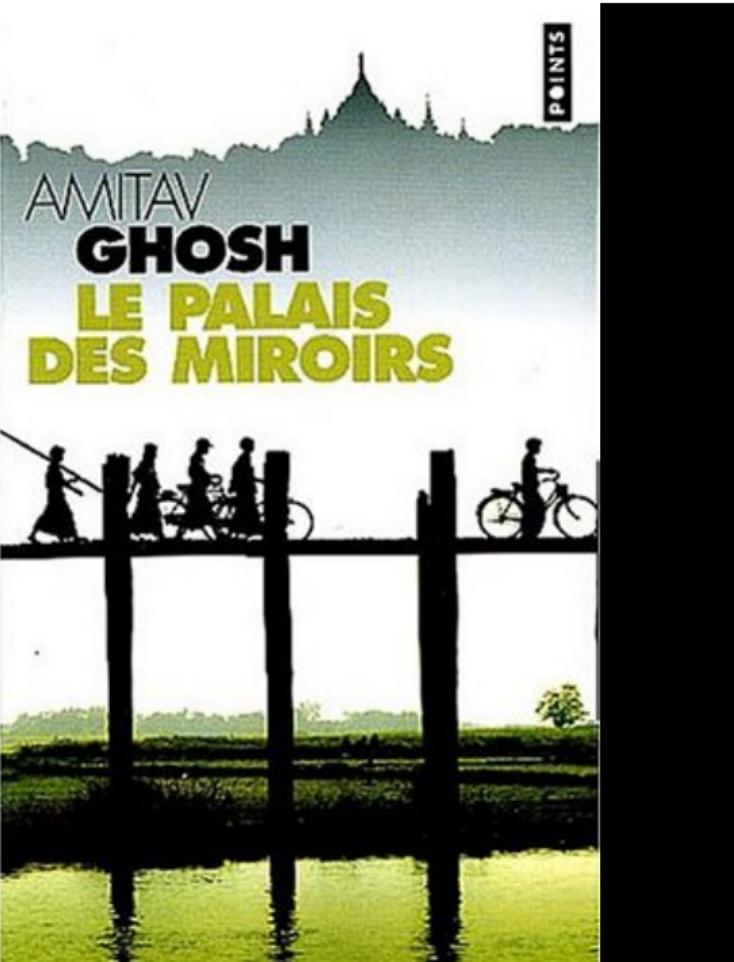
► Relations form a graph

- the nodes refer to the “real” data or contain some literal
- how the graph is represented in machine is immaterial for now

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Now the same book in French...

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Another bookstore data (dataset “F”)

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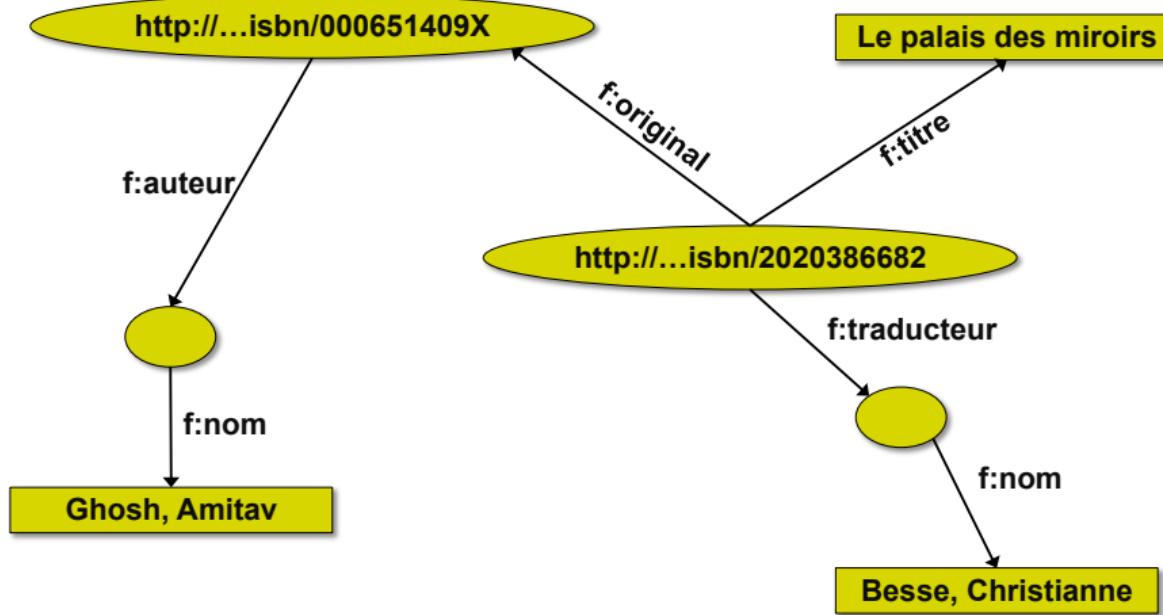
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A	B	C	D
1	ID	Titre	Traducteur
2	ISBN 2020286682	Le Palais des Miroirs	\$A12\$
3			
4			
5			
6	ID	Auteur	
7	ISBN 0-00-6511409-X	\$A11\$	
8			
9			
10	Nom		
11	Ghosh, Amitav		
12	Besse, Christianne		

2nd: export your second set of data



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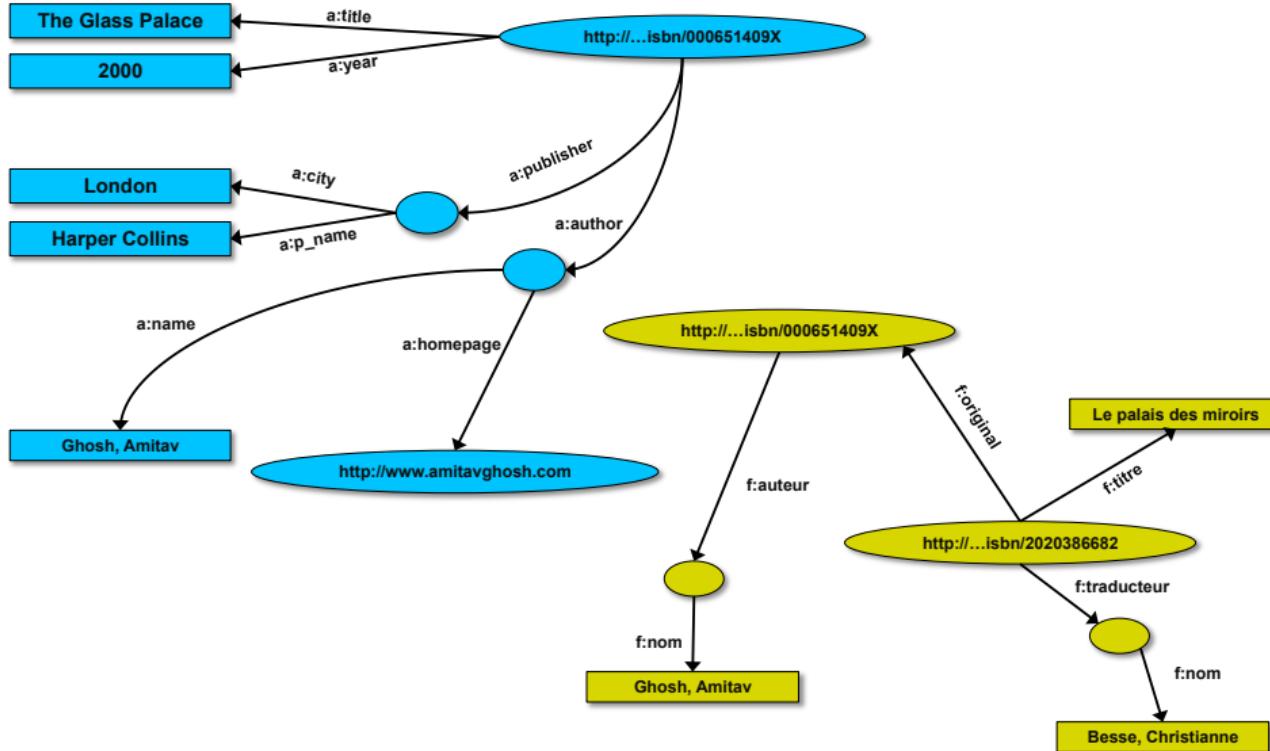
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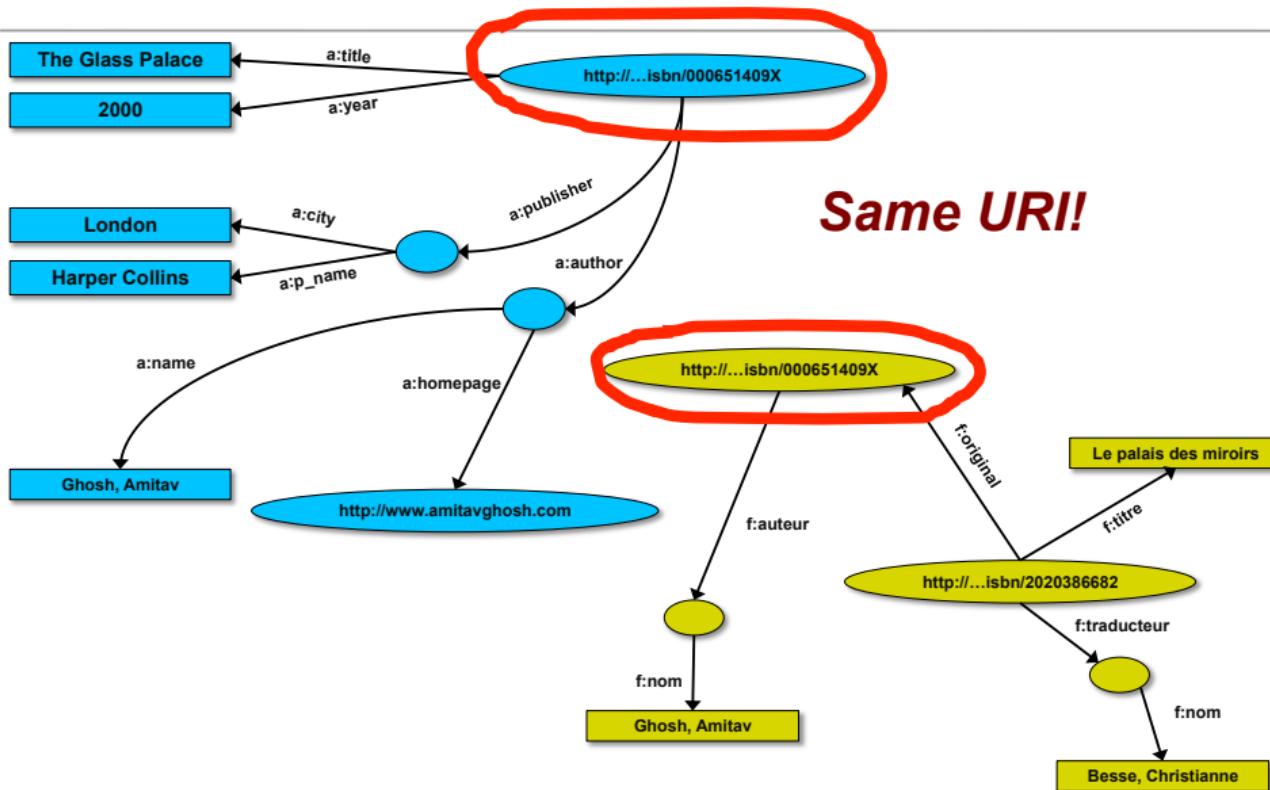
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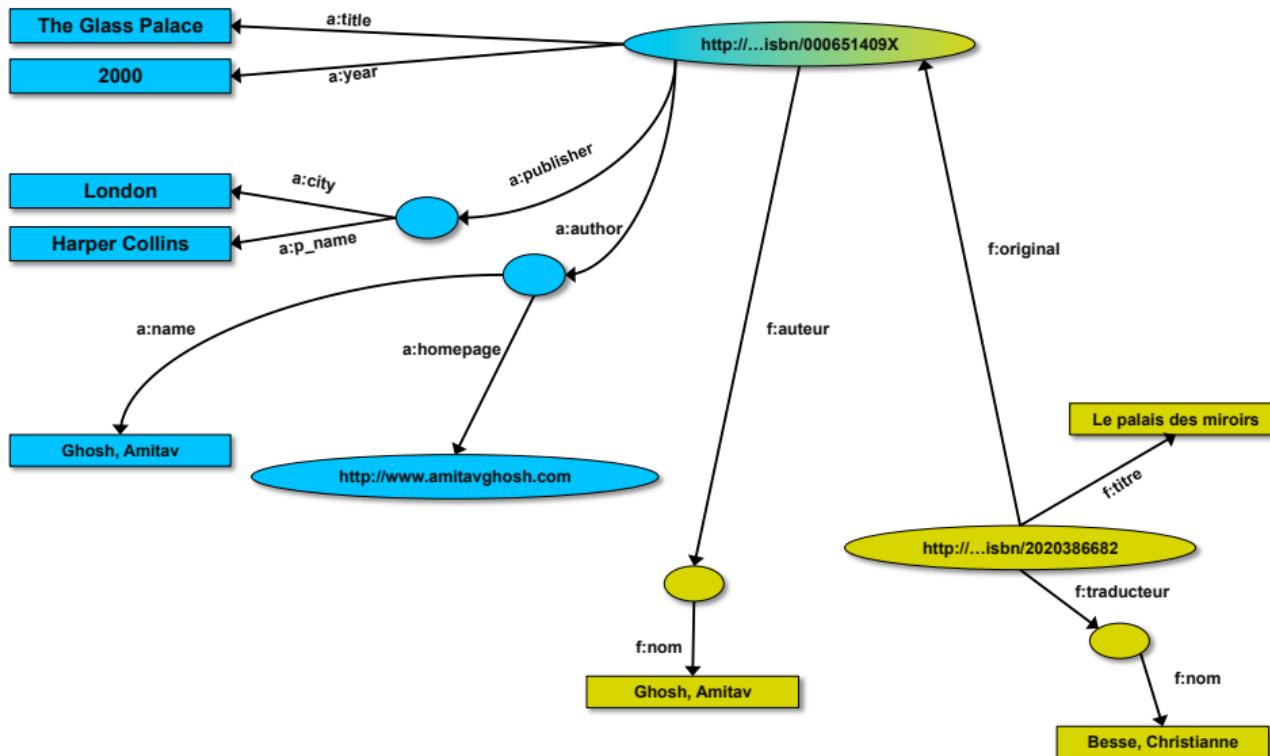
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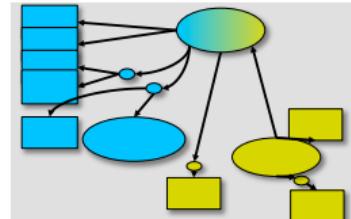
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Start making queries...

- ▶ User of data “F” can now ask queries like:
 - “give me the title of the original”
 - well, ... « donnez-moi le titre de l’original »
- ▶ This information is not in the dataset “F”...
- ▶ ...but can be retrieved by merging with dataset “A”!



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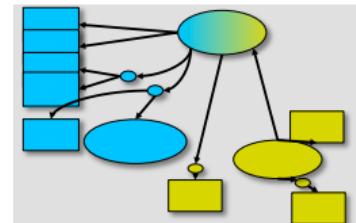
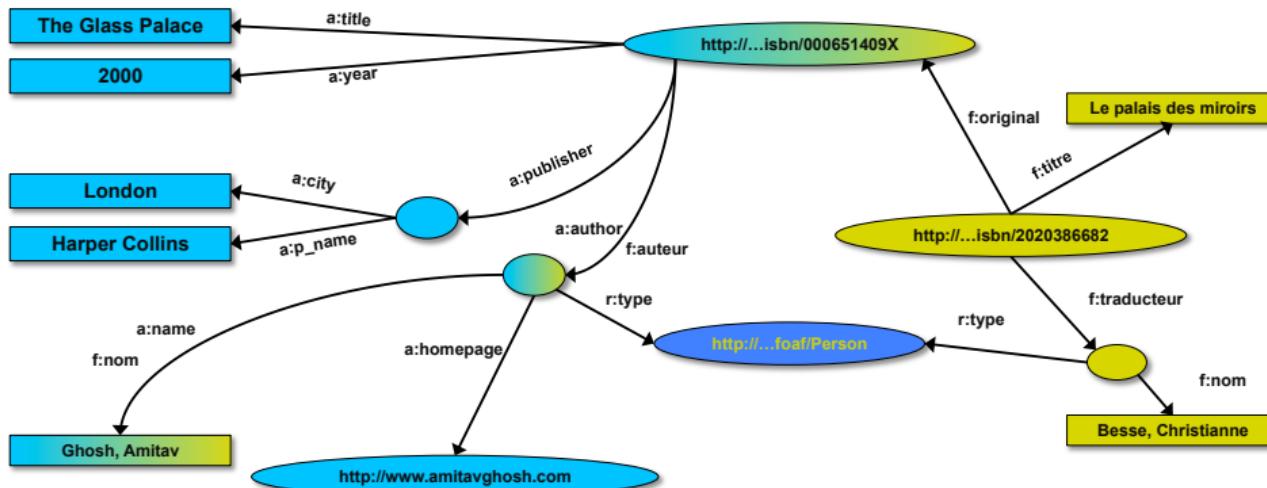
However, more can be achieved...

- ▶ We “feel” that a:author and f:auteur should be the same
- ▶ But an automatic merge does not know that!
- ▶ Let us add some extra information to the merged data:
 - a:author same as f:auteur
 - both identify a “Person”
 - a term that a community may have already defined:
 - a “Person” is uniquely identified by his/her name and, say, homepage
 - it can be used as a “category” for certain type of resources

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3rd revisited: use the extra knowledge

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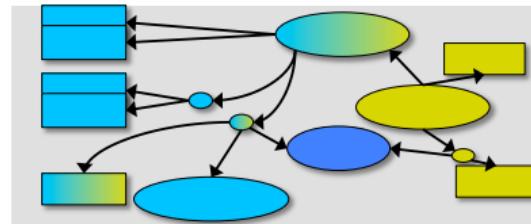
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Start making richer queries!

- ▶ User of dataset “F” can now query:
 - “donnes-moi la page d'accueil de l'auteur de l'original”
 - well... “give me the home page of the original's ‘auteur’”
- ▶ The information is not in datasets “F” or “A” ...
- ▶ ...but was made available by:
 - merging datasets “A” and datasets “F”
 - adding three simple extra statements as an extra “glue”



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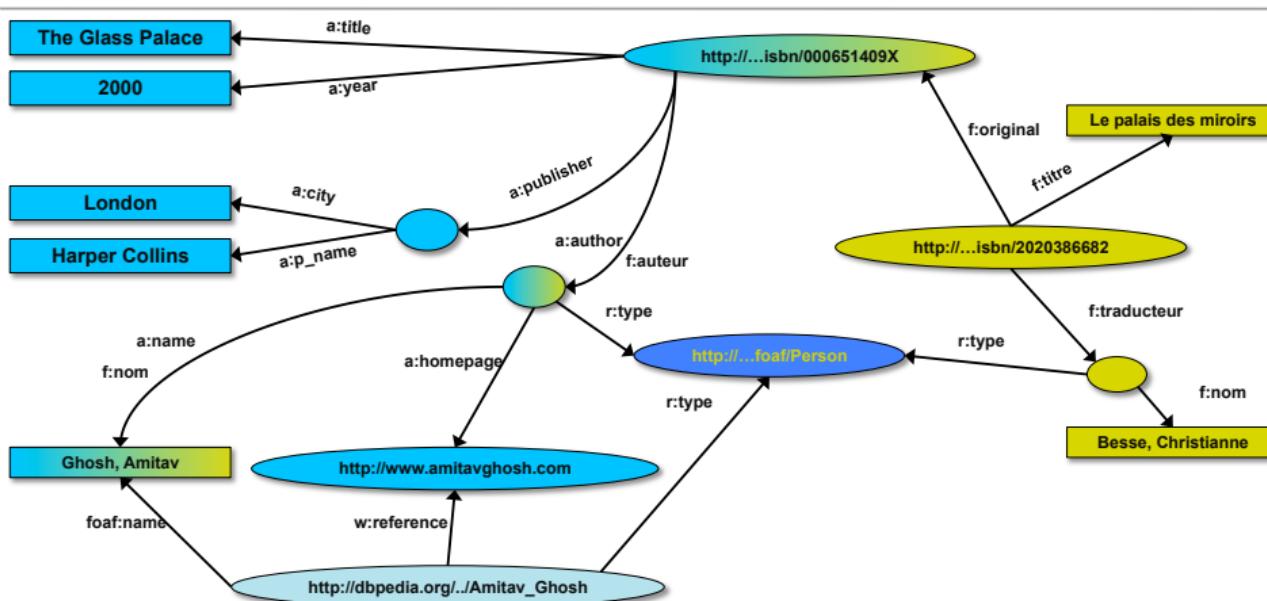
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Combine with different datasets

- ▶ Using, e.g., the “Person”, the dataset can be combined with other sources
- ▶ For example, data in Wikipedia can be extracted using dedicated tools
 - e.g., the “[dbpedia](#)” project can extract the “infobox” information from Wikipedia already...

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Merge with Wikipedia data



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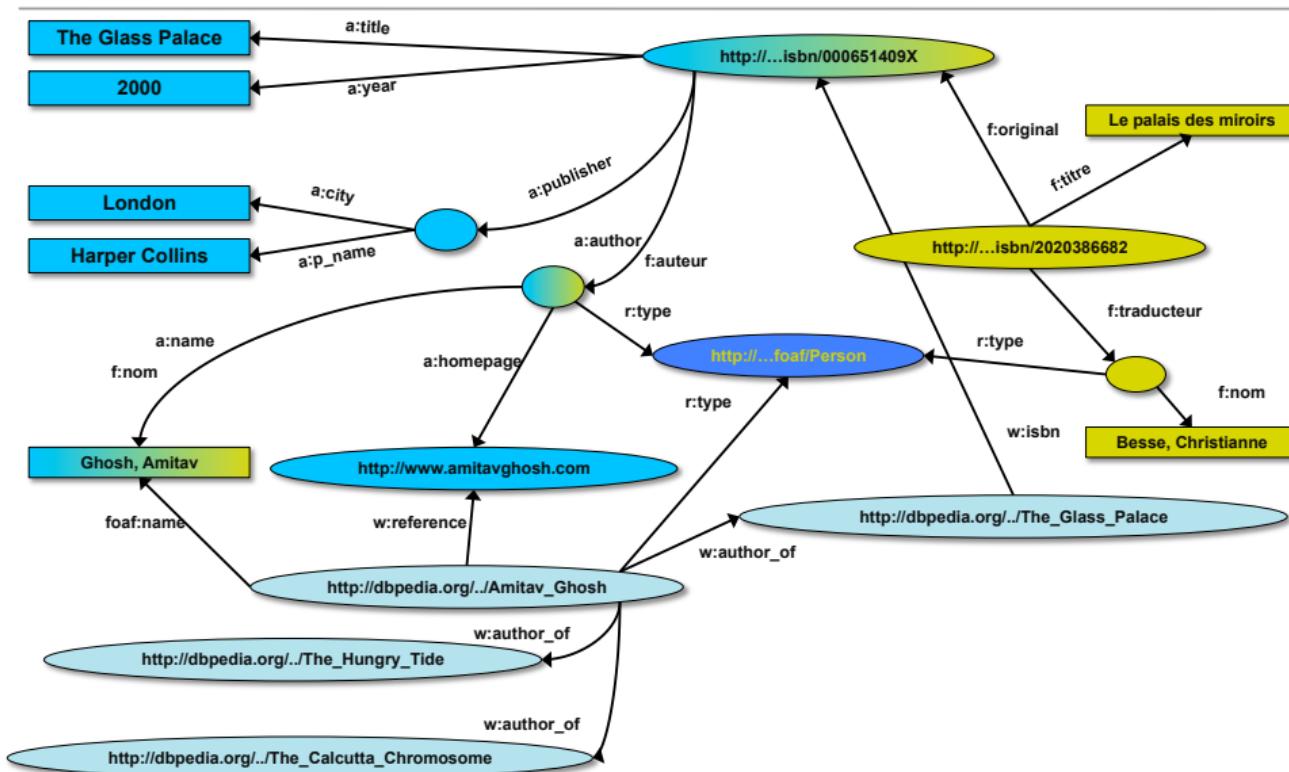
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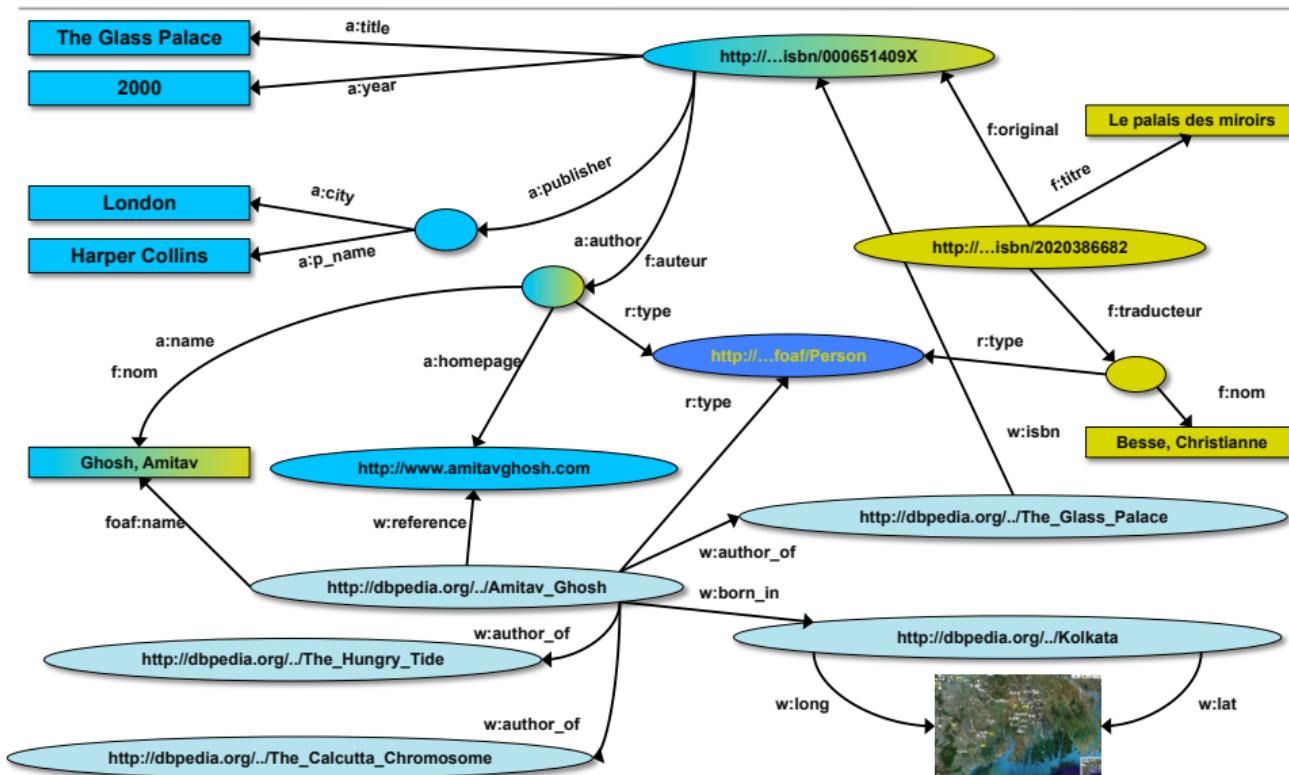
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Is that surprising?

- ▶ It may look like it but, in fact, it should not be...
- ▶ What happened via automatic means is done every day by Web users!
- ▶ The difference: a bit of extra rigour so that machines could do this, too

→ **Worksheet #1: Task 10**

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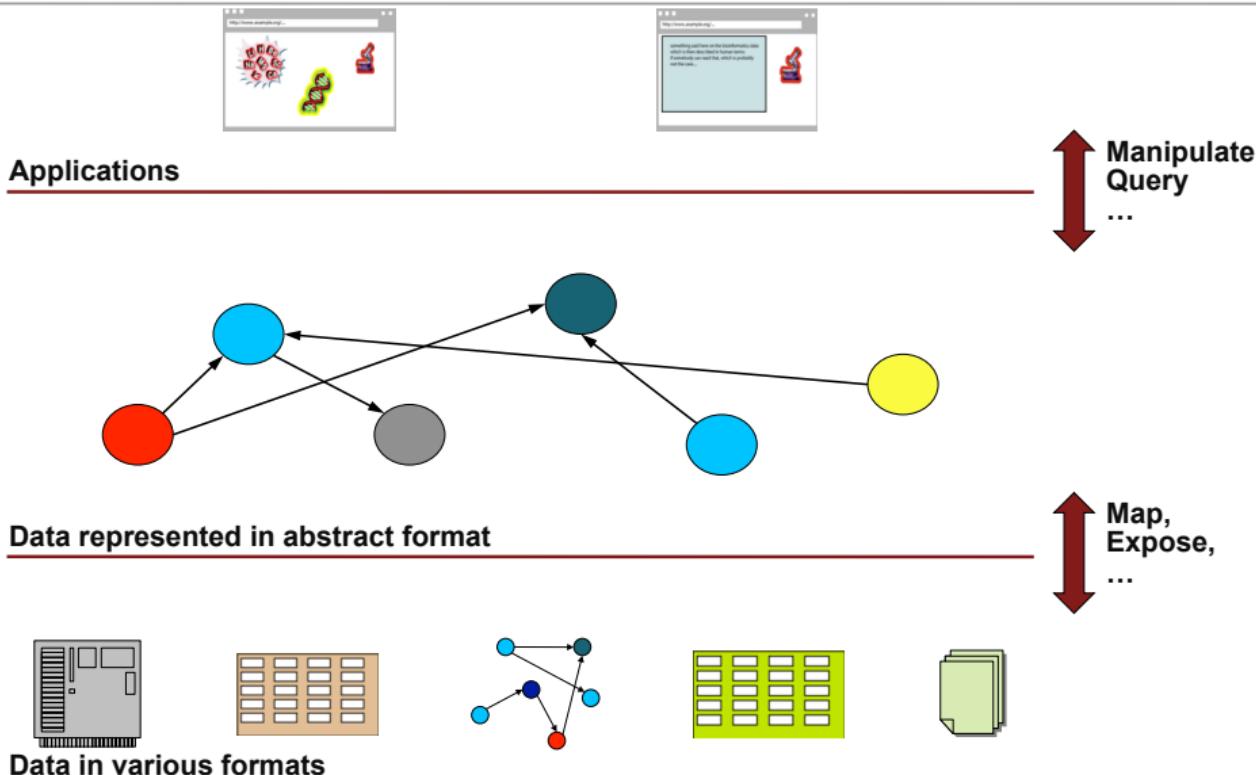
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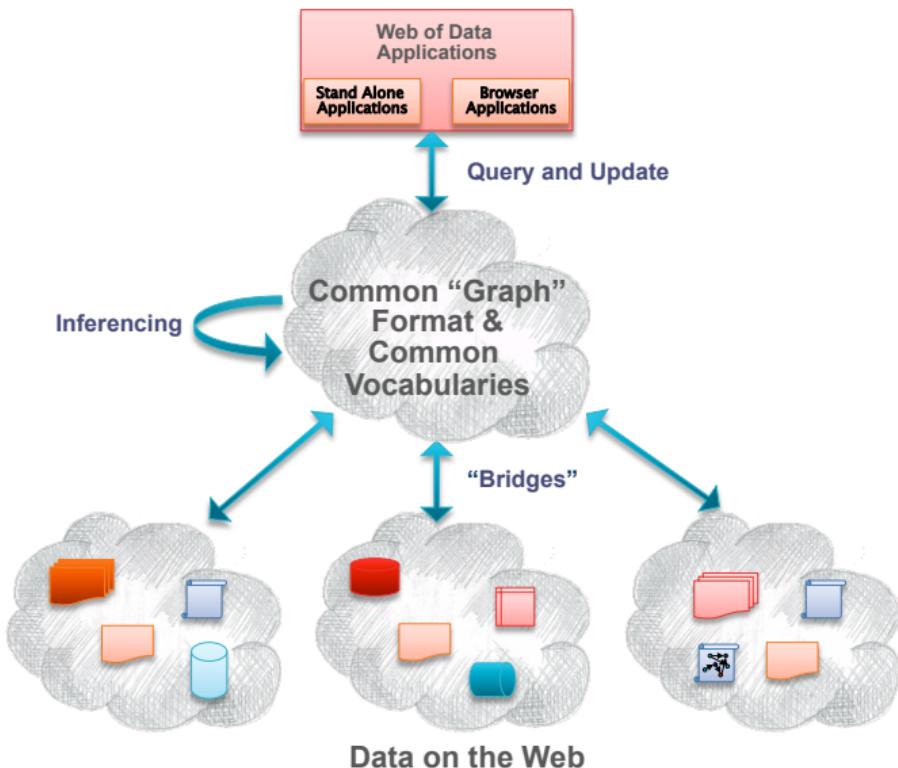
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What did we do? (alternate view)

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Google's Knowledge Graph (2012)

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Introducing the Knowledge Graph

<https://www.youtube.com/watch?v=mmQl6VGvX-c>

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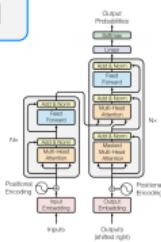
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LLMs Core function...To manipulate strings...

- GPT training focuses primarily on predicting the probability of text sequences and specifically for predicting which words come next in a sequence



LLM



Input

"When you play the game of thrones...."

Output

***...you win or you die.
There is no middle ground."***

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There is no need for this...!



when did Germany beat England by 5 goals to 1?



Germany beat England by 5 goals to 1 on September 1, 2001, in a World Cup qualifying match held at the Olympiastadion in Munich, Germany. This match is known for Germany's dominant performance and is often referred to as the "Munich Massacre" from the perspective of English football fans.



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Whereas we all know what The Truth is...



when did England beat Germany by 5 goals to 1?



England famously beat Germany by 5 goals to 1 on September 1, 2001,   
in a World Cup qualifying match held at the Olympiastadion in
Munich, Germany. This match is often referred to as the "Munich
Miracle" and is one of the most memorable victories for the England
national football team. Michael Owen was the standout player of the
match, scoring a hat-trick (three goals), while Steven Gerrard and
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when did England beat Germany by 5 goals to 1?



England famously beat Germany by 5 goals to 1 on September 1, 2001, in a World Cup qualifying match held at the Olympiastadion in Munich, Germany. This match is often referred to as the "Munich Miracle" and is one of the most memorable victories for the England national football team. Michael Owen was the standout player of the match, scoring a hat-trick (three goals), while Steven Gerrard and Emile Heskey also scored for England.



when did Germany beat England by 5 goals to 1?



Germany beat England by 5 goals to 1 on September 1, 2001, in a World Cup qualifying match held at the Olympiastadion in Munich, Germany. This match is known for Germany's dominant performance and is often referred to as the "Munich Massacre" from the perspective of English football fans.



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Making stuff up...

The ChatGPT Lawyer Explains Himself

In a cringe-inducing court hearing, a lawyer who relied on A.I. to craft a motion full of made-up case law said he “did not comprehend” that the chat bot could lead him astray.

 Share full article



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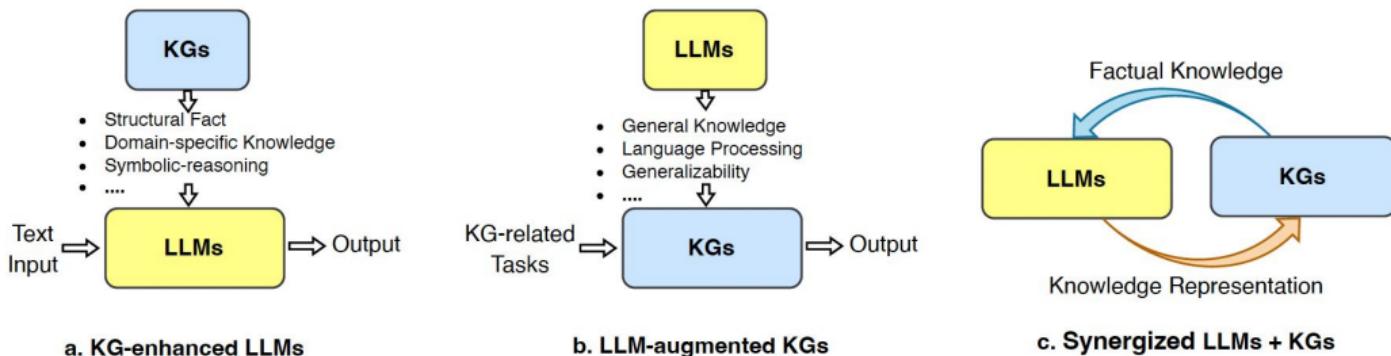


In Summary...

	Parrot	ChatGPT
Learns random sentences from random people	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
Talks like a person but doesn't really understand what it's saying	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
Occasionally speaks absolute non sense	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
Is a cute little bird	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>

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Three main ways to let LLM's work with your Graph


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How to Help LLMs Do Better?



Fine-Tuning

Provide additional training data to better tune GenAI to your use case

Few-Shot Learning

Provide completed examples “shots” to the AI as context in prompts.
a.k.a In-Context Learning

Grounding

Provide AI with the information to use for generating responses

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Grounding

Provide AI with the information to use for generating responses

Best of Both Worlds

Use the language understanding skills of LLMs but control the knowledge/sources it uses

- Improve accuracy & tailor to enterprise and use case
- Reduce hallucinations and other inconsistencies
- Control provenance

Methods

- Internet search, plugins, agents
- Query generation
- Retrieval Augmented Generation (RAG)

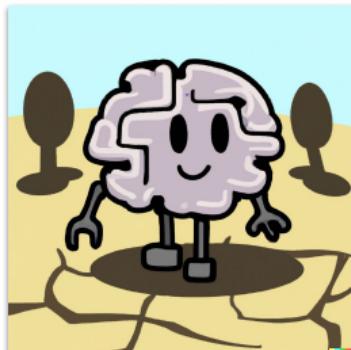
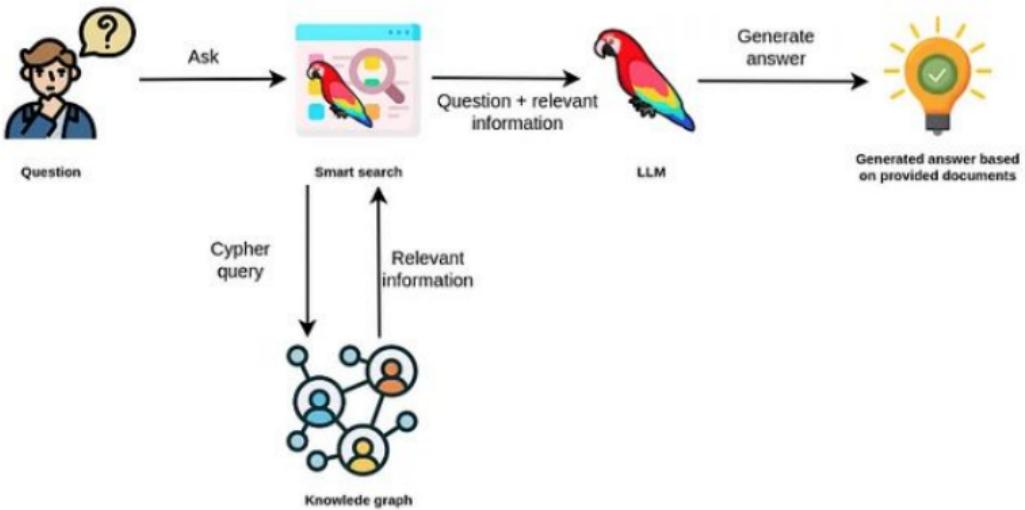


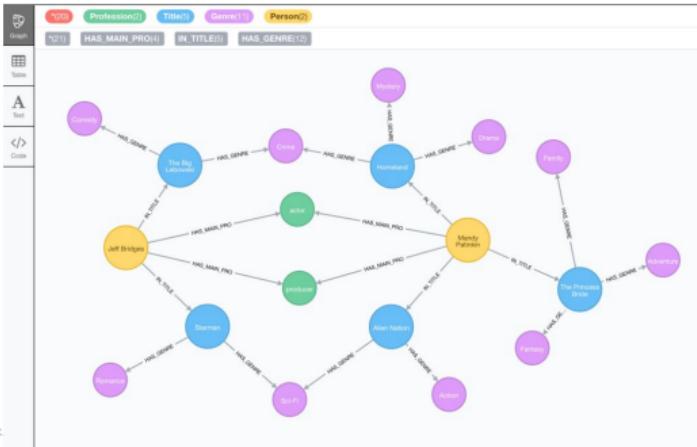
Image by GenAI (DALL-E)

Grounding with Retrieval Augmented Generation (RAG)


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Accuracy

LLMs can help generate **more accurate responses** by considering the connections and dependencies within the graph and **mapping new links as new data is identified**.



Relationships are data
that is used to return explicit results

Flexible Schema means it is easy to grow your knowledge base whenever new information is available

Vector Search adds semantic search

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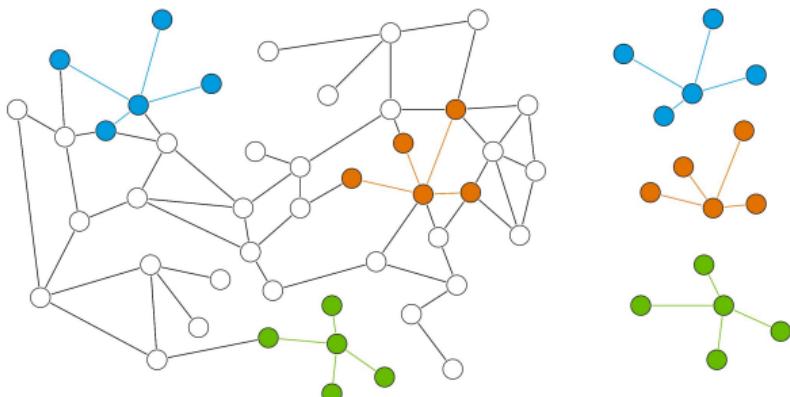
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Specificity

Knowledge graphs supply the LLM with information about your company so **answers are specific to your business**, giving more context for more accurate responses.



Add a layer of context over your LLM for **accuracy and specificity**

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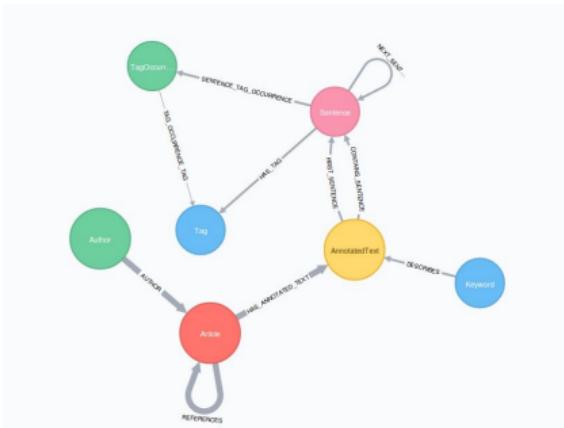
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Explainability

Verify the enriched responses from your LLM because each piece of information is linked to its sources and origins.



Represent data sources as nodes

Map relationships between search results and data source nodes

Add metadata or annotations

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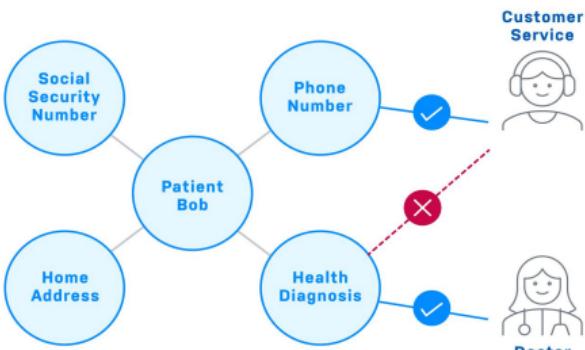
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Security & Privacy

LLM retrieves and returns information **governed by your enterprise security and access control policies** - down to the node level.



Integrates with identity and access management provider with SSO

Define policies by role or identity

Build constraints on nodes, labels, relationships, properties, specific parts of the graph, and even traversal depth

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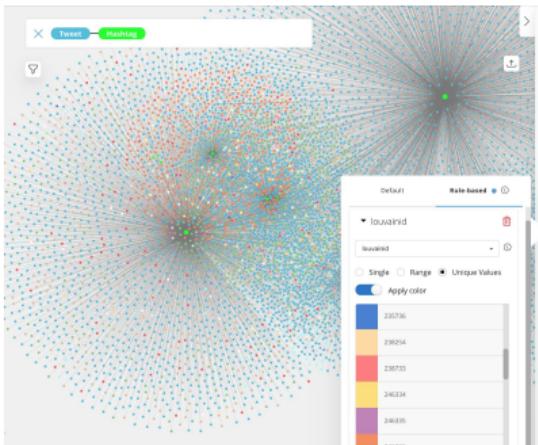
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Reliability & Low-latency

Knowledge graphs **scale** and are battle-tested to thousands of concurrent users, get answers quickly with incredibly fast query speeds.



Incredibly fast traversals with index free adjacency

Easily scale with autonomous clustering

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Required

- [Yu14, Chapters 1, 2] (Introduction, RDF)

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- [Wor14] (RDF Primer)

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- [Her] Ivan Herman.
Tutorial on Semantic Web Technologies.
<http://www.w3.org/People/Ivan/CorePresentations/RDFTutorial/>.
- [Wor14] World Wide Web Consortium (W3C).
RDF 1.1 Primer.
<http://www.w3.org/TR/rdf11-primer/>, 24 June 2014.
- [Yu14] Liyang Yu.
A Developer's Guide to the Semantic Web.
Springer-Verlag Berlin Heidelberg, 2nd edition, 2014.
<https://concordiauniversity.on.worldcat.org/oclc/897466408>.

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