Lecture 2

Knowledge Graphs

COMP 474/6741, Winter 2024

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Outline

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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

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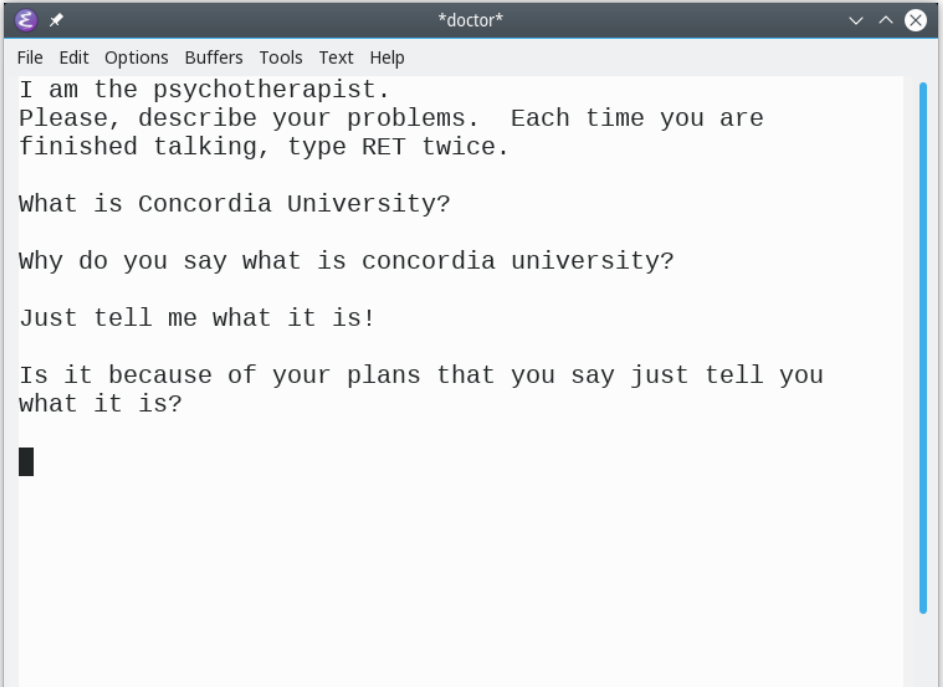
Eliza



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Google Assistant

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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

https://en.m.wikipedia.org › wiki

IBM Watson

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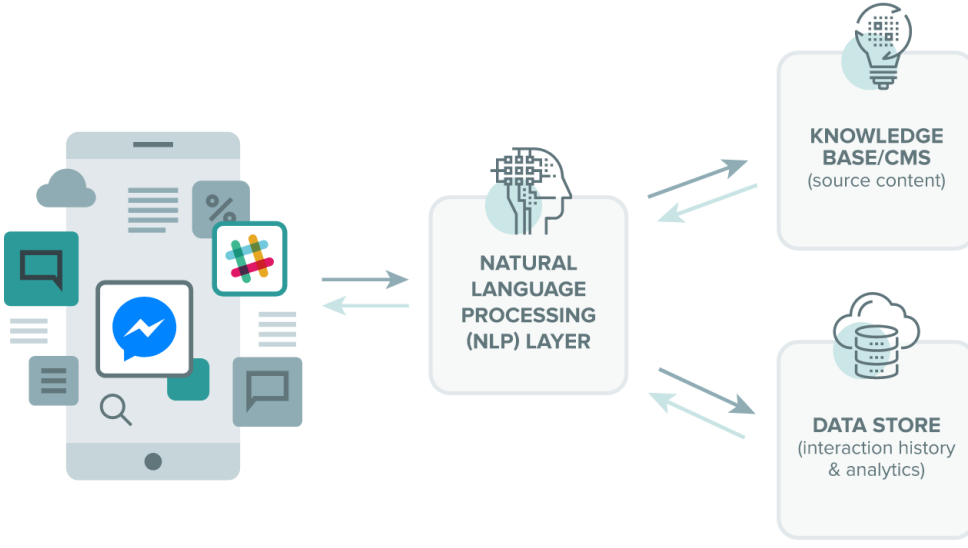
Generic Assistant Architecture



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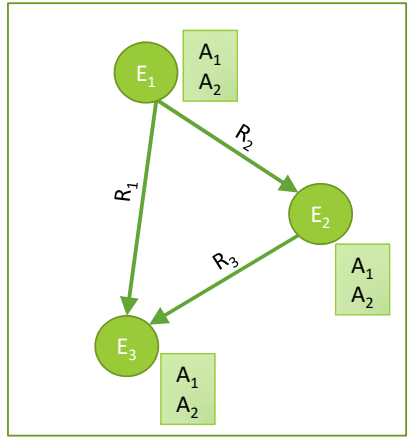
What is a knowledge graph?

- 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



Example knowledge graph

- Knowledge in graph form!
- Captures entities, attributes, and relationships
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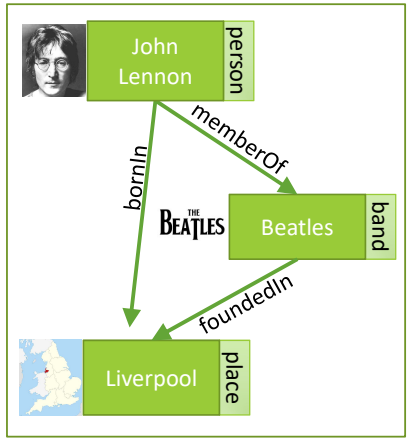
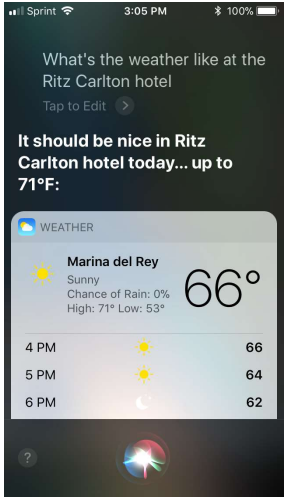
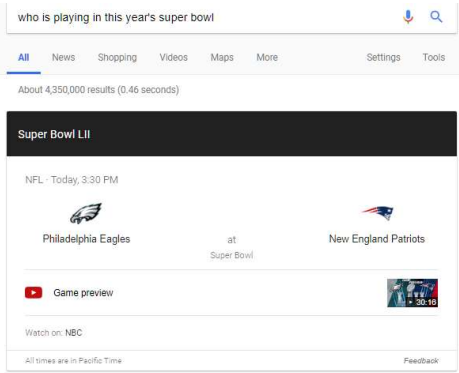


Why knowledge graphs?

- 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

Applications 1: QA/Agents





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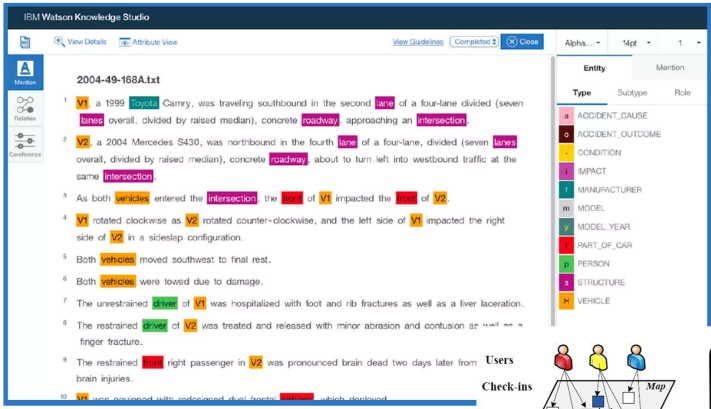
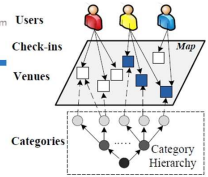
Applications 2: Decision Support





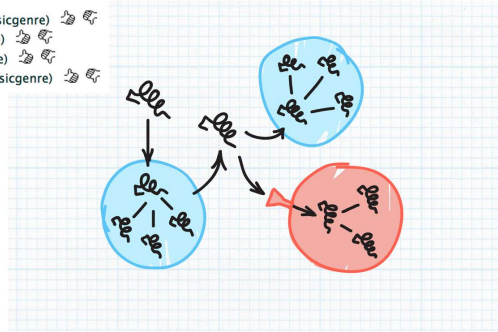
Applications 3: Fueling Discovery

beatles (musicartist)
literal strings: BEATLES, Beatles, beatles

Help NELL Learn!

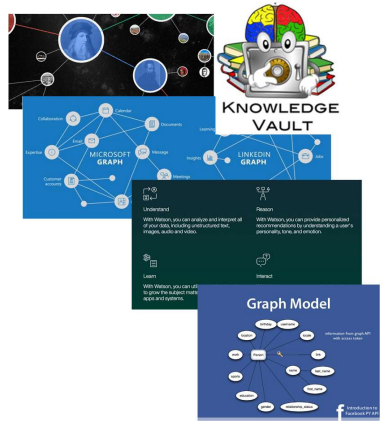
NELL wants to know if these be
If they are or ever were, click thumbs-up. O

- 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)



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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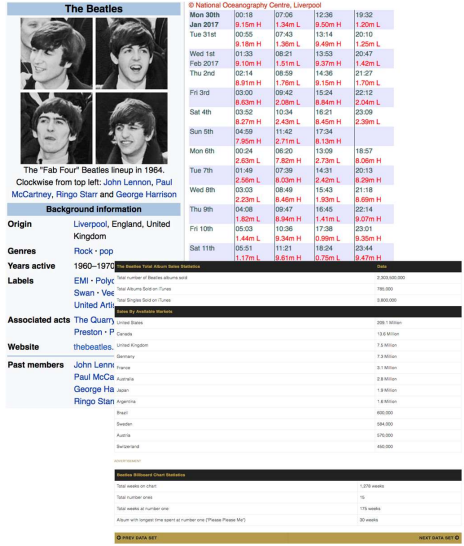
Where do knowledge graphs come from?

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



The Beatles

The "Fab Four" Beatles lineup in 1964. Clockwise from top left: John Lennon, Paul McCartney, Ringo Starr and George Harrison

Background information	
Origin	Liverpool, England, United Kingdom
Genres	Rock · pop
Years active	1960–1970
Labels	EMI · Polyc Swan · Vee United Artis
Associated acts	The Quarry Preston · P
Website	thebeatles.
Past members	John Lenn Paul McCa George Ha Ringo Starr

© National Oceanography Centre, Liverpool

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	1.43m 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	03:00	09:42	15:24	22:12
	8.63m H	2.08m L	8.84m H	2.04m L
Sat 4th	03:52	10:34	16:21	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
	2.63m L	7.82m H	2.73m L	8.06m H
Tue 7th	01:49	07:39	14:31	20:13
	2.56m L	8.03m H	2.42m L	8.29m H
Wed 8th	03:03	08:49	15:43	21:18
	2.23m L	8.46m H	1.93m L	8.69m H
Thu 9th	04:08	09:47	16:45	22:14
	1.82m L	8.94m H	1.41m L	9.07m H
Fri 10th	05:03	10:36	17:38	23:01
	1.44m L	9.34m H	0.99m L	9.35m H
Sat 11th	05:51	11:21	18:24	23:44
	1.17m L	9.61m H	0.75m L	9.47m H

The Beatles Total Album Sales Statistics	Data
Total number of Beatles albums sold	2,300,000,000
Total Albums Sold on iTunes	780,000
Total Singles Sold on iTunes	3,800,000

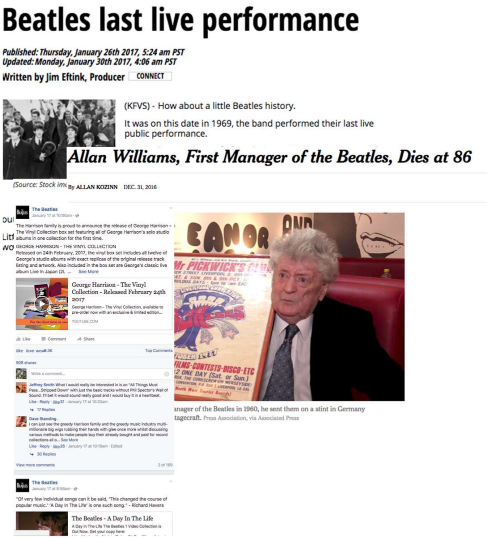
Sales By Available Markets	
United States	205.1 Million
Canada	13.6 Million
United Kingdom	7.5 Million
Germany	7.3 Million
France	3.1 Million
Australia	2.8 Million
Japan	1.9 Million
Argentina	1.6 Million
Brazil	600,000
Sweden	594,000
Austria	570,000
Switzerland	450,000

Beatles Billboard Chart Statistics	
Total weeks on chart	1,279 weeks
Total number ones	15
Total weeks at number one	175 weeks
Album with longest time spent at number one ("Please Please Me")	30 weeks

PREV DATA SET NEXT DATA SET

Where do knowledge graphs come from?

- Structured Text
  - Wikipedia Infoboxes, tables, databases, social nets
- Unstructured Text
  - WWW, news, social media, reference articles



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Where do knowledge graphs come from?

- Structured Text
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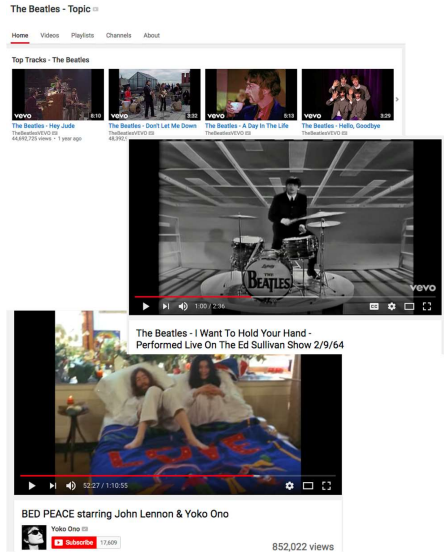
- Images

Where do knowledge graphs come from?

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



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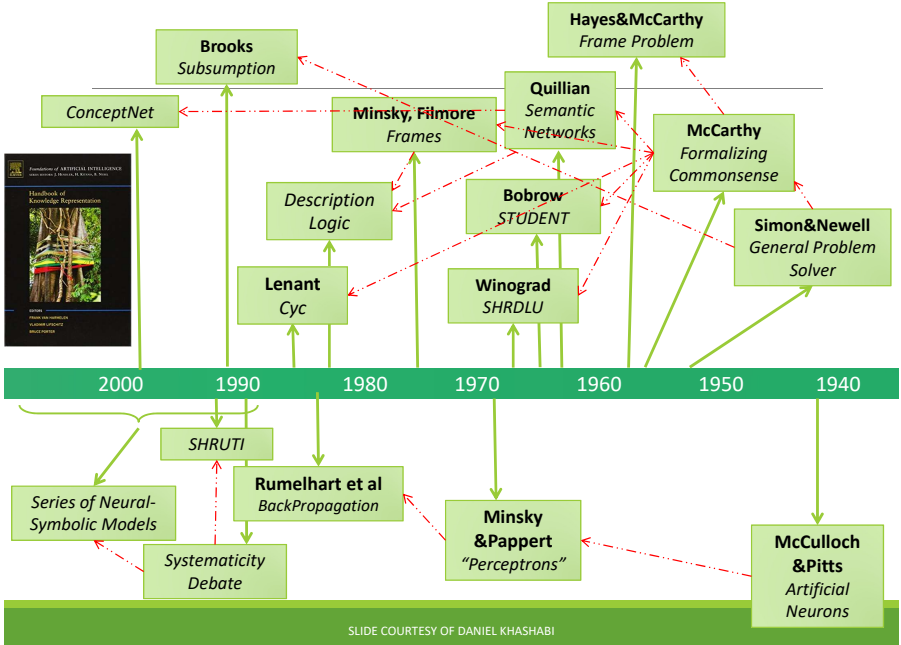
Outline

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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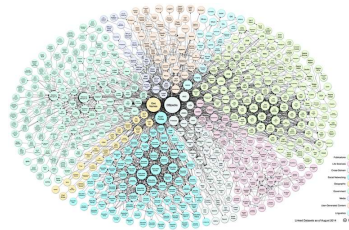
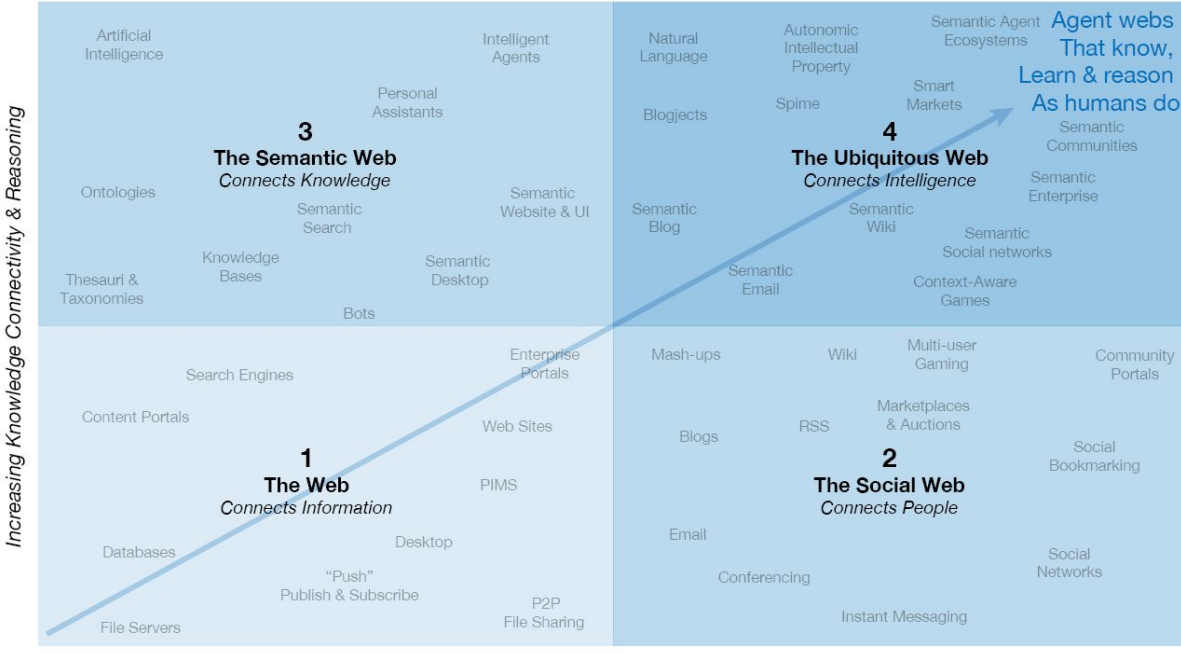
Semantic Web

- 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?




Increasing Knowledge Connectivity & Reasoning
Increasing Social Connectivity
Artificial Intelligence
Intelligent Agents
Personal Assistants
3
The Semantic Web
Connects Knowledge
Ontologies
Semantic Search
Semantic Website & UI
Knowledge Bases
Semantic Desktop
Thesauri & Taxonomies
Bots
Natural Language
Autonomic Intellectual Property
Semantic Agent Ecosystems
Agent webs That know, Learn & reason As humans do
Spime
Smart Markets
Blogjects
Semantic Communities
4
The Ubiquitous Web
Connects Intelligence
Semantic Enterprise
Semantic Blog
Semantic Wiki
Semantic Social networks
Semantic Email
Context-Aware Games
Enterprise Portals
Search Engines
Content Portals
Web Sites
1
The Web
Connects Information
PIMS
Databases
Desktop
"Push" Publish & Subscribe
P2P File Sharing
File Servers
Mash-ups
Wiki
Multi-user Gaming
Community Portals
Marketplaces & Auctions
Blogs
RSS
Social Bookmarking
2
The Social Web
Connects People
Email
Social Networks
Conferencing
Instant Messaging

Today

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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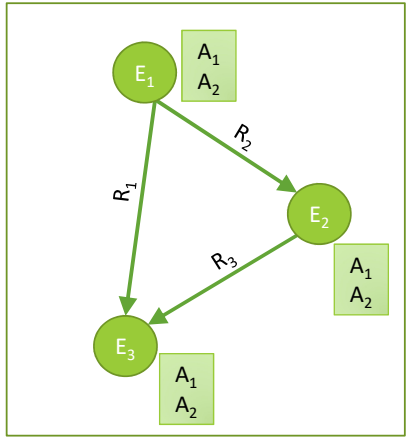

TBL at TED on “The Next Web” (2009)

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

https://www.youtube.com/watch?v=OM6XIICm_qo

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Outline

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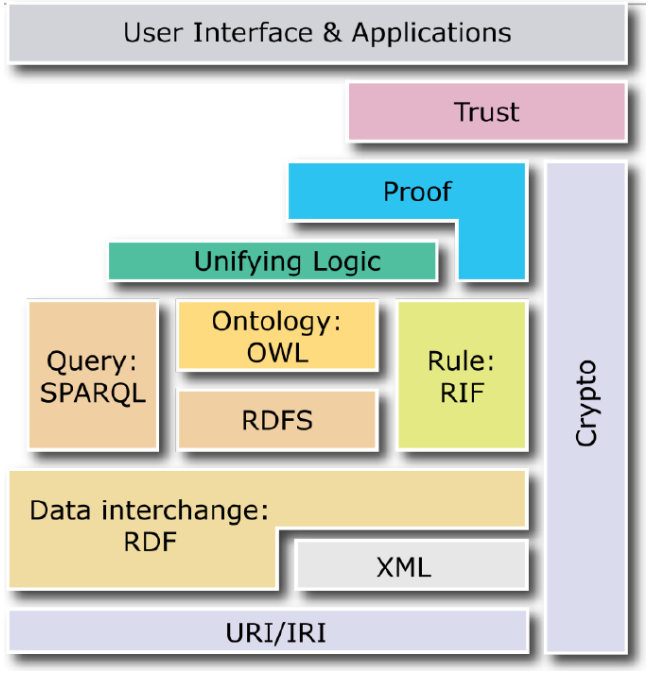
The W3C “Layer Cake”



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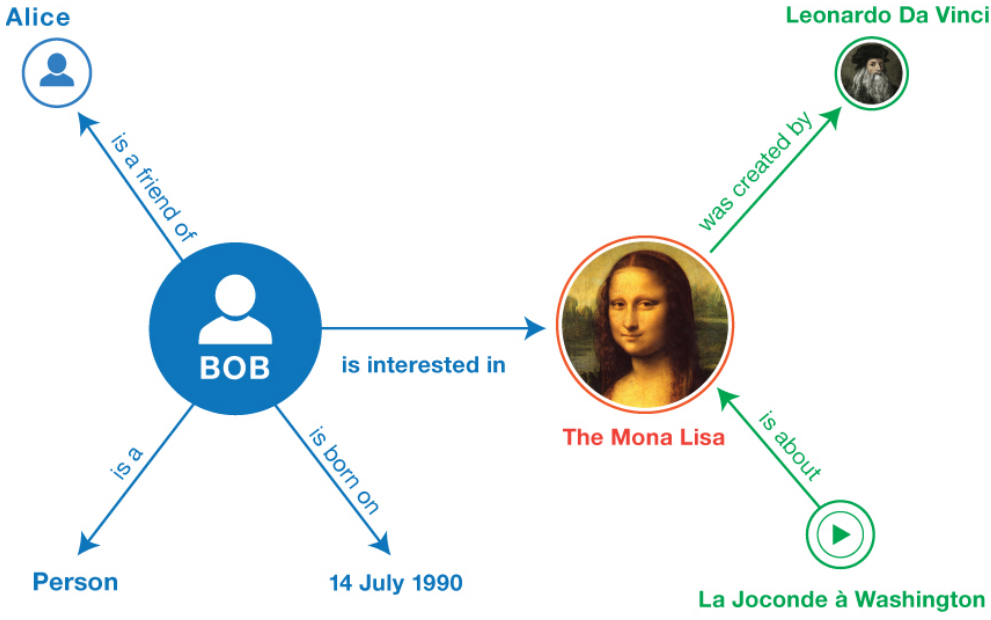
Knowledge as Graphs



→ **Worksheet #1: Tasks 1 & 2**

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

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Triples

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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**

Graphs vs. Triples

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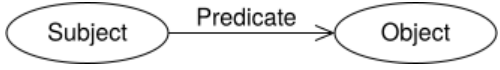
<subject> <predicate> <object>



RDF Triples

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, . . .

RDF Triples

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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**

RDF Literals

"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>`

All the details about datatypes: https://www.w3.org/TR/2014/REC-rdf11-concepts-20140225/#section-Datatypes

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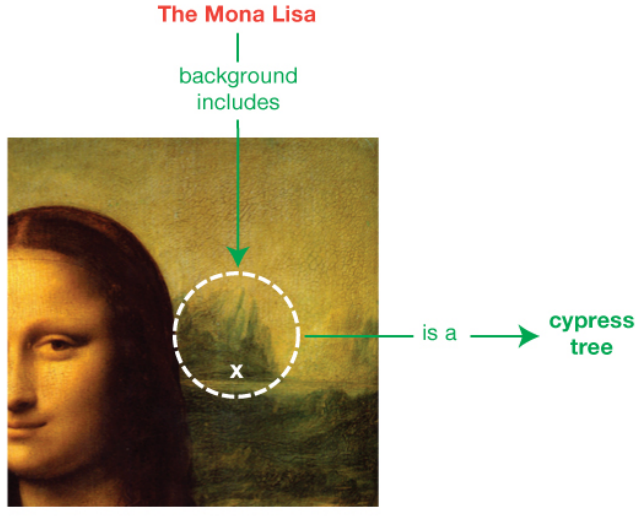
Blank Nodes




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

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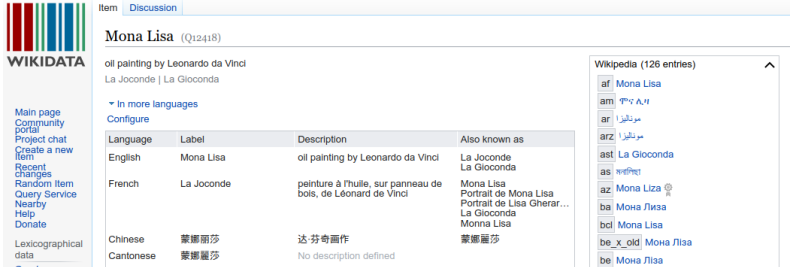
Wikidata

http://www.wikidata.org/entity/Q12418



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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DBpedia

http://dbpedia.org/resource/Leonardo_da_Vinci

DBpedia URIs

Similarly, make sure you use the correct DBpedia URIs:

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

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Namespaces

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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

Serialization

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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 `'.'`

Turtle

```
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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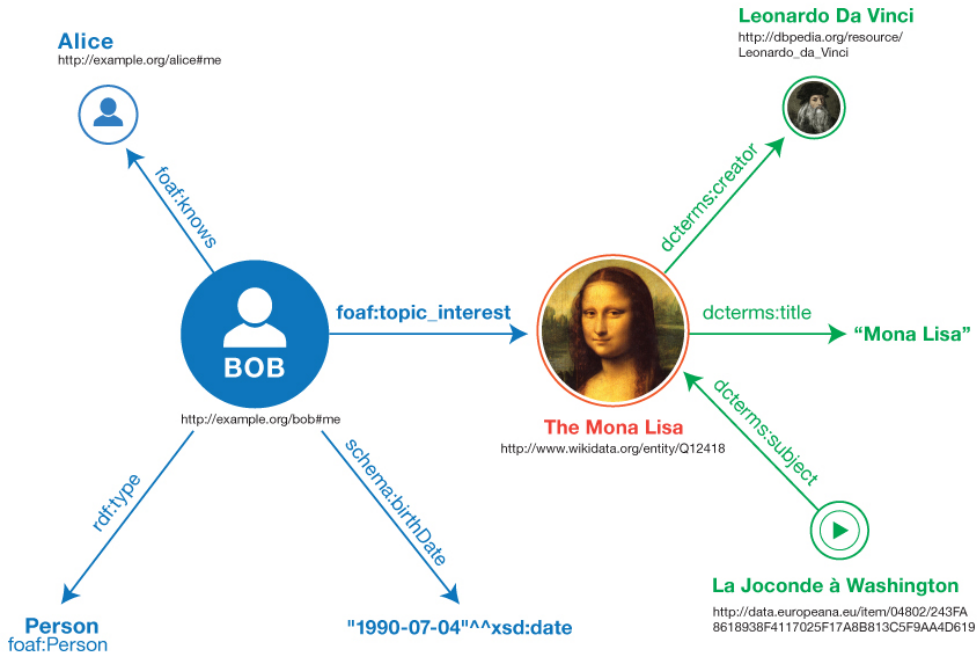
Graph corresponding to the Turtle example



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

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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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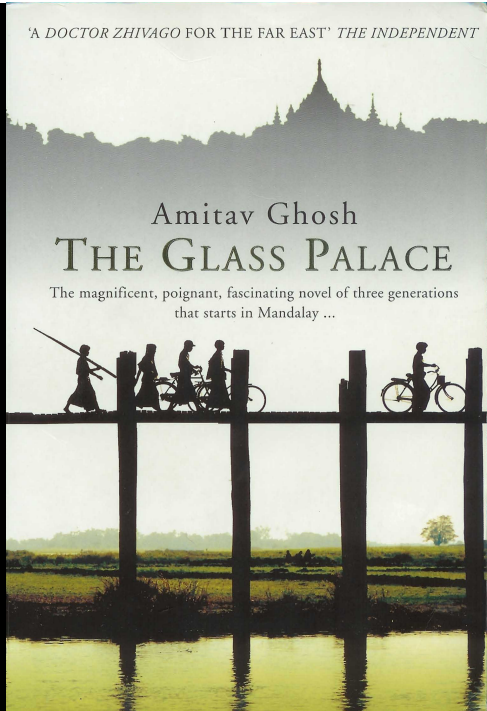
Python example using RDFLib

```
# create a graph from a file
graph = rdflib.Graph()
graph.parse("filename.rdf", format="rdfxml")
# 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)
```

Outline

Let's start with a Book...



A simplified bookstore data (dataset “A”)

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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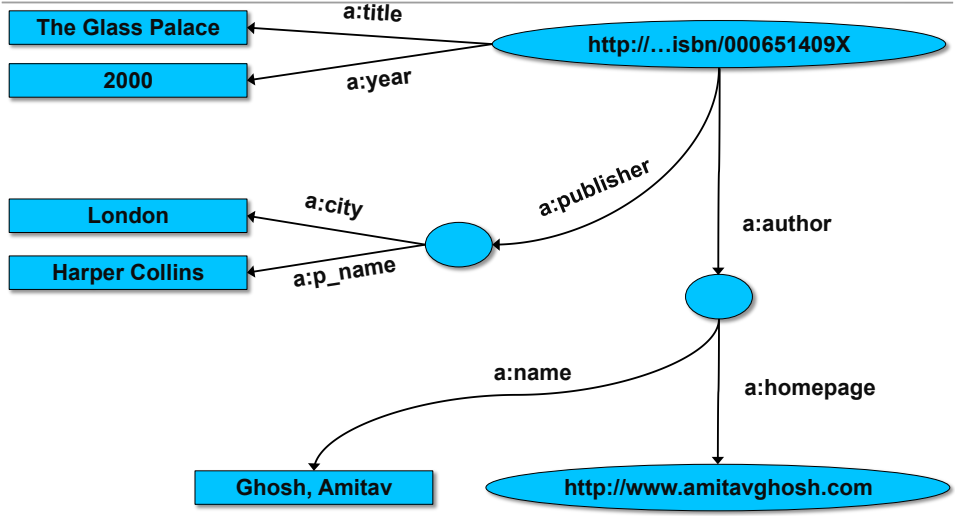
1st: export your data as a set of *relations*



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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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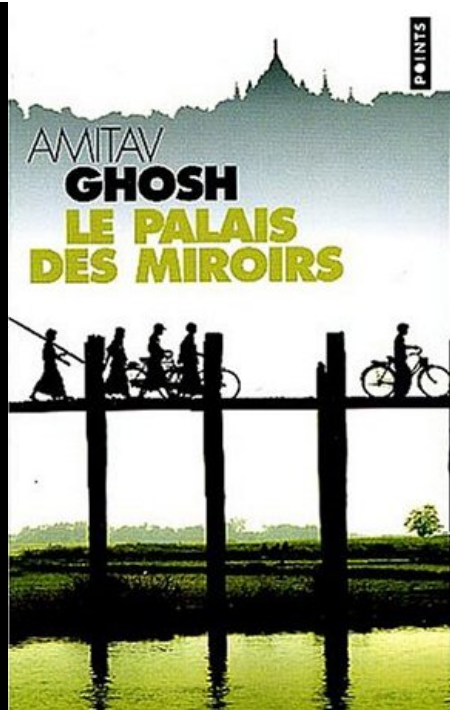
Now the same book in French. . .



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Another bookstore data (dataset “F”)

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

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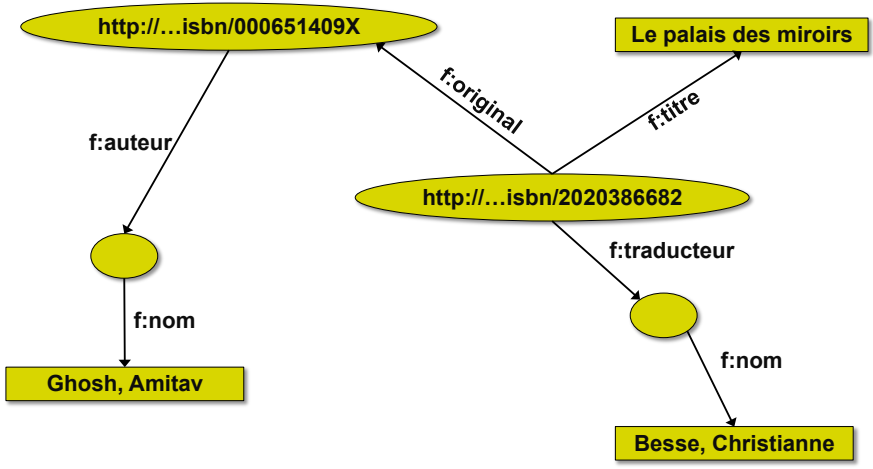
2nd: export your second set of data



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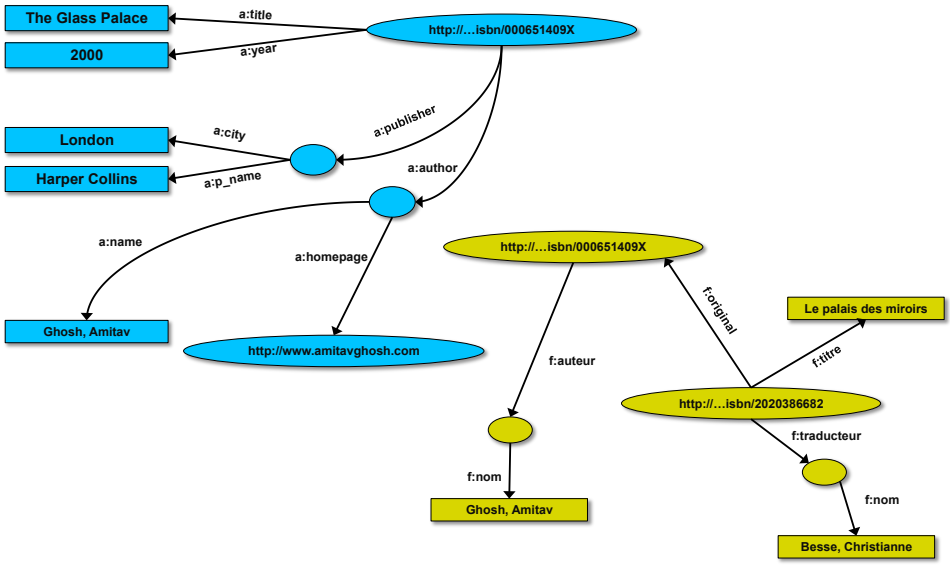
3rd: start merging your data



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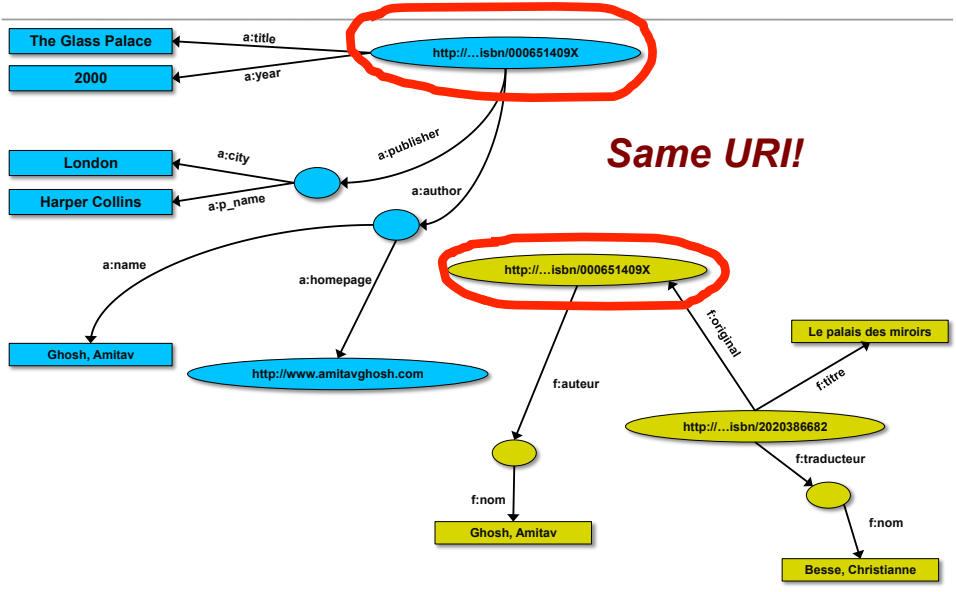
3rd: start merging your data (cont)



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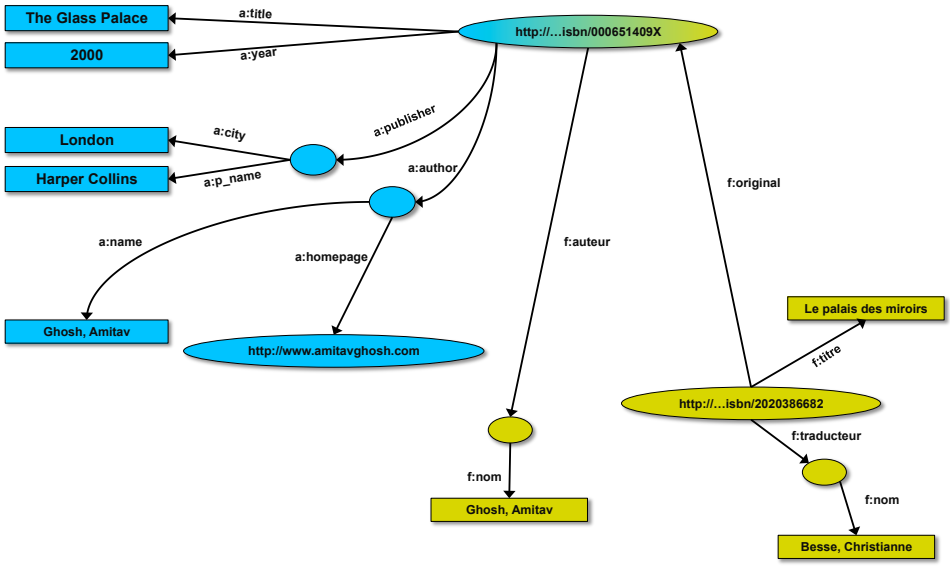
3rd: start merging your data



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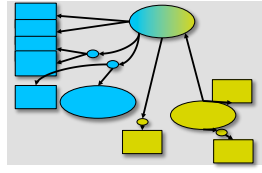
Start making queries…

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



However, more can be achieved…

- We “feel” that a:author and f:auteur should be the same
- But an automatic merge doest 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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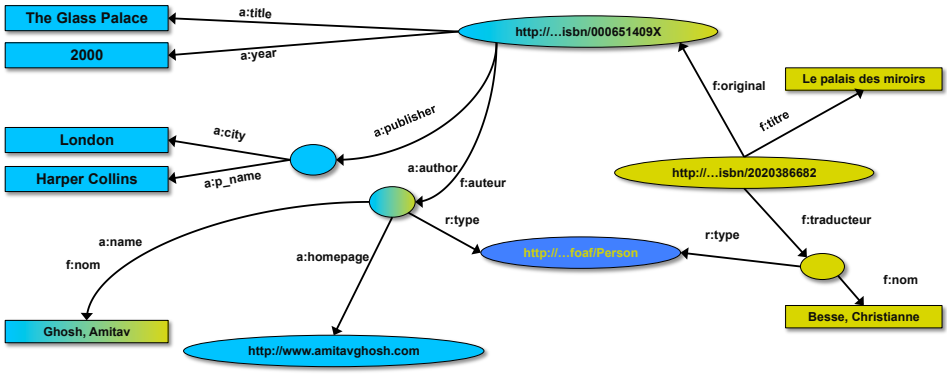
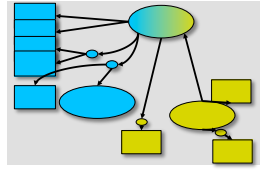
3rd revisited: use the extra knowledge





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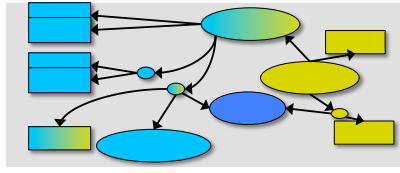
Start making richer queries!

- 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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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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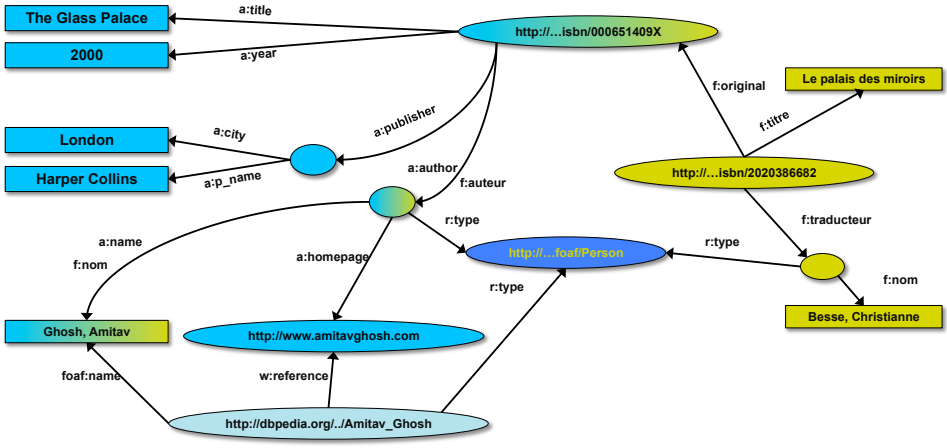
Merge with Wikipedia data



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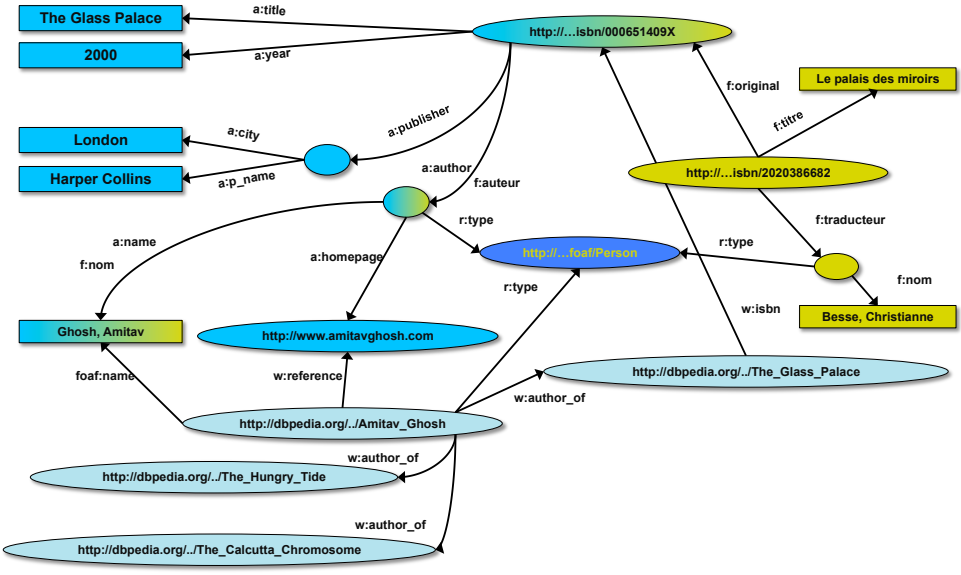
Merge with Wikipedia data



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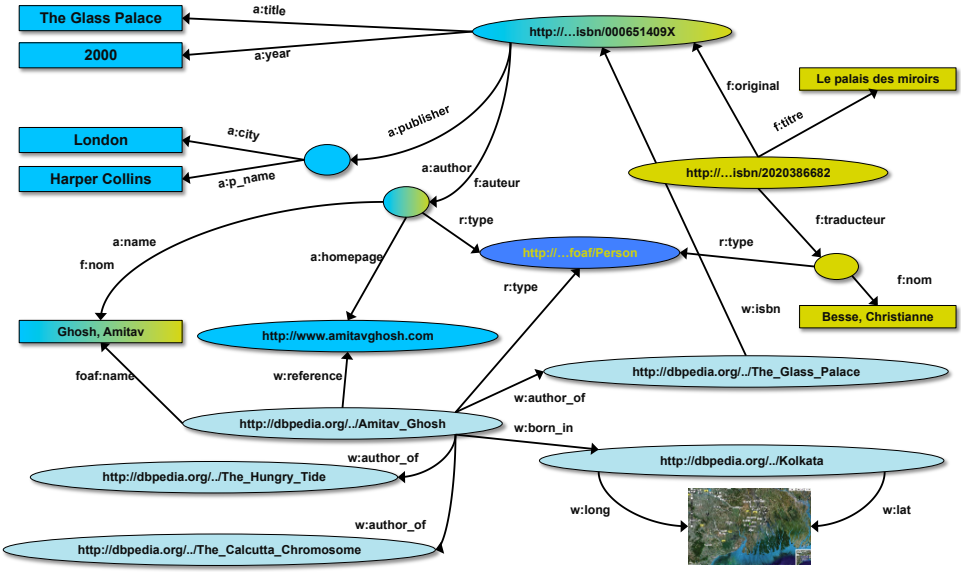
Merge with Wikipedia data



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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

Outline

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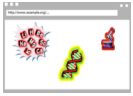
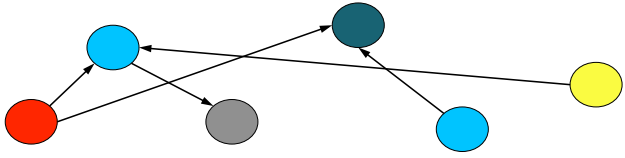
What did we do?



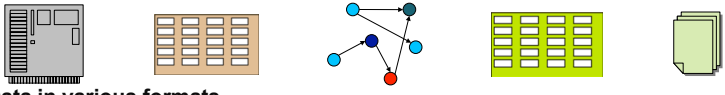
Applications

Manipulate
Query
…



Data represented in abstract format

Map,
Expose,
…



Data in various formats

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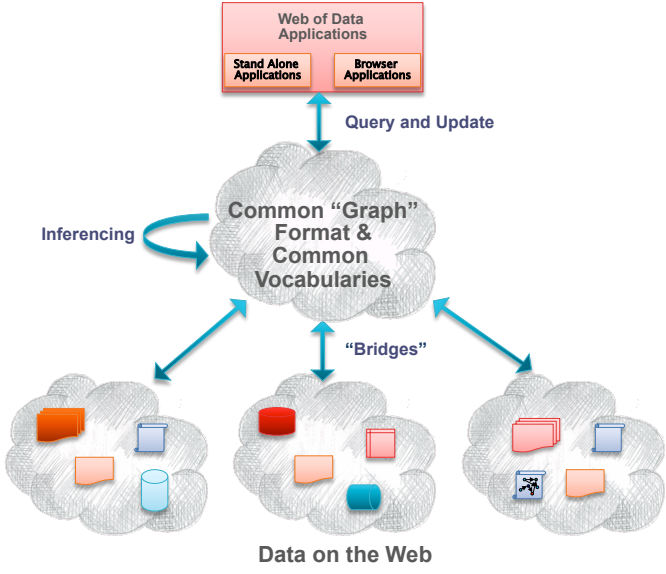
What did we do? (alternate view)



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Google's Knowledge Graph (2012)

Introducing the Knowledge Graph

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

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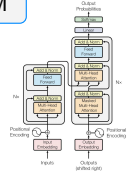
LLMs Core function…To manipulate strings…

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

Input

"When you play the game of thrones….

LLM



Output

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

neo4j

There is no need for this…!

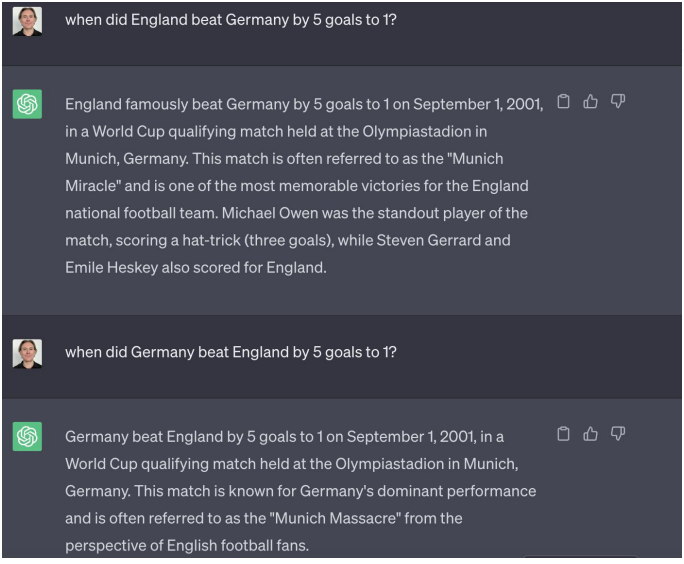
when did Germany beat England by 5 goals to 1?

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.

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 Emile Heskey also scored for England.



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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 267

In Summary…

	Parrot	ChatGPT
		
Learns random sentences from random people	☑	☑
Talks like a person but doesn't really understand what it's saying	☑	☑
Occasionally speaks absolute non sense	☑	☑
Is a cute little bird	☑	☒

neo4j

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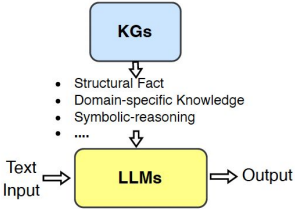
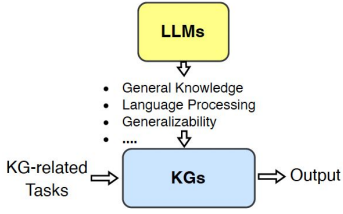
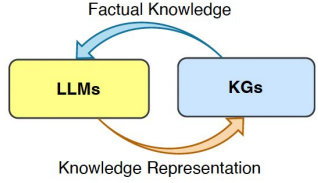
Three main ways to let LLM's work with your Graph



a. KG-enhanced LLMs



b. LLM-augmented KGs



c. Synergized LLMs + KGs

How to Help LLMs Do Better?

Fine-Tuning	Few-Shot Learning	Grounding
Provide additional training data to better tune GenAI to your use case	Provide completed examples “shots” to the AI as context in prompts. *a.k.a In-Context Learning*	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)

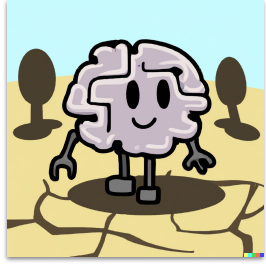
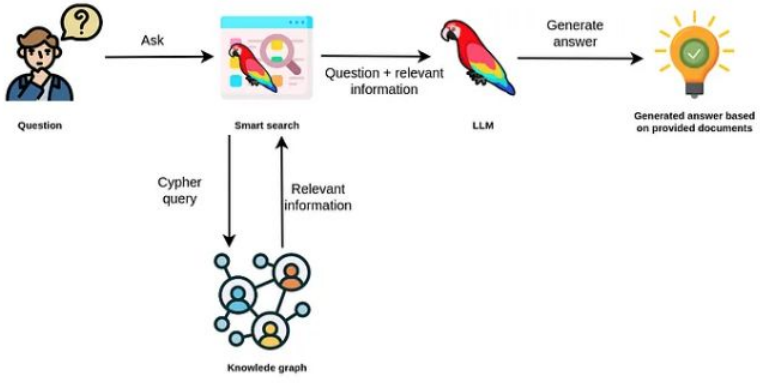


Image by GenAI (DALL-E)

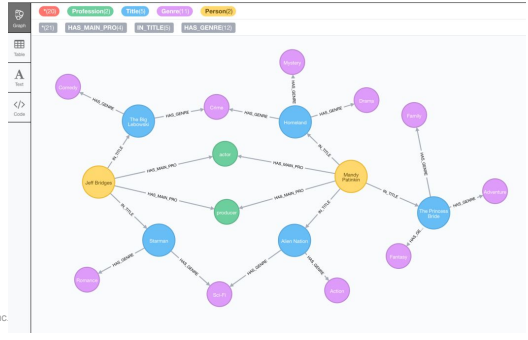
neo4j

Grounding with Retrieval Augmented Generation (RAG)



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.**



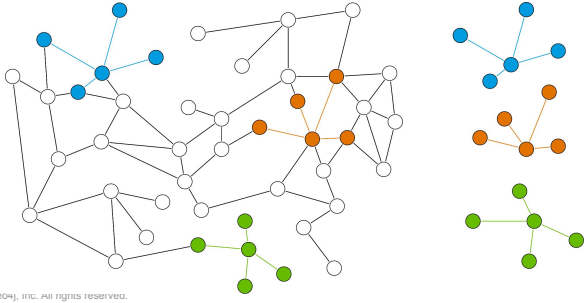
Relationships are data that is used to return explicit results

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

Vector Search adds semantic search

Specificity

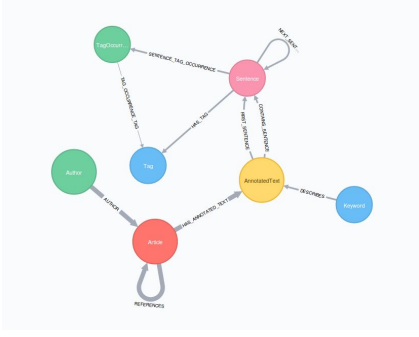
Knowledge graphs supply the LLM with information about your company so **answers are specific to your business,** giving more context for more accurate responses.



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

Explainability

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



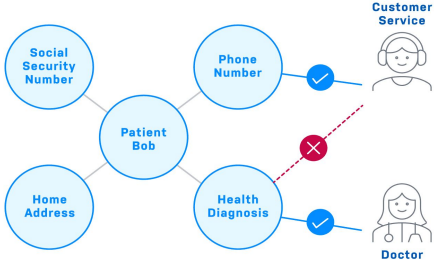
Represent **data sources as nodes**

Map relationships between search results and data source nodes

Add **metadata or annotations**

Security & Privacy

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



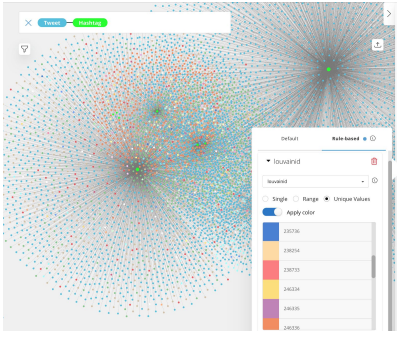
Integrates with identity and access management provider with SSO

Define policies by **role or identity**

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

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

Outline

Reading Material

Required

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

Supplemental

- [Wor14] (RDF Primer)

References

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