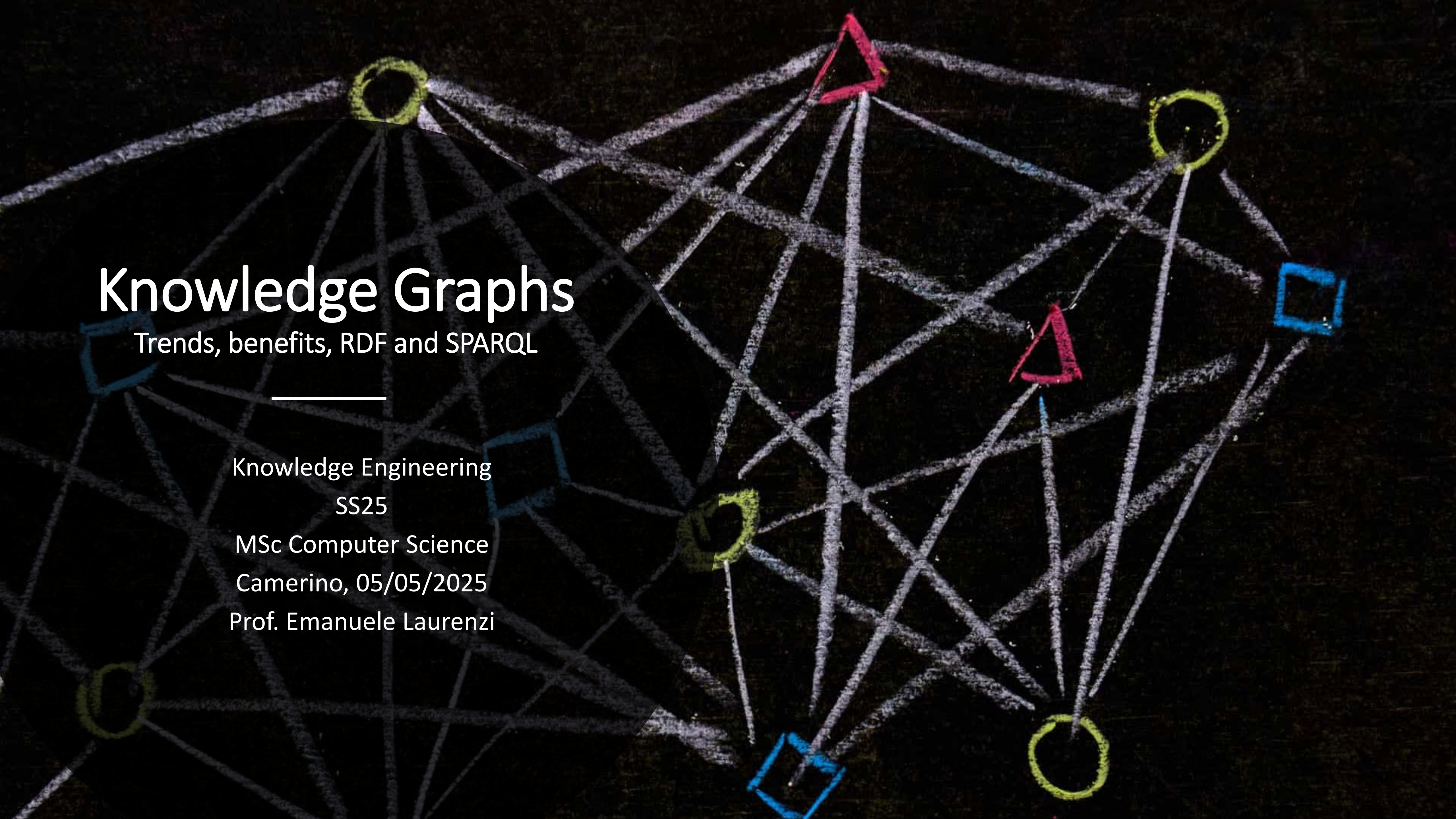


Knowledge Graphs

Trends, benefits, RDF and SPARQL

Knowledge Engineering
SS25
MSc Computer Science
Camerino, 05/05/2025
Prof. Emanuele Laurenzi

slido

What do you think of when you hear the term Knowledge Graph?

ⓘ Start presenting to display the poll results on this slide.

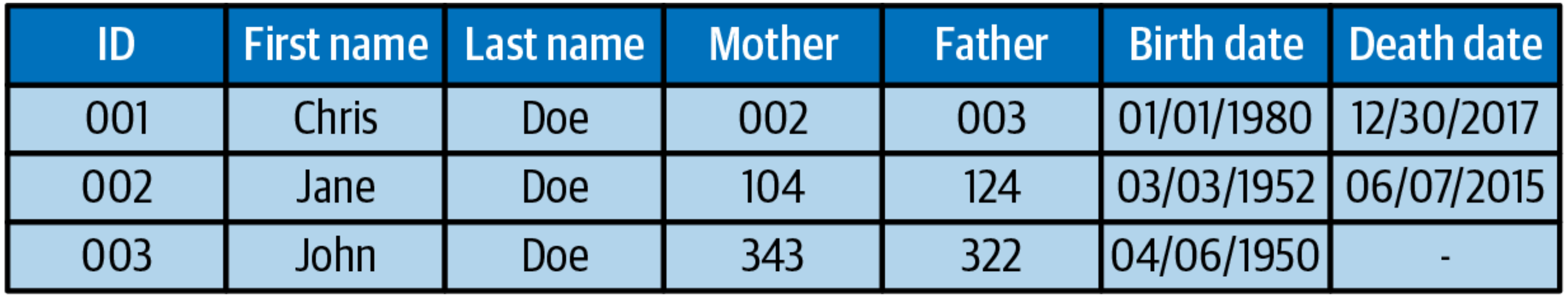
Knowledge Graph (KG) Definition

- A KG is a directed labeled graph in which domain-specific meaning are associated with nodes and edges.
- A node could represent any real-world entity,
  - for example, people, companies, computers,etc.
- An edge label captures the relationship of interest between the two nodes
  - for example, a friendship relationship between two people; a customer relationship between a company and person; or a network connection between two computers.
- Meaning of nodes and edges can be expressed in a:
  - Human interpretable language such as English -> knowledge is easily understood and verifiable by humans.
  - Machine interpretable language -> formal specification language such as first-order logic -> knowledge is computed and automated by machines.

Source: https://onlinelibrary.wiley.com/doi/10.1002/aaai.12033

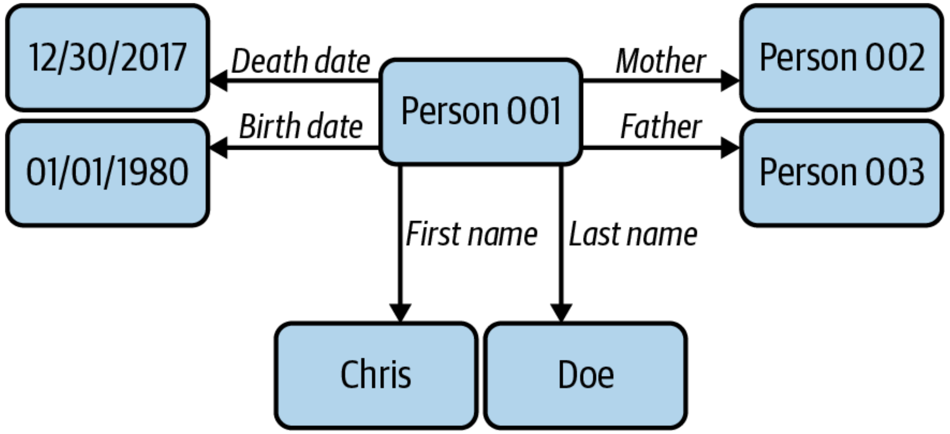
Example for human interpretability of a KG

– Who is the mother of whom?



ID	First name	Last name	Mother	Father	Birth date	Death date
001	Chris	Doe	002	003	01/01/1980	12/30/2017
002	Jane	Doe	104	124	03/03/1952	06/07/2015
003	John	Doe	343	322	04/06/1950	-

Tabular representation



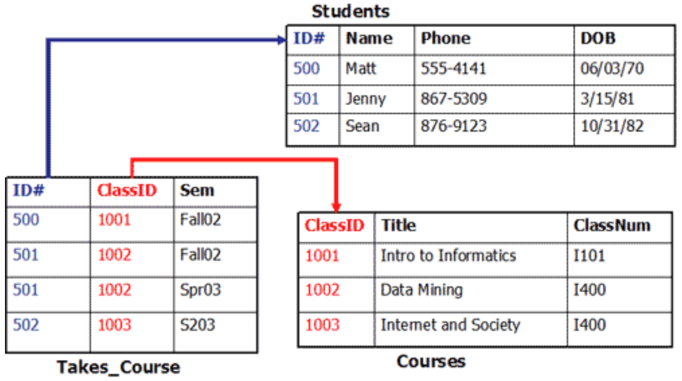
Graph representation

Higher flexibility in the way data is stored

Tabular representation of data.

Tree-like representation of data.

Graph-like representation of data. Loops, self-referencing and multiple relations to the same node are allowed.



Students

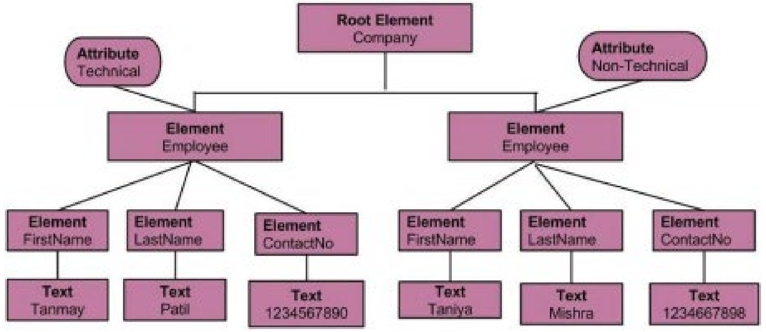
ID#	Name	Phone	DOB
500	Matt	555-4141	06/03/70
501	Jenny	867-5309	3/15/81
502	Sean	876-9123	10/31/82

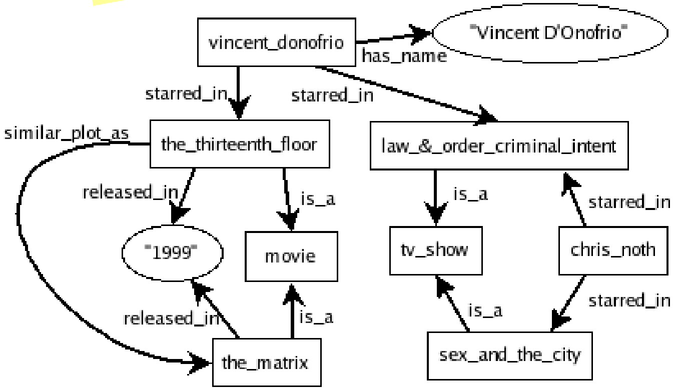
ID#	ClassID	Sem
500	1001	Fall02
501	1002	Fall02
501	1002	Spr03
502	1003	S203

Takes_Course

ClassID	Title	ClassNum
1001	Intro to Informatics	I101
1002	Data Mining	I400
1003	Internet and Society	I400

Courses





Tables
(SQL)

flexibility

Trees
(XML, JSON)

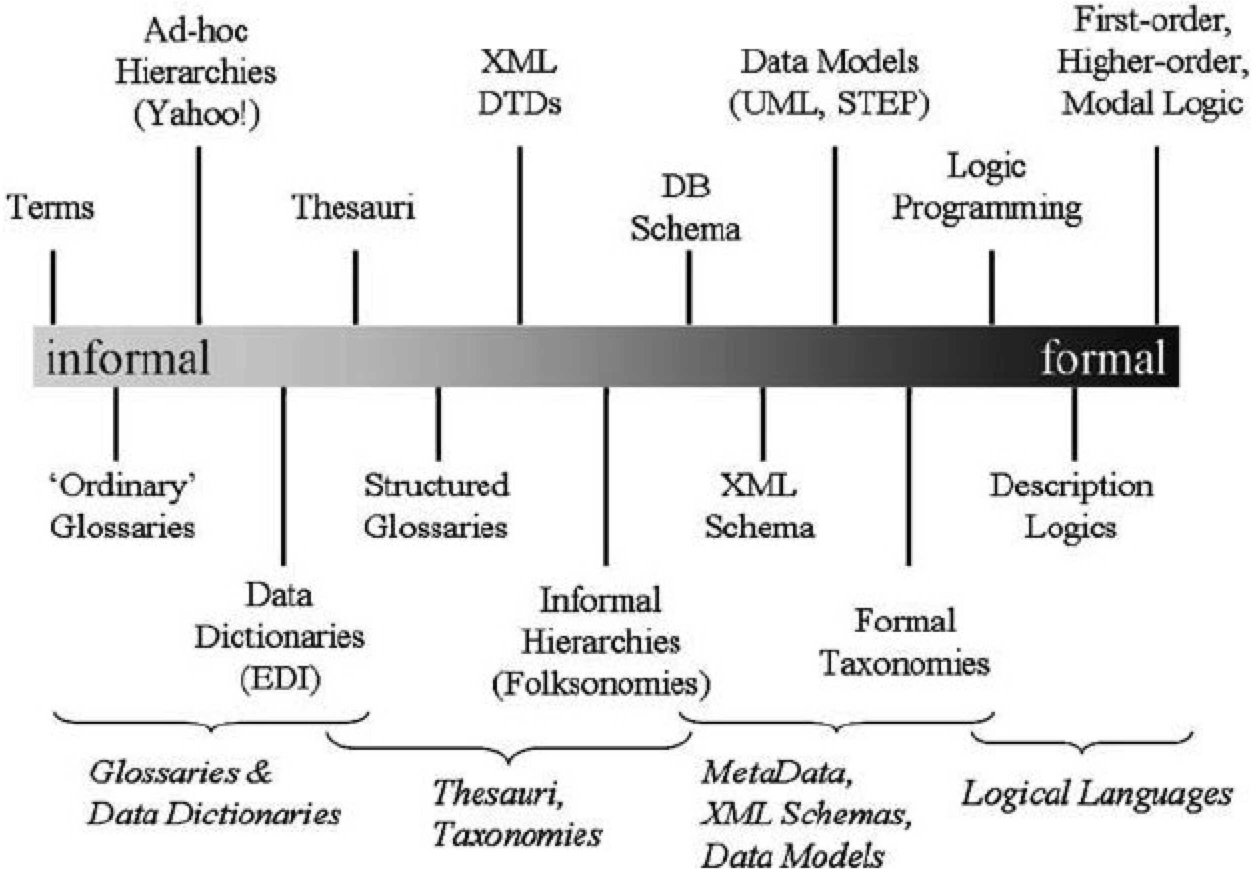
flexibility

Graphs
(RDF, LPG)

Logical Foundations

- A knowledge graph can be regarded as a lightweight ontology.
- "An ontology is a **formal**, **explicit specification** of a shared **conceptualization**" (Studer at all. 1998).
- There exist several logic-based languages (i.e., knowledge representation formalisms) for the specification of ontologies, from less to more expressive ones.
- A knowledge graph is typically represented with a low expressive formalism.
- **The formalism makes the knowledge machine-interpretable** and enables automation, aka machine reasoning.

Source: https://arxiv.org/ftp/arxiv/papers/1401/1401.3858.pdf



https://link.springer.com/chapter/10.1007/978-3-540-92673-3_0

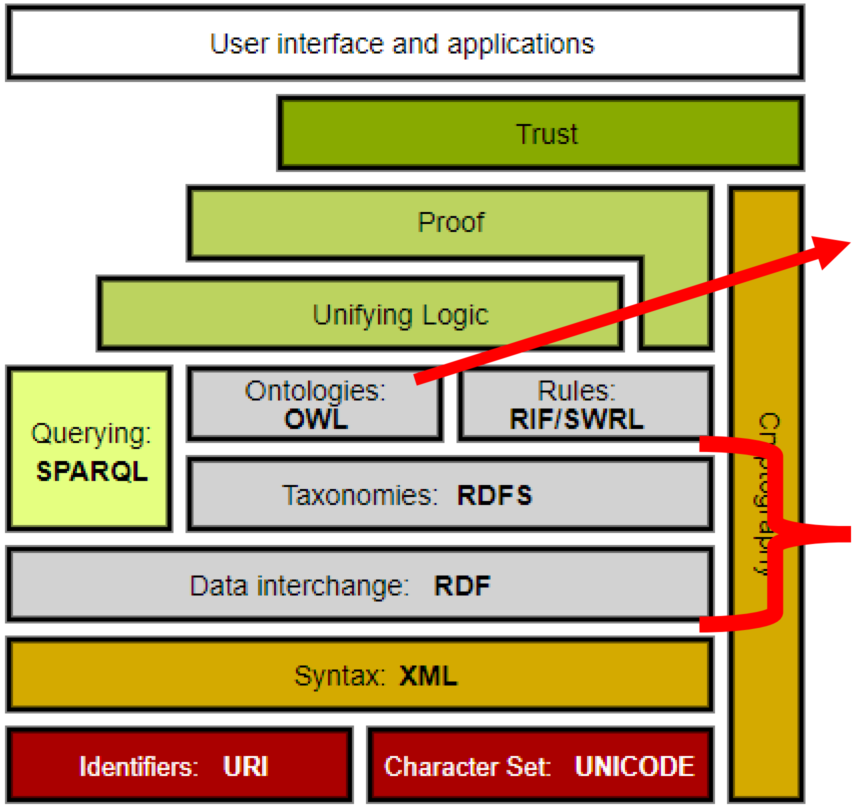
The expressive formalism of a language

- The **expressive formalism** (also referred to expressive power, expressiveness or expressivity) of a language is the breadth of ideas that can be represented and communicated in that language.
- The more expressive a language is, the greater the variety and quantity of ideas it can be used to represent.
- More specifically,
  - The expressivity is defined by the (logical) elements (like ***and*, *or*, *not*, etc**) that a language provides; more elements imply more expressivity.
  - The higher the expressivity, the harder and the longer to answer decision problems.

W3C - World Wide Web Consortium (W3C)

- The World Wide Web Consortium (W3C) is an international community that develops open standards to ensure the long-term growth of the Web.
- There are many more standards than what the Sematnic Web Stack shows.

Semantic Web Stack



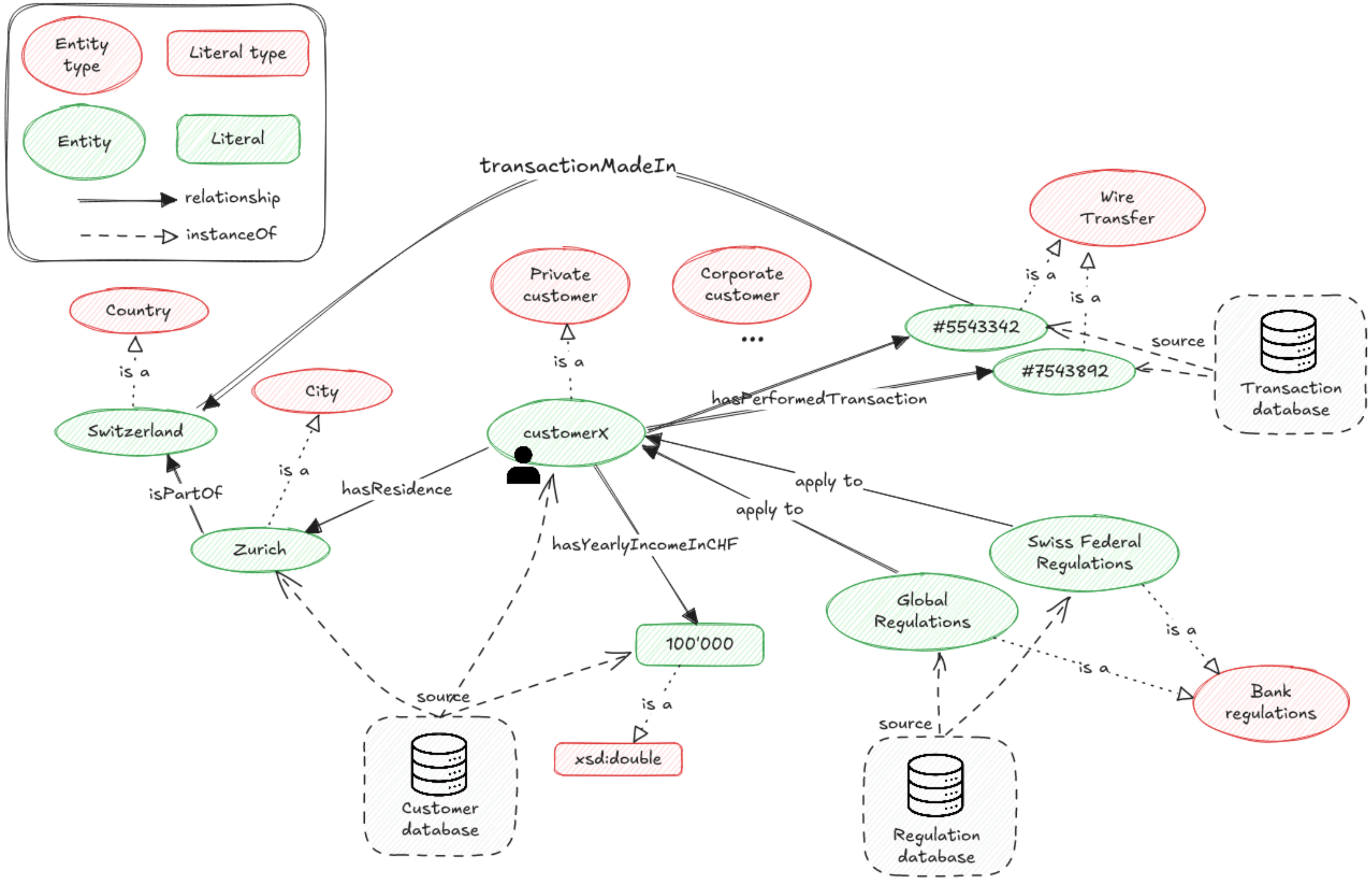
High expressive language.

Low Expressive languages.

https://www.w3.org/2004/Talks/0611-sb-wsswintro/slide18-0.html

Example

- A Knowledge Graph in the banking industry.
- The visualisation of this graph shows **RDF**



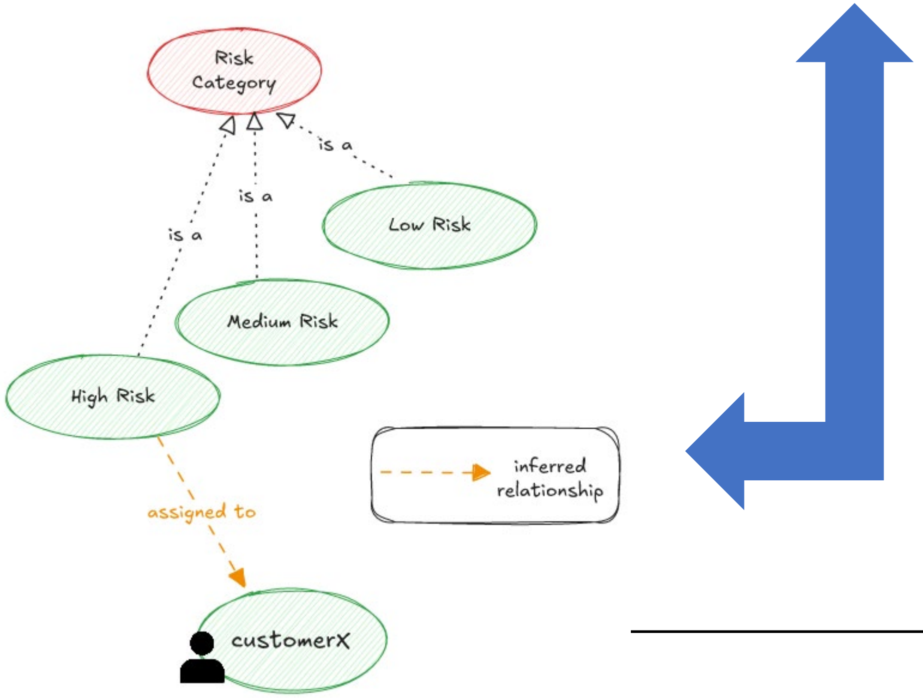
Example/2

- A Knowledge Graph contains concepts, relationships and data.
- When combining these with rules, we can trigger machine reasoning (i.e. logical deduction).

Inferecing example to support meaningful decision-making. Let's imagine the scenario in which our CustomerX opens an account in the British Virgin Islands (BVI) and transfers CHF 500'000 into his bank account declaring "investment purposes" but fails to provide supporting contracts or tax filings. Then, all the conditions from each of the two regulation sources (federal and global) must be checked to assess the customer.

One example of a rule is the following:

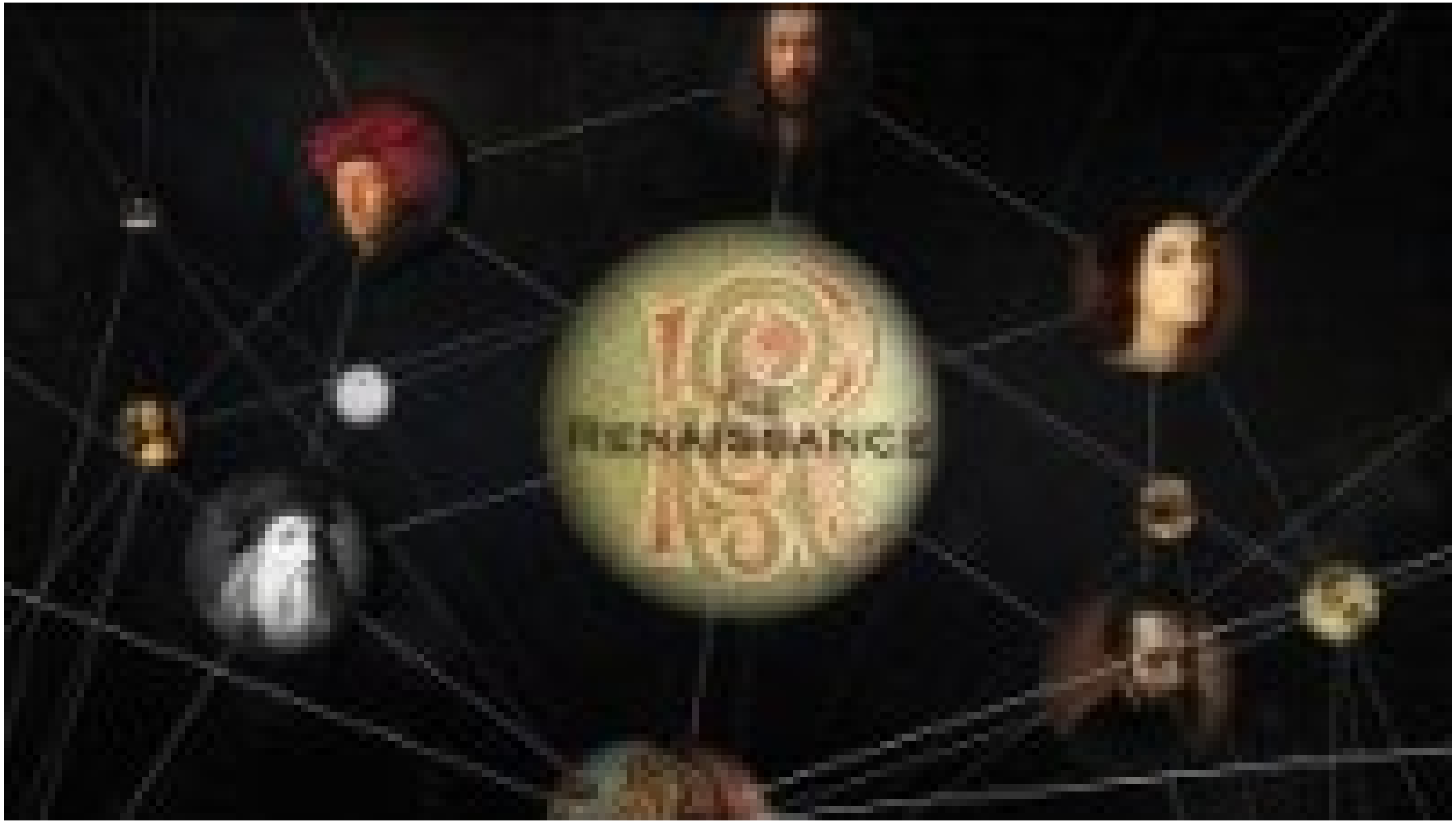
If a private customer holds an undeclared asset from an offshore account located in a high-risk jurisdiction and attempts to transfer more than CHF 100'000 into the bank account without a clear economic purpose, they are flagged as ***high risk*** *for potential tax evasion and money laundering.*



What’s the value of Knowledge Graphs for organizations?

Discussion.

The Knowledge Graph – According to Google



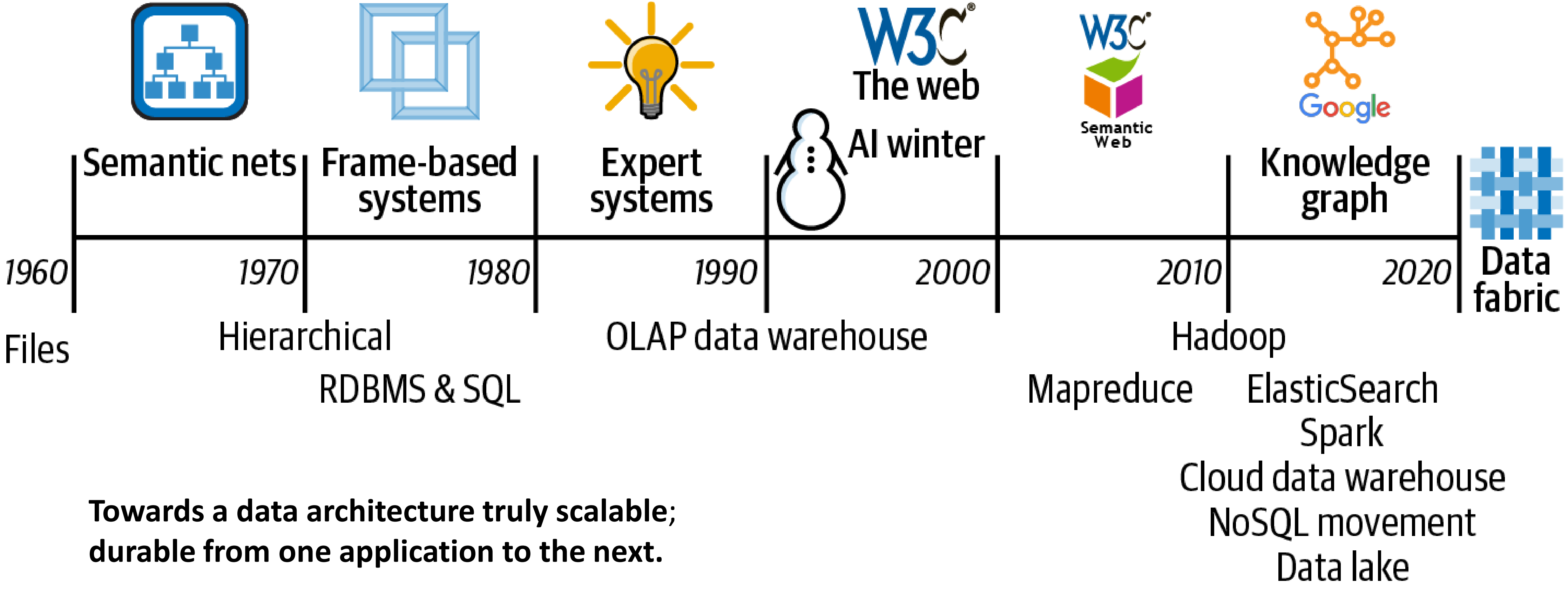
https://www.youtube.com/watch?v=mmQl6VGvX-c

“Why can’t I have relevant knowledge at my fingertips whenever they are needed, the way Google does it for the web?”

Company leaders ask.

https://info.cambridgesemantics.com/hubfs/The_Rise_of_the_Knowledge_Graph.pdf

Parallel history of knowledge-based technology and data management technology merging into the data fabric



Semantic nets

Frame-based systems

Expert systems

AI winter

W3C The web

W3C Semantic Web

Google Knowledge graph

Data fabric

1960 1970 1980 1990 2000 2010 2020

Files

Hierarchical

RDBMS & SQL

OLAP data warehouse

Mapreduce

Hadoop

ElasticSearch

Spark

Cloud data warehouse

NoSQL movement

Data lake

Towards a data architecture truly scalable; durable from one application to the next.

https://info.cambridgesemantics.com/hubfs/The_Rise_of_the_Knowledge_Graph.pdf

Knowledge Graph in Enterprises

- A Knowledge Graph in enterprises:
  - is a central data element in the organizational data management infrastructure.
  - is a repository for organization-wide master data AND integration hub for various legacy data sources, e.g., relational databases or data streams.
- It consists of a collection of interlinked descriptions of concepts, entities, relationships and events, exploitable for the support of decision-making in businesses.
- Data is put in context via the semantic meta-data (or schema), enabling meaningful reasoning, retrieval, sharing and integration of knowledge.

Things
Real world objects and abstract concepts with **unique identifiers**

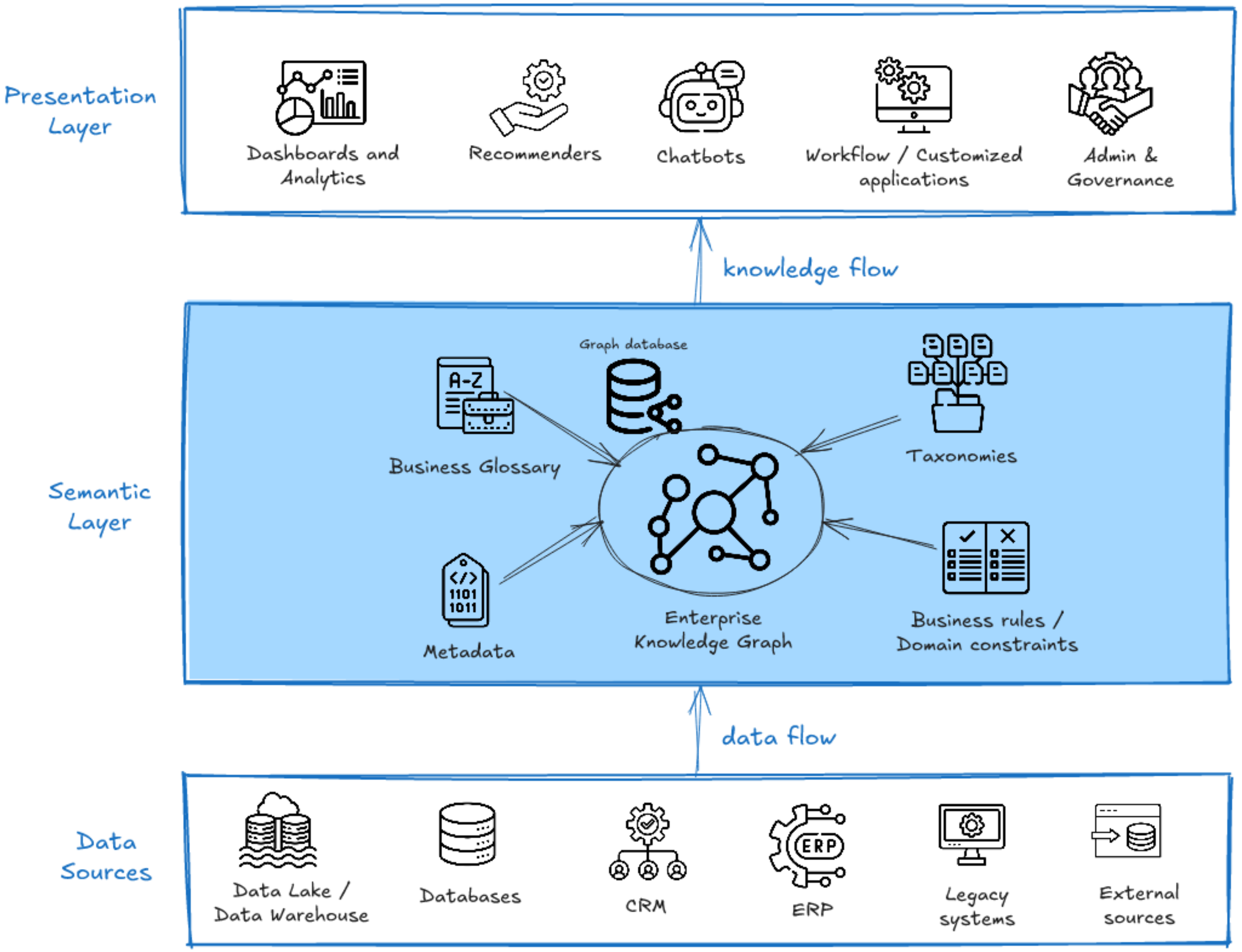
Relationships
How things are connected; First-class citizens

Semantics
The meaning of the data is encoded alongside the data (**metadata**)

Hogan et al. (2020), Fensel et al. (2020), Ehrlinger & Wöß (2016) and Jetschni & Meister (2017)

http://www.semantic-web-journal.net/system/files/swj2149.pdf

The Semantic Leyer of an Enterprise



Basic Benefits of Knowledge Graphs in Enterprises

Unifying: Heterogenous internal and external data are integrated seamlessly.

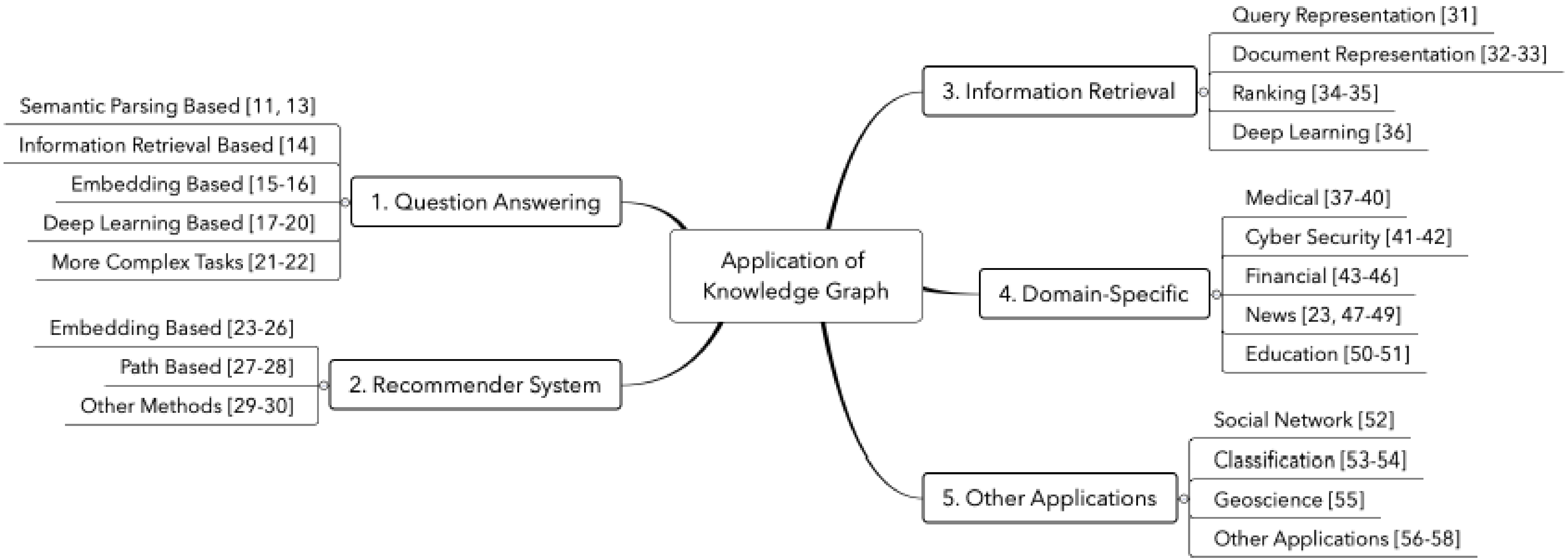
Flexible: Data and schema can be easily extended and connected.

Semantic: Data and its meaning are available in the same place.

Searchable: Unique IDs make all meta-levels searchable, sharable & accessible.

Trustworthy: Provenance information provides traceability and lineage.

Application fields of Knowledge Graph

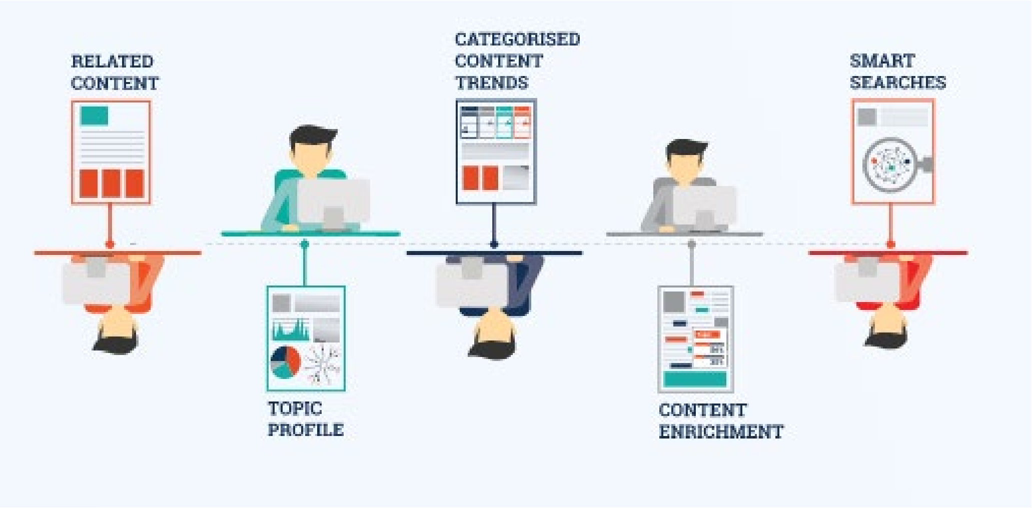


https://iopscience.iop.org/article/10.1088/1742-6596/1487/1/012016

Examples for use of Knowledge Graphs in Enterprises

In Media

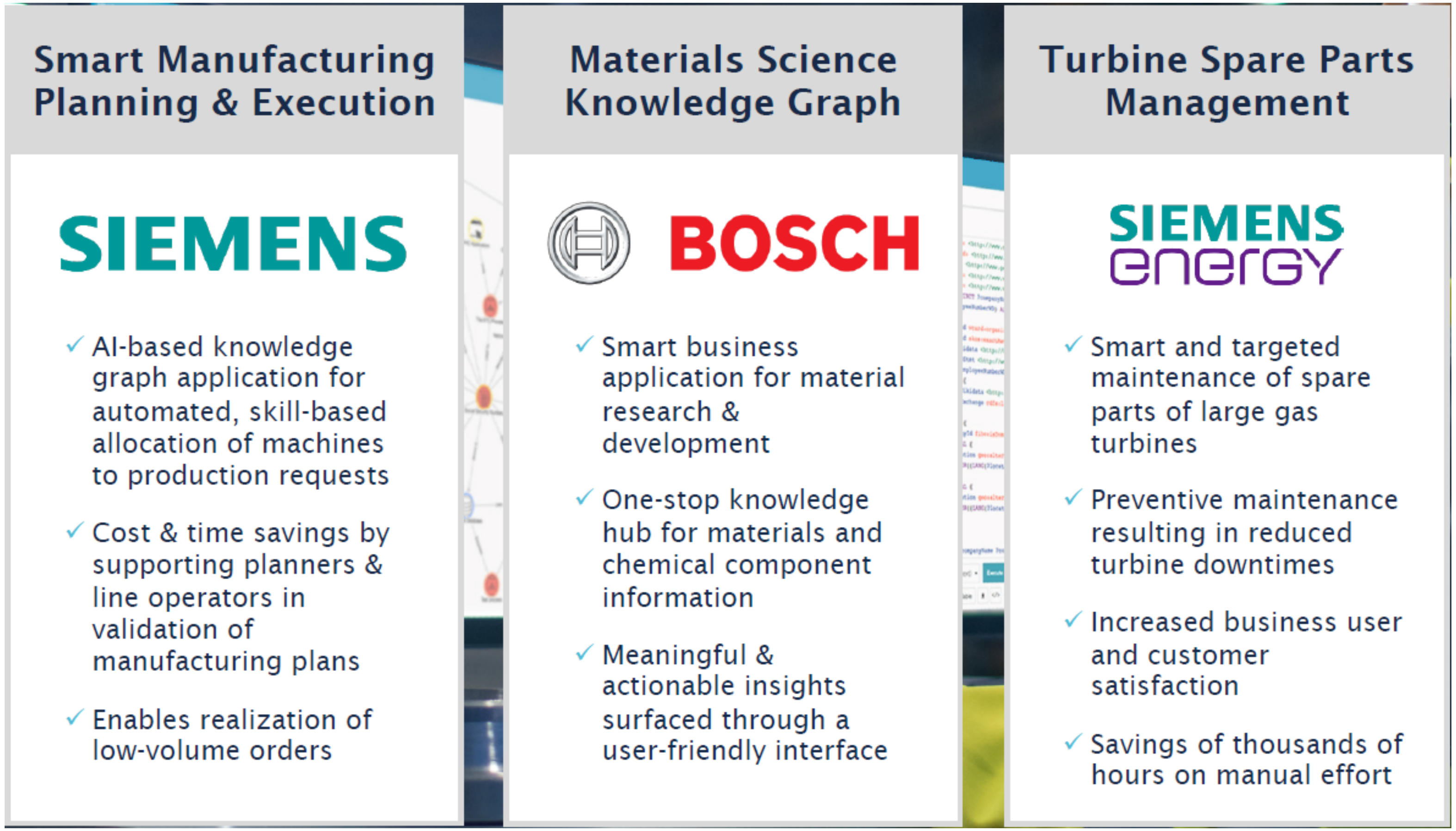
– Content reuse and repurposing



– The BBC case

https://youtu.be/9-g9A6zqFVw

In Engineering and Manufacturing



Smart Manufacturing Planning & Execution

SIEMENS

- ✓ AI-based knowledge graph application for automated, skill-based allocation of machines to production requests
- ✓ Cost & time savings by supporting planners & line operators in validation of manufacturing plans
- ✓ Enables realization of low-volume orders

Materials Science Knowledge Graph

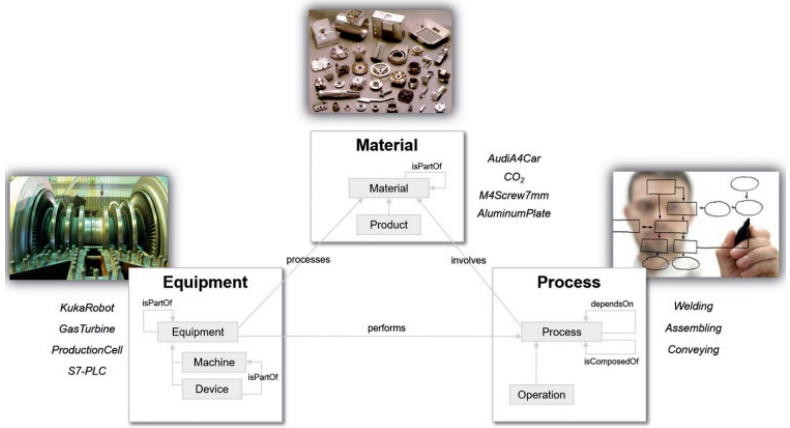
BOSCH

- ✓ Smart business application for material research & development
- ✓ One-stop knowledge hub for materials and chemical component information
- ✓ Meaningful & actionable insights surfaced through a user-friendly interface

Turbine Spare Parts Management

SIEMENS energy

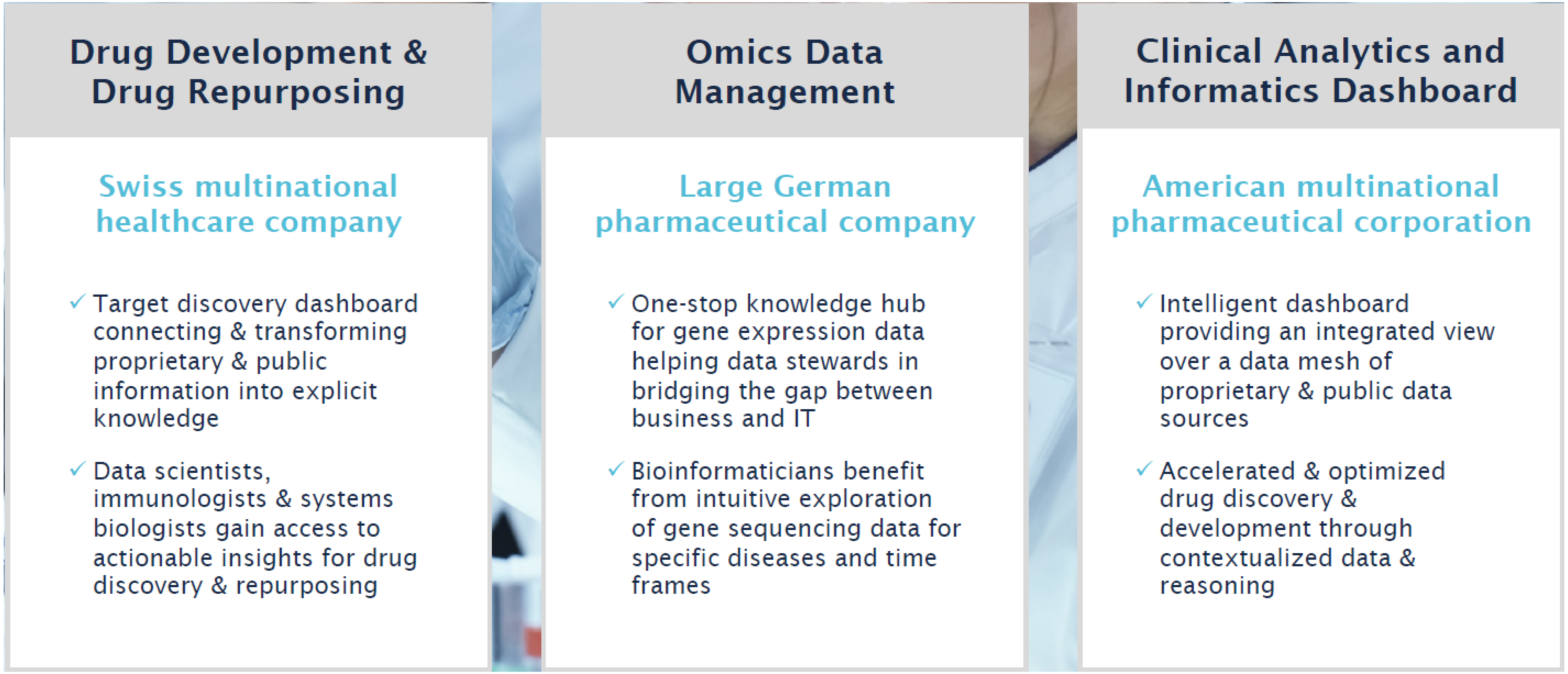
- ✓ Smart and targeted maintenance of spare parts of large gas turbines
- ✓ Preventive maintenance resulting in reduced turbine downtimes
- ✓ Increased business user and customer satisfaction
- ✓ Savings of thousands of hours on manual effort



https://metaphacts.com/images/PDFs/case-studies/metaphacts-Case-Study-Smart-Manufacturing-at-Siemens-with-metaphactory-Knowledge-Graph-Platform.pdf

https://metaphacts.com/resource-hub

In Pharma & Life Sciences



Drug Development & Drug Repurposing

Swiss multinational healthcare company

- ✓ Target discovery dashboard connecting & transforming proprietary & public information into explicit knowledge
- ✓ Data scientists, immunologists & systems biologists gain access to actionable insights for drug discovery & repurposing

Omics Data Management

Large German pharmaceutical company

- ✓ One-stop knowledge hub for gene expression data helping data stewards in bridging the gap between business and IT
- ✓ Bioinformaticians benefit from intuitive exploration of gene sequencing data for specific diseases and time frames

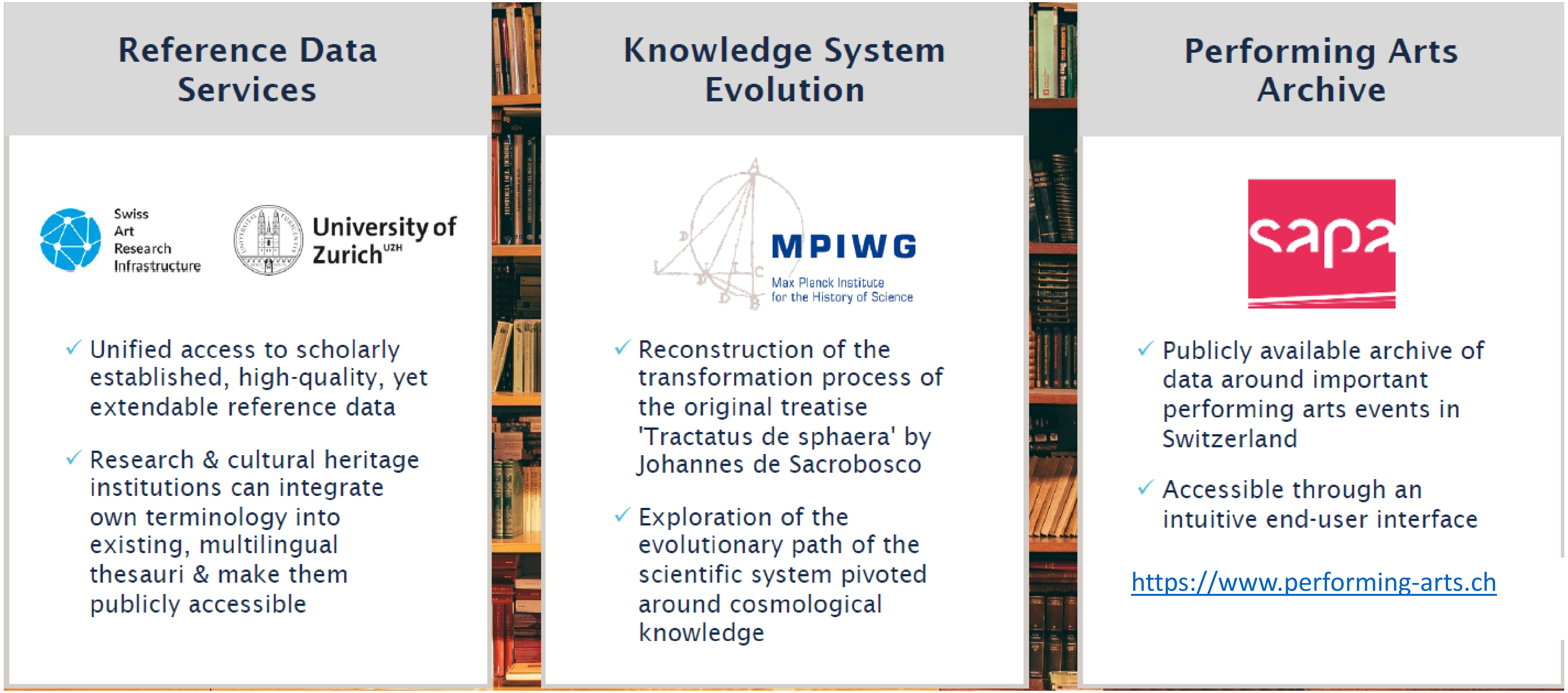
Clinical Analytics and Informatics Dashboard

American multinational pharmaceutical corporation

- ✓ Intelligent dashboard providing an integrated view over a data mesh of proprietary & public data sources
- ✓ Accelerated & optimized drug discovery & development through contextualized data & reasoning

https://metaphacts.com/resource-hub

In Cultural Heritage



Reference Data Services

Swiss Art Research Infrastructure

University of Zurich UZH

- ✓ Unified access to scholarly established, high-quality, yet extendable reference data
- ✓ Research & cultural heritage institutions can integrate own terminology into existing, multilingual thesauri & make them publicly accessible

Knowledge System Evolution

MPIWG Max Planck Institute for the History of Science

- ✓ Reconstruction of the transformation process of the original treatise 'Tractatus de sphaera' by Johannes de Sacrobosco
- ✓ Exploration of the evolutionary path of the scientific system pivoted around cosmological knowledge

Performing Arts Archive

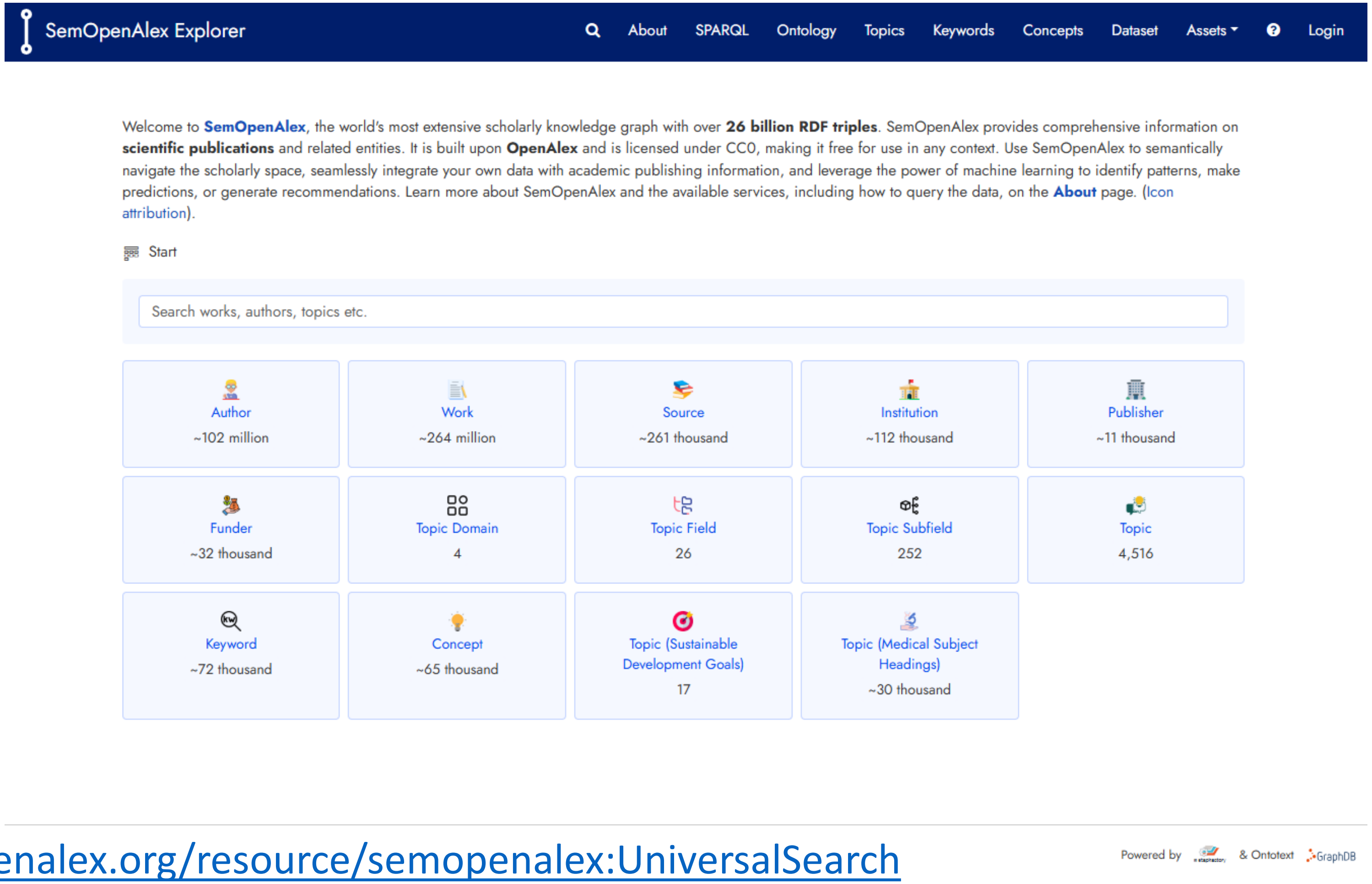
sapa

- ✓ Publicly available archive of data around important performing arts events in Switzerland
- ✓ Accessible through an intuitive end-user interface

https://www.performing-arts.ch

https://metaphacts.com/resource-hub

Research in a Knowledge Graph



Welcome to **SemOpenAlex**, the world's most extensive scholarly knowledge graph with over **26 billion RDF triples**. SemOpenAlex provides comprehensive information on **scientific publications** and related entities. It is built upon **OpenAlex** and is licensed under CC0, making it free for use in any context. Use SemOpenAlex to semantically navigate the scholarly space, seamlessly integrate your own data with academic publishing information, and leverage the power of machine learning to identify patterns, make predictions, or generate recommendations. Learn more about SemOpenAlex and the available services, including how to query the data, on the **About** page. (Icon attribution).

Start

Search works, authors, topics etc.

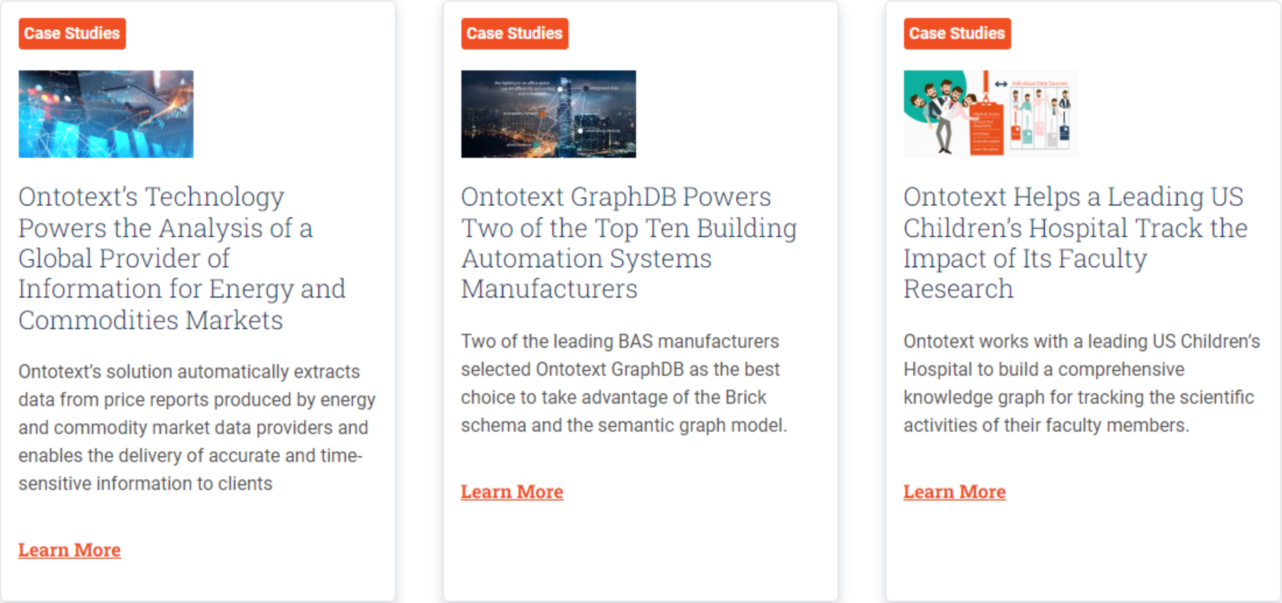
Author ~102 million	Work ~264 million	Source ~261 thousand	Institution ~112 thousand	Publisher ~11 thousand
Funder ~32 thousand	Topic Domain 4	Topic Field 26	Topic Subfield 252	Topic 4,516
Keyword ~72 thousand	Concept ~65 thousand	Topic (Sustainable Development Goals) 17	Topic (Medical Subject Headings) ~30 thousand	

Powered by & Ontotext GraphDB

https://semopenalex.org/resource/semopenalex:UniversalSearch

Additional resources with case studies and white papers

- Case studies:
- https://www.ontotext.com/knowledge-hub/case-studies/
- https://www.stardog.com/resources/#filter=.case-studies
- White papers:
- https://www.ontotext.com/knowledge-hub/white_paper/
- https://www.stardog.com/resources/#filter=.whitepapers



Case Studies

Ontotext's Technology Powers the Analysis of a Global Provider of Information for Energy and Commodities Markets

Ontotext's solution automatically extracts data from price reports produced by energy and commodity market data providers and enables the delivery of accurate and time-sensitive information to clients

Learn More

Case Studies

Ontotext GraphDB Powers Two of the Top Ten Building Automation Systems Manufacturers

Two of the leading BAS manufacturers selected Ontotext GraphDB as the best choice to take advantage of the Brick schema and the semantic graph model.

Learn More

Case Studies

Ontotext Helps a Leading US Children's Hospital Track the Impact of Its Faculty Research

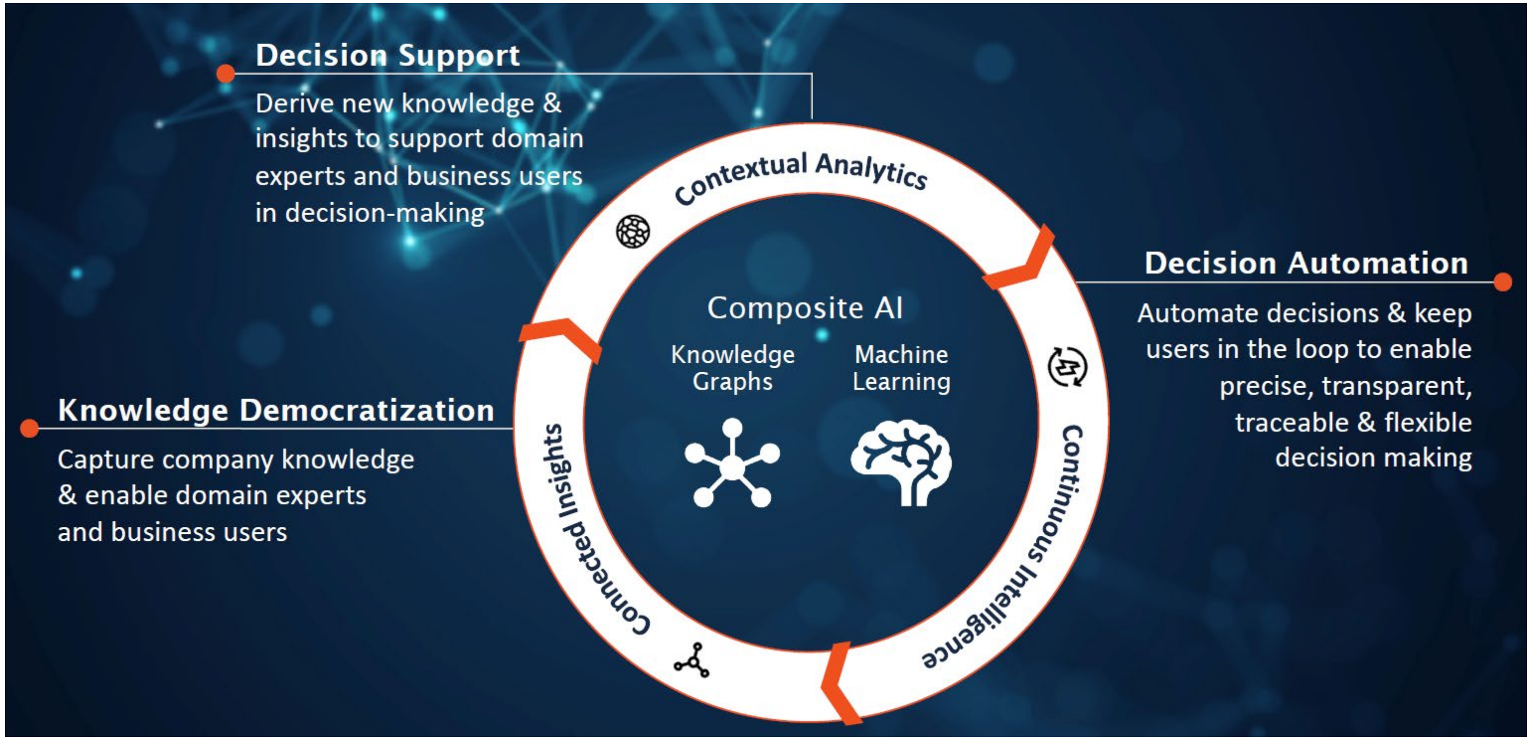
Ontotext works with a leading US Children's Hospital to build a comprehensive knowledge graph for tracking the scientific activities of their faculty members.

Learn More

Trends for Knowledge Graphs

Knowledge Graphs for Intelligent Enterprises

– Knowledge Graph is used as a basis for decision intelligence.



Decision Support

Derive new knowledge & insights to support domain experts and business users in decision-making

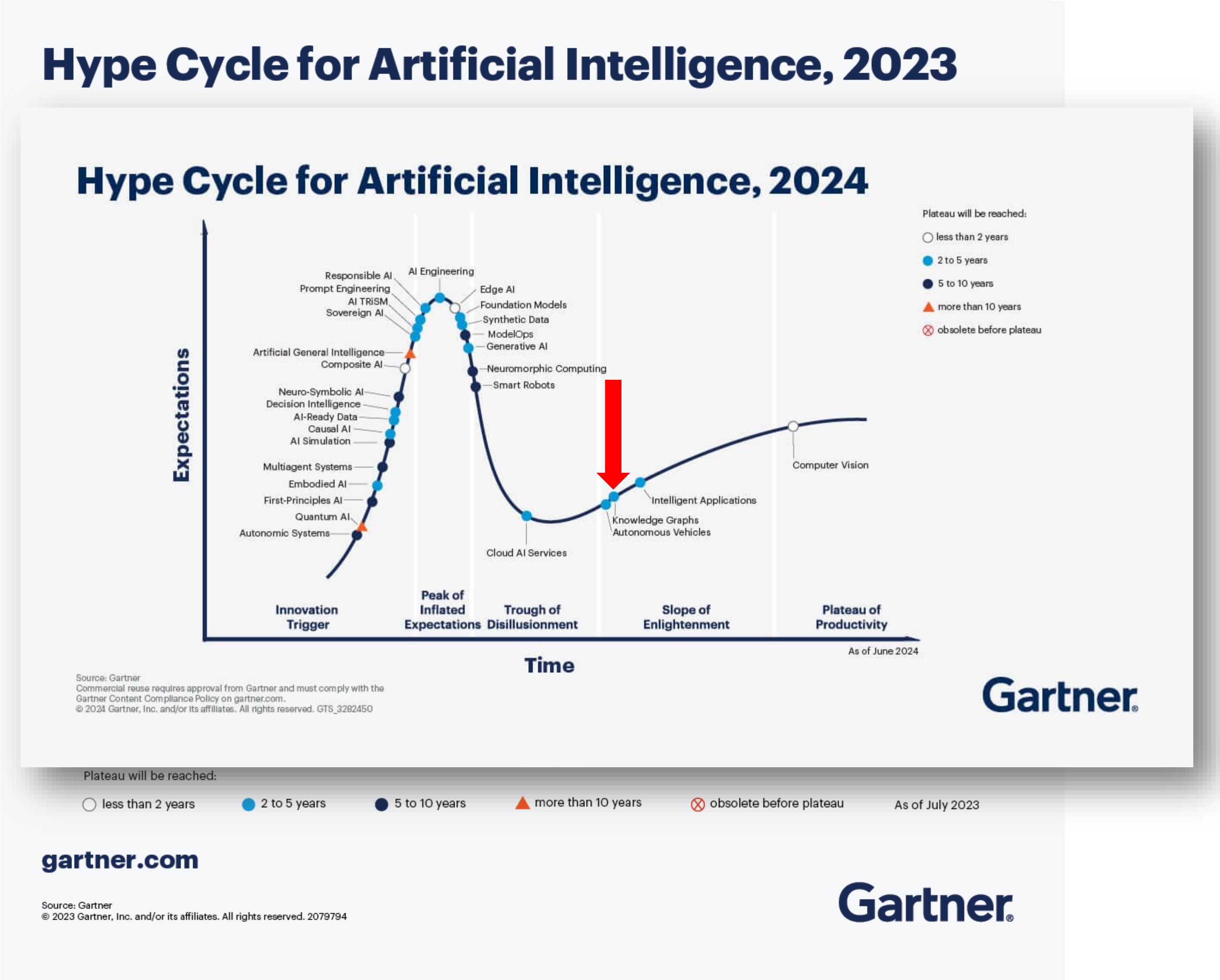
Decision Automation

Automate decisions & keep users in the loop to enable precise, transparent, traceable & flexible decision making

Knowledge Democratization

Capture company knowledge & enable domain experts and business users

- The Gartner Hype Cycle™ for Artificial Intelligence (AI) identifies innovations and techniques that offer significant and even transformational benefits.
- Gartner Hype Cycle methodology gives you a view of how a technology or application will evolve over time, providing a source of insight to manage its deployment within the context of specific business goals.



Hype Cycle for Artificial Intelligence, 2023

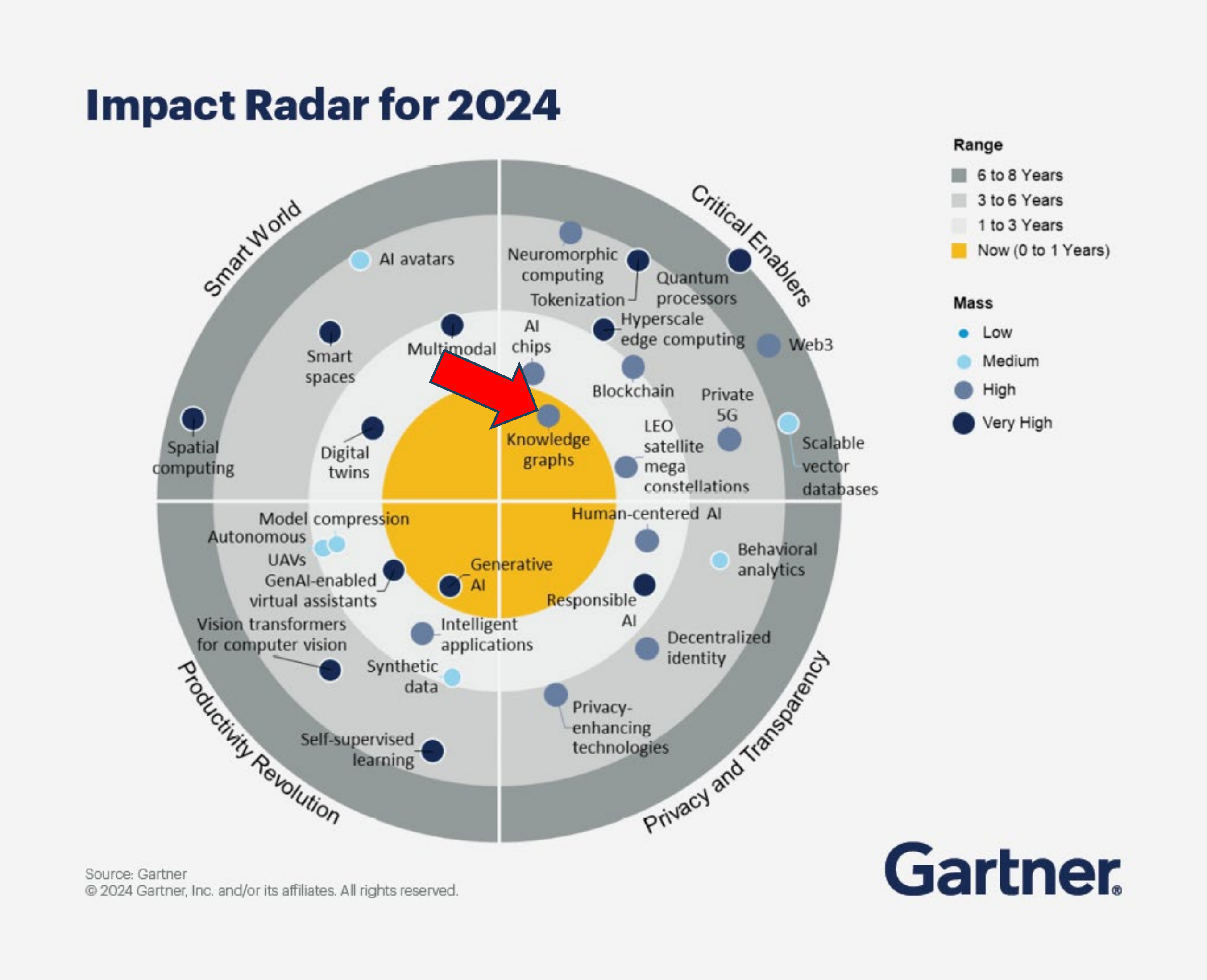
Hype Cycle for Artificial Intelligence, 2024

Source: Gartner
Commercial reuse requires approval from Gartner and must comply with the Gartner Content Compliance Policy on gartner.com.
© 2024 Gartner, Inc. and/or its affiliates. All rights reserved. GTS_3282450

Source: Gartner
© 2023 Gartner, Inc. and/or its affiliates. All rights reserved. 2079794

https://www.gartner.com/en/articles/what-s-new-in-artificial-intelligence-from-the-2023-gartner-hype-cycle

The **Gartner Emerging Tech Impact Radar** highlights the **technologies and trends** with the greatest potential to disrupt a broad cross-section of markets.



Impact Radar for 2024

Source: Gartner
© 2024 Gartner, Inc. and/or its affiliates. All rights reserved.

https://www.gartner.com/en/articles/30-emerging-technologies-that-will-guide-your-business-decisions

Some initiatives /1

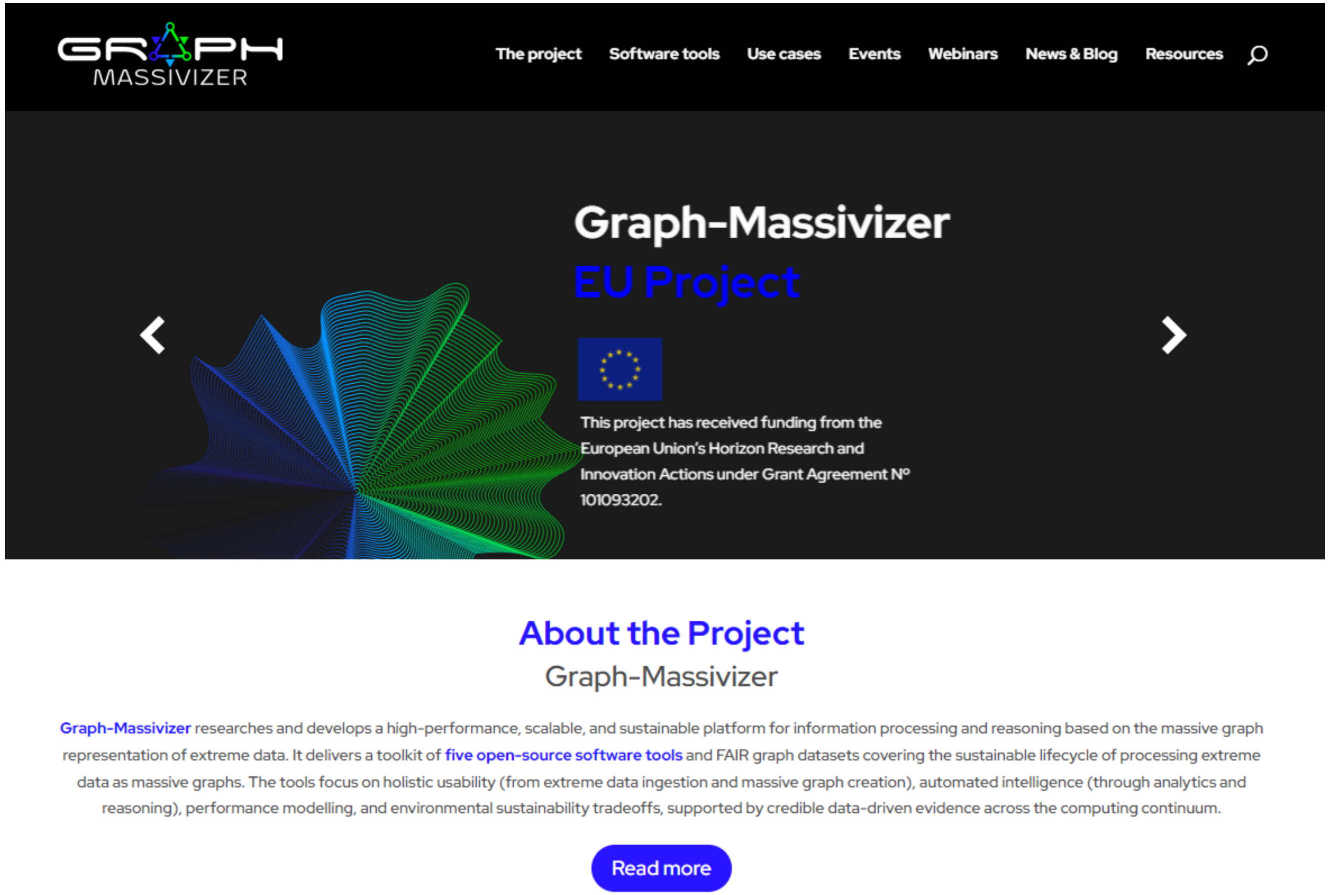
KGC The Knowledge Graph Conference
Search here..
KGC 2024
Community
About KGC
Previous Events
The Knowledge Graph Conference
JOIN US

The Knowledge Graph Conference 2024

May 6 – 10, 2024 | Cornell Tech NYC

80+ Presentations
20+ Workshops & Masterclasses
100+ Speakers
Networking Events

https://www.knowledgegraph.tech/



Graph-Massivizer
EU Project

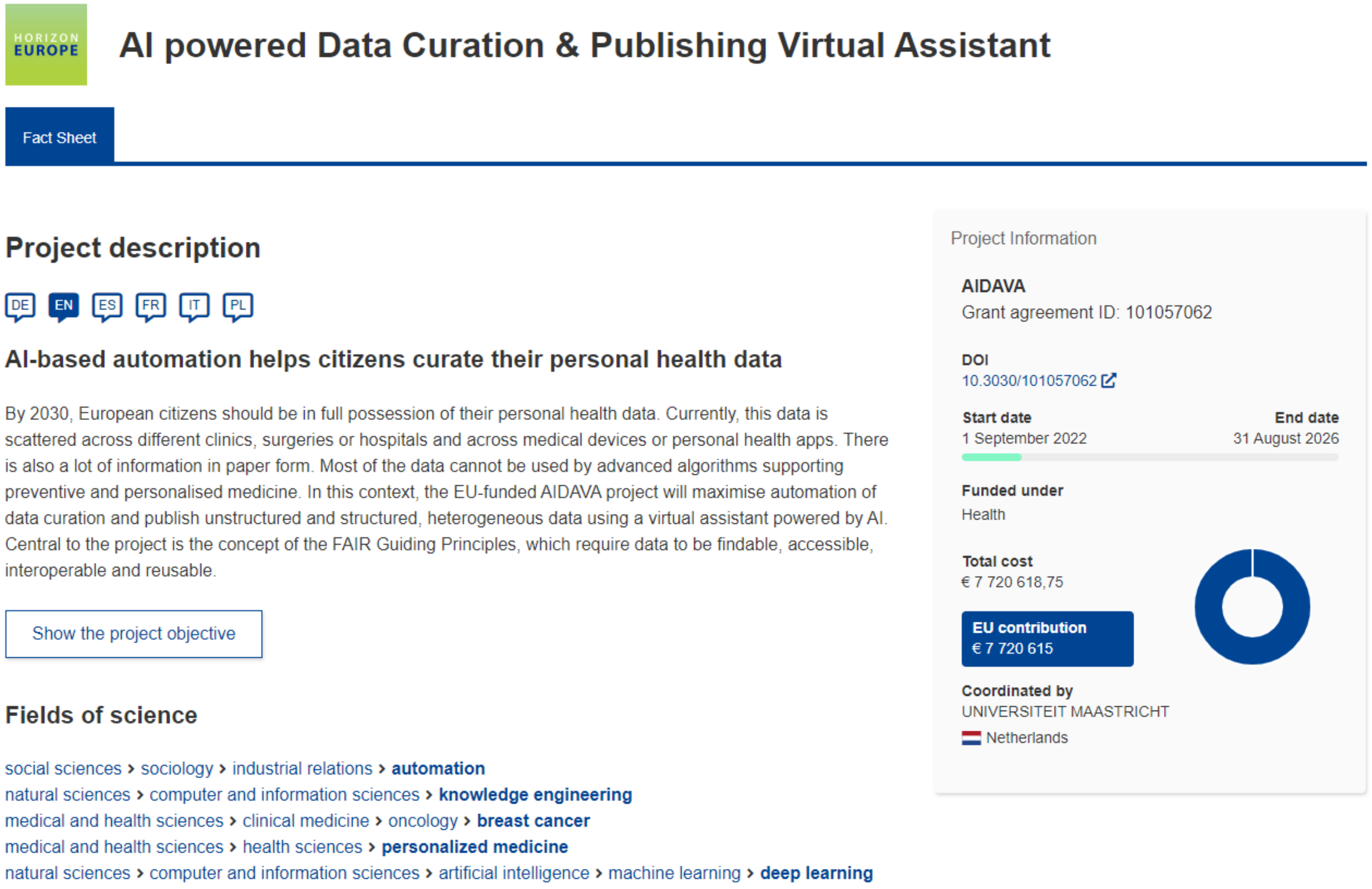
This project has received funding from the European Union's Horizon Research and Innovation Actions under Grant Agreement Nº 101093202.

About the Project
Graph-Massivizer

Graph-Massivizer researches and develops a high-performance, scalable, and sustainable platform for information processing and reasoning based on the massive graph representation of extreme data. It delivers a toolkit of five open-source software tools and FAIR graph datasets covering the sustainable lifecycle of processing extreme data as massive graphs. The tools focus on holistic usability (from extreme data ingestion and massive graph creation), automated intelligence (through analytics and reasoning), performance modelling, and environmental sustainability tradeoffs, supported by credible data-driven evidence across the computing continuum.

https://graph-massivizer.eu/

Some initiatives /2



AI powered Data Curation & Publishing Virtual Assistant

Project description

AI-based automation helps citizens curate their personal health data

By 2030, European citizens should be in full possession of their personal health data. Currently, this data is scattered across different clinics, surgeries or hospitals and across medical devices or personal health apps. There is also a lot of information in paper form. Most of the data cannot be used by advanced algorithms supporting preventive and personalised medicine. In this context, the EU-funded AIDAVA project will maximise automation of data curation and publish unstructured and structured, heterogeneous data using a virtual assistant powered by AI. Central to the project is the concept of the FAIR Guiding Principles, which require data to be findable, accessible, interoperable and reusable.

Fields of science

social sciences › sociology › industrial relations › **automation**
natural sciences › computer and information sciences › **knowledge engineering**
medical and health sciences › clinical medicine › oncology › **breast cancer**
medical and health sciences › health sciences › **personalized medicine**
natural sciences › computer and information sciences › artificial intelligence › machine learning › **deep learning**

Project Information

AIDAVA
Grant agreement ID: 101057062

DOI
10.3030/101057062

Start date
1 September 2022

End date
31 August 2026

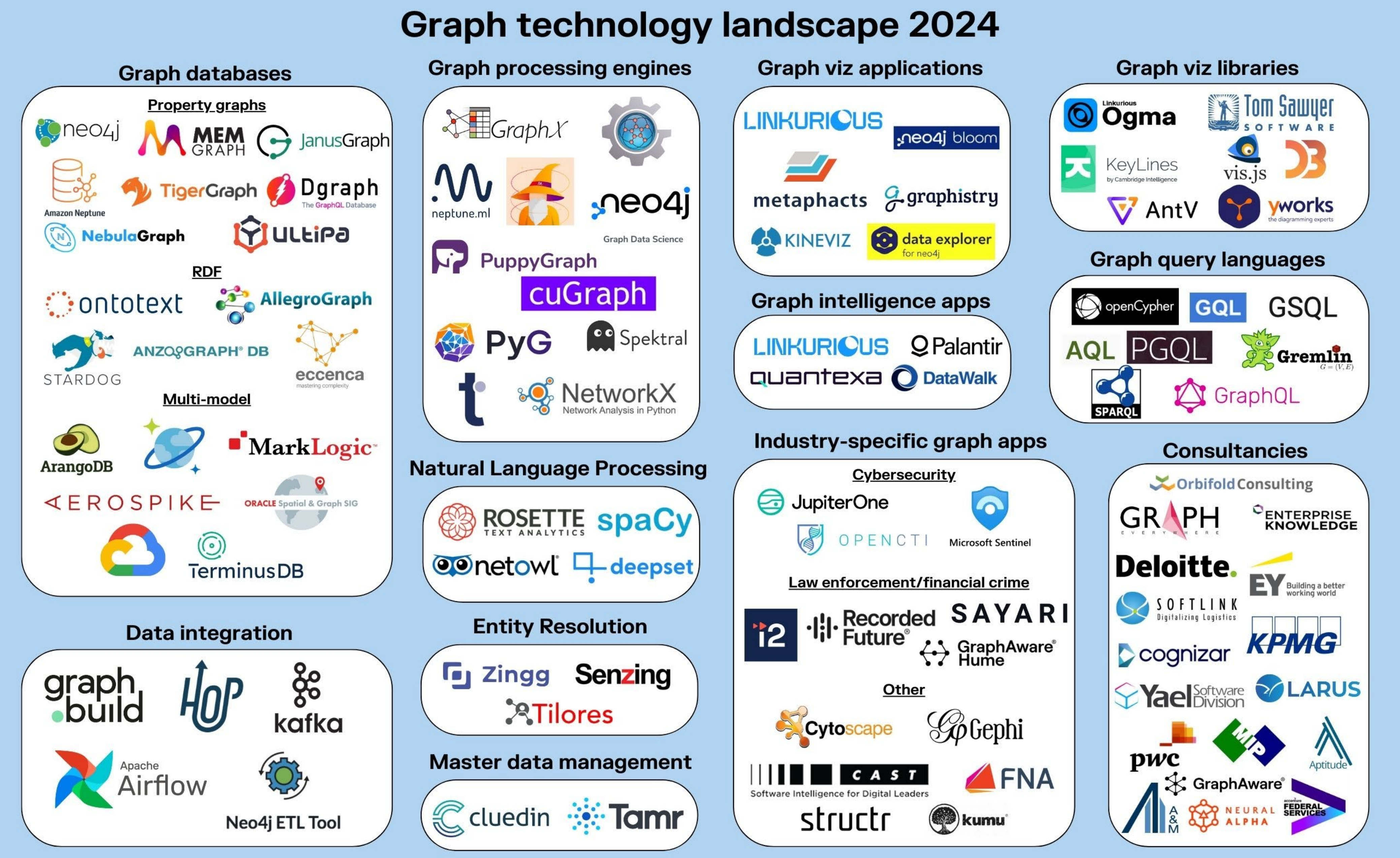
Funded under
Health

Total cost
€ 7 720 618,75

EU contribution
€ 7 720 615

Coordinated by
UNIVERSITEIT MAASTRICHT
Netherlands

https://cordis.europa.eu/project/id/101057062



Graph technology landscape 2024

Graph databases

Property graphs

- neo4j
- MEMGRAPH
- JanusGraph
- Amazon Neptune
- TigerGraph
- Dgraph The GraphQL Database
- NebulaGraph
- ULTIPA

RDF

- ontotext
- AllegroGraph
- STARDOG
- ANZOGRAPH® DB
- eccenca mastering complexity

Multi-model

- ArangoDB
- MarkLogic
- AEROSPIKE
- ORACLE Spatial & Graph SIG
- TerminusDB

Graph processing engines

- GraphX
- neptune.ml
- neo4j Graph Data Science
- PuppyGraph
- cuGraph
- PyG
- Spektral
- NetworkX Network Analysis in Python

Graph viz applications

- LINKURIOUS
- neo4j bloom
- metaphacts
- graphistry
- KINEVIZ
- data explorer for neo4j

Graph viz libraries

- Linkurious Ogma
- Tom Sawyer Software
- KeyLines by Cambridge Intelligence
- vis.js
- D3
- AntV
- yworks the diagramming experts

Graph intelligence apps

- LINKURIOUS
- Palantir
- quantexa
- DataWalk

Graph query languages

- openCypher
- GQL
- GSQL
- AQL
- PGQL
- Gremlin $G = (V, E)$
- SPARQL
- GraphQL

Natural Language Processing

- ROSETTE TEXT ANALYTICS
- spaCy
- netowl
- deepset

Entity Resolution

- Zingg
- Senzing
- Tilores

Master data management

- cluedin
- Tamr

Data integration

- graph.build
- HOP
- kafka
- Apache Airflow
- Neo4j ETL Tool

Industry-specific graph apps

Cybersecurity

- JupiterOne
- OPENCTI
- Microsoft Sentinel

Law enforcement/financial crime

- i2
- Recorded Future®
- SAYARI
- GraphAware® Hume

Other

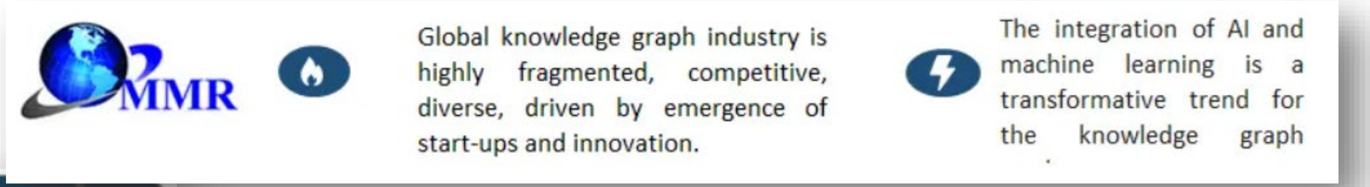
- Cytoscape
- Gephi
- CAST Software Intelligence for Digital Leaders
- FNA
- structr
- kumu

Consultancies

- Orbifold Consulting
- GRAPH EVERYWHERE
- ENTERPRISE KNOWLEDGE
- Deloitte.
- EY Building a better working world
- SOFTLINK Digitalizing Logistics
- KPMG
- cognizar
- Yael Software Division
- LARUS
- pwc
- Aptitude
- GraphAware®
- A&M
- NEURAL ALPHA
- accenture FEDERAL SERVICES

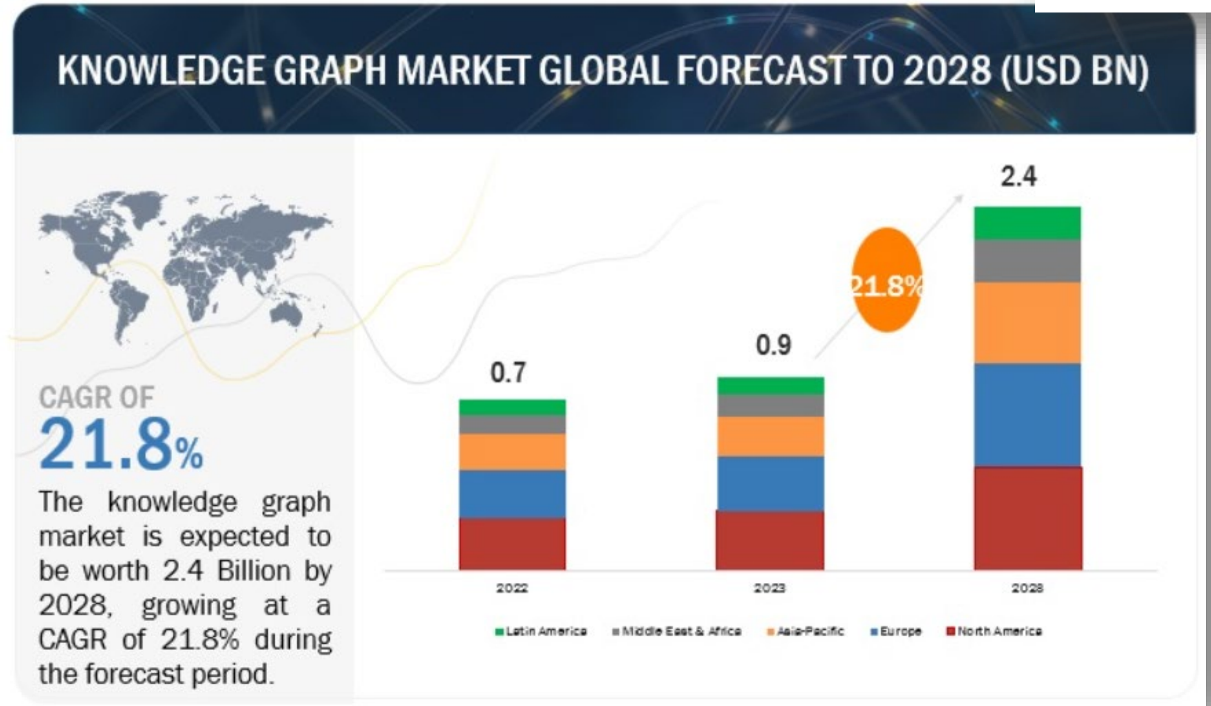
https://linkurious.com/blog/introduction-graph-technology-landscape/

Market forecast about Knowledge Graphs



Global knowledge graph industry is highly fragmented, competitive, diverse, driven by emergence of start-ups and innovation.

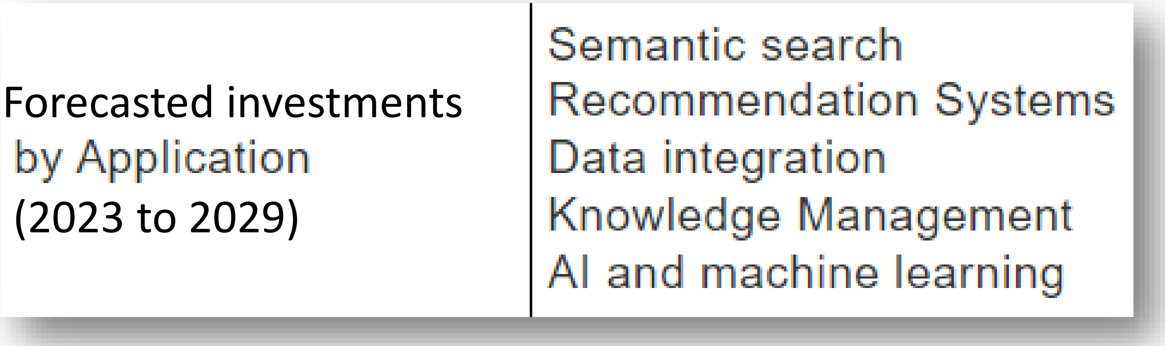
The integration of AI and machine learning is a transformative trend for the knowledge graph.



KNOWLEDGE GRAPH MARKET GLOBAL FORECAST TO 2028 (USD BN)

CAGR OF 21.8%

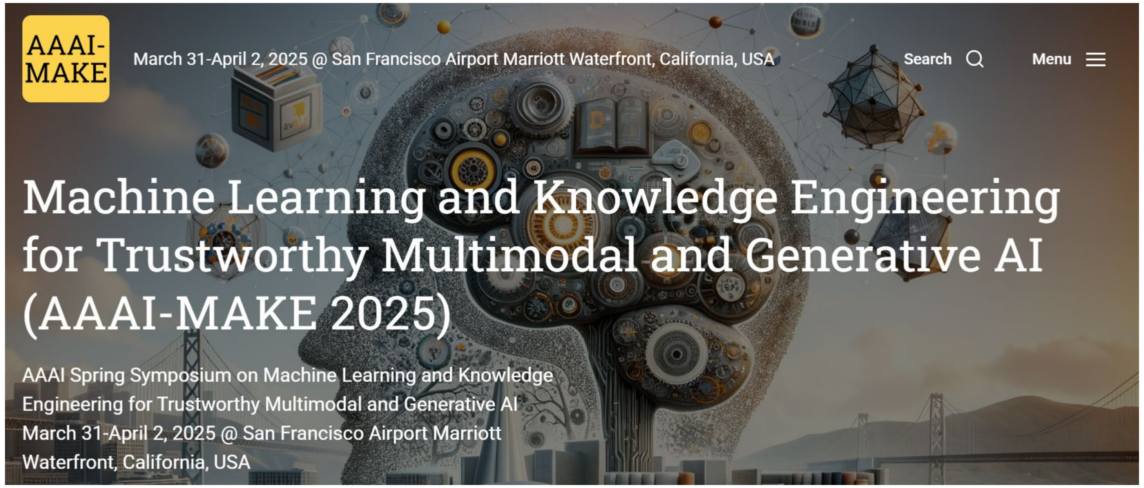
The knowledge graph market is expected to be worth 2.4 Billion by 2028, growing at a CAGR of 21.8% during the forecast period.



Forecasted investments by Application (2023 to 2029)	Semantic search Recommendation Systems Data integration Knowledge Management AI and machine learning

https://www.marketsandmarkets.com/Market-Reports/knowledge-graph-market-217920811.html
https://www.maximizemarketresearch.com/market-report/knowledge-graph-market/221742/

Scientific…and also industry trend: Knowledge Graphs + Machine Learning/GenAI

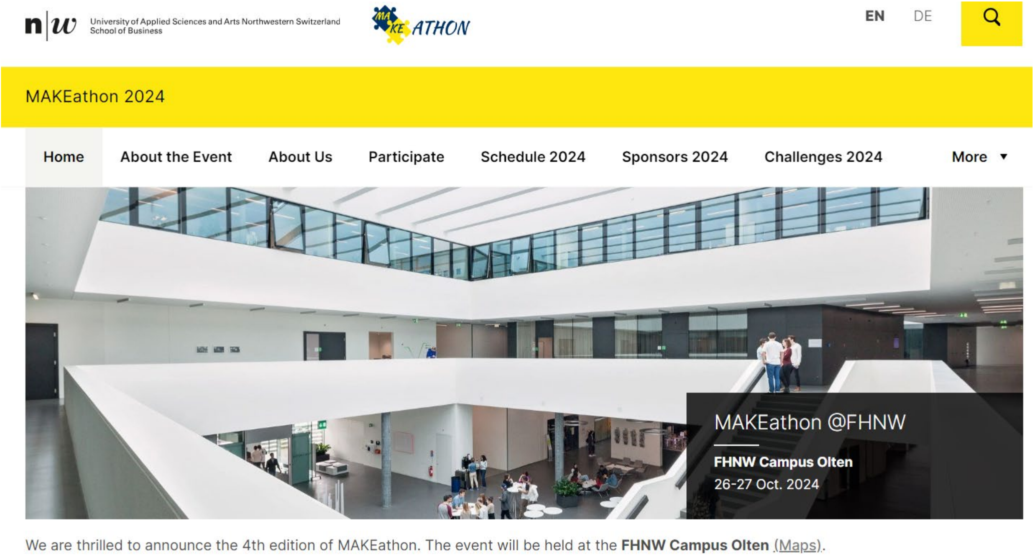


March 31-April 2, 2025 @ San Francisco Airport Marriott Waterfront, California, USA

Machine Learning and Knowledge Engineering for Trustworthy Multimodal and Generative AI (AAAI-MAKE 2025)

AAAI Spring Symposium on Machine Learning and Knowledge Engineering for Trustworthy Multimodal and Generative AI
March 31-April 2, 2025 @ San Francisco Airport Marriott Waterfront, California, USA

https://www.aaai-make.info/

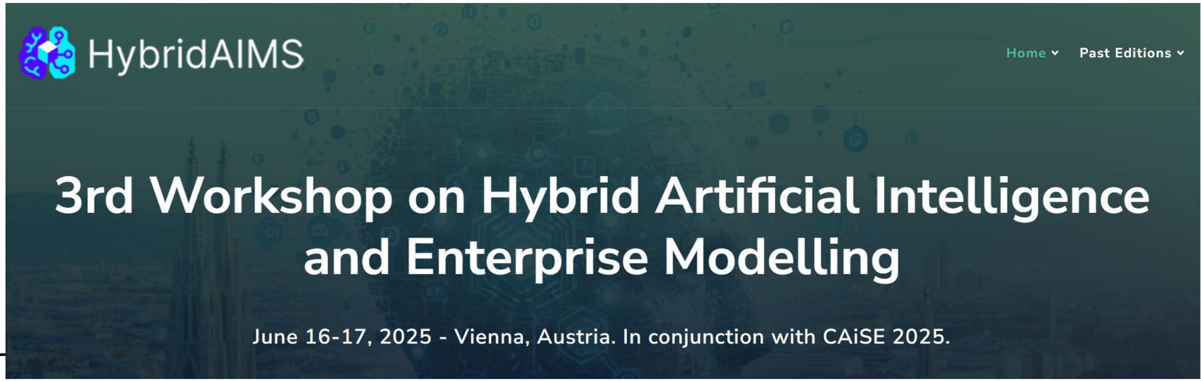


MAKEathon 2024

MAKEathon @FHNW
FHNW Campus Olten
26-27 Oct. 2024

We are thrilled to announce the 4th edition of MAKEathon. The event will be held at the **FHNW Campus Olten** (Maps).

https://makeathonfhnw.ch/



3rd Workshop on Hybrid Artificial Intelligence and Enterprise Modelling

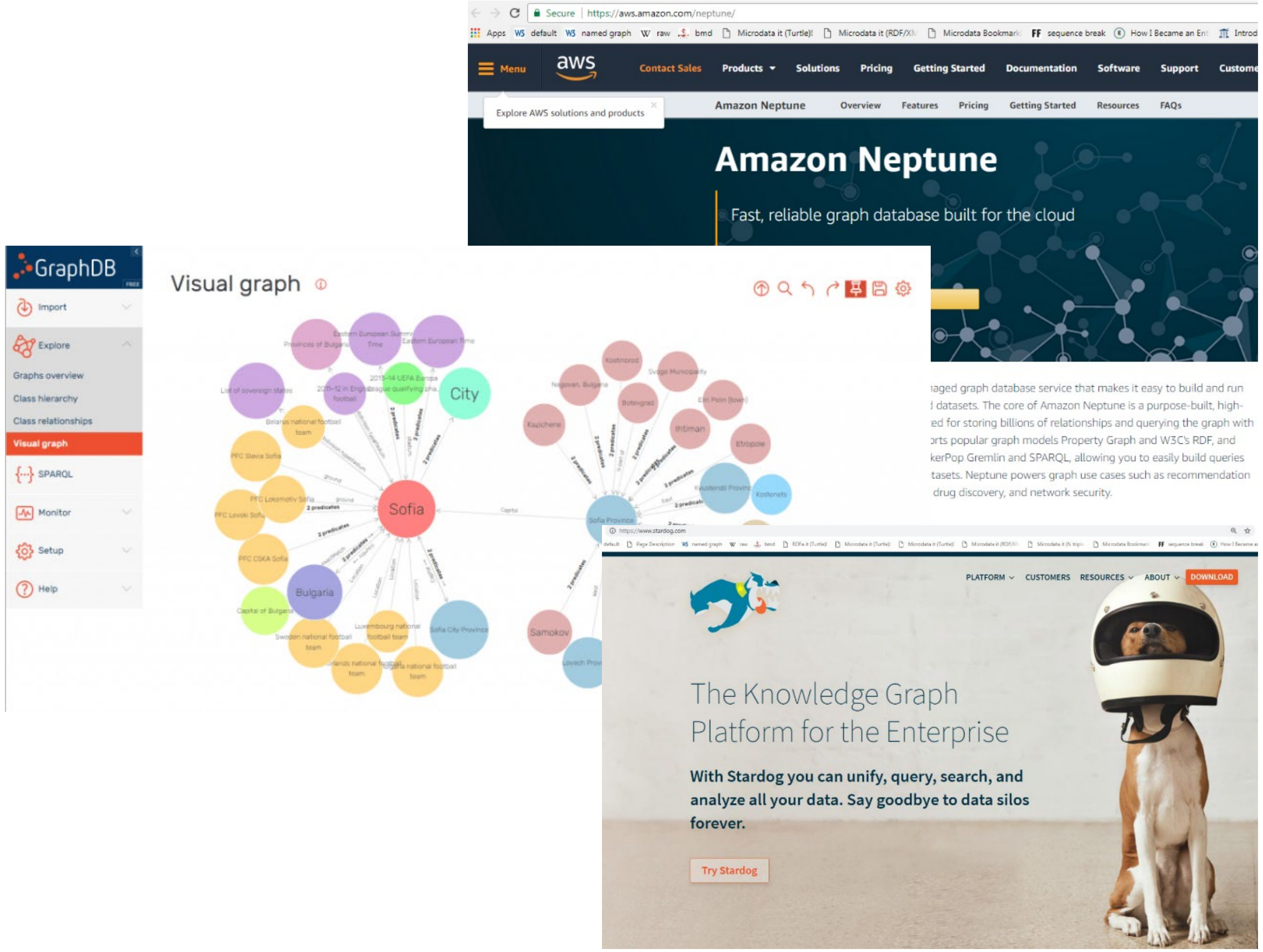
June 16-17, 2025 - Vienna, Austria. In conjunction with CAiSE 2025.

https://hybridaims.com/

Popular Knowledge Graphs Technologies for W3C standards

Graph Databases Servers

- Neptun (part of AWS)
- GraphDB
- Stardog
- …



Secure | https://aws.amazon.com/neptune/

Amazon Neptune

Fast, reliable graph database built for the cloud

…aged graph database service that makes it easy to build and run …l datasets. The core of Amazon Neptune is a purpose-built, high- …ed for storing billions of relationships and querying the graph with …orts popular graph models Property Graph and W3C's RDF, and …kerPop Gremlin and SPARQL, allowing you to easily build queries …tasets. Neptune powers graph use cases such as recommendation … drug discovery, and network security.

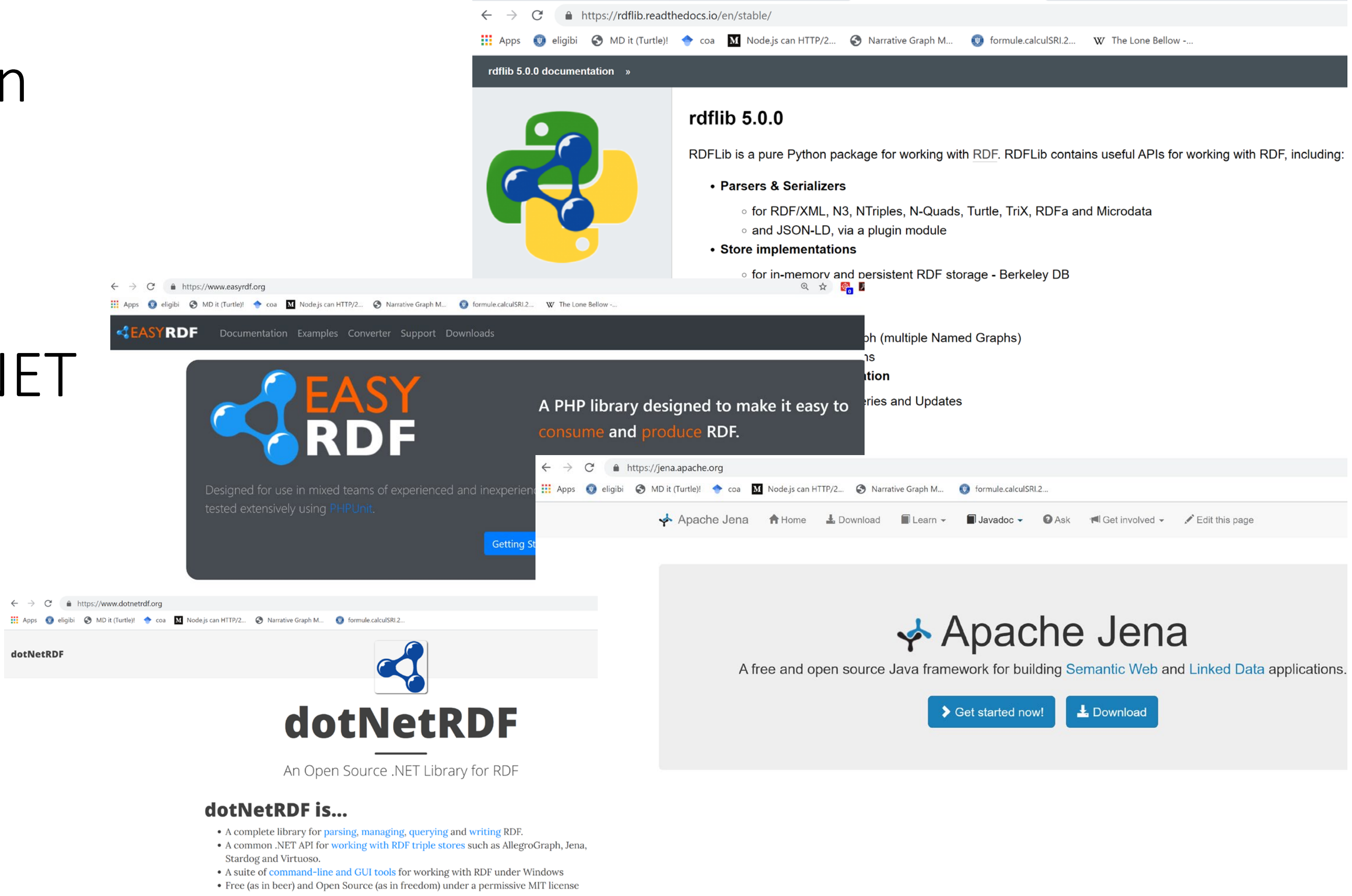
Visual graph

The Knowledge Graph Platform for the Enterprise

With Stardog you can unify, query, search, and analyze all your data. Say goodbye to data silos forever.

Programming Libraries for Knowledge Graphs

- RDFLib for Python
- EasyRDF for PHP
- Jena for Java
- dotNetRDF for .NET



rdflib 5.0.0

RDFLib is a pure Python package for working with RDF. RDFLib contains useful APIs for working with RDF, including:

- Parsers & Serializers
  - for RDF/XML, N3, NTriples, N-Quads, Turtle, TriX, RDFa and Microdata
  - and JSON-LD, via a plugin module
- Store implementations
  - for in-memory and persistent RDF storage - Berkeley DB

ph (multiple Named Graphs)
ns
tion
ries and Updates

EASY RDF

A PHP library designed to make it easy to consume and produce RDF.

Designed for use in mixed teams of experienced and inexperien
tested extensively using PHPUnit.

Apache Jena

A free and open source Java framework for building Semantic Web and Linked Data applications.

dotNetRDF

An Open Source .NET Library for RDF

dotNetRDF is...

- A complete library for parsing, managing, querying and writing RDF.
- A common .NET API for working with RDF triple stores such as AllegroGraph, Jena, Stardog and Virtuoso.
- A suite of command-line and GUI tools for working with RDF under Windows
- Free (as in beer) and Open Source (as in freedom) under a permissive MIT license

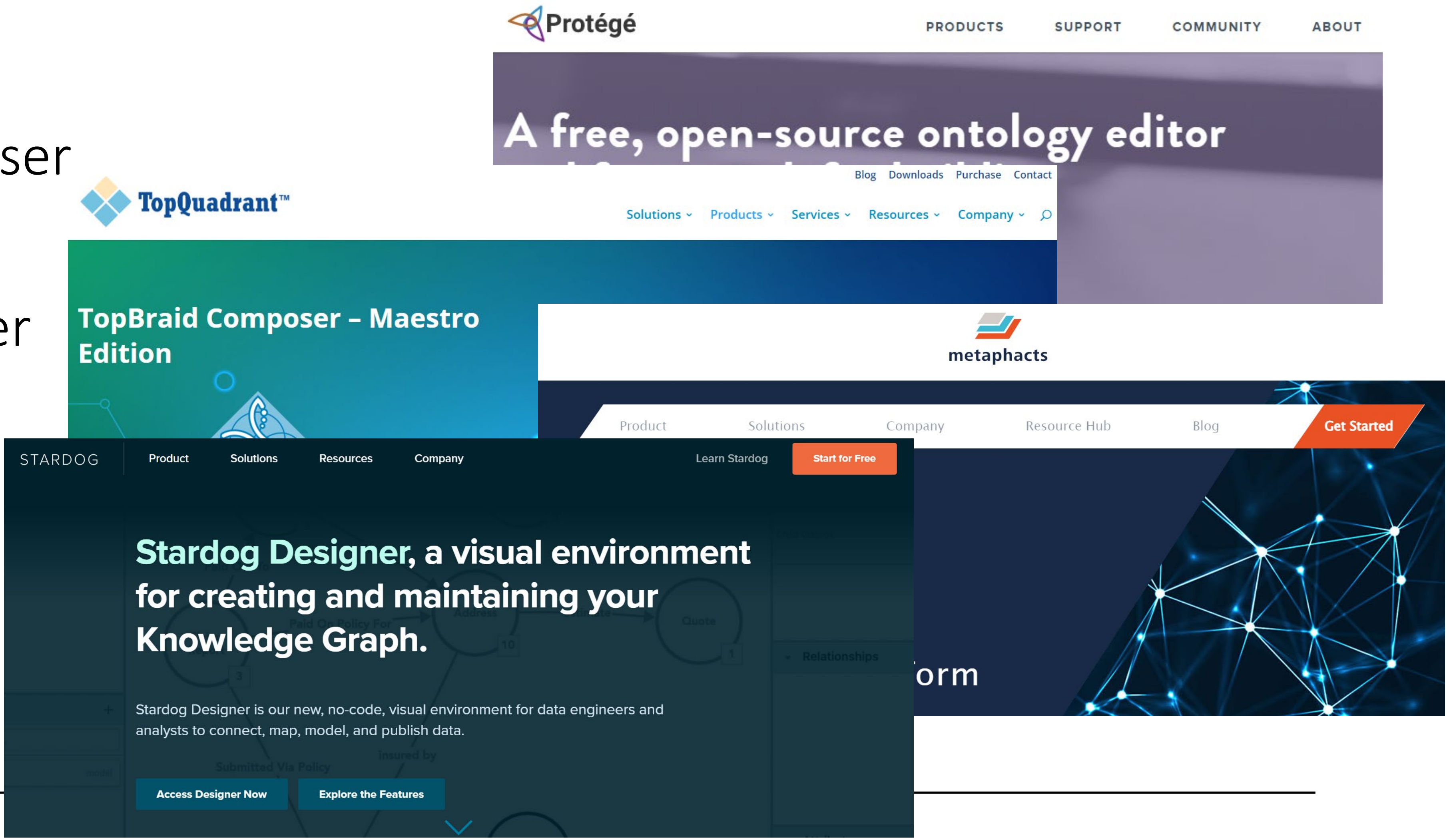
Tools for Ontology Engineering

– Protégé

– TopBraid Composer

– Metaphactory

– Startdog Designer



Protégé

A free, open-source ontology editor

TopQuadrant™

TopBraid Composer – Maestro Edition

metaphacts

orm

STARDOG

Stardog Designer, a visual environment for creating and maintaining your Knowledge Graph.

Stardog Designer is our new, no-code, visual environment for data engineers and analysts to connect, map, model, and publish data.

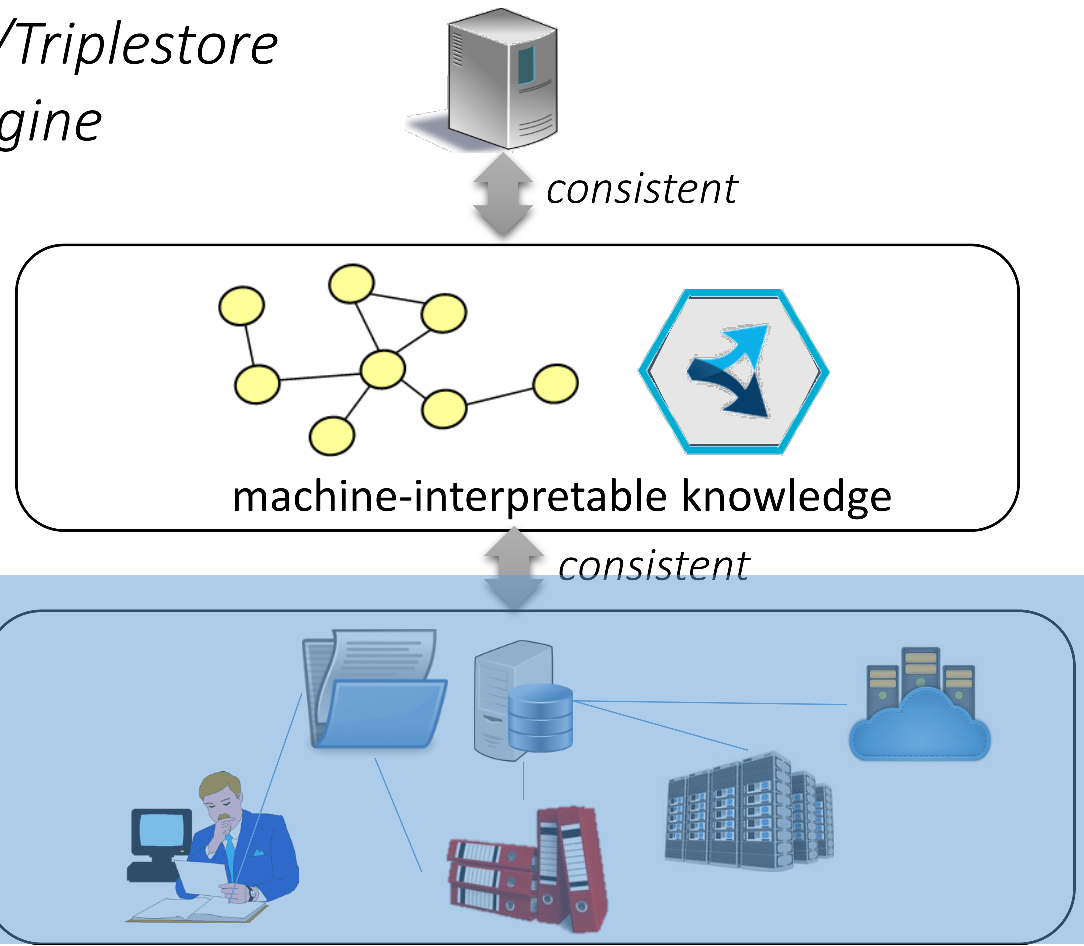
Knowledge Representation and Reasoning

A pragmatic view.

Knowledge-Representation and Reasoning

Graph Database/Triplestore and inference engine

Storing, integration, querying, reasoning.



consistent

machine-interpretable knowledge

consistent

Knowledge representation formalism

RDF, RDF(S), OWL, SPARQL, SHACL…

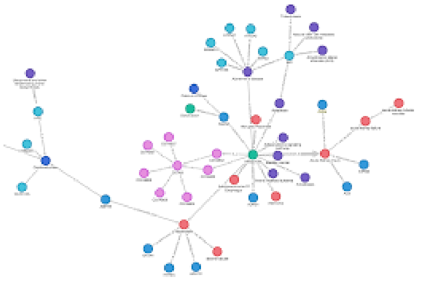
Representation of reality

Not formally represented

Adapted from lecture of Prof. Dr. Knut Hinkelmann

Representation of Reality. Exercise in Pair (5+5 min)

- Describe your family tree to your nearest classmate. If possible, mention what your family component(s) likes and/or where he/she works or study.
  - Switch roles after 5 min – the one who speaks listens and vice-vera.
- Constraints:
  - The one who listens has to note his understanding down in the following triple structure:
    - Subject - Predicate - Object
    - E.g., Emanuele - works at - FHNW
  - **Do not** specify the types for the subjects or objects.
    - Each subject and object should stick to a representation of individuals (or instances). Do not make abstractions like class mother, or father etc. These shall be defined in the predicates,
    - e.g. hasMother, hasFather etc.



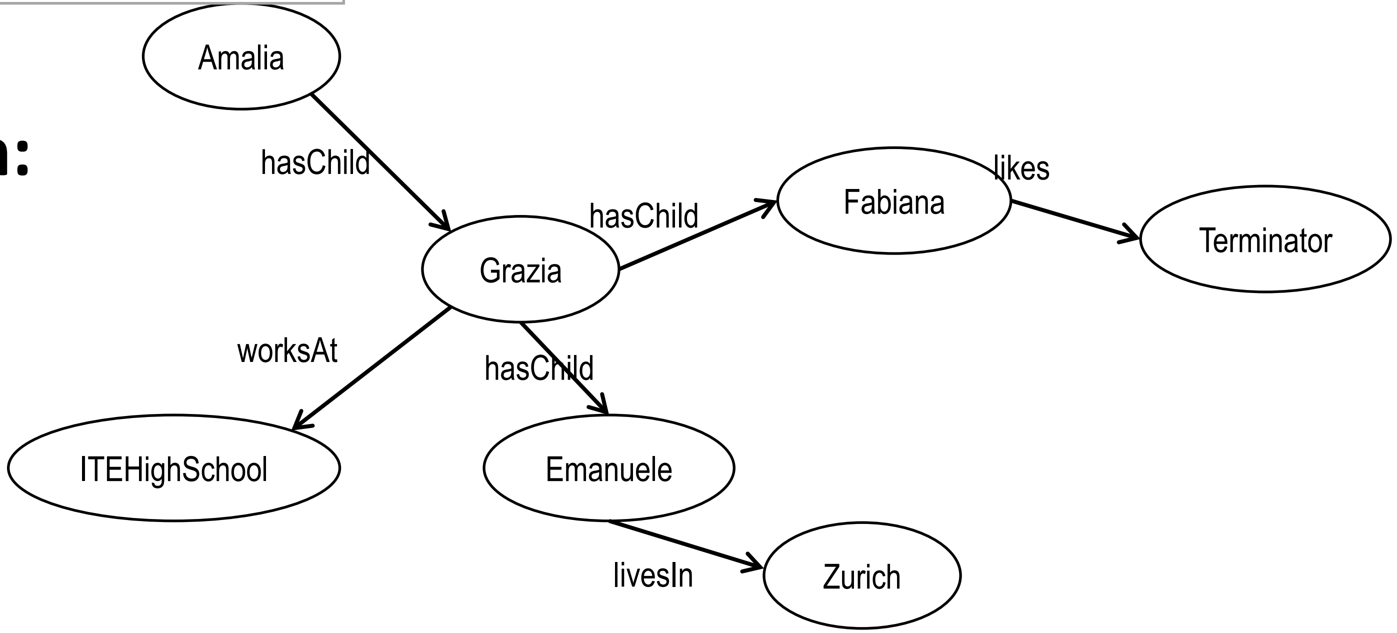
Individual Exercise (5 min)

- Take the triples that were listed by your classmate and create a graph.
  - Every subject and object is a node;
  - Every predicate is an edge (i.e., a link or relation);
  - Nodes are connected by edges.

A possible solution

Subject	predicate	Object
:Grazia	:worksAt	:ITEHighSchool.
:Fabiana	:likes	:Terminator.
:Emanuele	:livesIn	:Zurich.
:Amalia	:hasChild	:Grazia.
:Grazia	:hasChild	:Fabiana, :Emanuele.

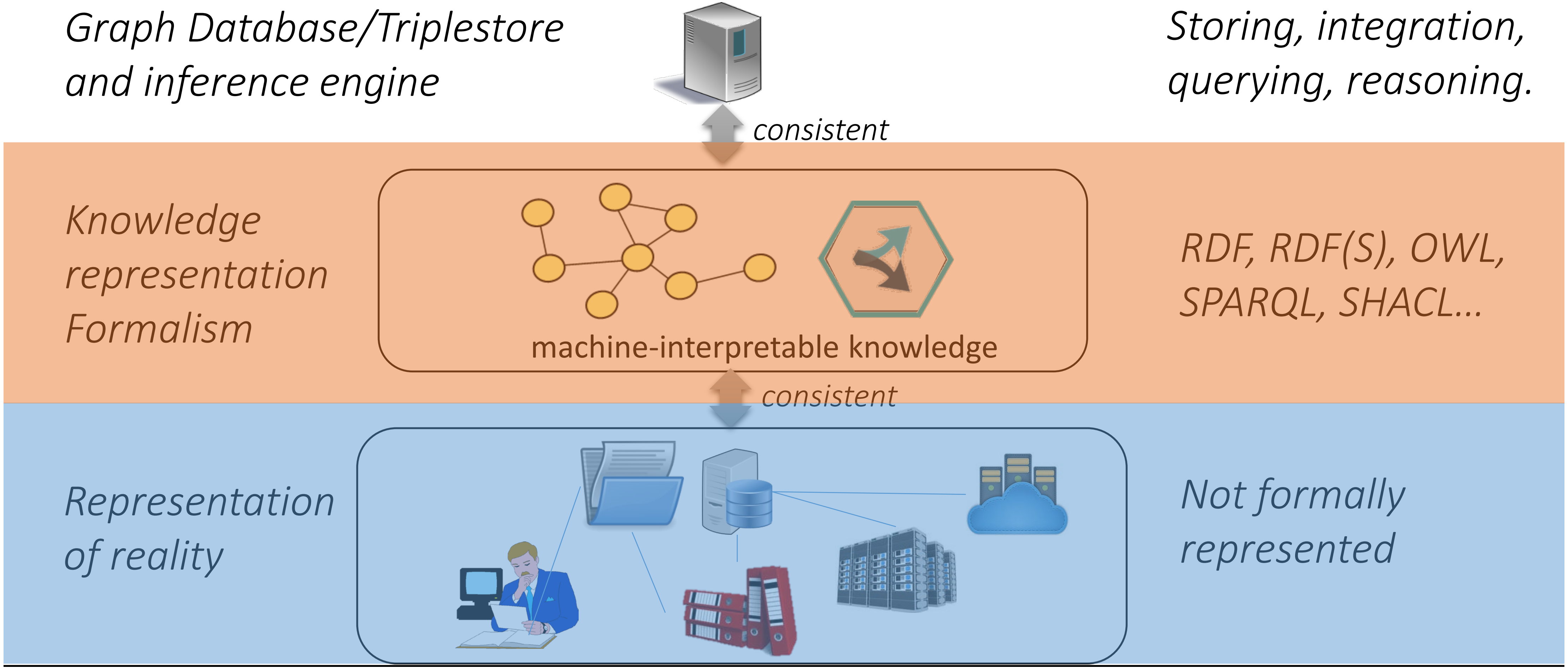
The resulting graph:



RDF

Resource Description Framework

Knowledge-Representation and Reasoning



Graph Database/Triplestore and inference engine

Storing, integration, querying, reasoning.

consistent

Knowledge representation Formalism

machine-interpretable knowledge

RDF, RDF(S), OWL, SPARQL, SHACL…

consistent

Representation of reality

Not formally represented

Adapted from lecture of Prof. Dr. Knut Hinkelmann

About RDF

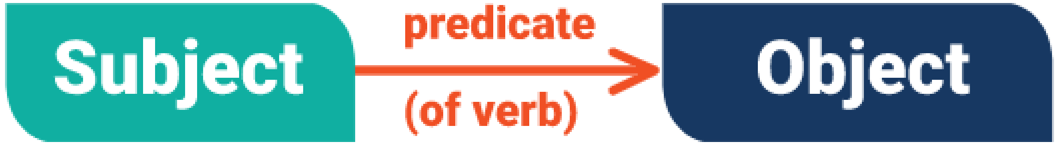
RDF is a standard for data interchange

- It stands for Resource Description Framework.
- A World Wide Web Consortium (W3C) standard.
- It is used to describe and exchange information/data model in the Web.
- Key data structure: RDF graphs.
- Graphs are a set of statements.
- A statement is also called triple.
- Each statement or triple consists of 2 nodes connected by a predicates:
  - *Subject-Predicate-Object*
- Every resource is identified by a URI (Universal Resource Identifier), i.e., an object in the "web", e.g.
  - *https://www.wikidata.org/wiki/Q12418*

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

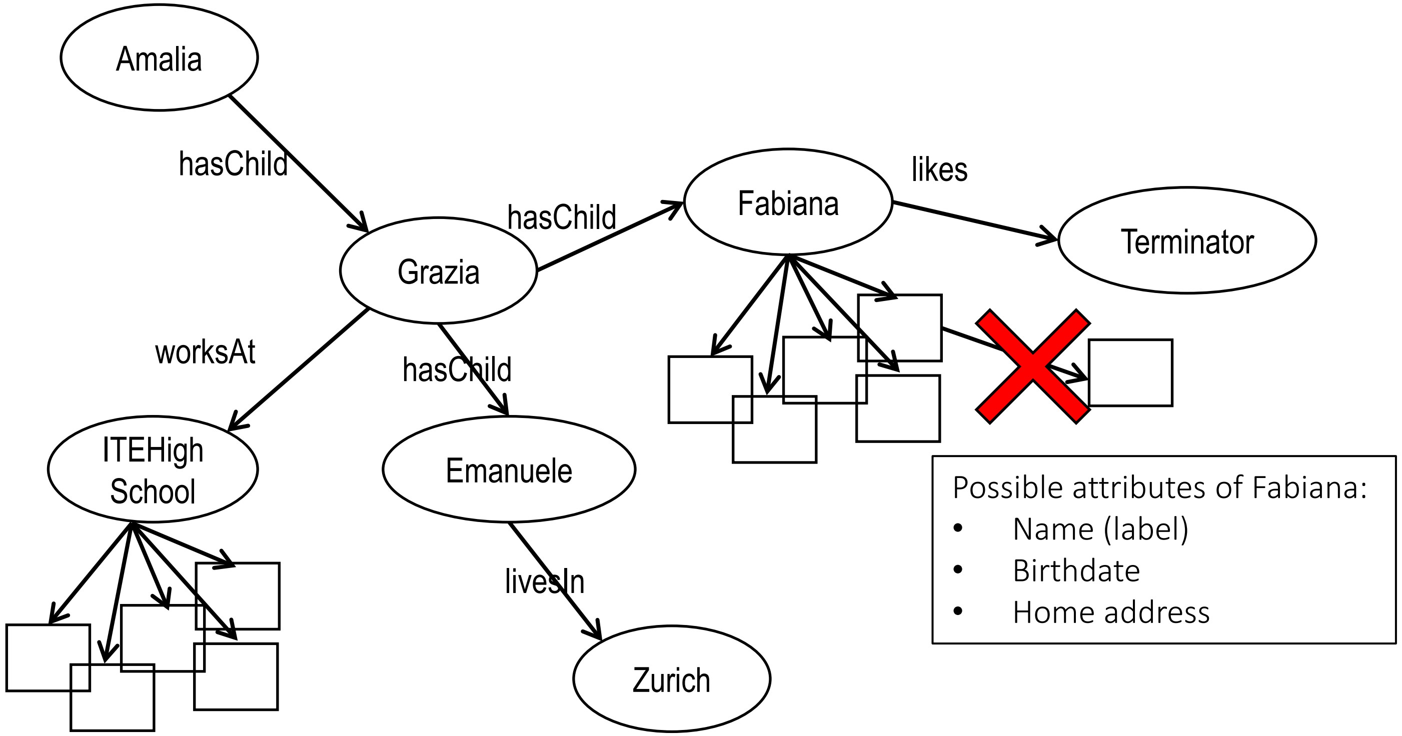
RDF Triples: Three components

- The subject, is a resource (URI) or a blank node.
- The predicate, is a resource (URI).
- The object, is a resource (URI), a literal or a blank node.
  - A literal is a terminal node = data values (strings, numbers, etc).



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

Example of a RDF Graph with Data Values



Possible attributes of Fabiana:

- Name (label)
- Birthdate
- Home address

Data values are terminal nodes! They can only occur at the end of a Turtle statement =>

:Fabiana :hasAge 34.

Not allowed:

34 :ageOf :Fabiana.

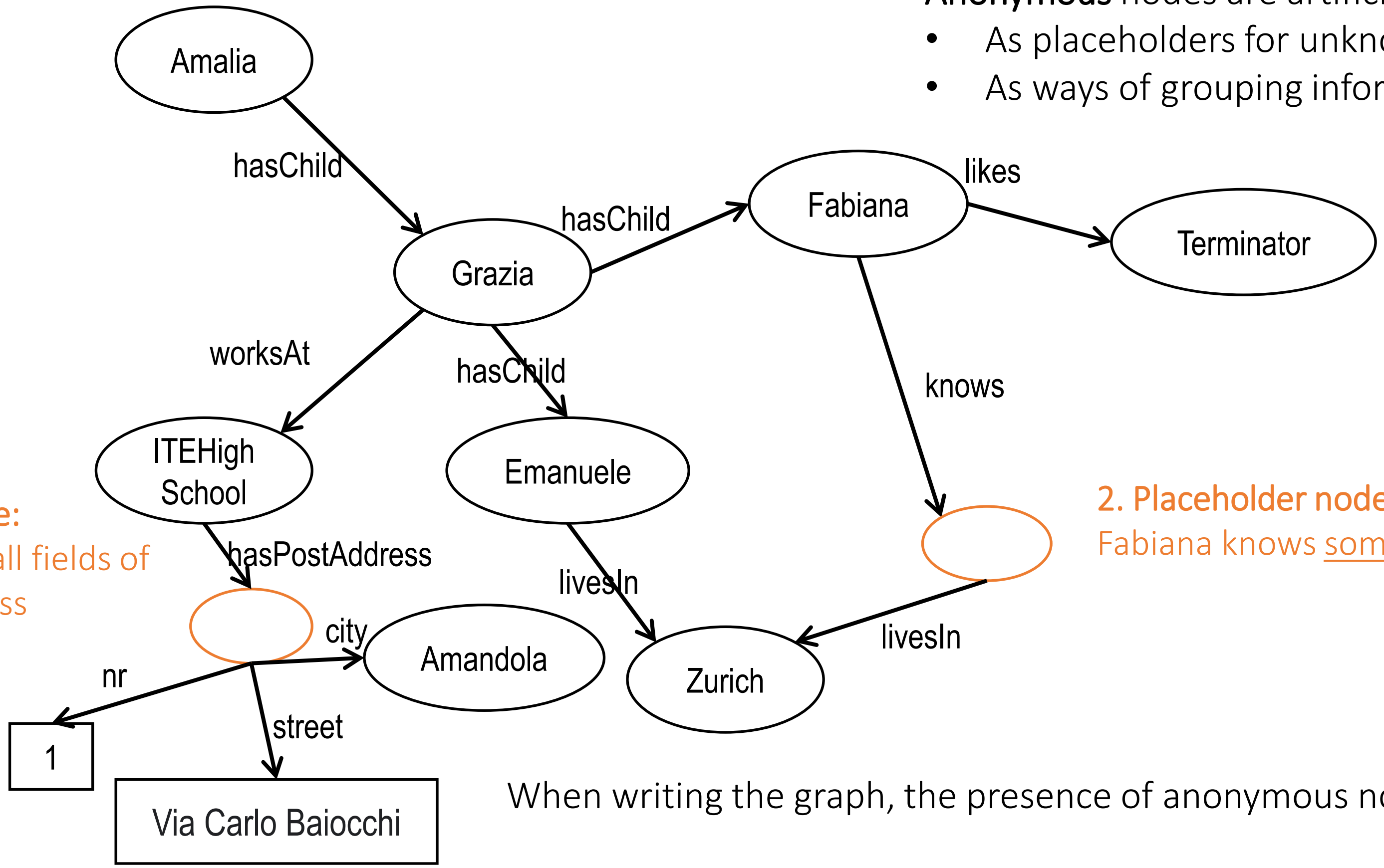
Data values are terminal nodes ("hanging fruits" that can be attached to any ID node).

Adapted from lecture of Prof. Dr. Buchmann

Anonymous (blank) nodes

Anonymous nodes are artificially introduced:

- As placeholders for unknown IDs
- As ways of grouping information ("data structures")



1. Grouping node: Keeps together all fields of the postal address

2. Placeholder node: we can express that Fabiana knows someone who lives in Zurich

When writing the graph, the presence of anonymous nodes is indicated with […]:

1. :ITEHighSchool :hasPostAddress [:nr 1; :street “Via Carlo Baiocchi"; :city :Amandola].
2. :Fabiana :knows [:livesIn :Zurich].

Adapted from lecture of Prof. Dr. Buchmann

Syntax for RDF Graphs

- RDF statements come in the form of graphs.
- Syntax for writing RDF graphs (data format/notation for storing RDF data):
  - Turtle (Terse RDF Triple Language) – the most human readable format, the most used.
  - JSON-LD
  - RDF/XML
  - …

https://www.w3.org/TR/2014/REC-turtle-20140225/

Formal Foundation

– Every “statement” (or triple) is a logical predicate (similar to Prolog).

Subject (ID)	predicate (ID)	Object (ID)
:Grazia	:worksAt	:ITEHighSchool.
:Fabiana	:likes	:Terminator.
:Emanuele	:livesIn	:Zurich.
:Amalia	:hasChild	:Grazia.
:Grazia	:hasChild	:Fabiana, :Emanuele.

statement

:Emanuele :livesIn :Zurich.

⟺

livesIn(Emanuele, Zurich)

Knowledge Graphs are object-oriented.
Prolog is predicate oriented.

– Syntactical delimeters to write more complex phrases:

```
Emanuele :livesIn   :Zurich;
         :worksAt :FHNW;
         :hasWorkAddress [:street “Riggenbachstrasse”; :nr 16].
```

Formal Foundation

Subject (ID)	predicate (ID)	Object (ID)
:Grazia	:worksAt	:ITEHighSchool.
:Fabiana	:likes	:Terminator.
:Emanuele	:livesIn	:Zurich.
:Amalia	:hasChild	:Grazia.
:Grazia	:hasChild	:Fabiana, :Emanuele.

– Syntactical delimeters to write more complex phrases:

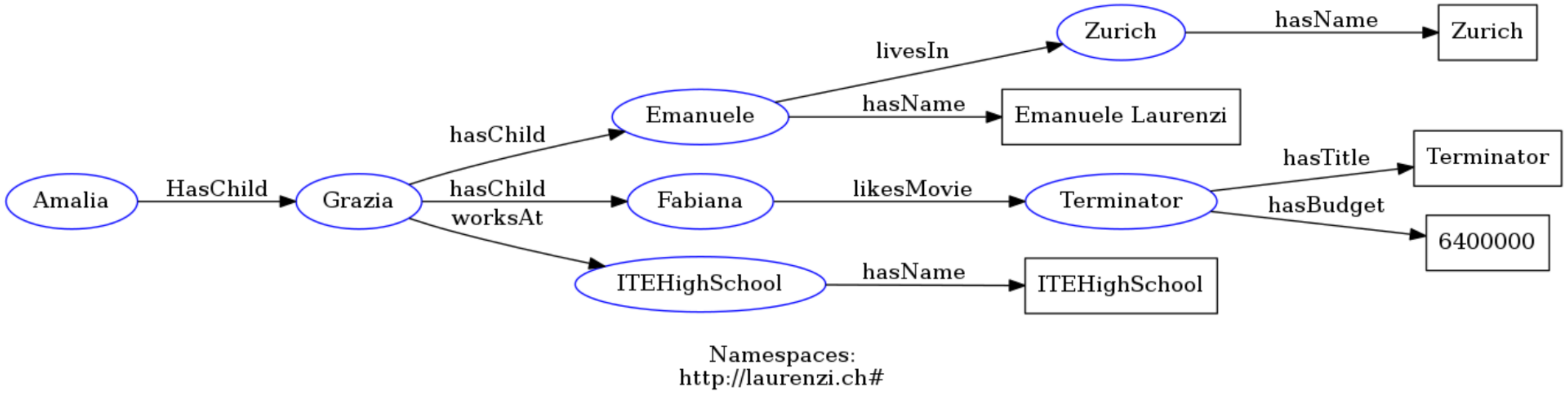
```
Emanuele  :livesIn    :Zurich;
          :worksAt :FHNW;
          :hasWorkAddress [:street “Riggenbachstrasse”; :nr 16].
```

Adapted from lecture Prof. Dr. Buchmann

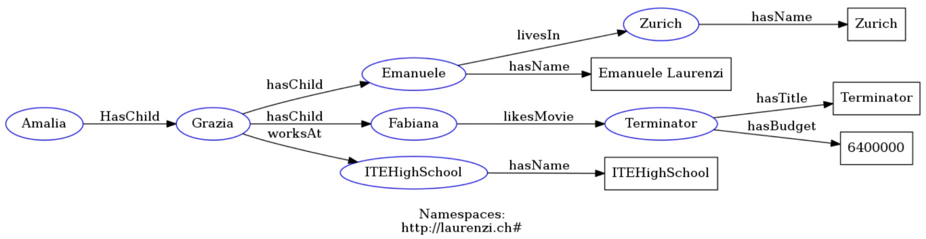
Turtle File – Family Tree

```
@prefix : <http://laurenzi.ch#>.

:Amalia
  :HasChild :Grazia ;
.
:Emanuele
            :livesIn :Zurich ;
            :hasName "Emanuele Laurenzi" ;
.
:Fabiana
            :likesMovie :Terminator ;
.
:Terminator
           :hasTitle "Terminator";
           :hasBudget "6400000" ;
.
:Grazia
            :hasChild :Emanuele ;
            :hasChild :Fabiana ;
            :worksAt :ITEHighSchool ;
.
:ITEHighSchool
            :hasName    "ITEHighSchool";
.
:Zurich
            :hasName "Zurich" ;
.
```



https://www.ldf.fi/service/rdf-grapher



Knowledge Representation Formalism. Individual Exercise (5 min)

- Turn your statements in Turtle notation.
- Use https://www.ldf.fi/service/rdf-grapher to validate the statements and to automatically create the graph.

Entity Types = Classes

- We distinguish between:
  - Concrete things (individual objects) in the domain:
    - Amalia, Grazia, Emanuele, Fabiana, Zurich, ITE High School, Terminator.
  - Set of individuals sharing properties called **classes**:
    - Person, Movie, City, High School.
- Individual objects that belong to a class are referred to as instances of that class.
- The standard relationship **rdf:type** or **a** are used to state that a resource is an instance of a class.

Kinds of Nodes

- All nodes in previous examples are identifiers (IDs, also called URIs, IRIs)

- Other kinds of nodes in RDF graphs:
  - data types (integers, booleans etc.)
  - entity types (classes)
  - anonymous nodes (placeholders, helpers)

Kinds of Nodes: An Example

```
:Emanuele     a             :Lecturer, :Italian, :Person;
              rdfs:label    "Emanuele Laurenzi";
              :hasAge       36;
              :married      false;
              :hasParents   :Omar, :Grazia;
              :authorOf     [a :Book;  :yearOfPublication   2022;
                               :hasTitle "Domain-Specific Conceptual
                               Modeling"@en];
              :livesIn      [:street "Gablerstrasse"@de;  :nr 47];
              :bought       [:product :Bananas;
                            :quantity [rdf:value 1; :unit "kilogram"];
                            :price [rdf:value 2.3; :currency  "CHF"]].
```

Comma devides different values for the same attribute and different objects.

Semicolon devides different attributes.

https://www.w3.org/TR/turtle/
Section 2.5 Literals
Quoted Literals (String) and Numbers

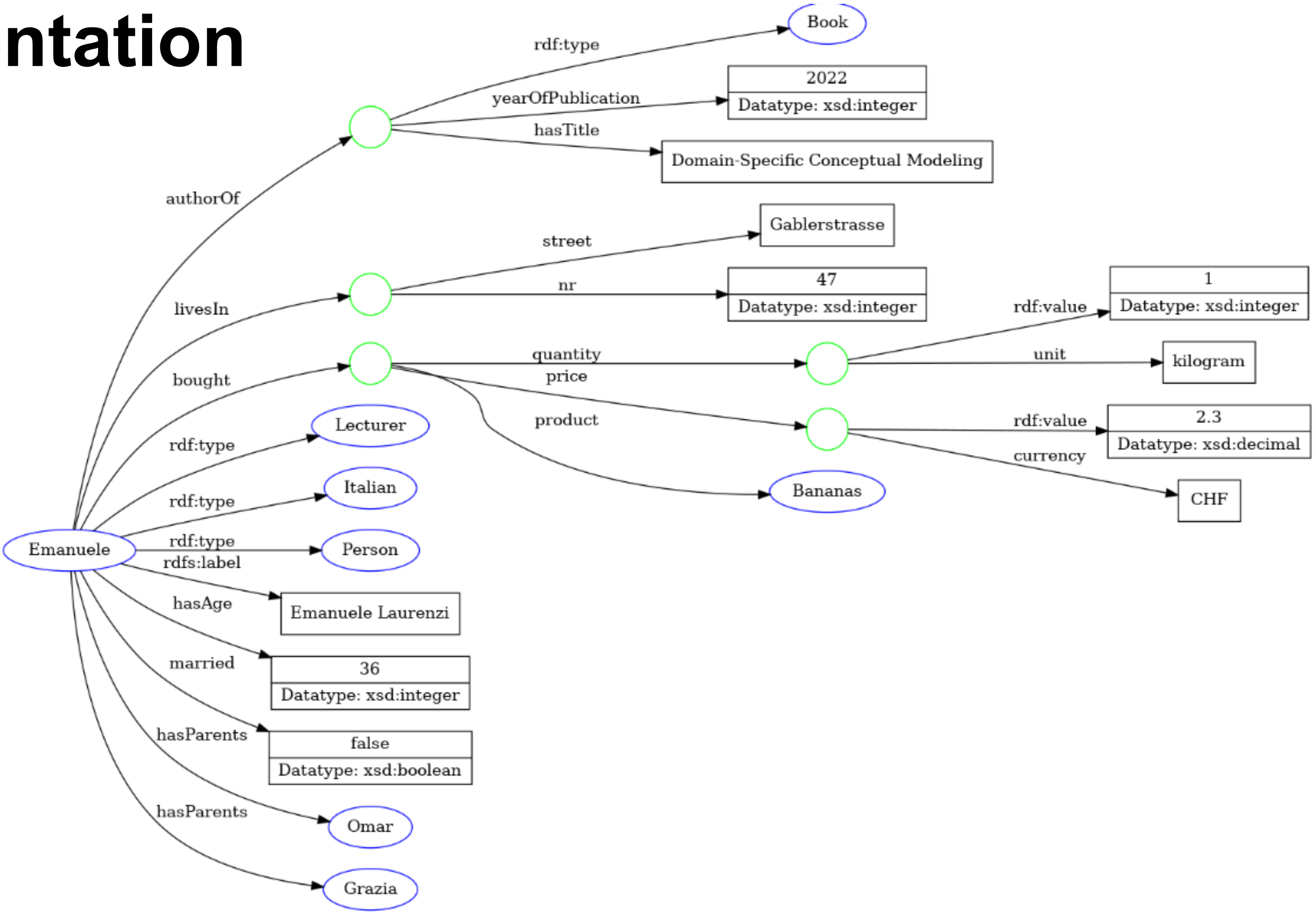
- Datatypes (Integer, Decimal, Double, String) are automatically associated based on the data value of the literal, e.g.
  36 is associated to Integer,
  false/true is associated to Boolean,
  4.3 is associated to a Decimal,
  1.663E-4 is associated to a Double,
  “Gablerstrasse” is associated to String.
  The String data type wants the “ ”
- XML Schema datatypes can be added to the value, e.g.,
  “Gablerstrasse”^^xsd:string
- Language tag can be attached to the String datatype, e.g.
  “Gablerstrasse”@de OR “Hi there!”@en
- Datatypes are predefined in XSD (XML Schema Definition).
- Specify the namespace for XSD when using datatypes:

@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .

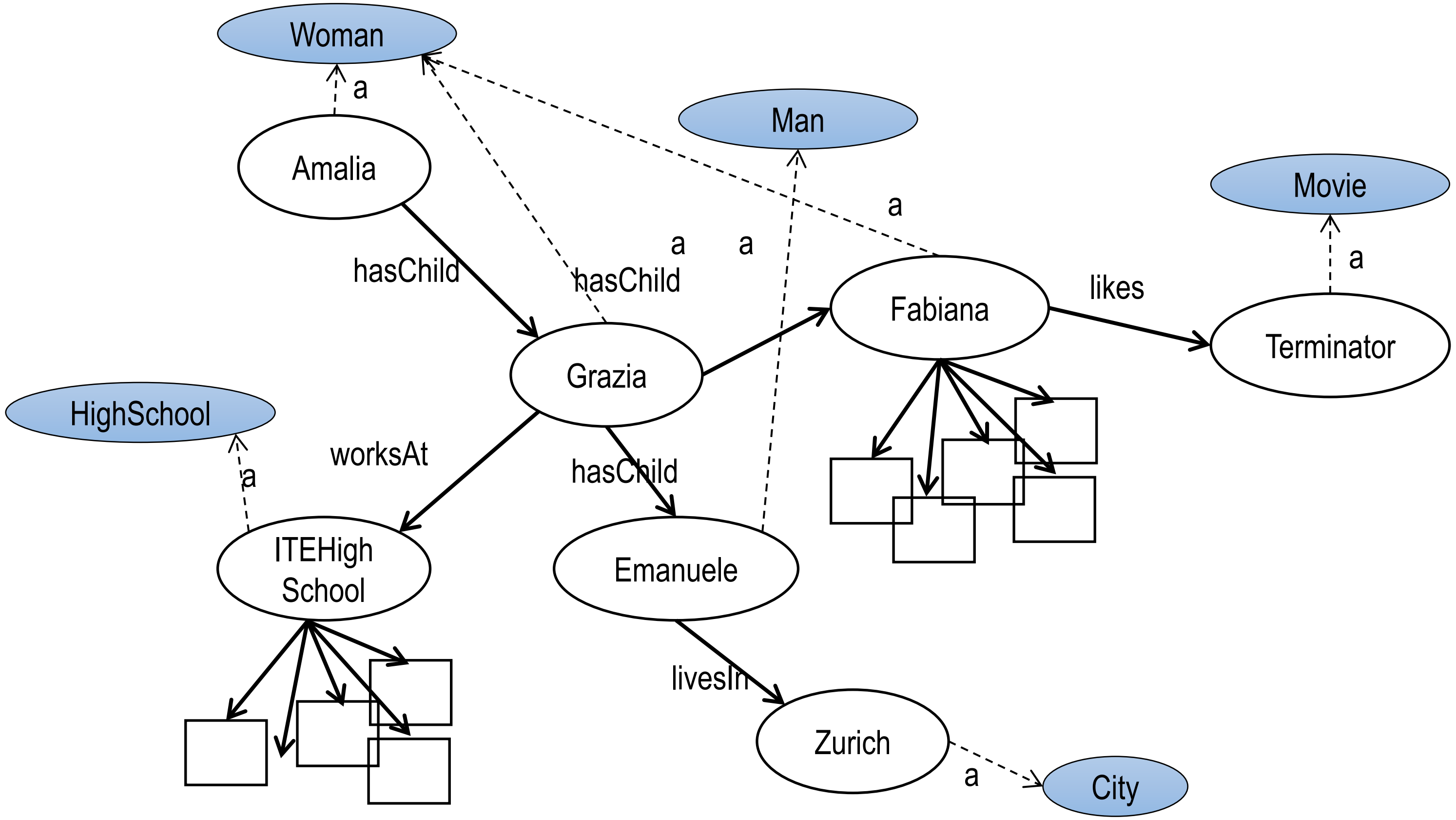
- Notice the semi-colon “;” after each row and the full-stop “.” after the last statement that refers to the subject “Emanuele”.

Graph Representation

- Where are the terms for nodes and edges from?



Entity Types
(WHAT are the things mentioned in the graph?)



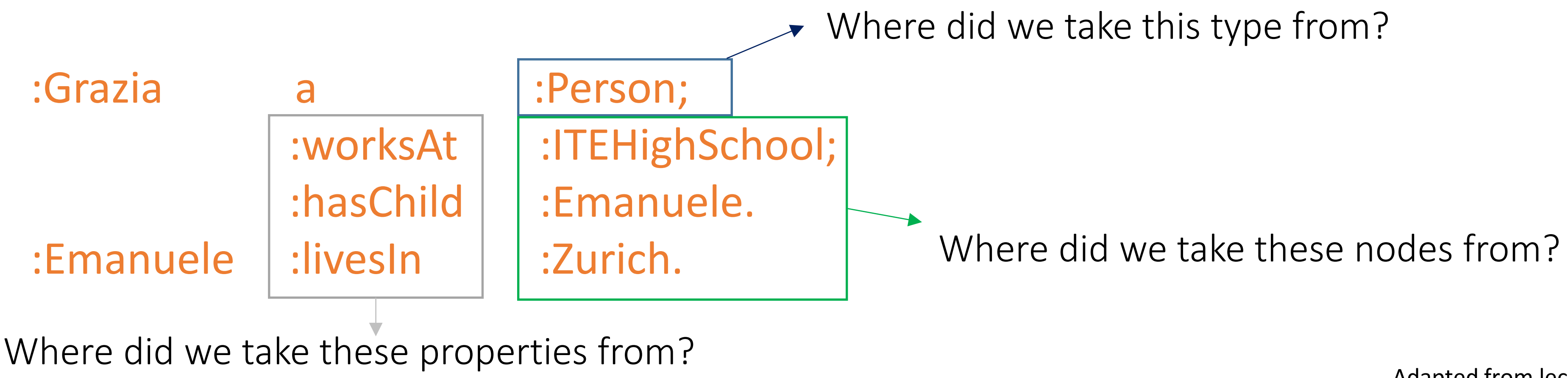
Now we know that Terminator is a movie and not the online shop about electrical product.

https://terminator.ae/

Provenance of Terms in RDF Statements

Possible sources:

- the **creator of the graph can improvise all terms** (similarly to how we are free to decide what JSON fields or XML tags we can use).
- terms **can be picked from public sources** (public graphs, public ontologies).
- our own terms **can be freely combined** with terms from other provenances.



```
:Grazia     a          :Person;
            :worksAt   :ITEHighSchool;
            :hasChild  :Emanuele.
:Emanuele   :livesIn   :Zurich.
```

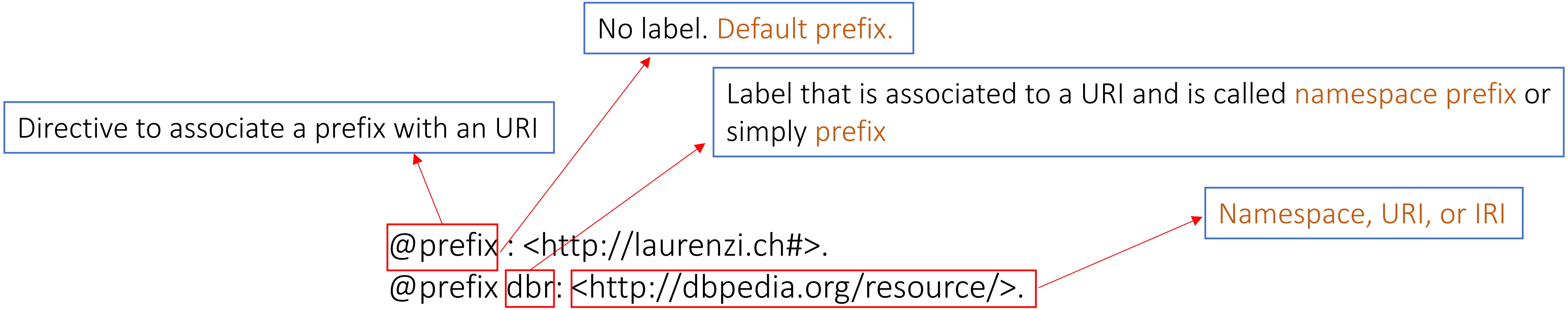
Where did we take this type from?

Where did we take these nodes from?

Where did we take these properties from?

Adapted from lecture of Prof. Dr. Buchmann

Prefix and Namespaces (URI or IRI)



No label. Default prefix.

Directive to associate a prefix with an URI

Label that is associated to a URI and is called namespace prefix or simply prefix

Namespace, URI, or IRI

@prefix : <http://laurenzi.ch#>.
@prefix dbr: <http://dbpedia.org/resource/>.

The **prefix declarations** is mandatory for all prefixes used in a graph.

The provenance of terms determines the namespace prefixes that shall be declared.

- Default prefix. Improvise our own terms and IDs , e.g.,
  - @prefix : <http://laurenzi.ch#>.
- Use an ID of a public source, e.g.,
  - @prefix dbr: <http://dbpedia.org/resource/>.
- You can also add a label to characterize your dataset, e.g.,
  - @prefix el: <http://laurenzi.ch#>.
    - This helps to identify a graph or its scope in the whole Web. E.g.,
      - in dbr:The_Terminator, *dbr* identifies the Graph of DBPedia, which describes Wikipedia pages.

Examples of Public Sources

- Schema.org – public ontology (we can take from there properties and types)
- DBPedia – public Knowledge Graph (offers Wikipedia information in graph form, we can also take from there IDs)

Example written with terms of varying provenance.

```
@prefix   :          <http://laurenzi.ch#>.  (default prefix for my own terms)
#Alternative -> @prefix       el:        <http://laurenzi.ch#>.  (prefix “el”for my own terms)
@prefix   s:         <http://schema.org/>. (prefix for terms from Schema.org)
@prefix   dbr:       <http://dbpedia.org/resource/>. (prefix for DBPedia terms)

:Emanuele       a                  s:Person;
                s:worksFor         dbr:University_of_Applied_Sciences_and_Arts_Northwestern_Switzerland;
                s:homeLocation     dbr:Zürich.
```

https://schema.org/Person

https://schema.org/worksFor

https://schema.org/homeLocation

https://dbpedia.org/page/Zürich

https://dbpedia.org/page/University_of_Applied_Sciences_and_Arts_Northwestern_Switzerland

Adapted from lecture of Prof. Dr. Buchmann

Deferencing

- Dereferencing = accessing the URL address obtained from namespace + local ID/term
- It can return something useful about a term, typically:
  - A Webpage about the term
  - A subgraph with all information available about the term
  - Nothing at all because it's a global identifier and not an address.

For example:

@prefix : <http://laurenzi.ch#>.

-> http://laurenzi.ch/ + Emanuele = http://Laurenzi.ch/Emanuele

It returns nothing.

@prefix dbr: <http://dbpedia.org/resource/>.

@prefix s: <http://schema.org/>.

:Emanuele s:homeLocation dbr:Zürich.

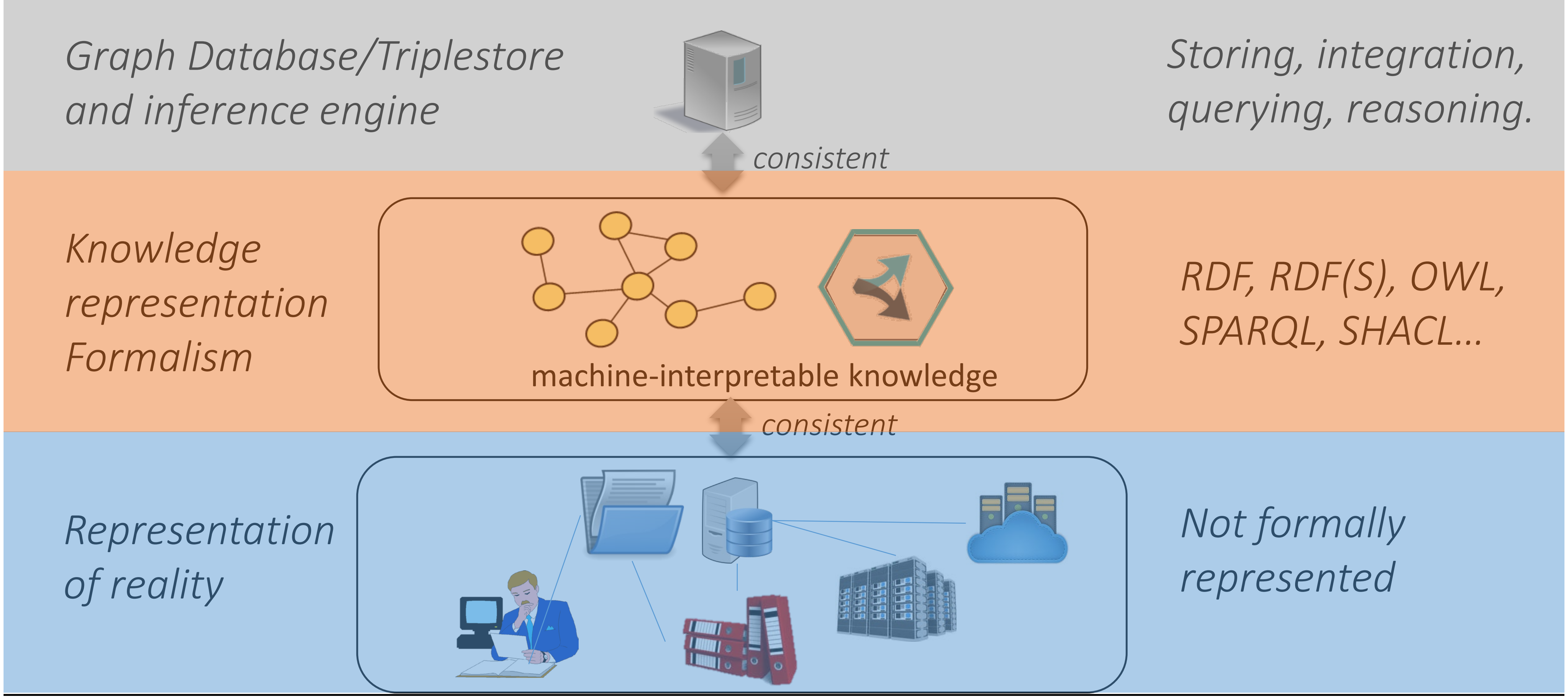
-> http://dbpedia.org/resource/ + Zürich = http://dbpedia.org/resource/Zürich

If you try to access it in a browser (through HTTP) it returns information about the city of Zurich.

Querying an RDF Graph

Queries are mostly about navigating the graph in search of some patterns.

Knowledge-Representation and Reasoning



Graph Database/Triplestore and inference engine

Storing, integration, querying, reasoning.

consistent

Knowledge representation Formalism

machine-interpretable knowledge

RDF, RDF(S), OWL, SPARQL, SHACL…

consistent

Representation of reality

Not formally represented

Adapted from lecture of Prof. Dr. Knut Hinkelmann

SPARQL Query Syntax

A World Wide Web Consortium (W3C) standard.

SPARQL similar to select-from-where syntax (like SQL):

- *PREFIX*: prefix information. The left-hand side of ":" can contain an acronym to denote the name of the Turtle file.

```
  prefix
          : <http://www.fhnw.ch#>
```

- *SELECT*: the entities (variables) you want to return.

```
  select ?X ?Y ?A
```

- *WHERE*: the (sub)graph you want to get the information from.

```
  where  { ?X friend ?Y. ?Y age ?A.
```

- additional constraints on objects, using operators.

```
              FILTER  ?A > 25. }
```

From lecture of Prof. Dr. Holger Wache

SPARQL

- It provides facilities to:
  - Extract information in the form of URIs, blank nodes, plain and typed literals.
  - Extract RDF subgraphs.
  - Construct new RDF graphs based on information in the queried graphs.
- Feature
  - Matching graph patterns.
  - Query terms – based on Turtle syntax.
  - Terms delimited by "<>" are relative URI references.
  - Data description format – Turtle.

From lecture of Prof. Dr. Holger Wache

Popular SPARQL Forms

- SELECT
  - returns all, or a subset of the variables bound in a query pattern match.
- CONSTRUCT
  - returns an RDF graph constructed by substituting variables in a set of triple templates.

Our focus

- DESCRIBE
  - returns an RDF graph that describes the resources found.
- ASK
  - returns whether a query pattern matches or not.

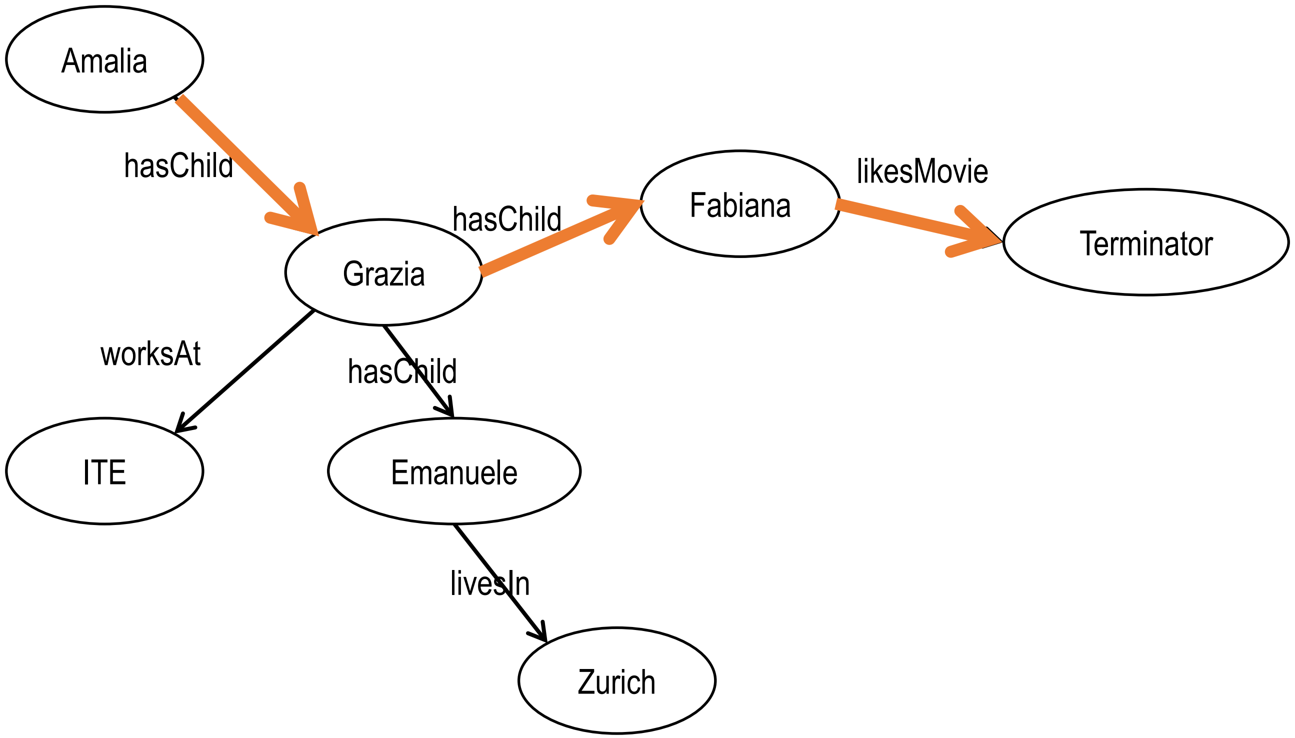
From lecture of Prof. Dr. Holger Wache

Hands-on with SPARQL

- Download zip familytree_without_schema.zip -> unzip it
- Launch GraphDB
- Create a graph database Family Tree
- Load .ttl file familytree_without_schema to GraphDB

SELECT

to 1. navigate along a graph path, 2. unknown length and 3. navigate a path in reverse



1. Navigating along a graph path

SELECT ?x WHERE
{:Amalia **:hasChild/:hasChild/:likesMovie** ?x}
(what does Amalia's grandchild like?)

2. Navigating a path of unknown length

SELECT ?x WHERE
{:Amalia **:hasChild+/:likesMovie** ?x}
(what do all Amalia's descendants like?)

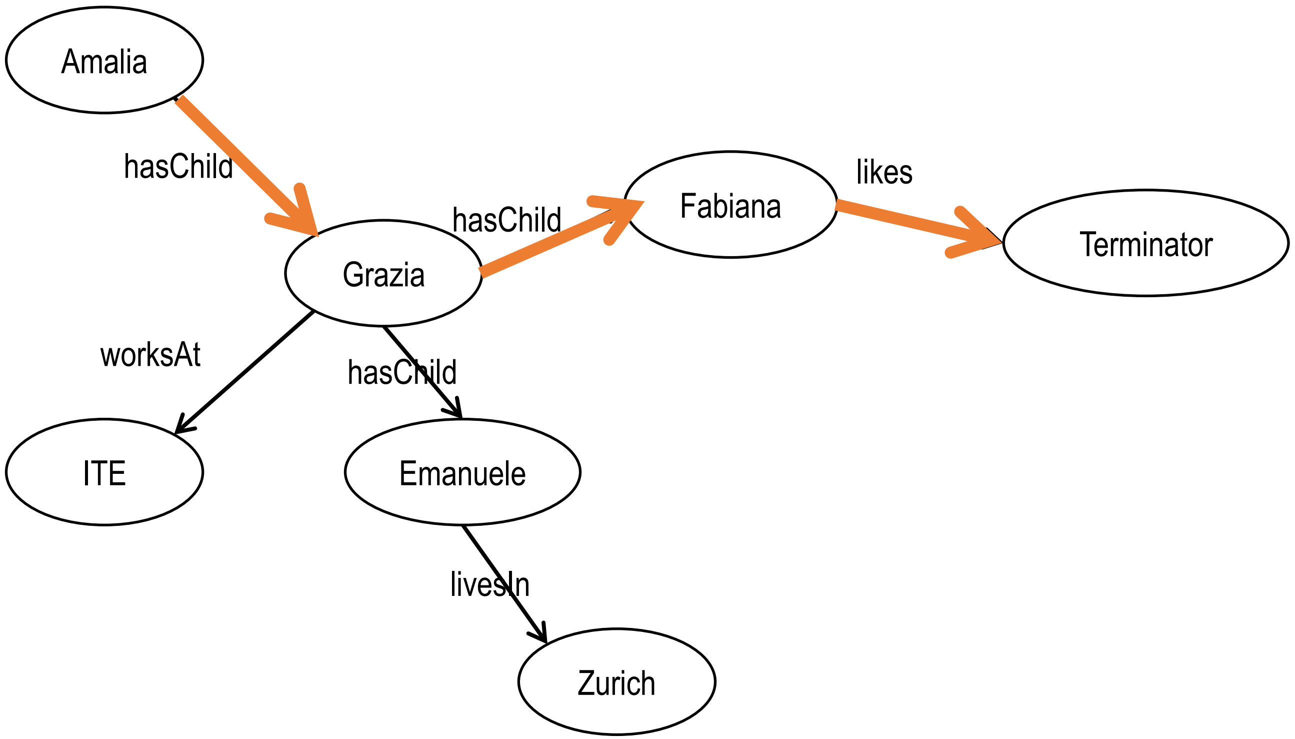
3. Navigating a path in reverse:

SELECT ?x WHERE
{?x **^:likesMovie/^:hasChild/^:hasChild** :Amalia}

Adapted from lecture Prof. Dr. Buchmann

SELECT

to 4. navigate a path and 5. to retrieve potential missing information



4. Step-wise navigation of a path

(it can retrieve intermediate nodes and edges)

```
SELECT ?a ?b ?x WHERE
{:Amalia    :hasChild   ?a.
?a          :hasChild   ?b.
?b          :likesMovie ?x}
```

**the decomposition into statements complies with the Turtle syntax*

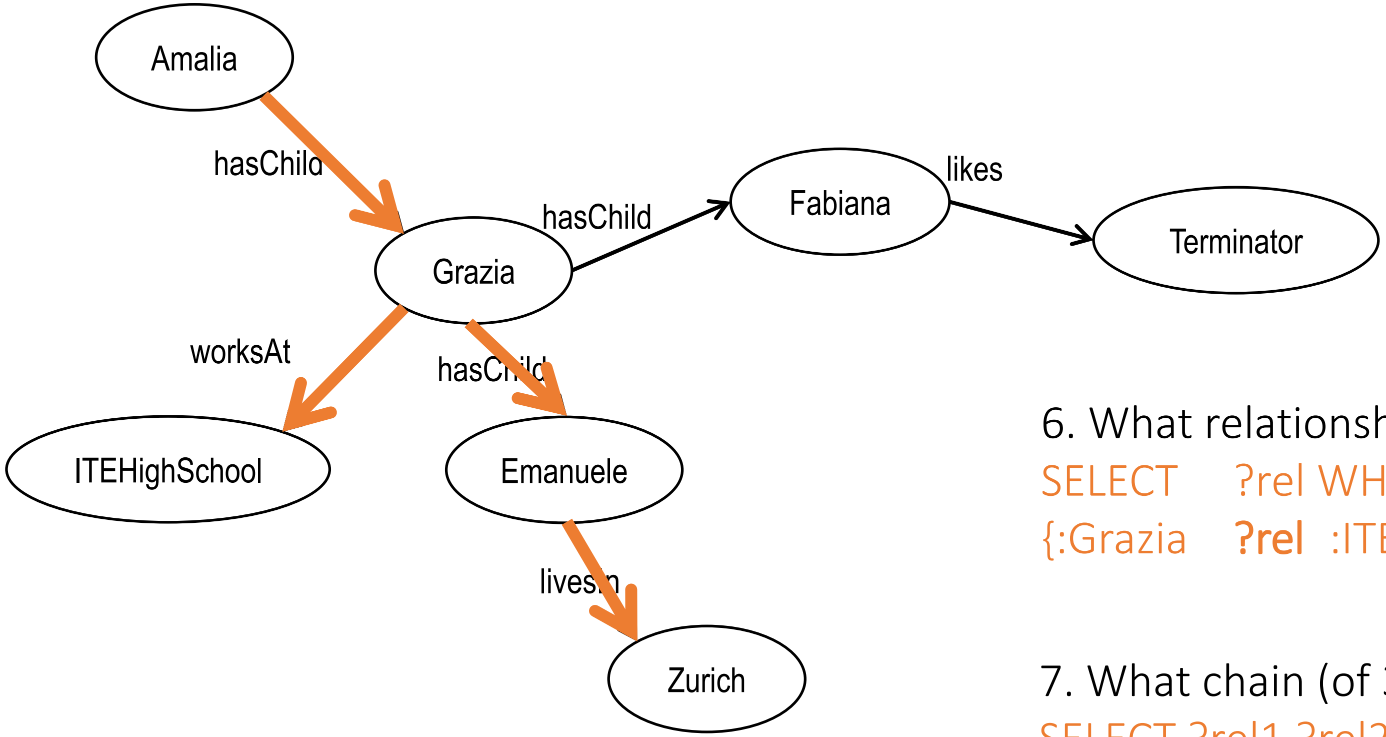
5. Retrieving potentially missing information

(give me all parents and, IF AVAILABLE, their work place)

```
SELECT ?a ?c WHERE
{?a  :hasChild  ?b.
OPTIONAL
      {?a  :worksAt  ?c}}
```

Adapted from lecture Prof. Dr. Buchmann

SELECT to discover relationships



6. What relationship exists between Grazia and ITEHighSchool?

SELECT ?rel WHERE
{:Grazia **?rel** :ITEHighSchool}

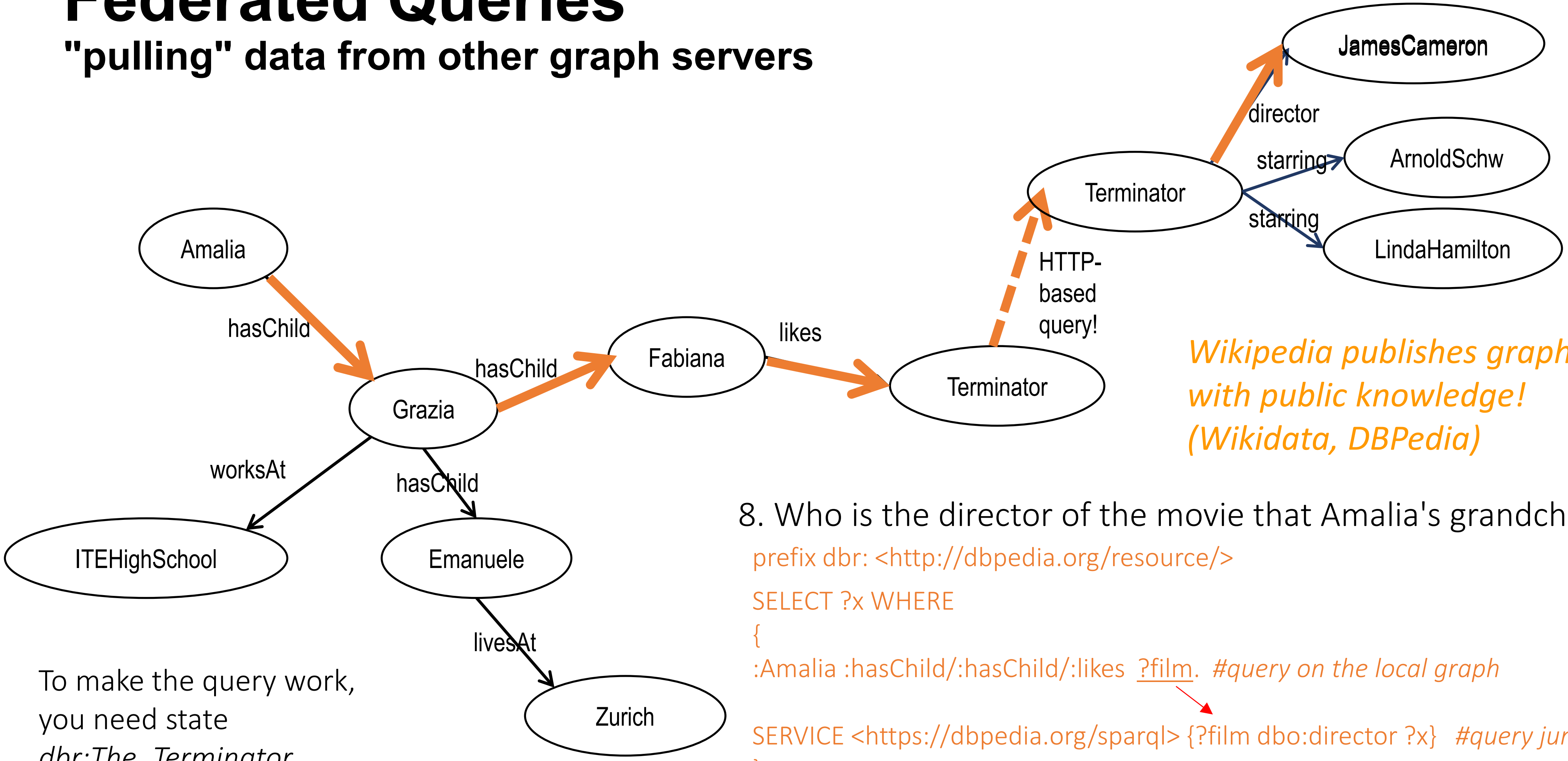
7. What chain (of 3 relationships) exists between Amalia and Zurich?

SELECT ?rel1 ?rel2 ?rel3 WHERE
{:Amalia **?rel1** ?intermediary1.
?intermediary1 **?rel2** ?intermediary2.
?intermediary2 **?rel3** :Zurich}

Adapted from lecture Prof. Dr. Buchmann

Federated Queries

"pulling" data from other graph servers



Wikipedia publishes graphs with public knowledge! (Wikidata, DBPedia)

8. Who is the director of the movie that Amalia's grandchild likes?

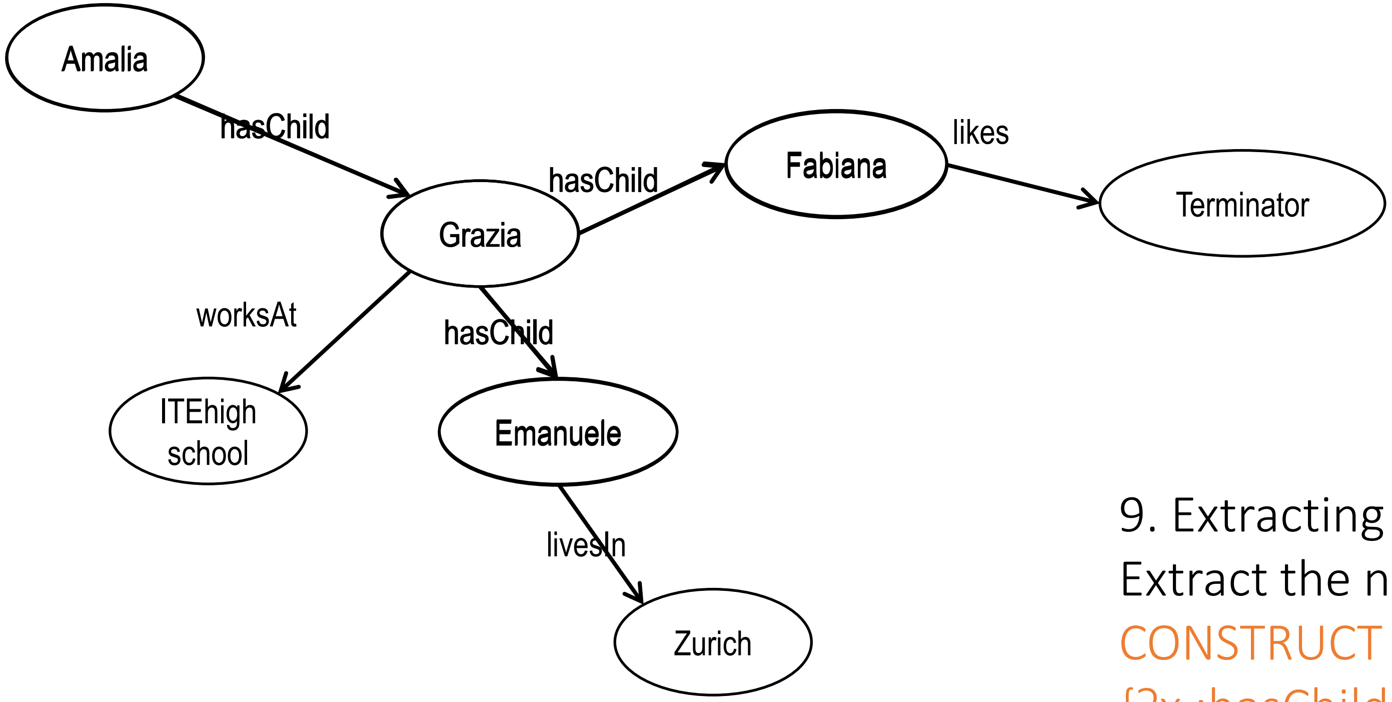
```
prefix dbr: <http://dbpedia.org/resource/>
SELECT ?x WHERE
{
:Amalia :hasChild/:hasChild/:likes  ?film.  #query on the local graph

SERVICE <https://dbpedia.org/sparql> {?film dbo:director ?x}   #query jumps to public graph
}
```

To make the query work, you need state *dbr:The_Terminator* in your dataset.

Adapted from lecture Prof. Dr. Buchmann

CONSTRUCT to extract a subgraph



9. Extracting a subgraph

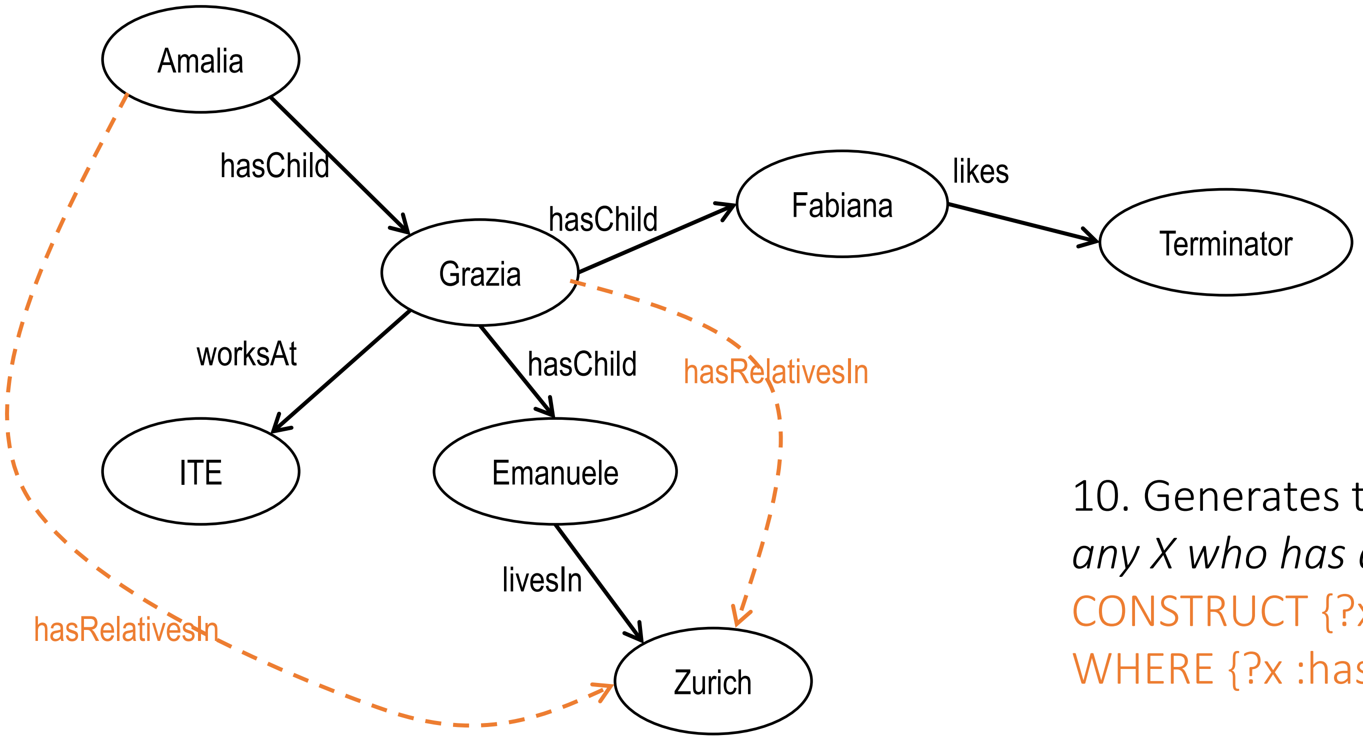
Extract the network of child relationships

CONSTRUCT WHERE
{?x :hasChild ?y}

Adapted from lecture Prof. Dr. Buchmann

CONSTRUCT for Machine Reasoning

supported directly in the query language!

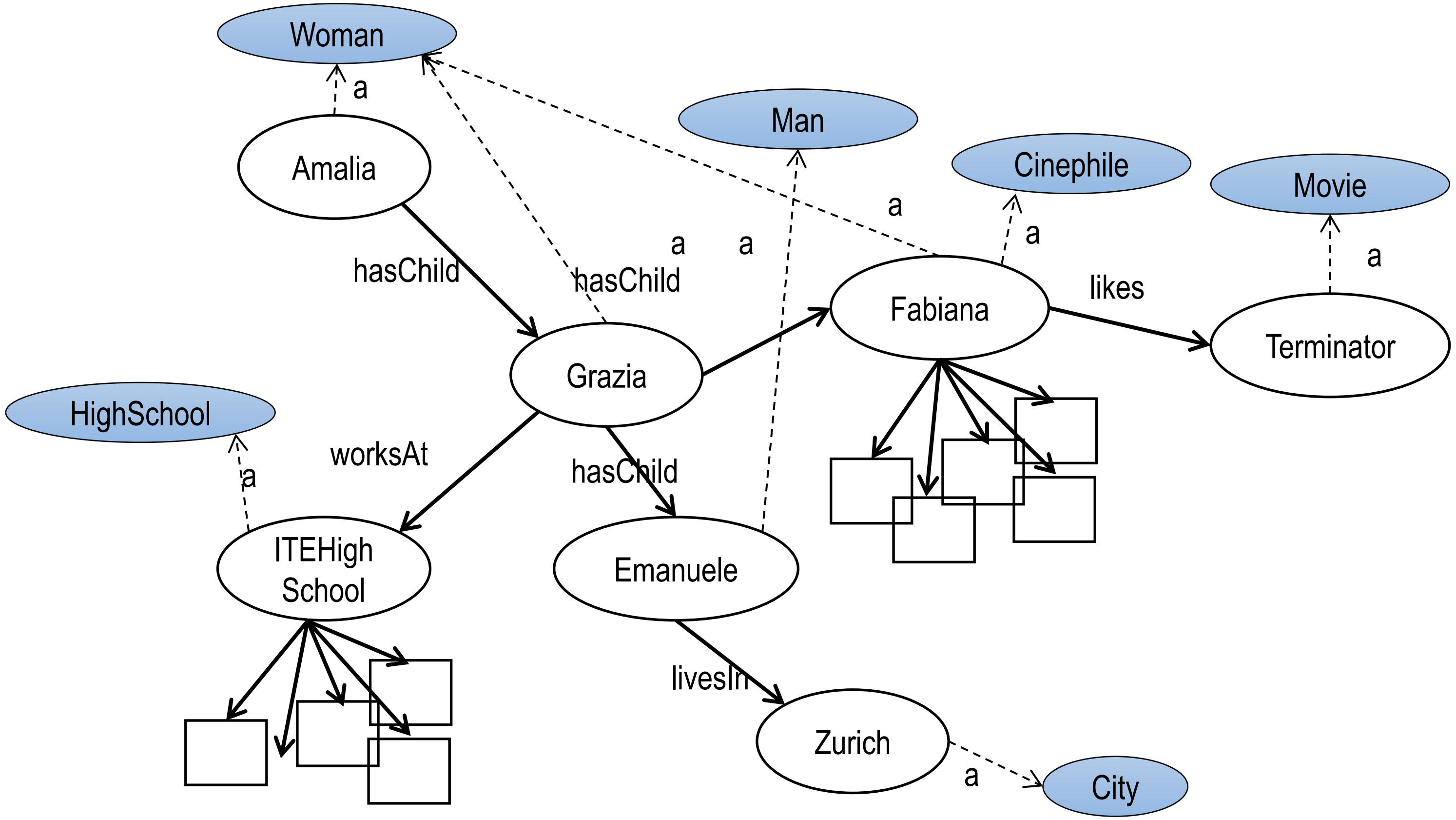


10. Generates the statement "X hasRelatives in Y" for *any X who has descendants living in Y*:

```
CONSTRUCT {?x :hasRelativesIn ?y}
WHERE {?x :hasChild+/:livesIn ?y}
```

Adapted from lecture Prof. Dr. Buchmann

Entity Types
(WHAT are the things mentioned in the graph?)



Types can be attached to the nodes:

- a standard relationship denoted “a” is used for this purpose.
- some types can be generated through deductive reasoning, e.g.:
  - *11. if X likes Terminator, she/he is a Cinephile:*

    CONSTRUCT {?x a :Cinephile}
    WHERE {?x :likes dbr:The_Terminator}
  - *12. if X likes movies, she/he is a Cinephile:*

    CONSTRUCT {?x a :Cinephile}
    WHERE {?x :likes/a :Movie}