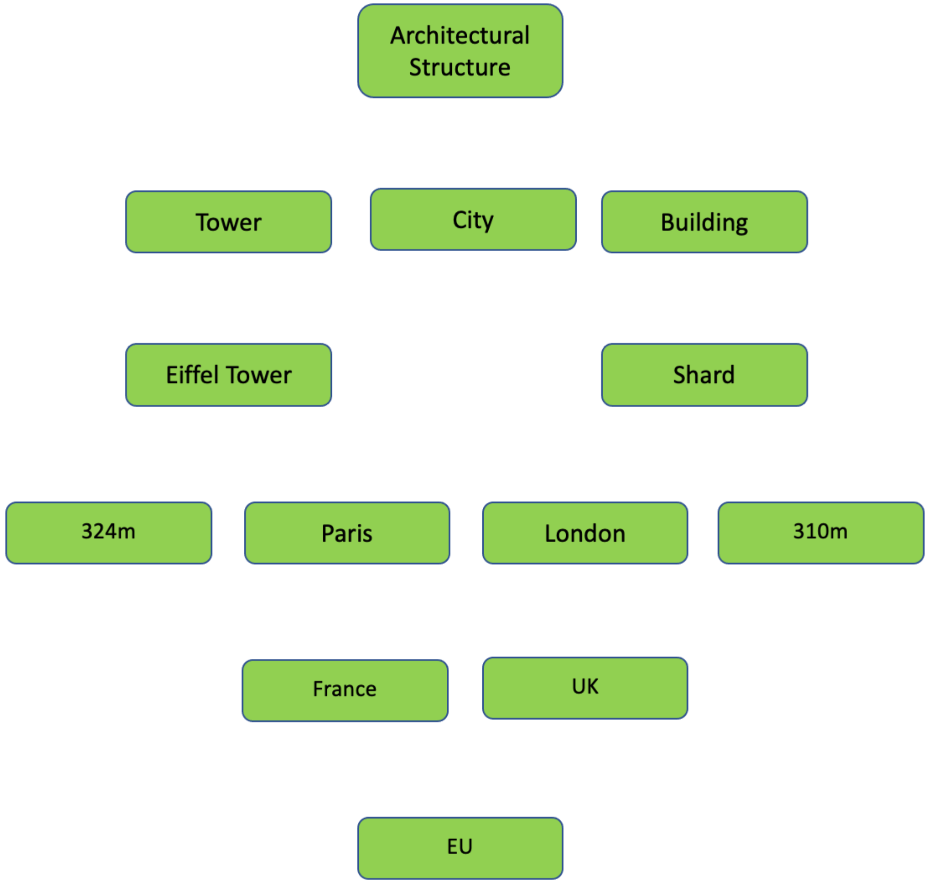
Reasoning over Knowledge Graphs: Motivation, Theory and Practice

Ian Horrocks

UNIVERSITY OF OXFORD
DEPARTMENT OF COMPUTER SCIENCE

Introduction to Knowledge Graphs

Anatomy of a Knowledge Graph



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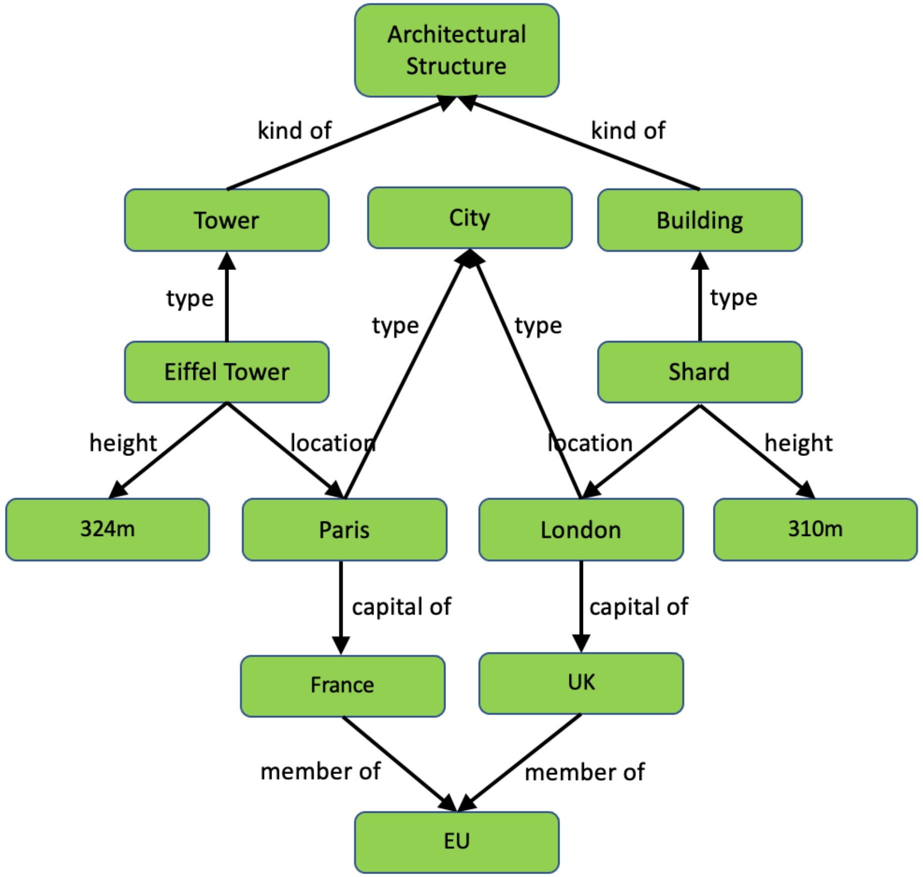

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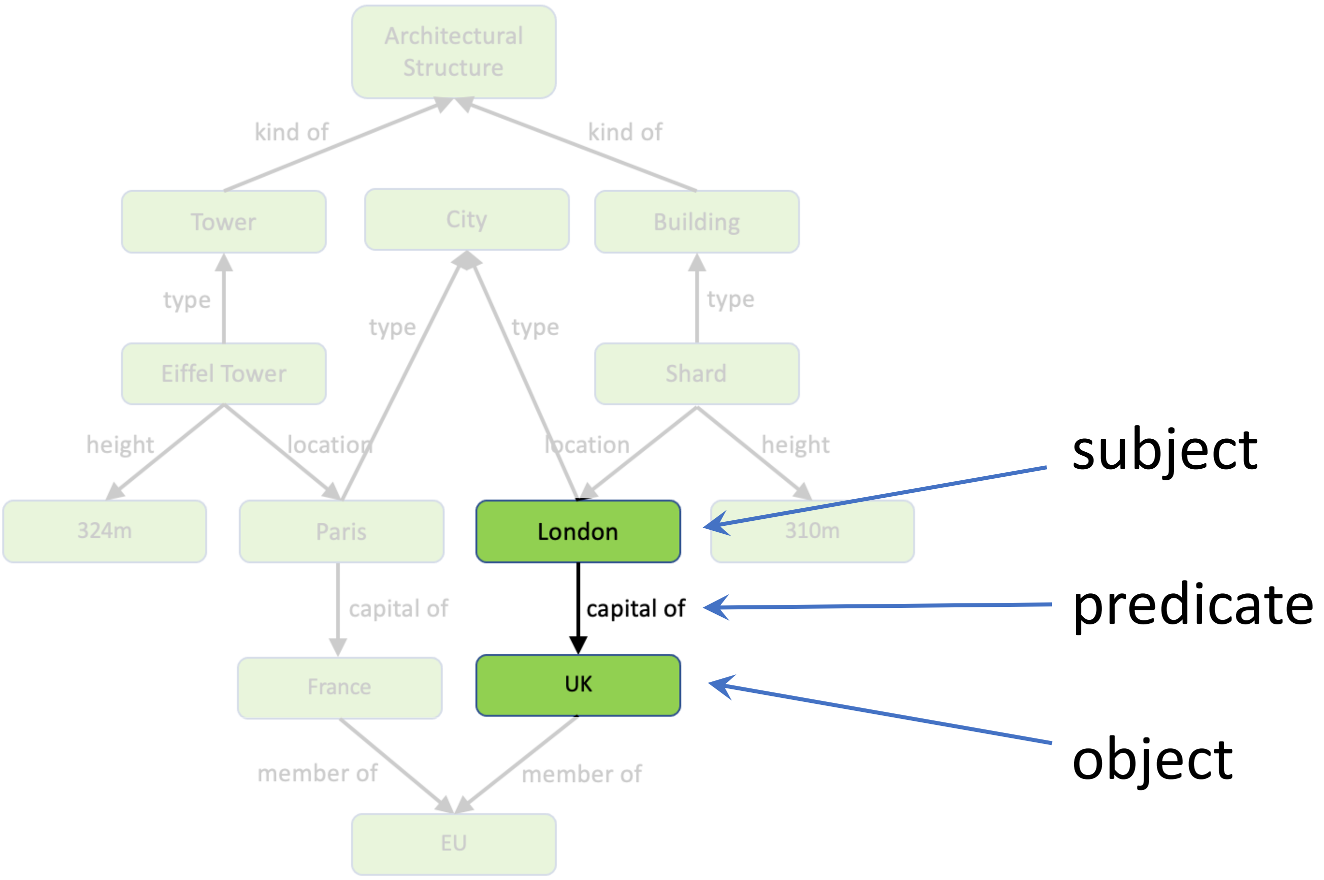

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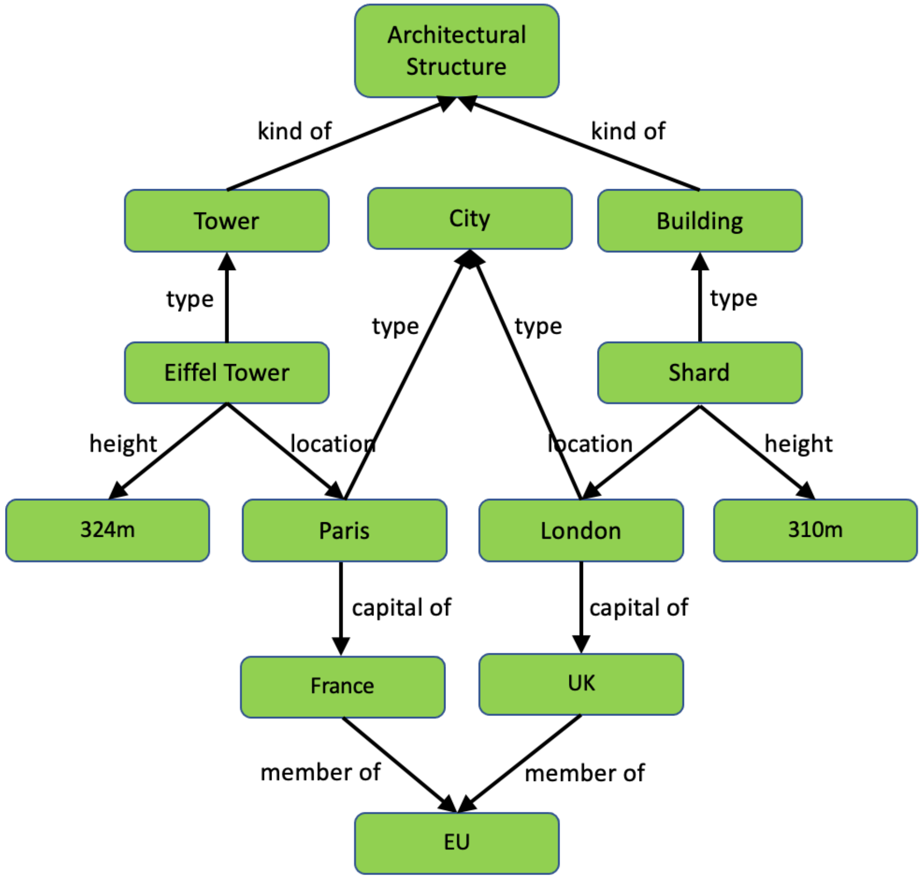

$\sim$

Architectural Structure		
Name	Height	Location
Eiffel Tower	324	Paris
Shard	310	London

Tower
Name
Eiffel Tower

Building
Name
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City	
Name	Capital Of
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Member	
Country	Union
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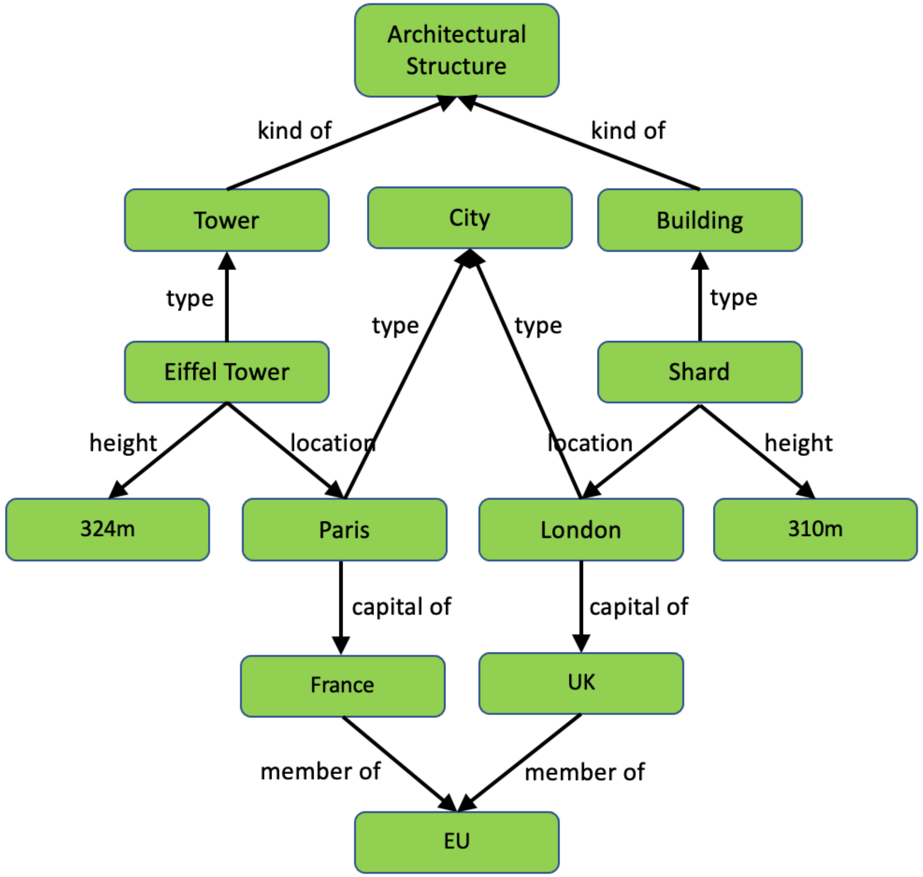

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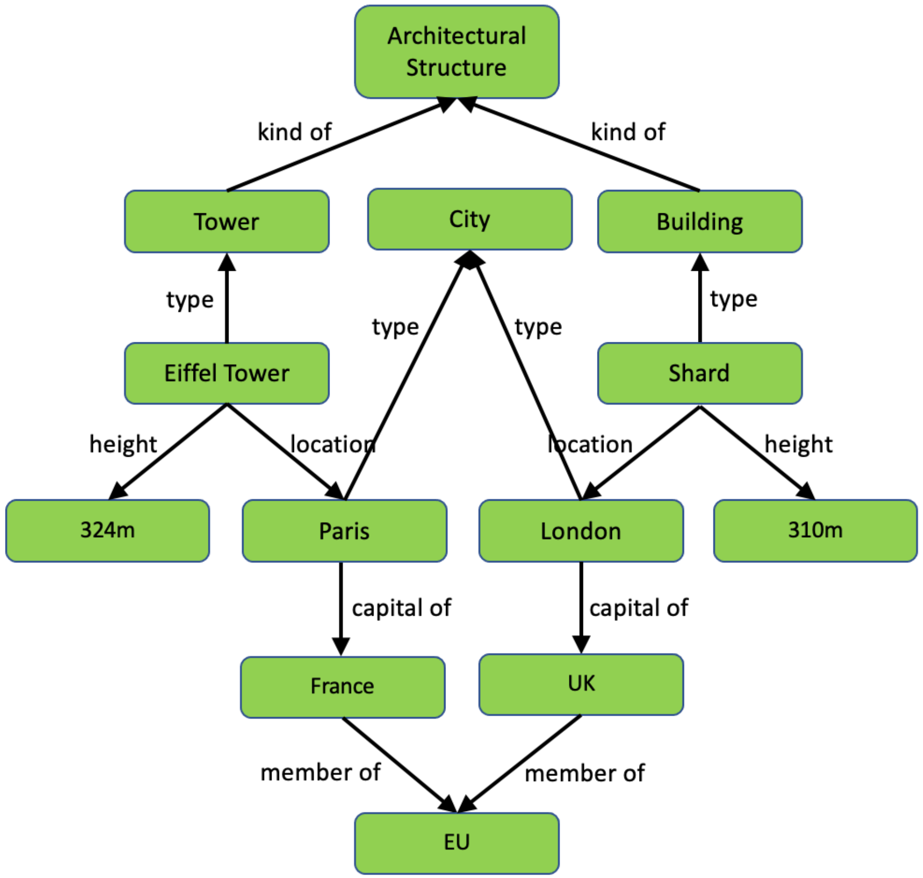

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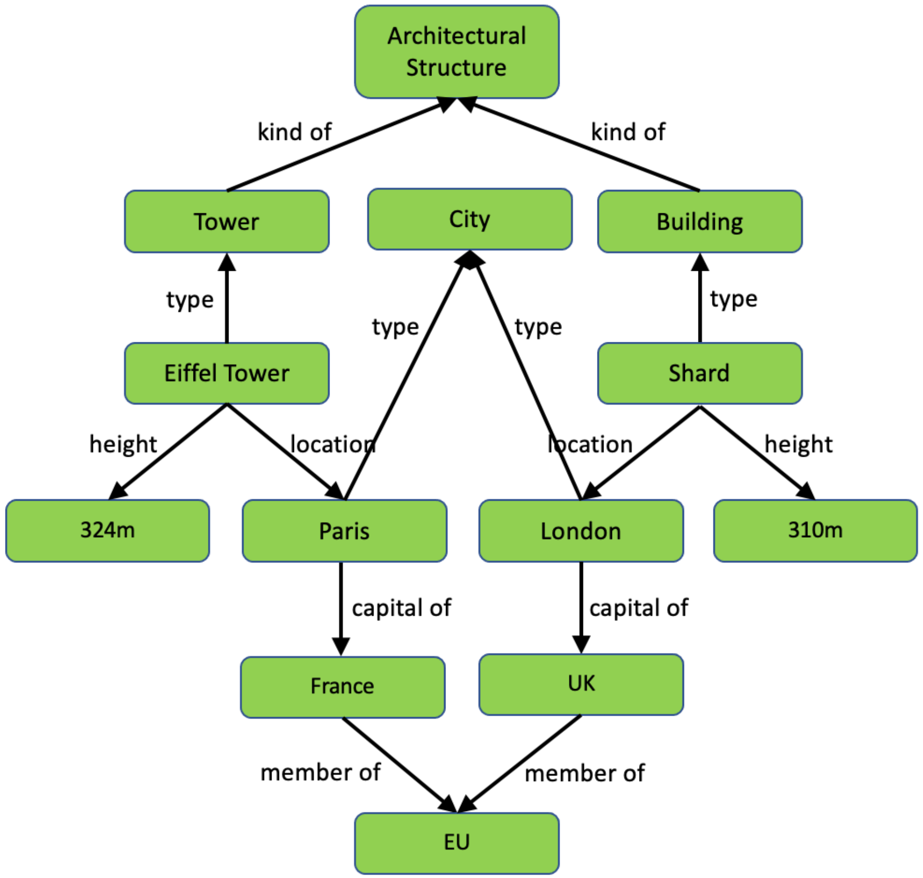

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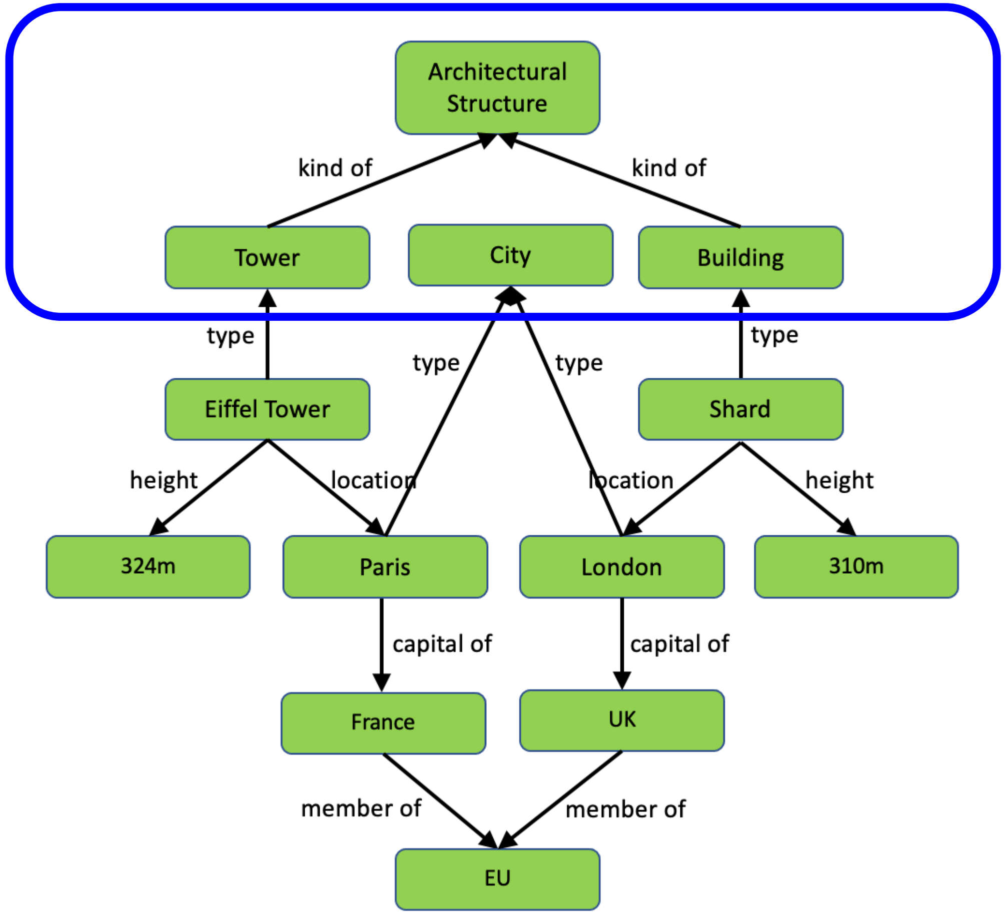

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- ✓ **Data** + **schema (ontology)**

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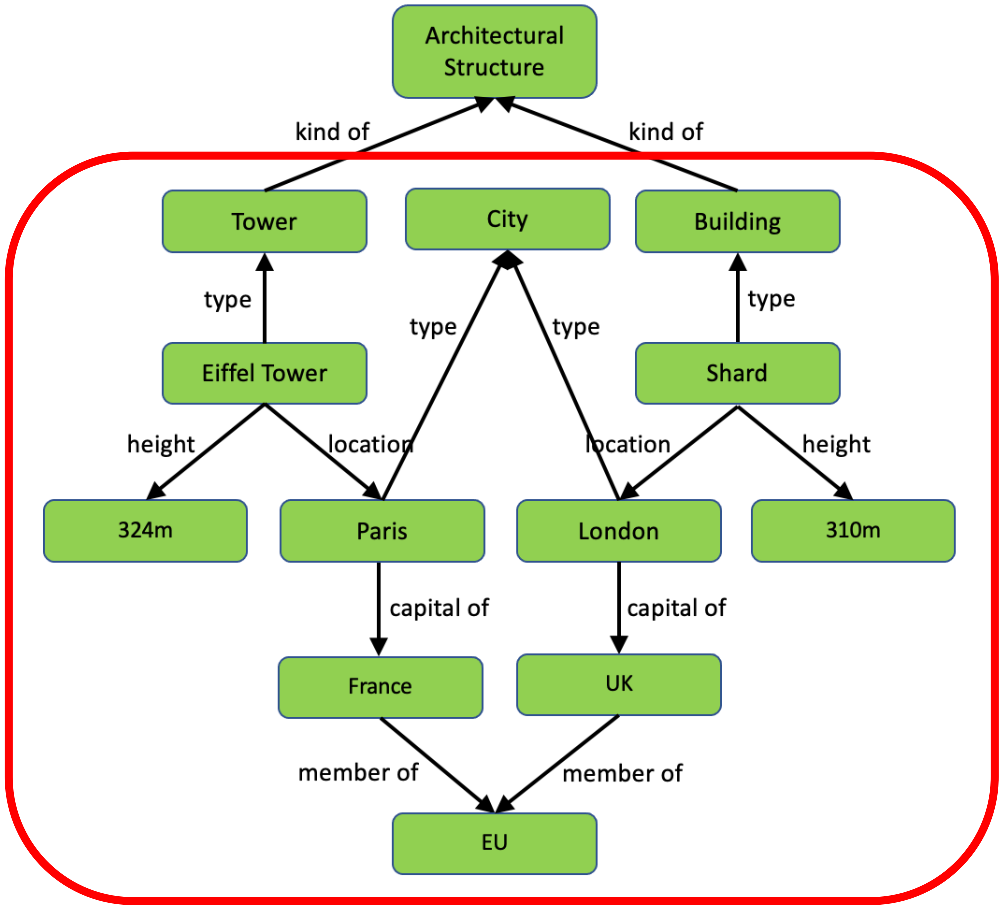

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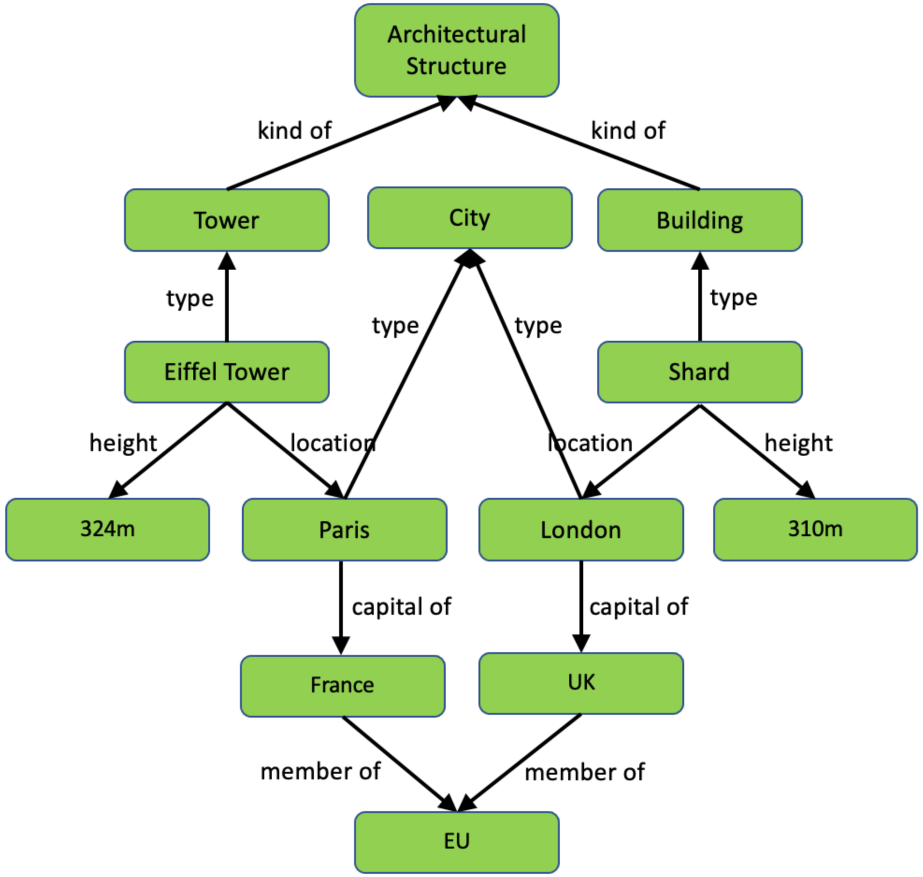

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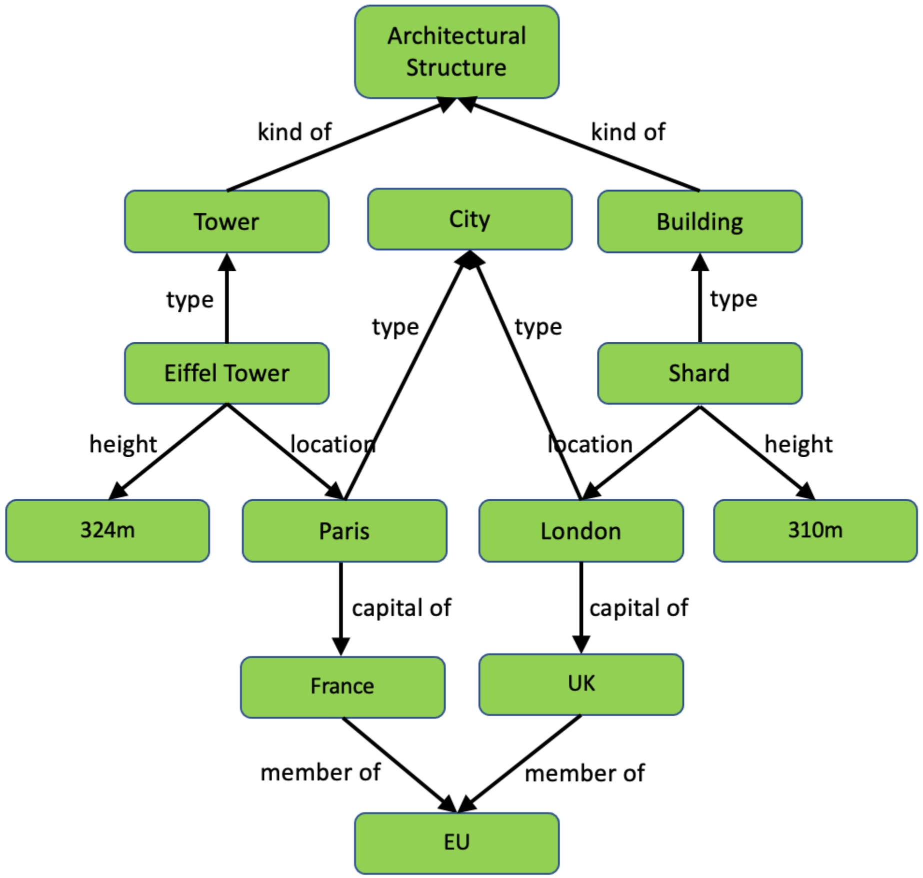

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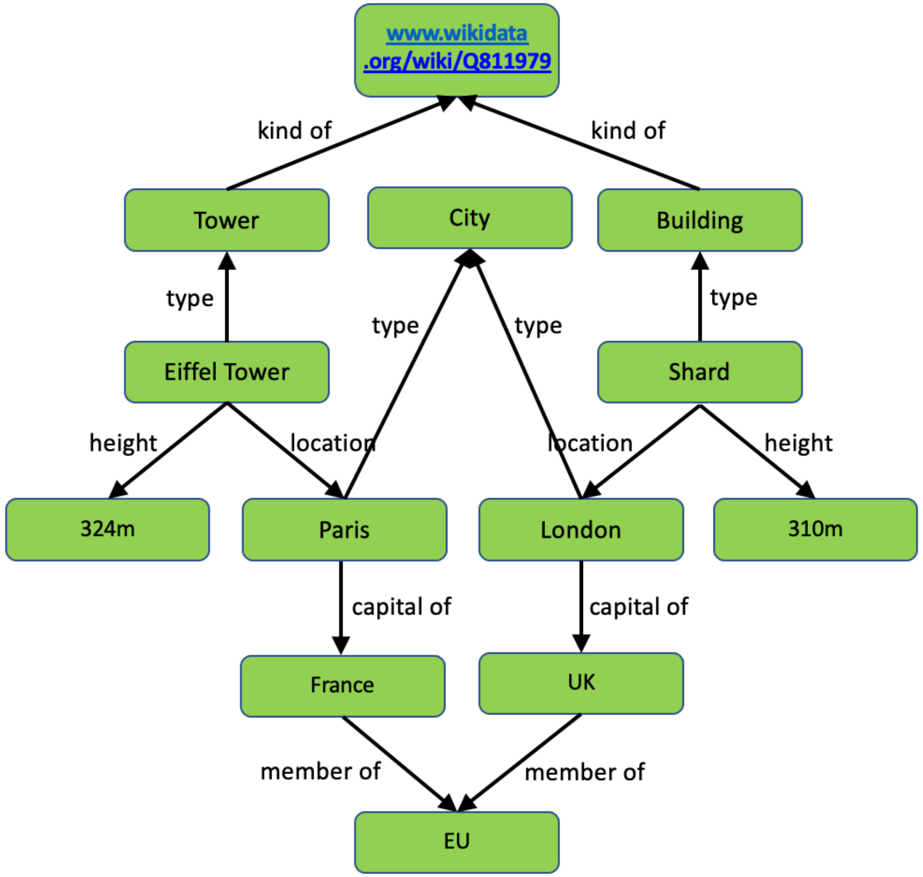

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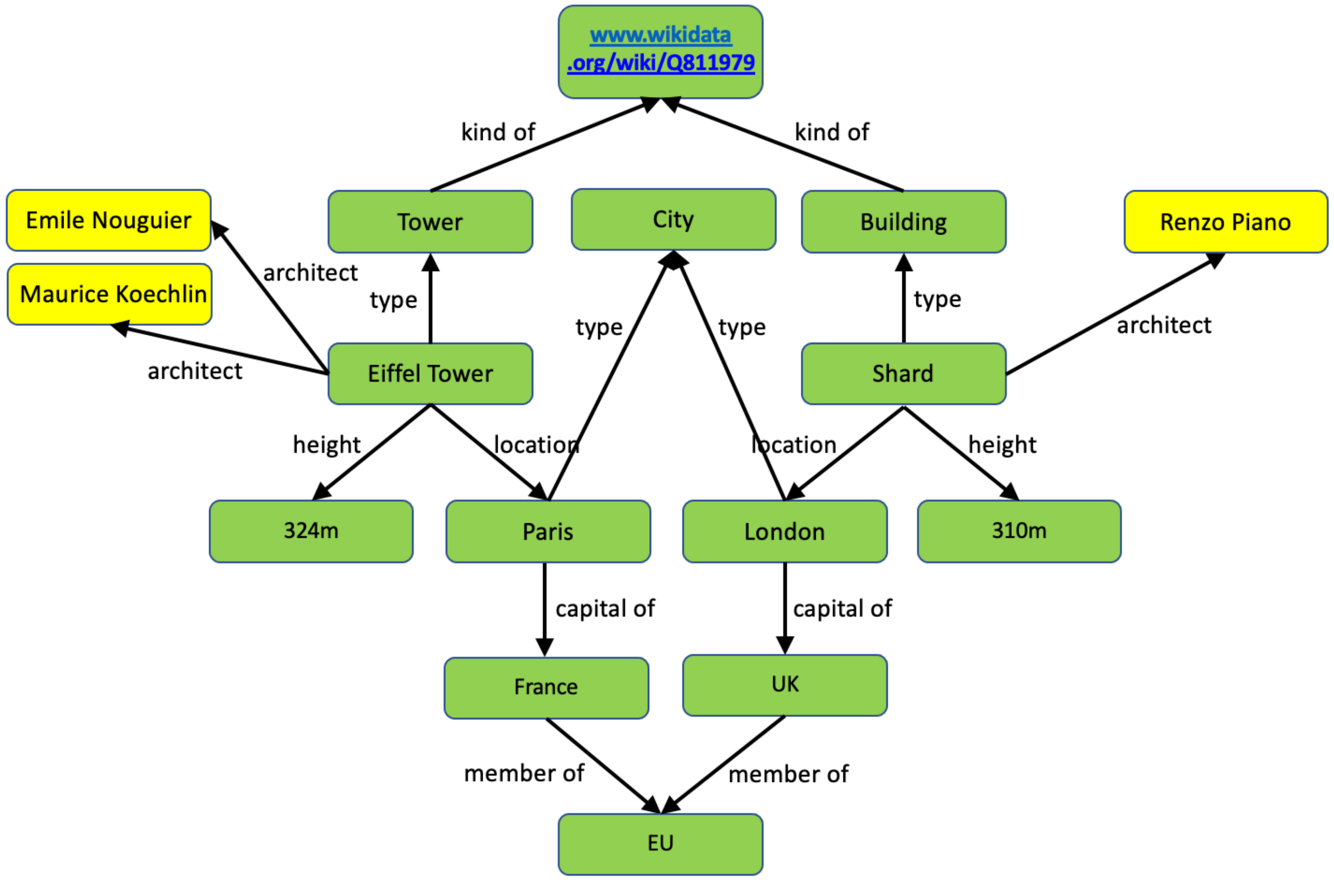

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- ✓ Flexible & extensible

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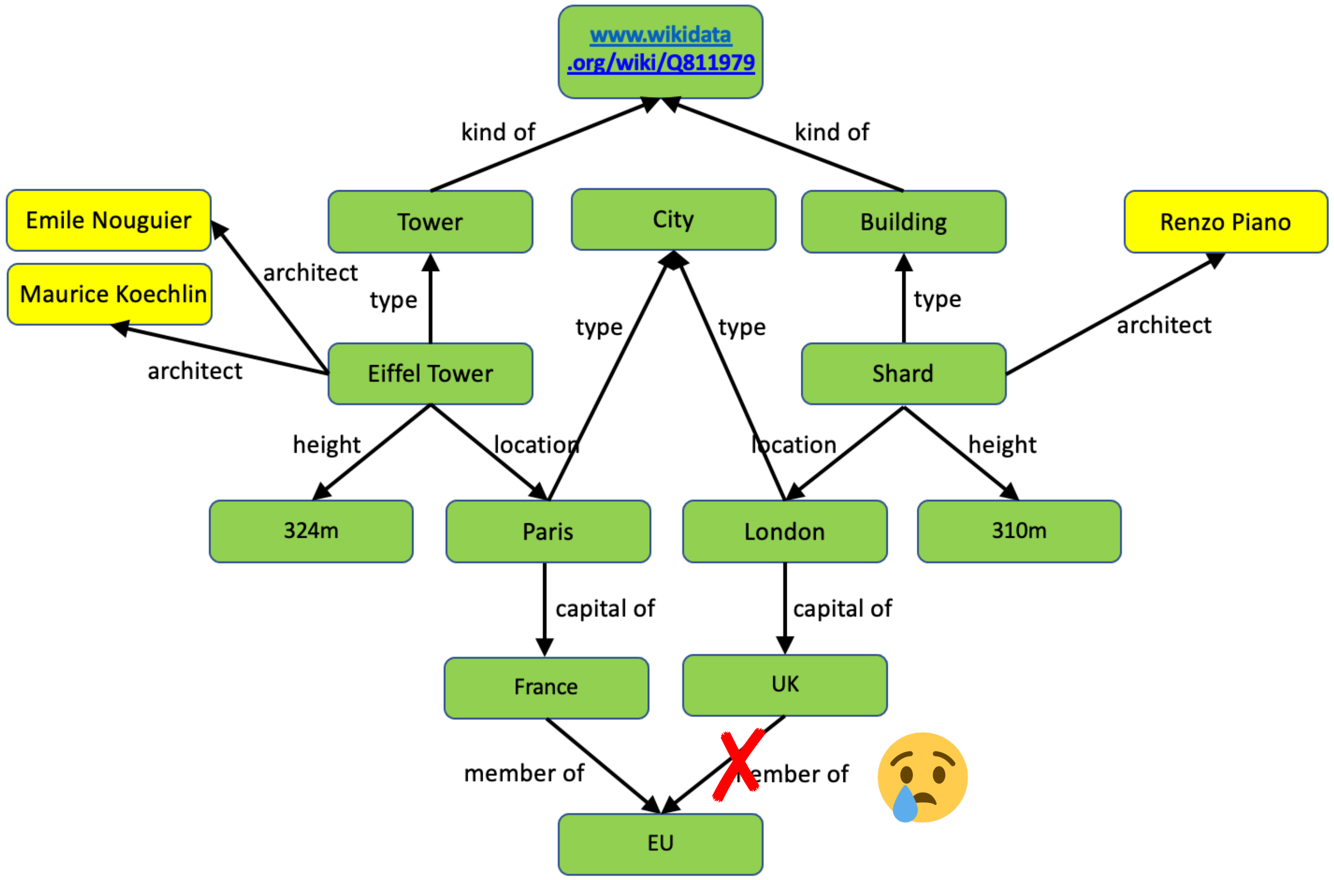

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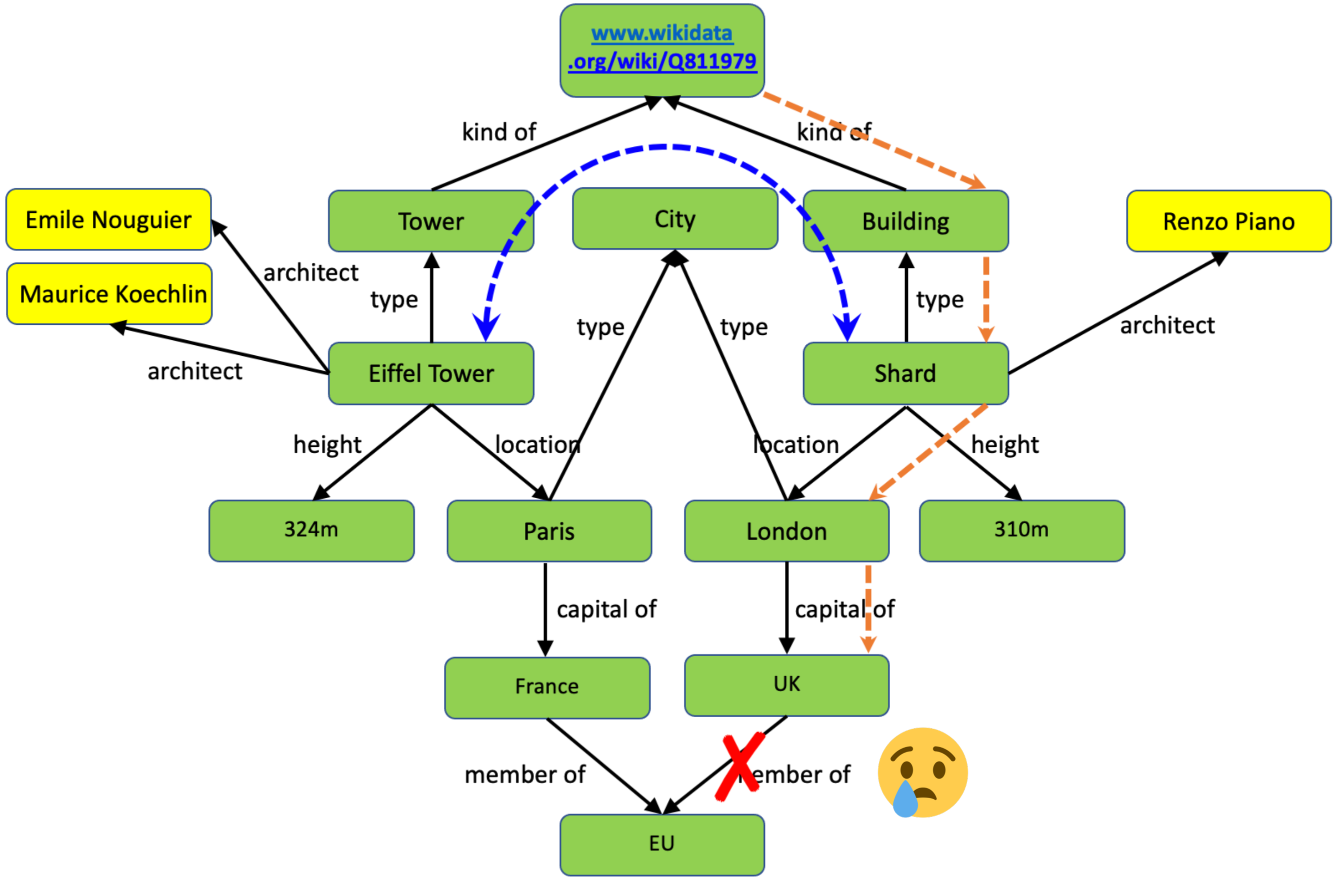

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- ✓ Other kinds of query
  - navigation
  - similarity & locality

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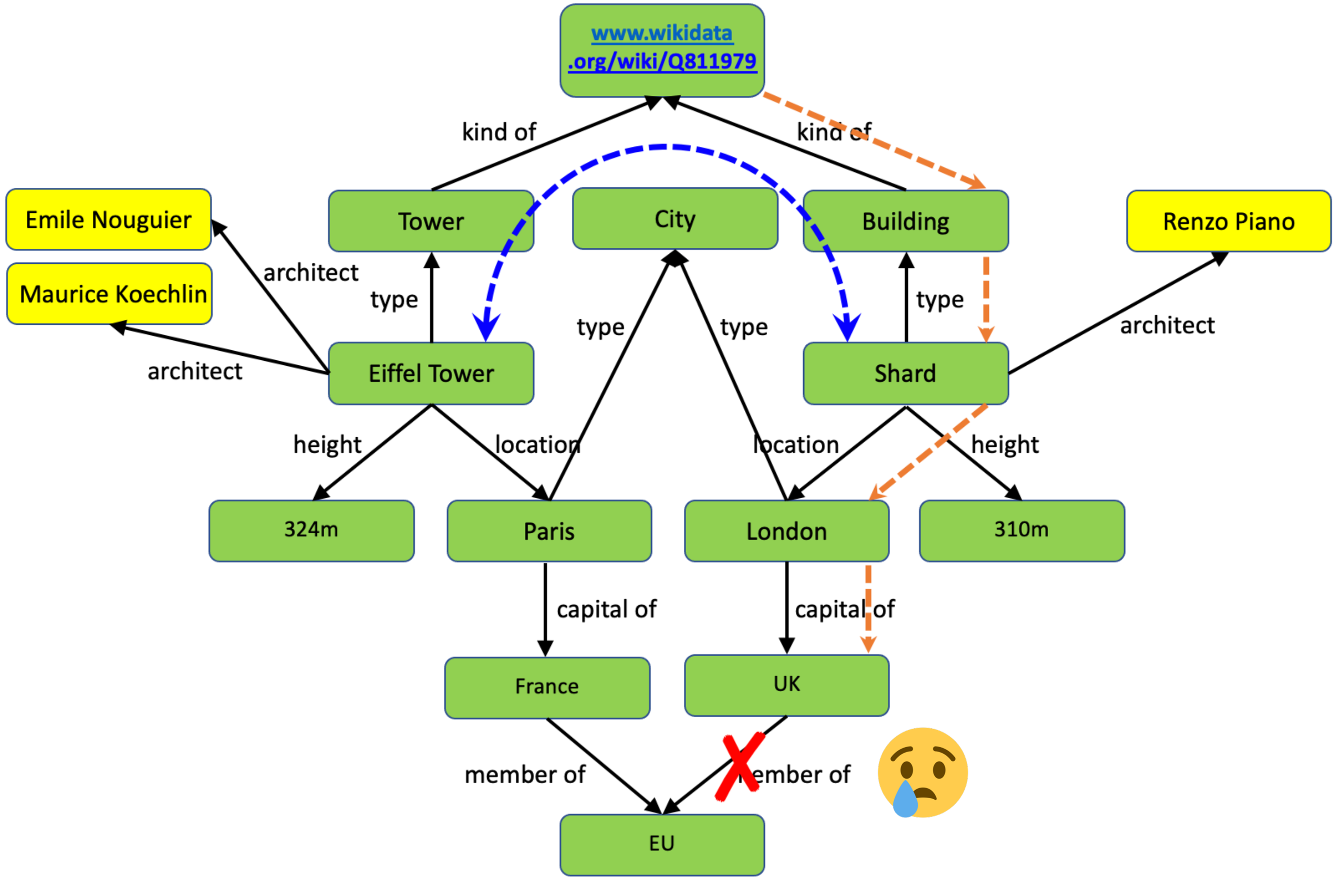

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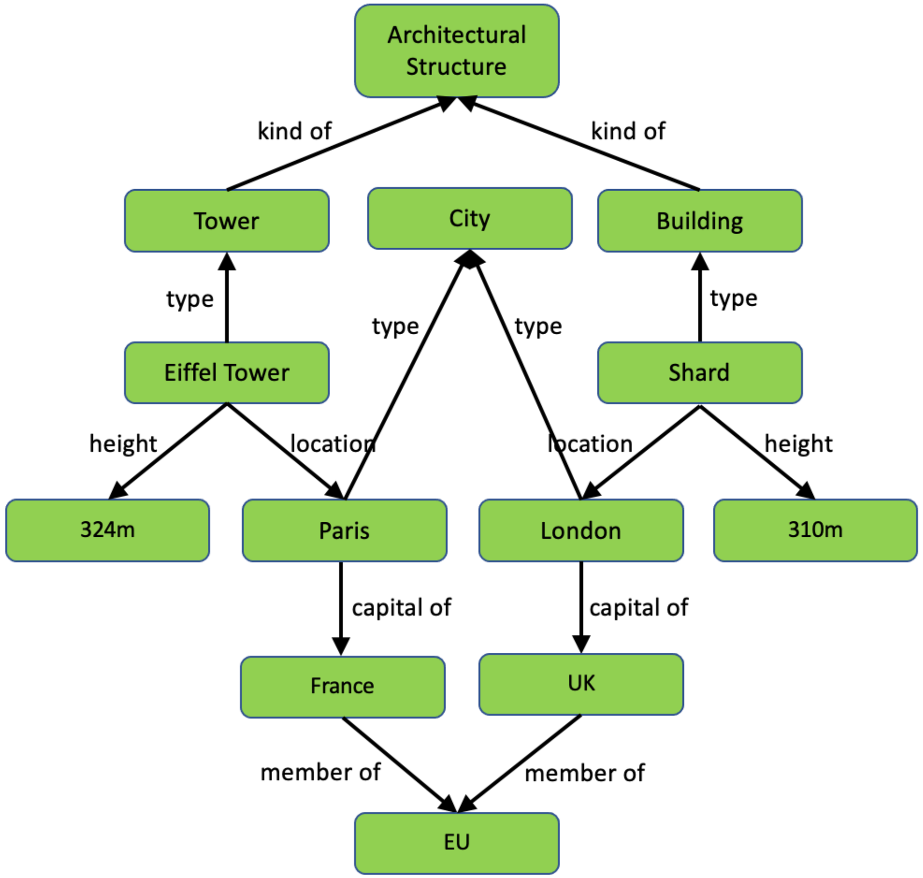
  - similarity & locality

✗ Views
- Data integration & restructuring
- Security
- Query simplification & optimization
- …

Knowledge Graph Semantics

Knowledge Graph Semantics



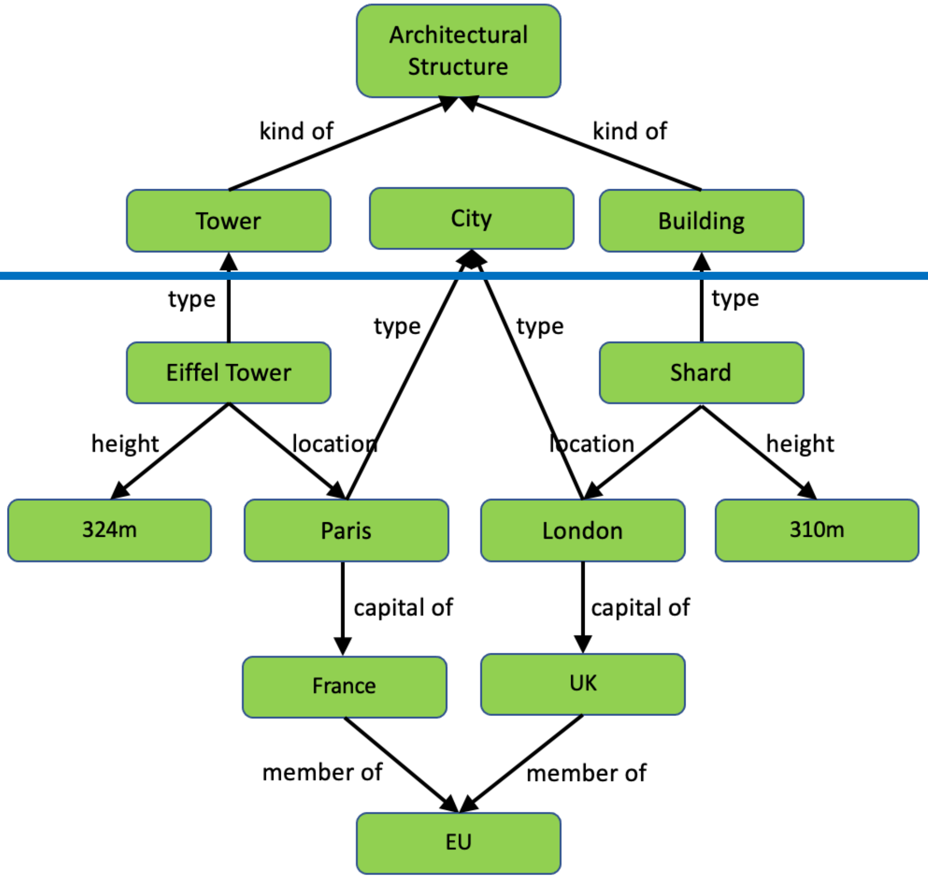
Why do we need semantics?

- To tell us how to use KG
- E.g., how to answer queries:
  - Architectural Structures with location in the EU?

Knowledge Graph Semantics

(OWL) ontology / conceptual schema

$$\forall x\ \mathsf{Tower}(x) \rightarrow \mathsf{ArchitecturalStructure}(x)$$
$$\forall x\ \mathsf{Building}(x) \rightarrow \mathsf{ArchitecturalStructure}(x)$$



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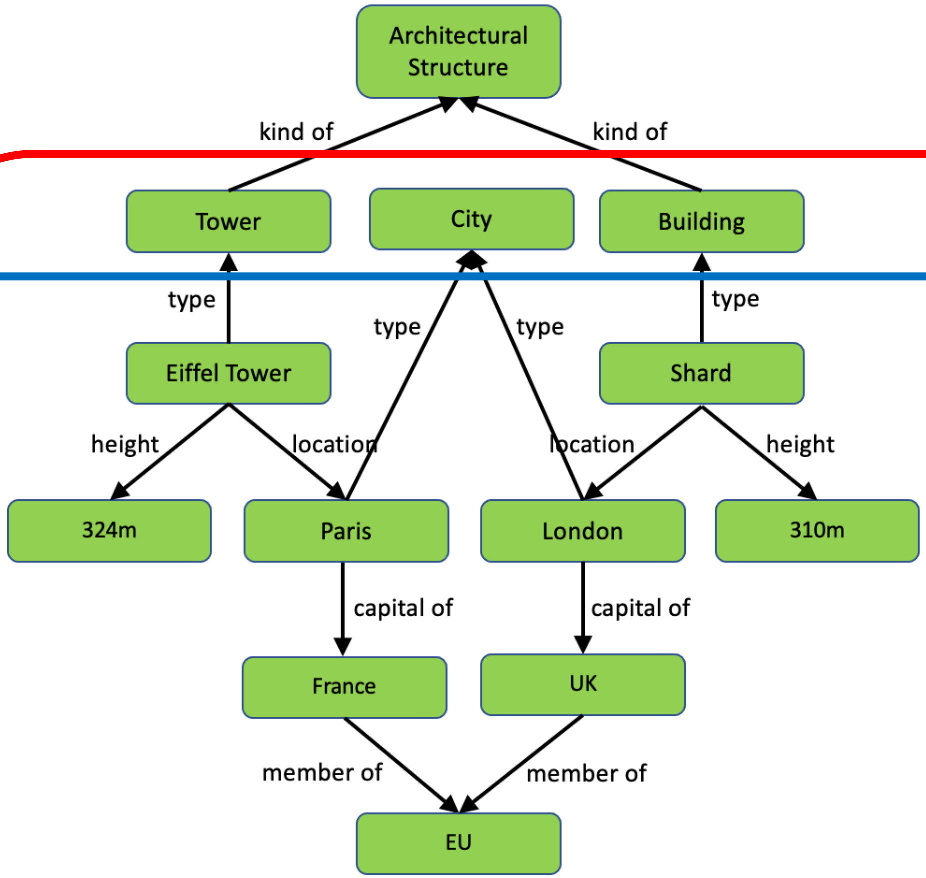

$\forall x \ \text{Tower}(x) \rightarrow \text{ArchitecturalStructure}(x)$
$\forall x \ \text{Building}(x) \rightarrow \text{ArchitecturalStructure}(x)$

Tower(EiffelTower)
City(Paris)
location(EiffelTower, Paris)
location(Shard, London)
capital_of(Paris, France)
member_of(France, EU)

Building(Shard)
City(London)
height(EiffelTower, 324m)
height(Shard, 310m)
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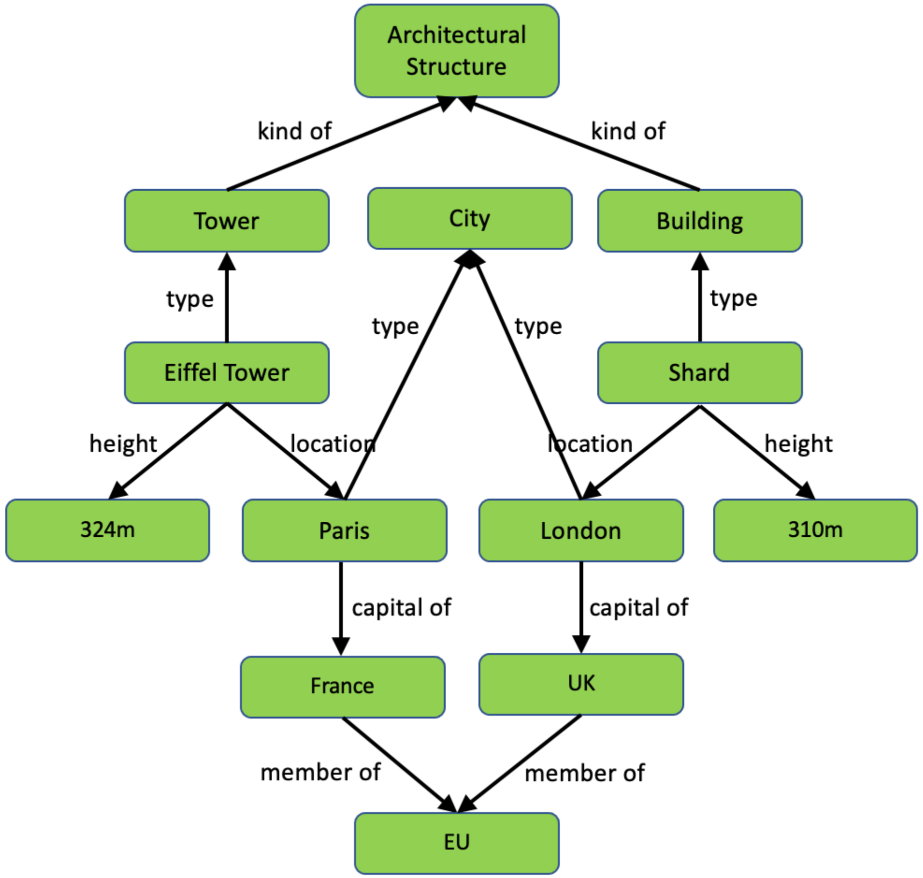
(RDF) graph / facts / data

Knowledge Graph Semantics

Knowledge base/graph



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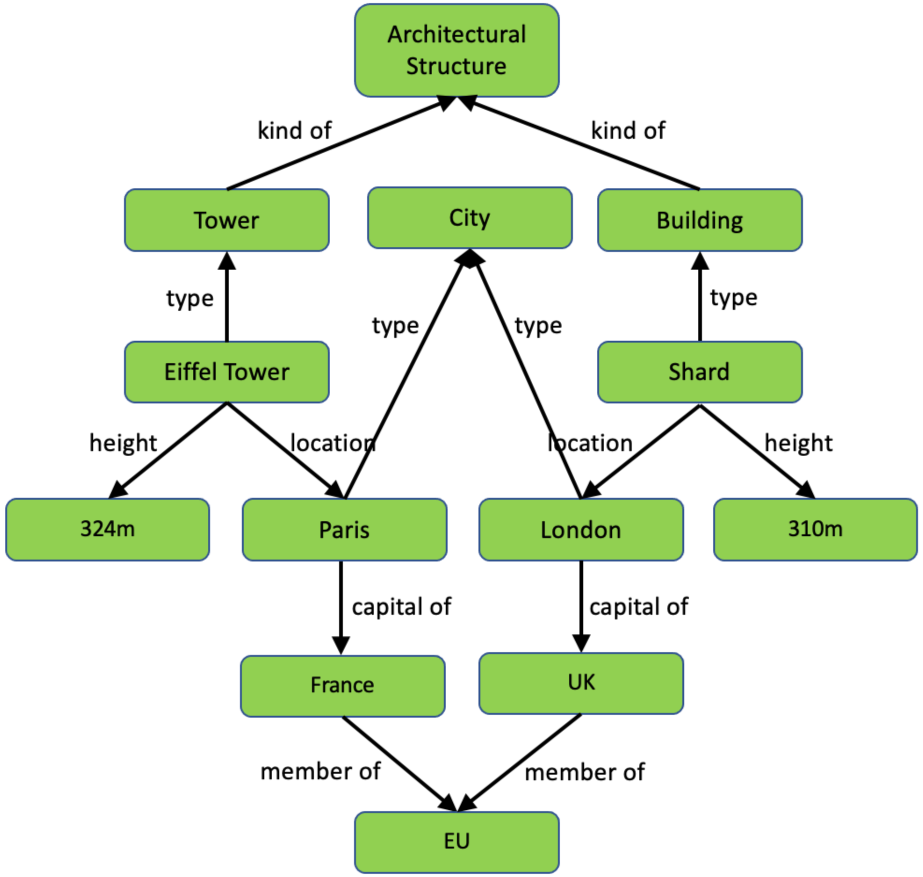
Knowledge Graph Rules

Knowledge base/graph



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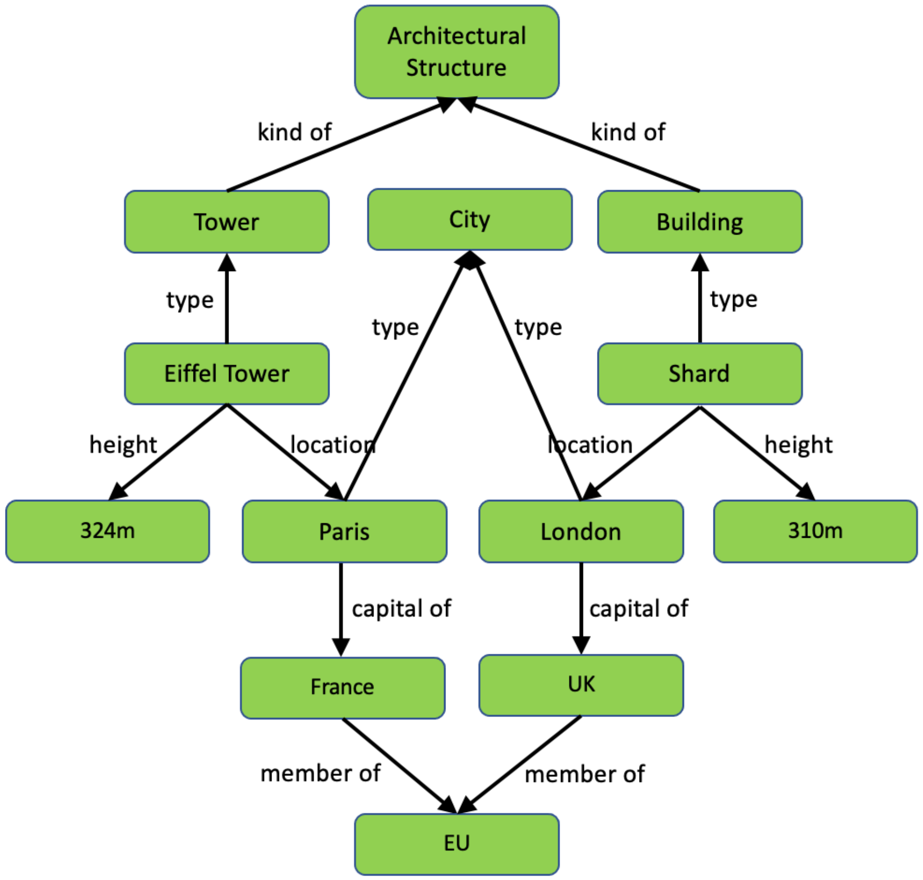

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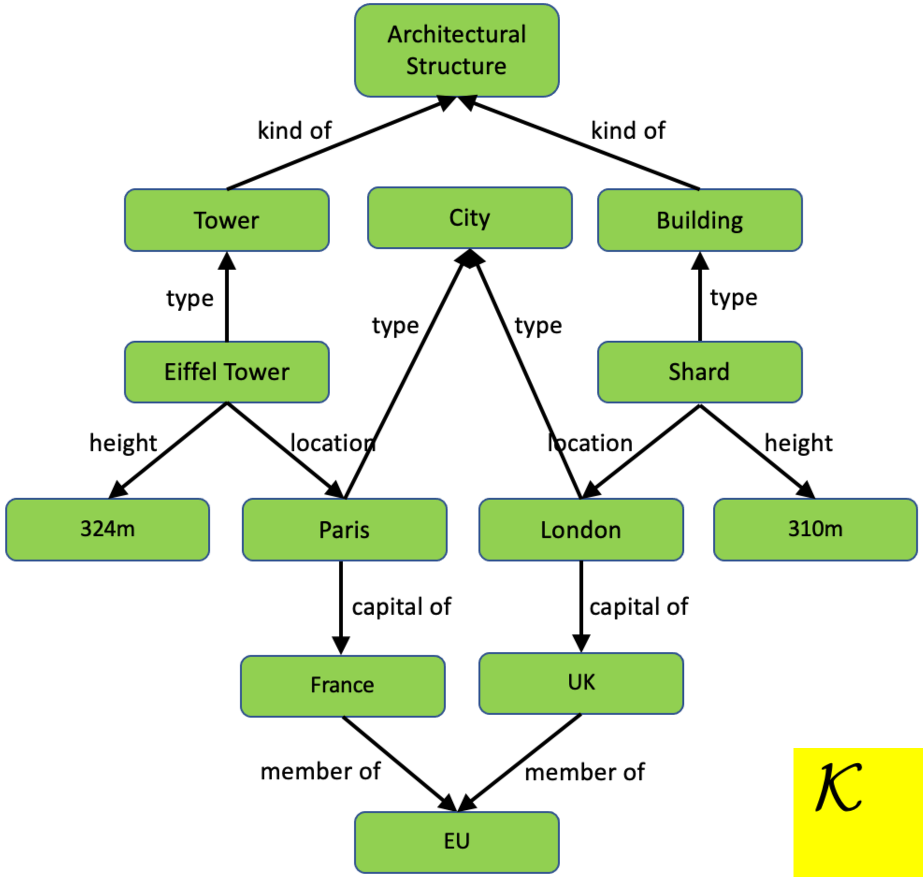
Knowledge Graph Query Answering

Knowledge base/graph



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$\mathcal{K} \models \mathsf{ArchitecturalStructure}(\mathsf{EiffelTower}) \wedge \mathsf{location}(\mathsf{EiffelTower}, \mathsf{EU})$

Knowledge Graph Query Answering

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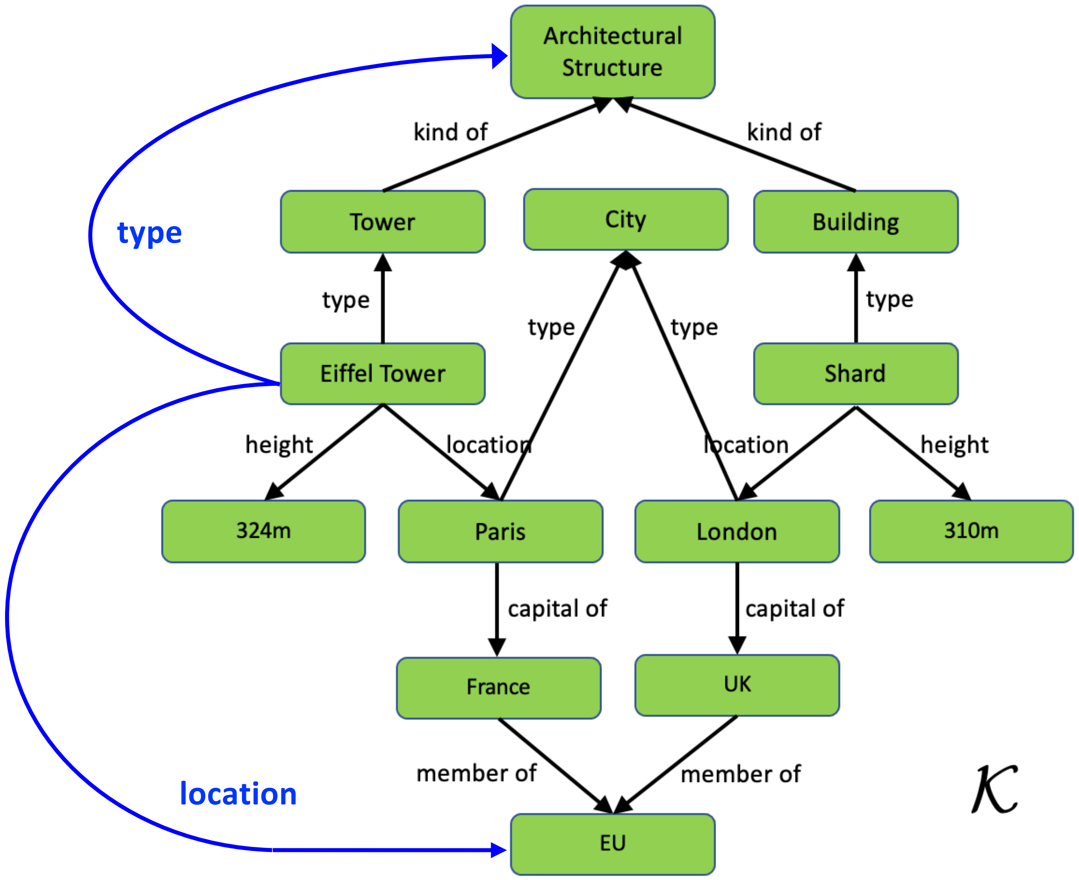

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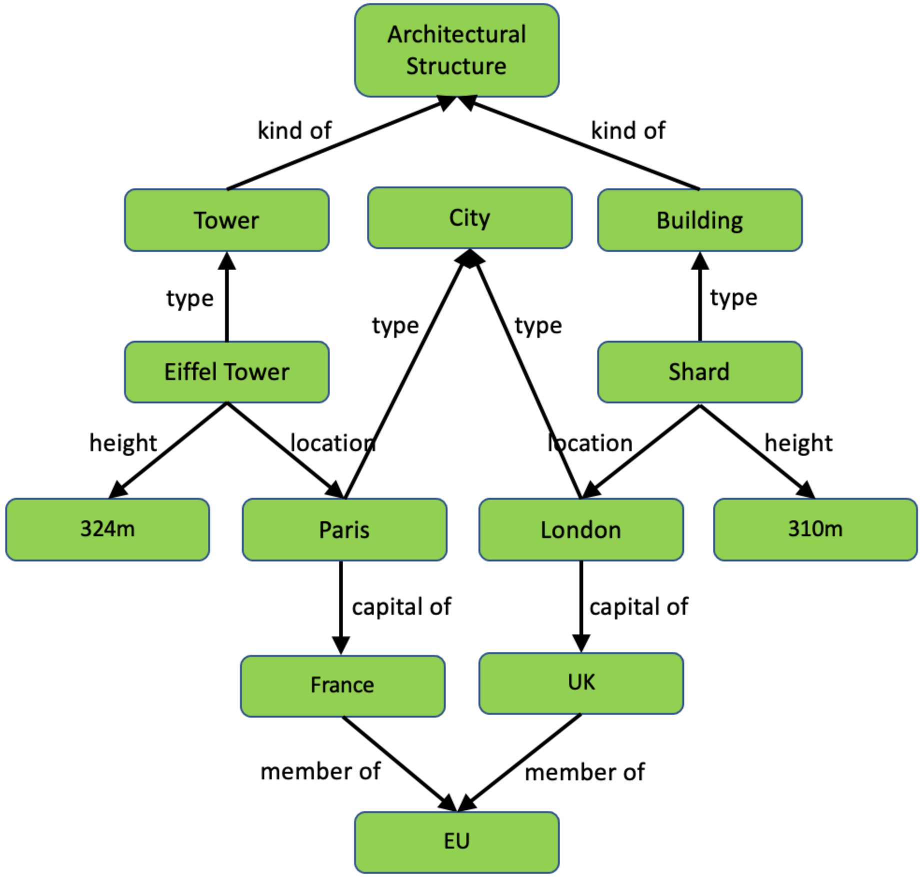
Rules and Views



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$\text{ArchitecturalStructure}(x) \wedge \text{location}(x, EU) \rightarrow \text{EUStruc}(x)$

Views & Rules

- Integration & restructuring (e.g., introduce EUStruc)
- Security (e.g., only allow access to EUStruc)
- Simplification (e.g., use EUSruc in other queries/rules)
- Optimisation (e.g., materialize EUStruc)

Rules

- Recursive definitions (e.g., location)
- Critical for, e.g., part-whole, connectivity, causation, …

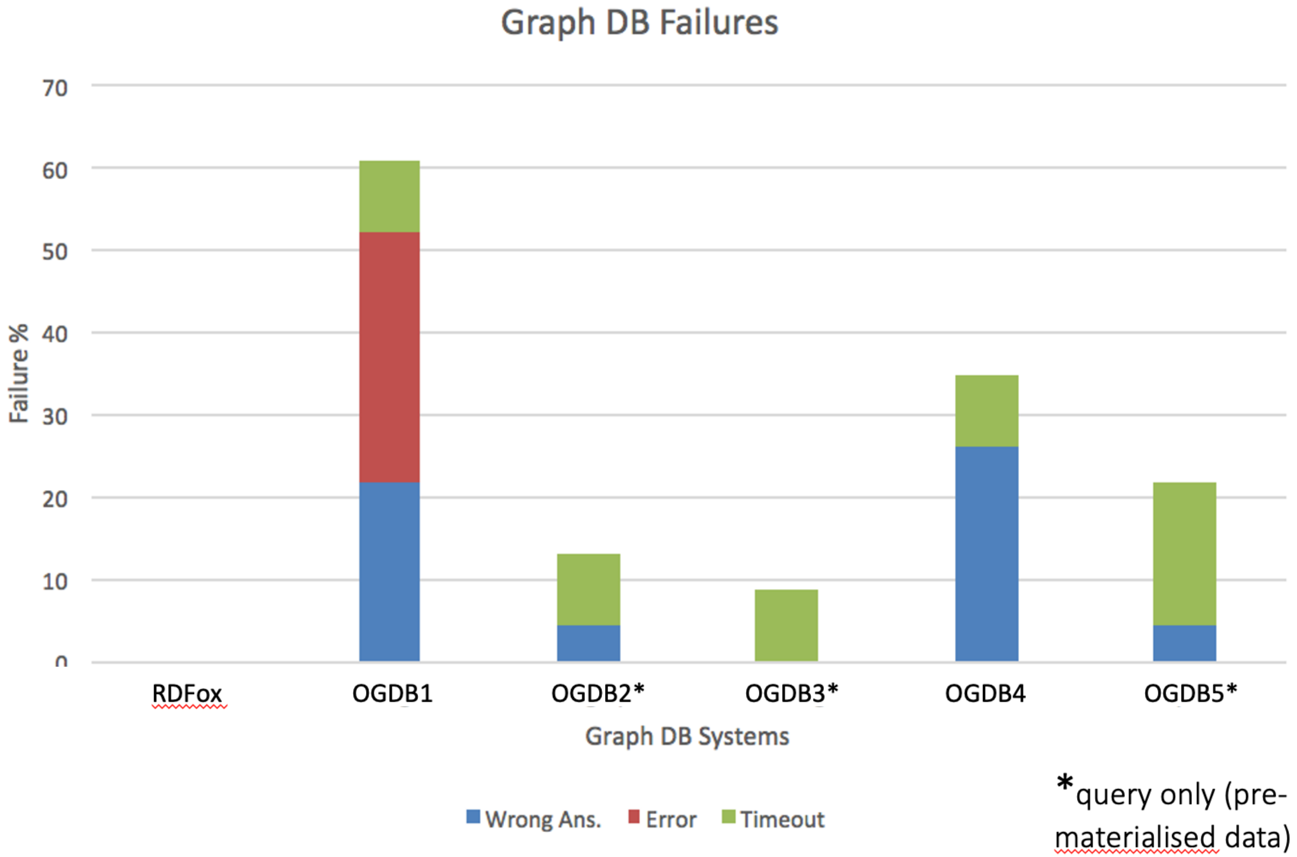
Knowledge Graph Systems

RDFOX

- Materialization reasoning seems ideal for data-centric applications
  - Can support expressive ontology/rule languages
  - Fast query answering over very large graphs
- Challenges
  - Materialisation can be costly in time and memory
  - How to deal with (rapidly) changing data
  - Reliability and correctness!
- Solution: RDFox
  - Optimised materialization exploiting modern multi-core architectures
  - Incremental maintenance as data changes
  - Formally specified and proven-correct algorithms

RDFOX

- **Novel algorithms developed at Oxford**
  - Proven correctness & performance



*query only (pre-materialised data)

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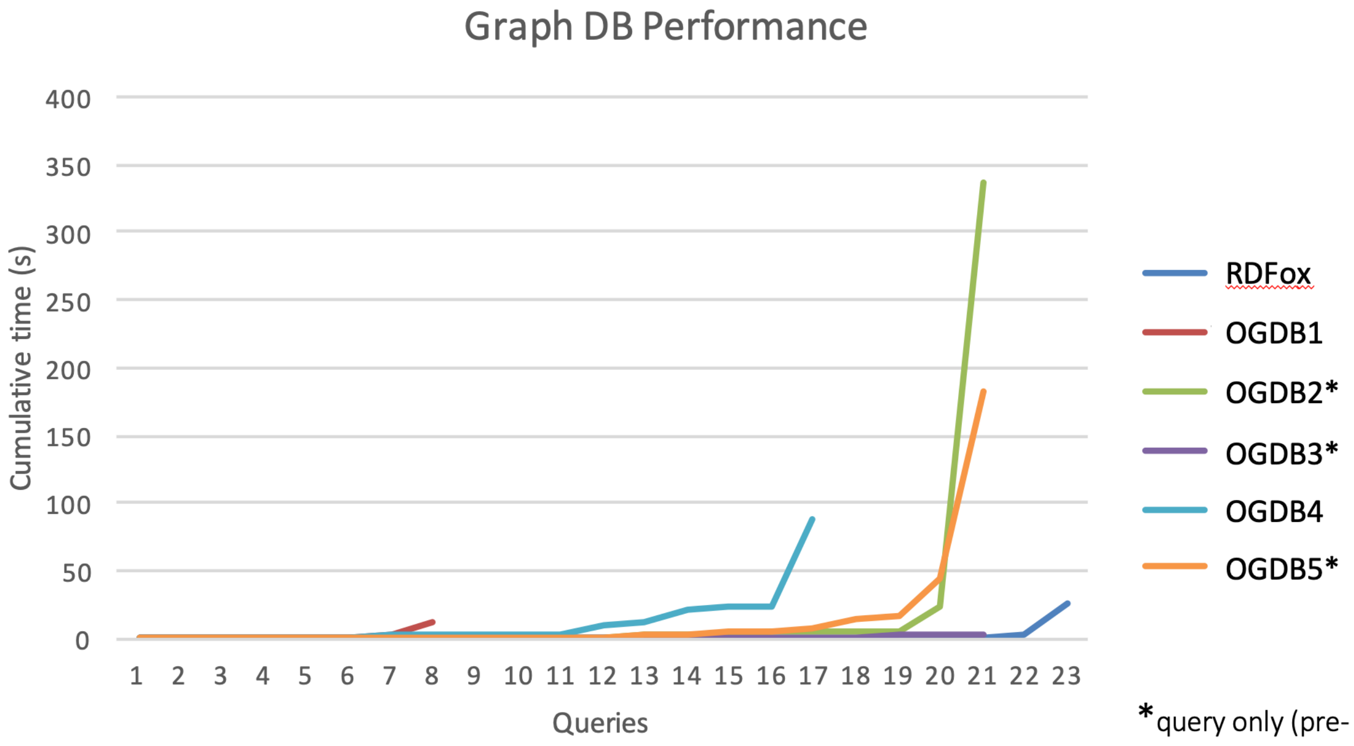

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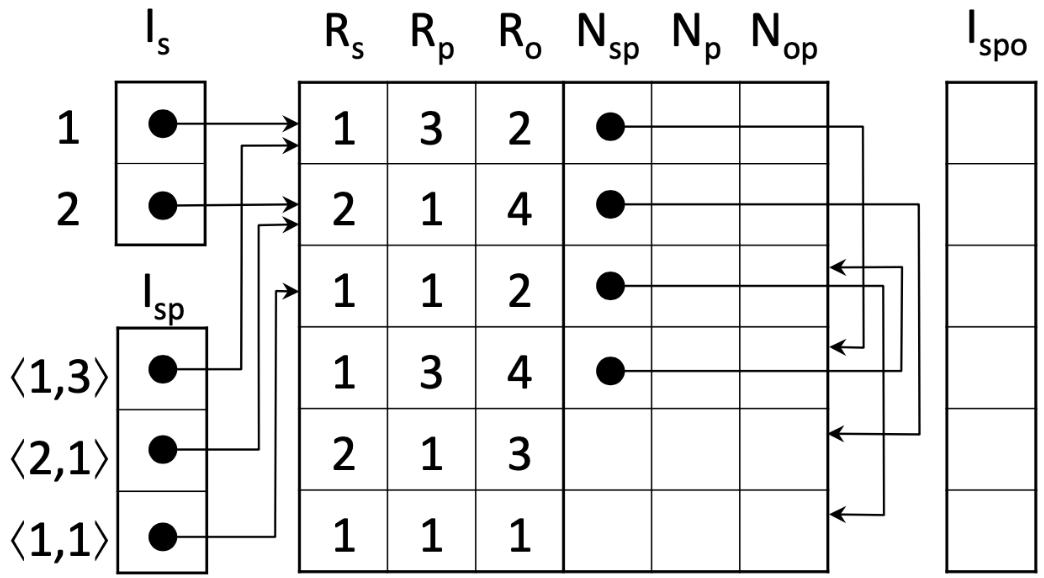

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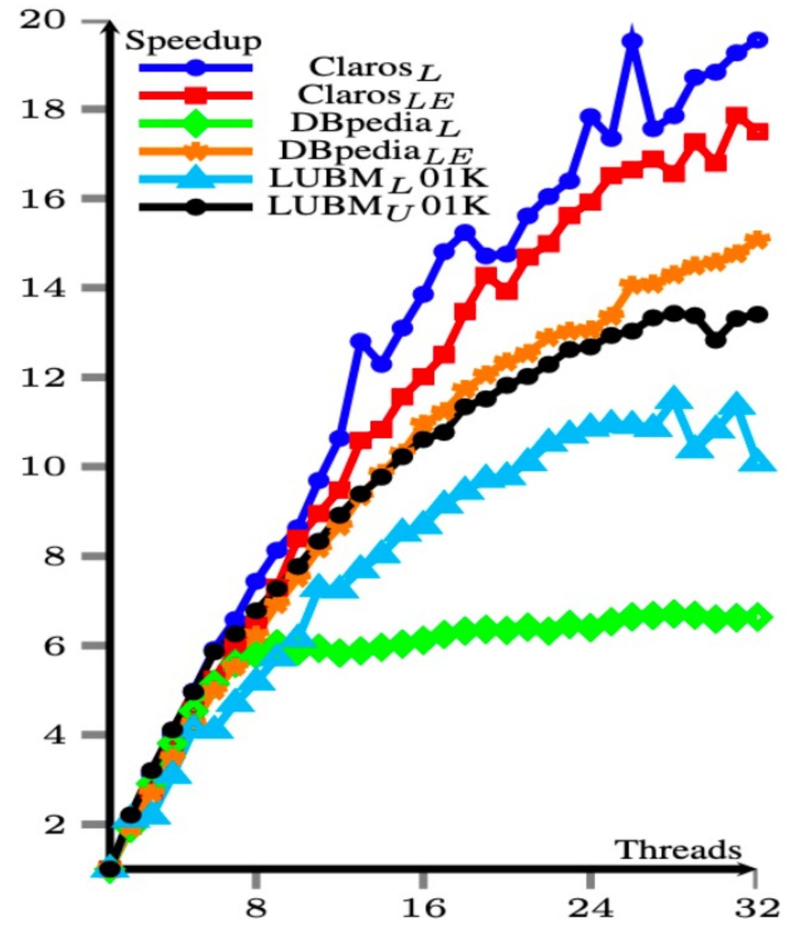

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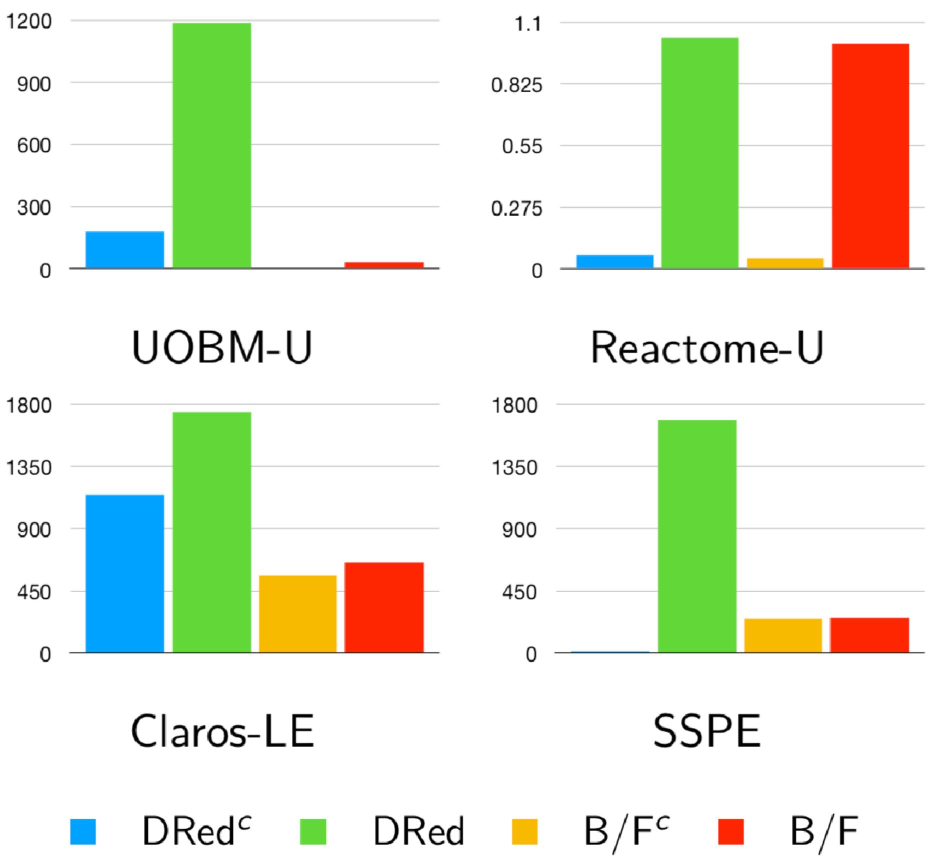
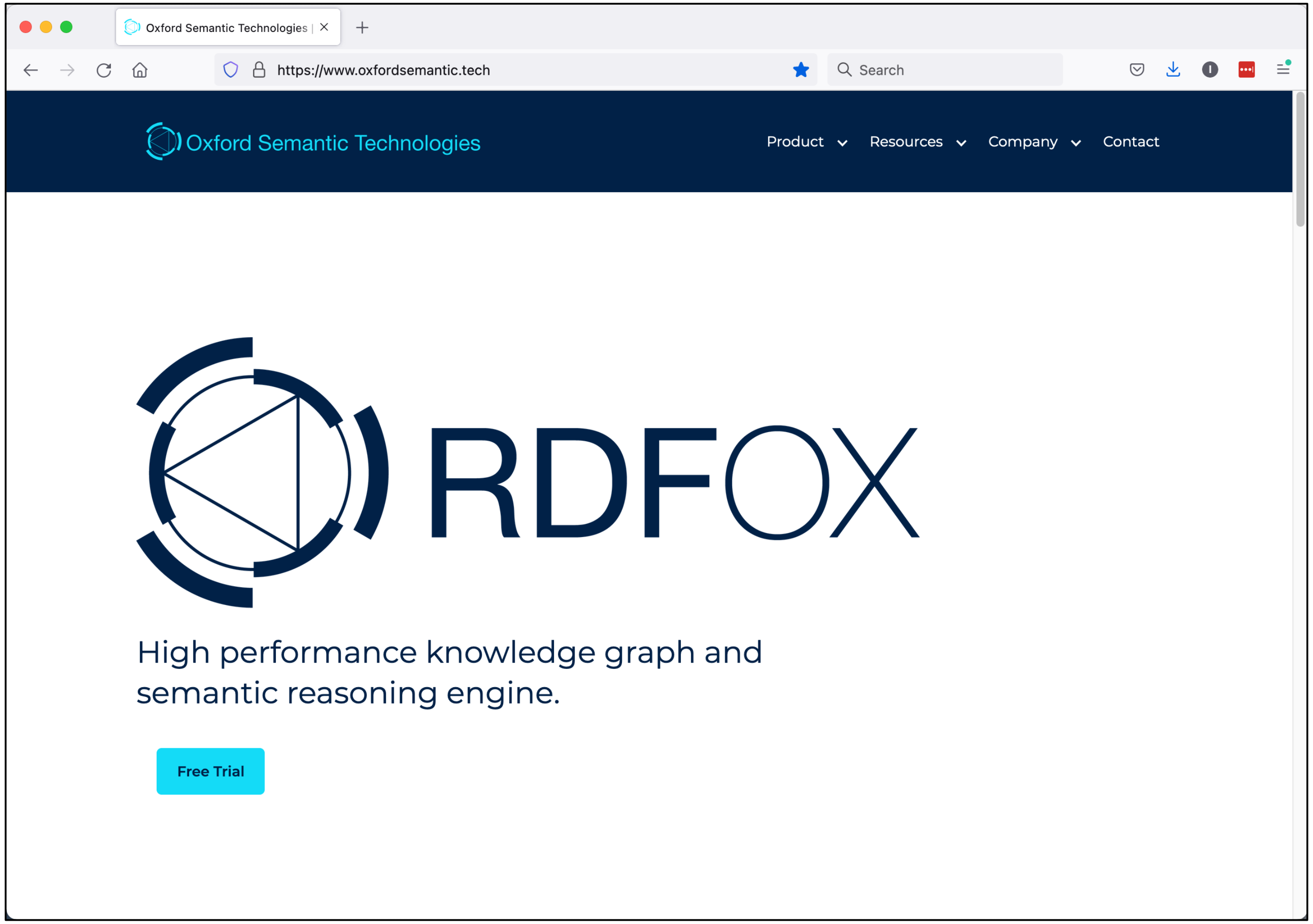
- **Incremental addition and retraction**
  - Novel B/F materialisation maintenance algorithm

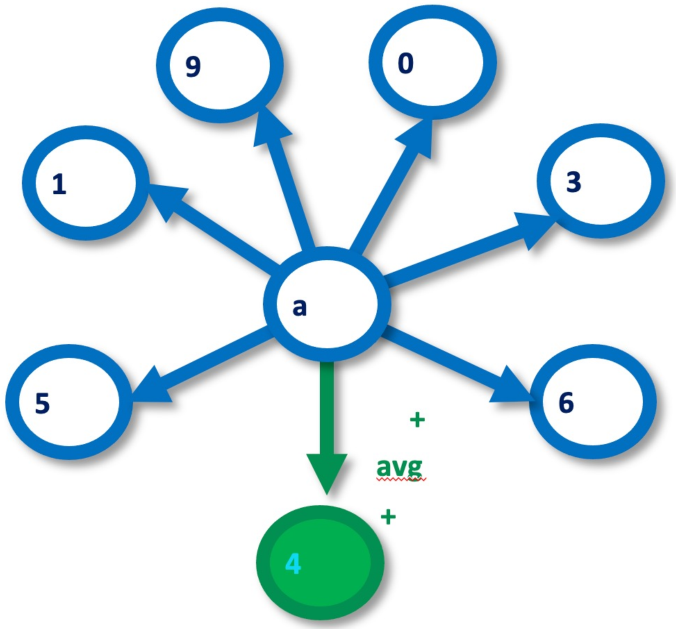


Oxford Semantic Technologies

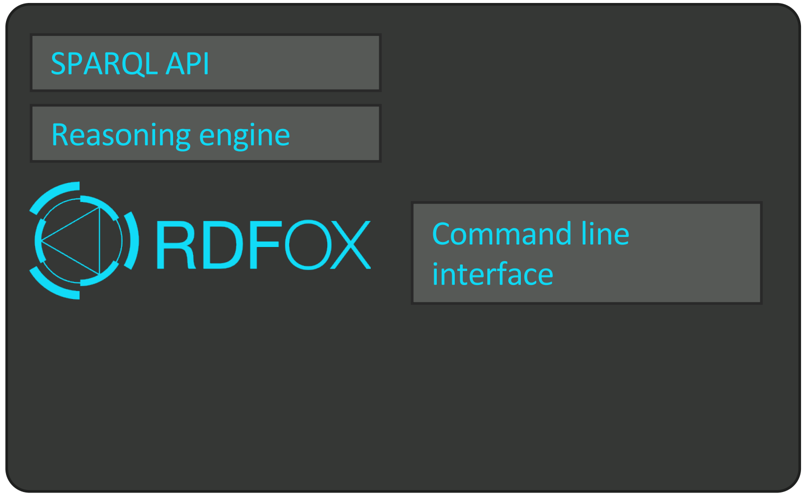


Extensions (beyond OWL RL)

- Arbitrary rules
  - No restriction to OWL RL (tree-shaped) rules
- Data types and values
  - Numbers, strings, dates, …
  - Built in functions and aggregation
- Value invention
  - Add new (possibly computed) values to graph
  - Add new URI nodes to graph
- Constraints and negation as failure
  - SHACL+



System Architecture



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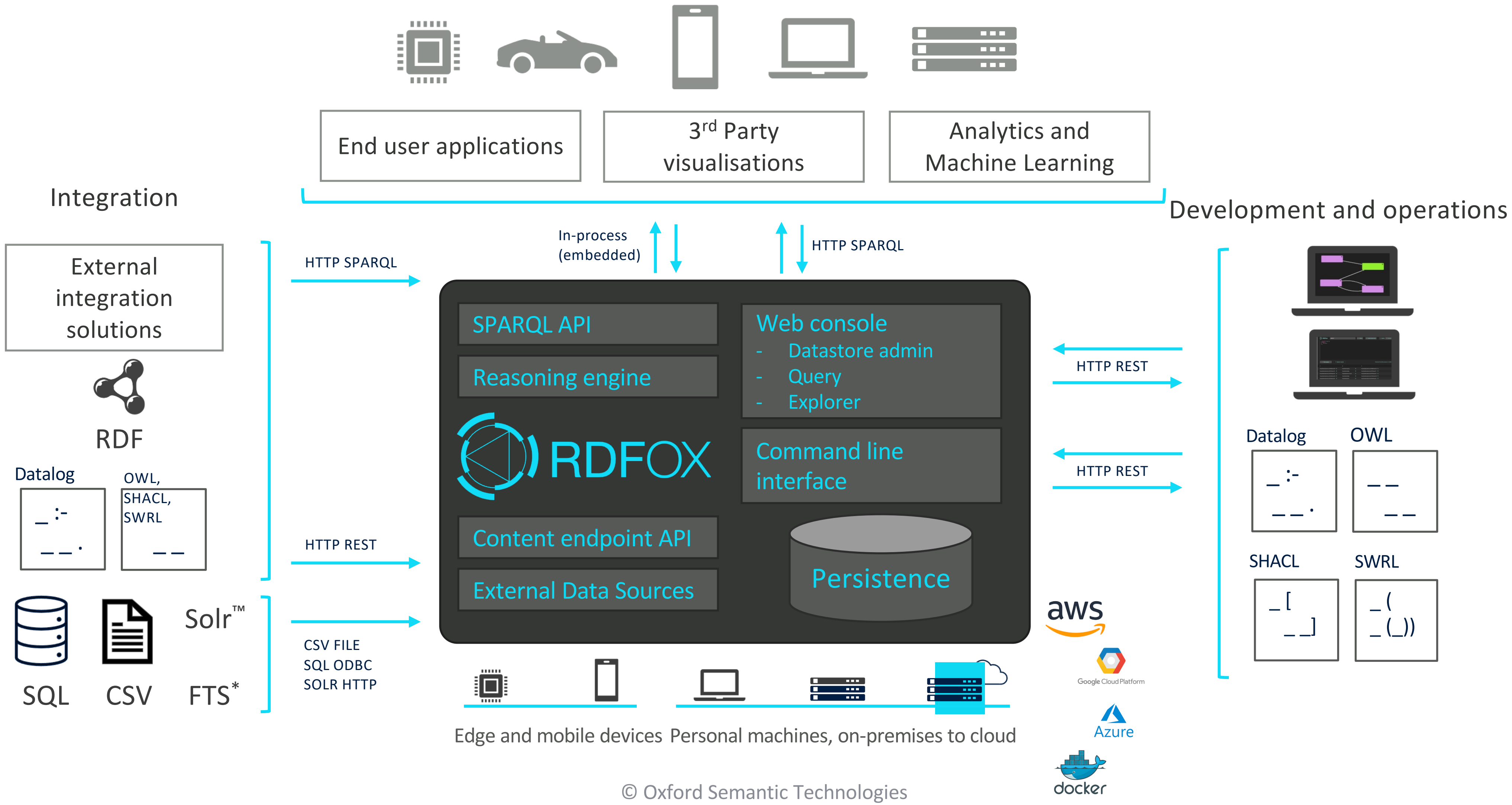
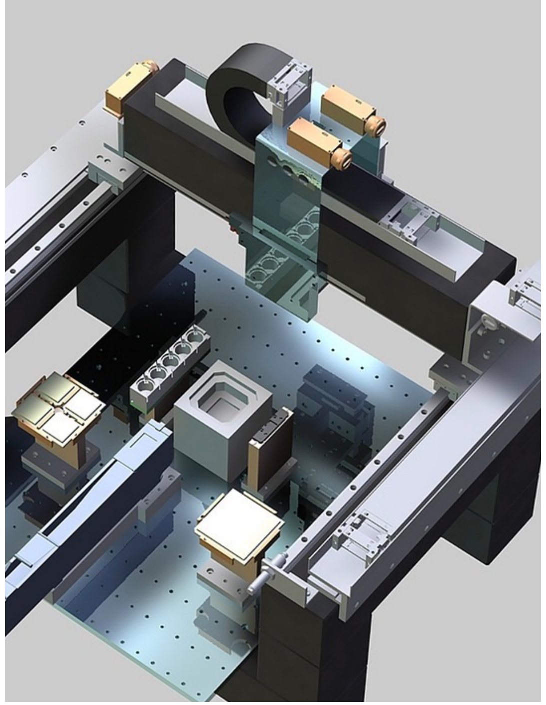
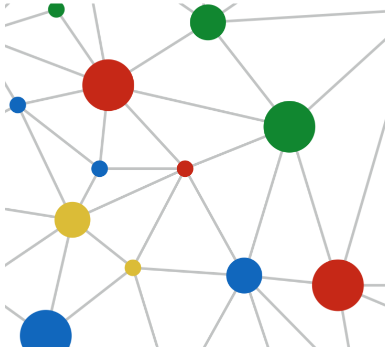


Knowledge Graph Applications

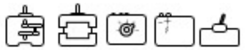
Configuration management

FESTO

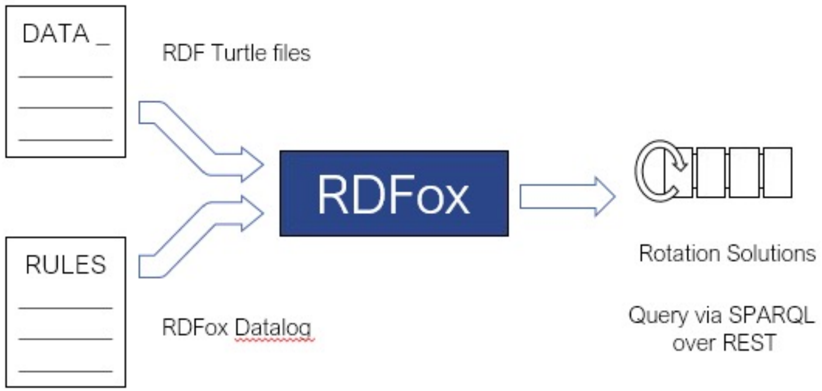


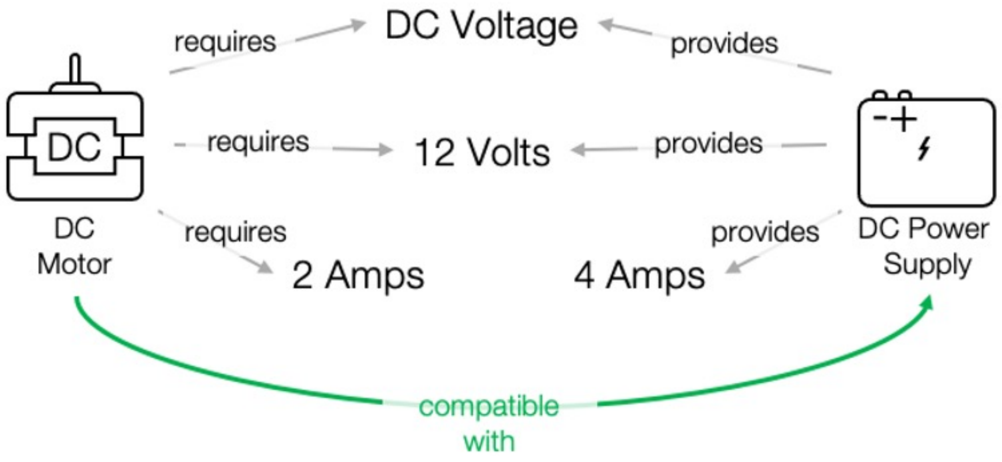


- Components
- Their attributes & constraints



- Definitions of compatibility &
- Valid configurations



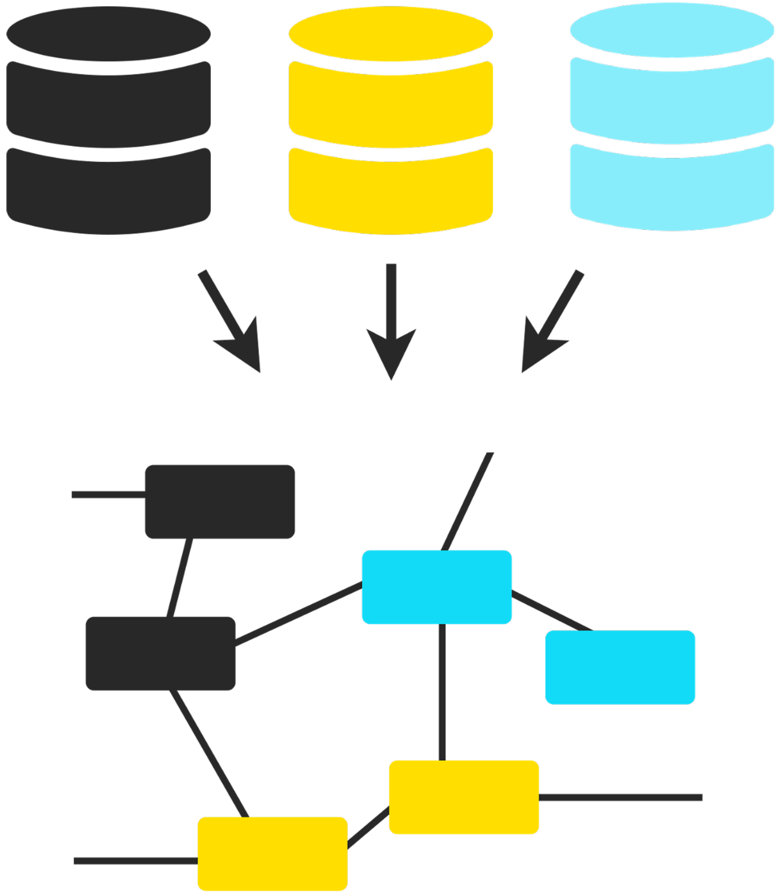



```
[?M, :compatibleWith, ?PS] :-
  :DCMotor[?M] ,
  :DCPowerSupply[?PS] ,
  [?PS, :provides, :DCVoltage] ,
  [?PS, :providedVoltage, ?pv] ,
  [?PS, :providedCurrent, ?pc] ,
  [?M,  :requires, :DCVoltage] ,
  [?M,  :requiredVoltage, ?rv] ,
  [?M,  :requiredCurrent, ?rc] ,
  FILTER (?pv = ?rv && ?pc >= ?rc) .
```

Data Integration

DOW JONES

- Integrate data from multiple sources
  - Companies
  - Executives
  - Stock markets
  - Geonames
  - Articles from WSJ, Factiva, …
- Query integrated data
  - Competitor companies that are NASDAQ listed and have subsidiaries in same or related sector
  - Article published between 2020-05-24 and 2020-05-26 that talk about company C and mention an African country



Wrap-up

Summary

- **KGs are powerful tool** for representing & reasoning about knowledge
- **Many applications**: configuration, data integration, fraud detection, …
- **Technical challenges**: scalability, correctness, **knowledge engineering** …
- **Solutions** based on **foundational research + systems engineering**

Thanks for Listening
Any Questions?

RDFOX : **www.oxfordsemantic.tech**

Background reading:

- **Description Logic:** Baader, Horrocks, Lutz, and Sattler. *An Introduction to Description Logic*. Cambridge University Press, 2017.
- **OWL:** Horrocks, Patel-Schneider, and van Harmelen. *From SHIQ and RDF to OWL: The Making of a Web Ontology Language*. J. of Web Semantics, 1(1):7-26, 2003.
- **RDFox algorithms & data structures:** Motik, Nenov, Piro, Horrocks, and Olteanu. *Parallel Materialisation of Datalog Programs in Centralised, Main-Memory RDF Systems*. AAAI 2014.
- **Incremental maintenance:** Motik, Nenov, Robert Piro, and Horrocks. *Maintenance of datalog materialisations revisited*. Artificial Intelligence, 269:76-136, 2019.