Linked Data on the Web

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Guest Lecture
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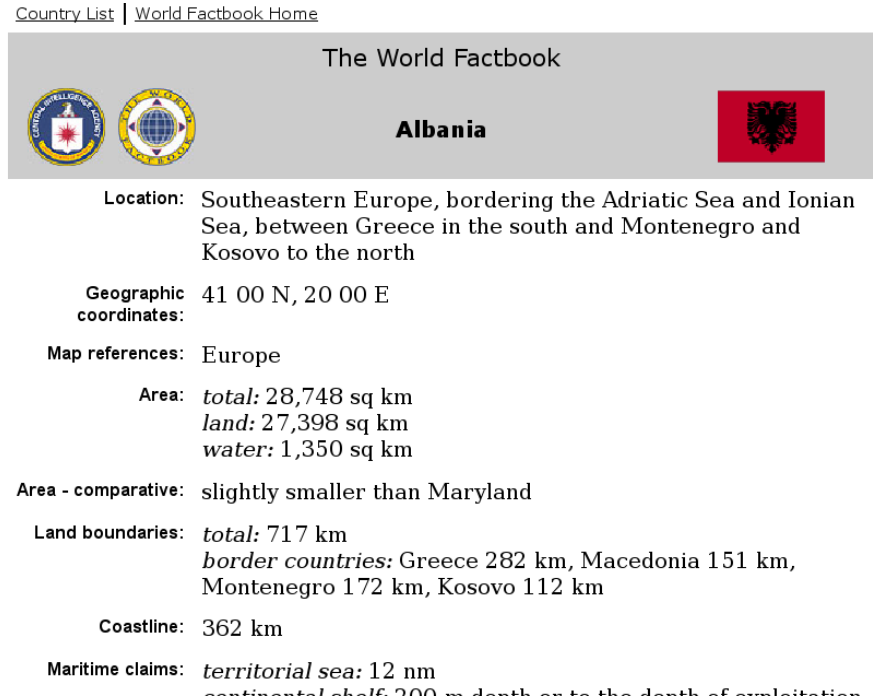
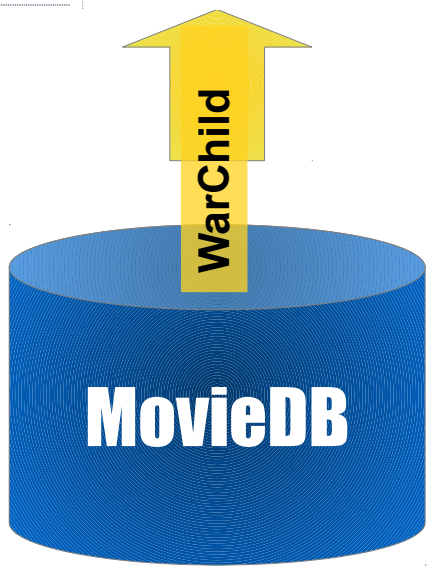
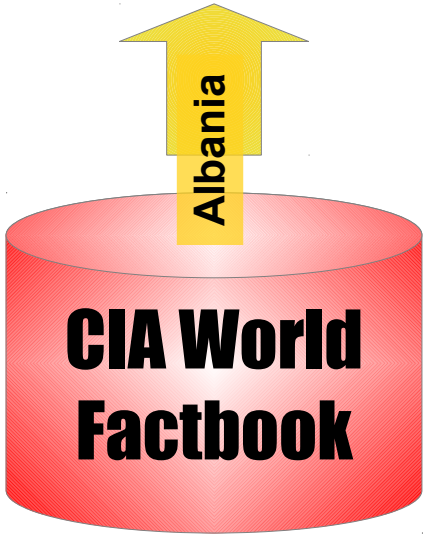
Data on the Traditional, Hypertext Web





Data exposed to the Web via HTML



Data on the Traditional, Hypertext Web

So what is the problem?

- Web content is only loosely structured
- Difficult for applications to do smart things

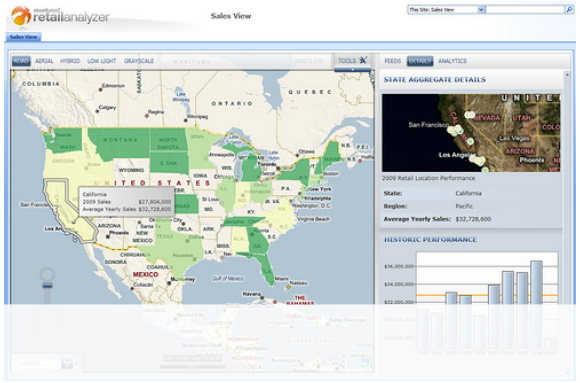
Solution:

- Increase the structure of Web content
- Publish data in a machine-friendly way

But wait…
don't we do that already?

Web APIs

- **Content providers offer access via Web APIs**
- **Mashups combine this data**



Shortcomings:

- APIs are proprietary
- Mashups are based on a fixed set of data sources
- You can not set hyperlinks between data object

Towards a Web of Linked Data

By using the following, well-established Web technologies the WWW evolves into a Web of Linked Data.

- Access mechanism: Hypertext Transfer Protocol (HTTP)
- Data model: The Resource Description Framework (RDF)
- Globally unique identifiers: Uniform Resource Identifier (URI)

Outline

(1) The Foundation: Linked Data on the Web

- The RDF Data Model and URIs
- The SPARQL Query Language
- The Linked Data Publishing Principles

(2) Querying Linked Data

The Resource Description Framework

- **A resource may basically be everything**
  - e.g. persons, places, Web documents, abstract concepts
- **Descriptions of resources**
  - Attributes
  - Relations
- **The framework contains:**
  - A data model, and
  - Languages and syntaxes

RDF Data Model

- **Data comes as a set of triples (subject, predicate, object)**

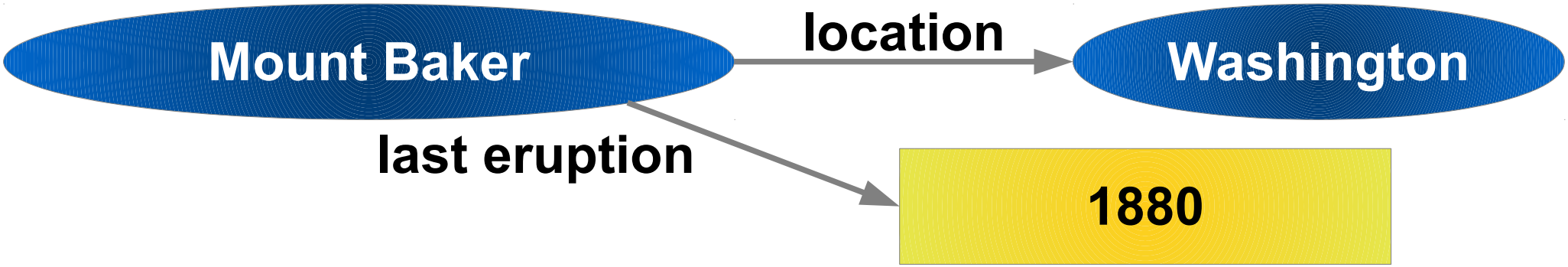
- **Subject: resources**
- **Predicate: properties**
- **Object: literals or resources**

- **Examples:**
  - (Mount Baker , last eruption , 1880)
  - (Mount Baker , location , Washington)

RDF Data Model (cont'd)

- **RDF based data may be understood as a graph:**
  - Triples as directed edges
  - Subjects and objects as vertices
  - Edges labeled by predicate

- **Example:**
  - (Mount Baker , last eruption , 1880)
  - (Mount Baker , location , Washington)



Uniform Resource Identifier (URI)

- **URIs extend the concept of URLs**
  - Globally unique identifier for resources
  - URL of a Web document usually used as its URI
  - Attention: URIs identify not only Web documents
- **Example:**
  - Me:

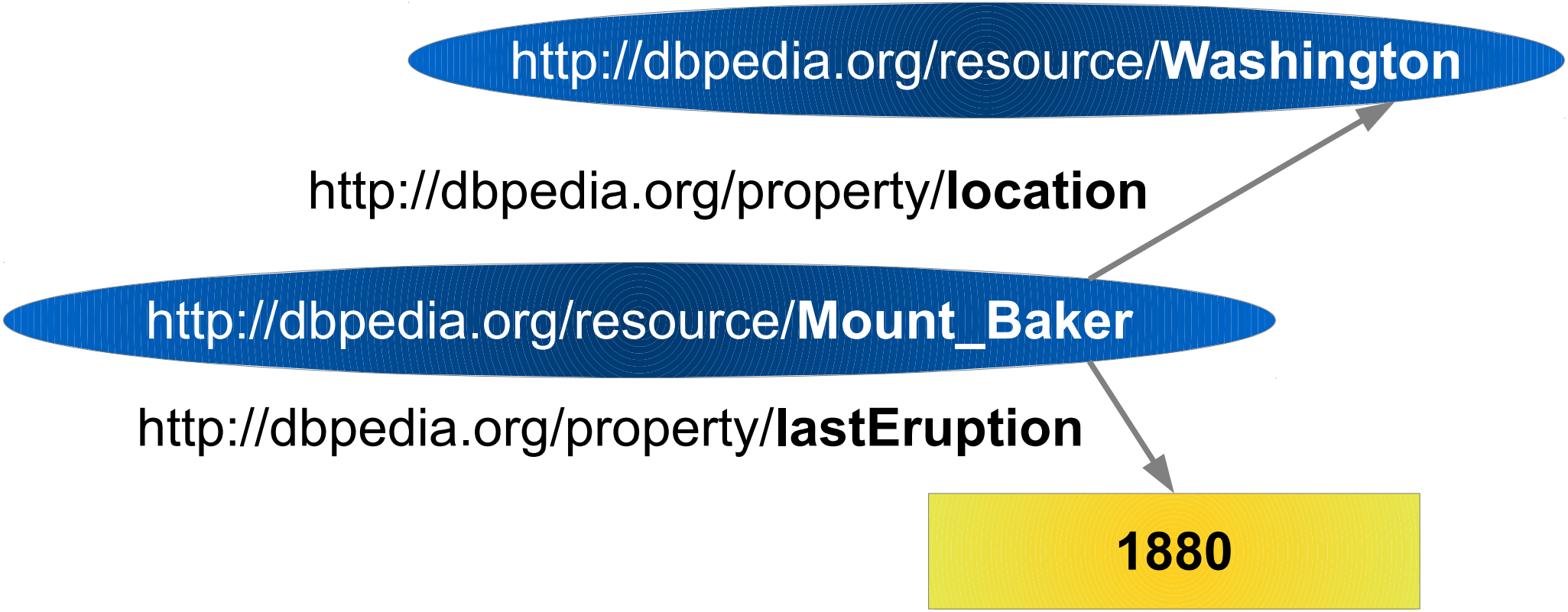
    http://olafhartig.de/foaf.rdf#olaf
  - RDF document about me:

    http://olafhartig.de/foaf.rdf
  - HTML document about me:

    http://olafhartig.de/index.html

Example (revisited)

- (http://dbpedia.org/resource/**Mount_Baker**, http://dbpedia.org/property/**lastEruption**, **1880**)
- (http://dbpedia.org/resource/**Mount_Baker**, http://dbpedia.org/property/**location**, http://dbpedia.org/resource/**Washington**)



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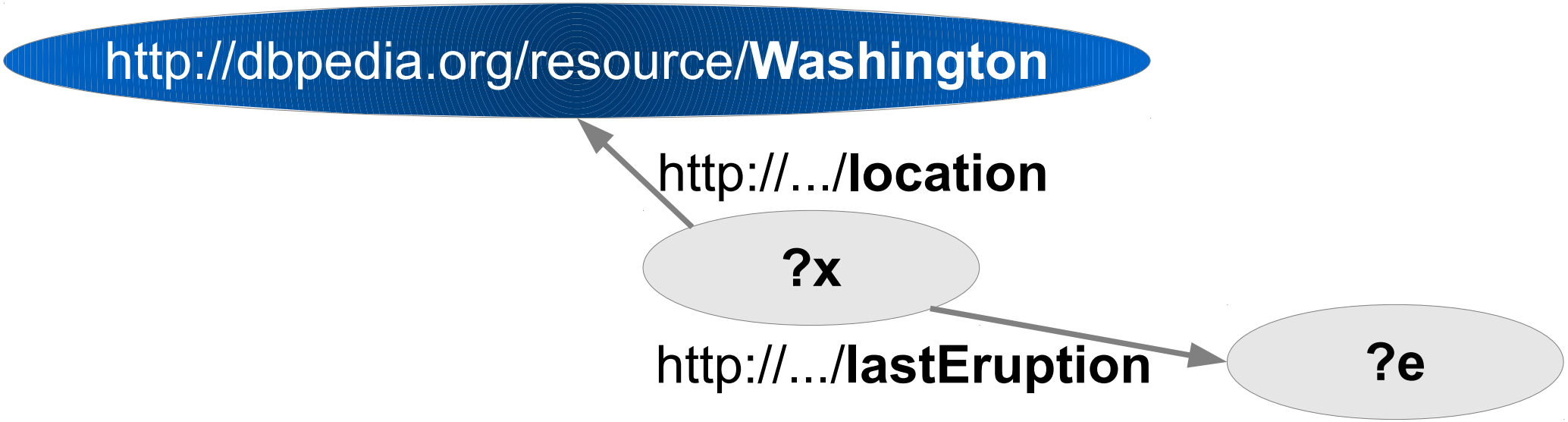
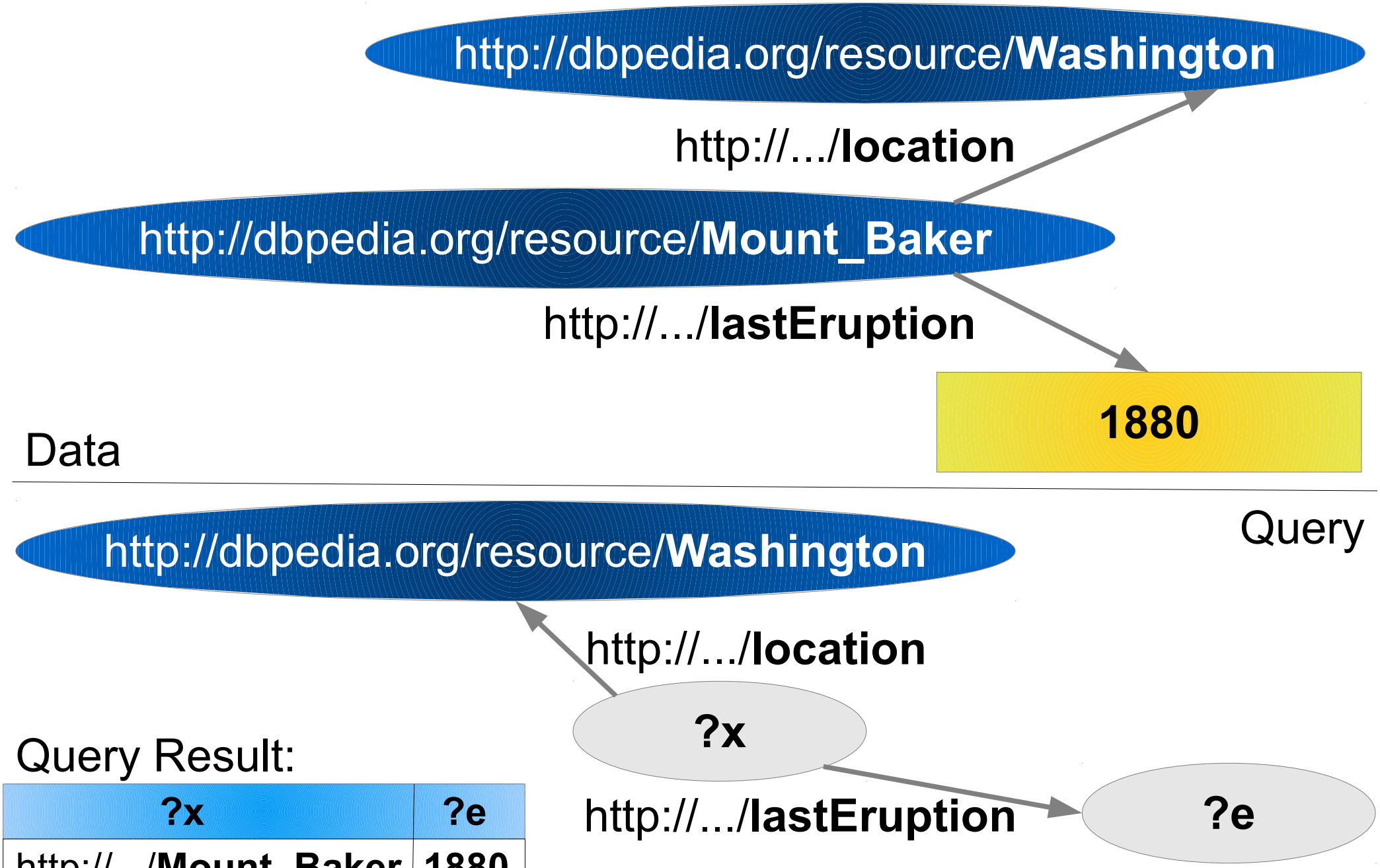
Querying RDF Data

- **SPARQL: Declarative query language for RDF data**
- **Main idea: pattern matching**
  - Describe subgraphs of the queried RDF graph
  - Subgraphs that match your description yield a result
  - Mean: graph patterns (i.e., RDF graphs with variables)



SPARQL Pattern Matching



Query Result:

?x	?e
http://.../Mount_Baker	1880

Components of a SPARQL Query

```
SELECT ?e ?name
FROM <http://example.org/myGeoData>
WHERE {
  ?x <http://.../location> <http://.../Washington> .
  ?x <http://.../lastEruption> ?e .
  OPTIONAL { ?x <http://.../name> ?name . }
}
ORDER BY ?e
```

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- **Result form specification:**
  - SELECT for projection
    (similar to projection in relational algebra)
  - Other forms: DESCRIBE, CONSTRUCT, and ASK

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- **Dataset specification:**
  - Specify the RDF dataset to be queried (use URIs that identify particular RDF graphs in your RDF database)

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- **Query Pattern:**
  - WHERE clause specifies the graph pattern to be matched
  - Expressive power equivalent to relational algebra
  - SPARQL 1.1 goes beyond (e.g., aggregation, property paths)

Components of a SPARQL Query

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- **Solution modifiers:**
  - Only for SELECT queries
  - Modify the result set as a whole (not single solutions)
  - Keywords: DISTINCT, ORDER BY, LIMIT, and OFFSET

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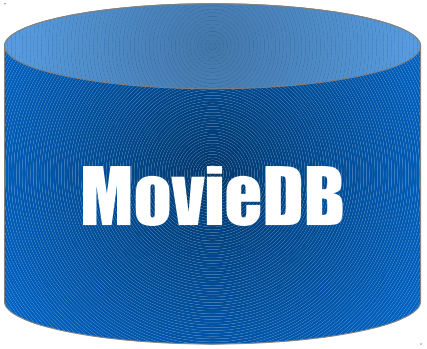
The Linked Data Principles

(http://...imdb.../WarChild , release date , 12 July 1999)
(http://...imdb.../WarChild , filming location , http://cia.../Albania)
(http://...imdb.../MichaelDavie , directed , http://...imdb.../WarChild)
.

Is this real?

,
yment rate , 13.2%)
:



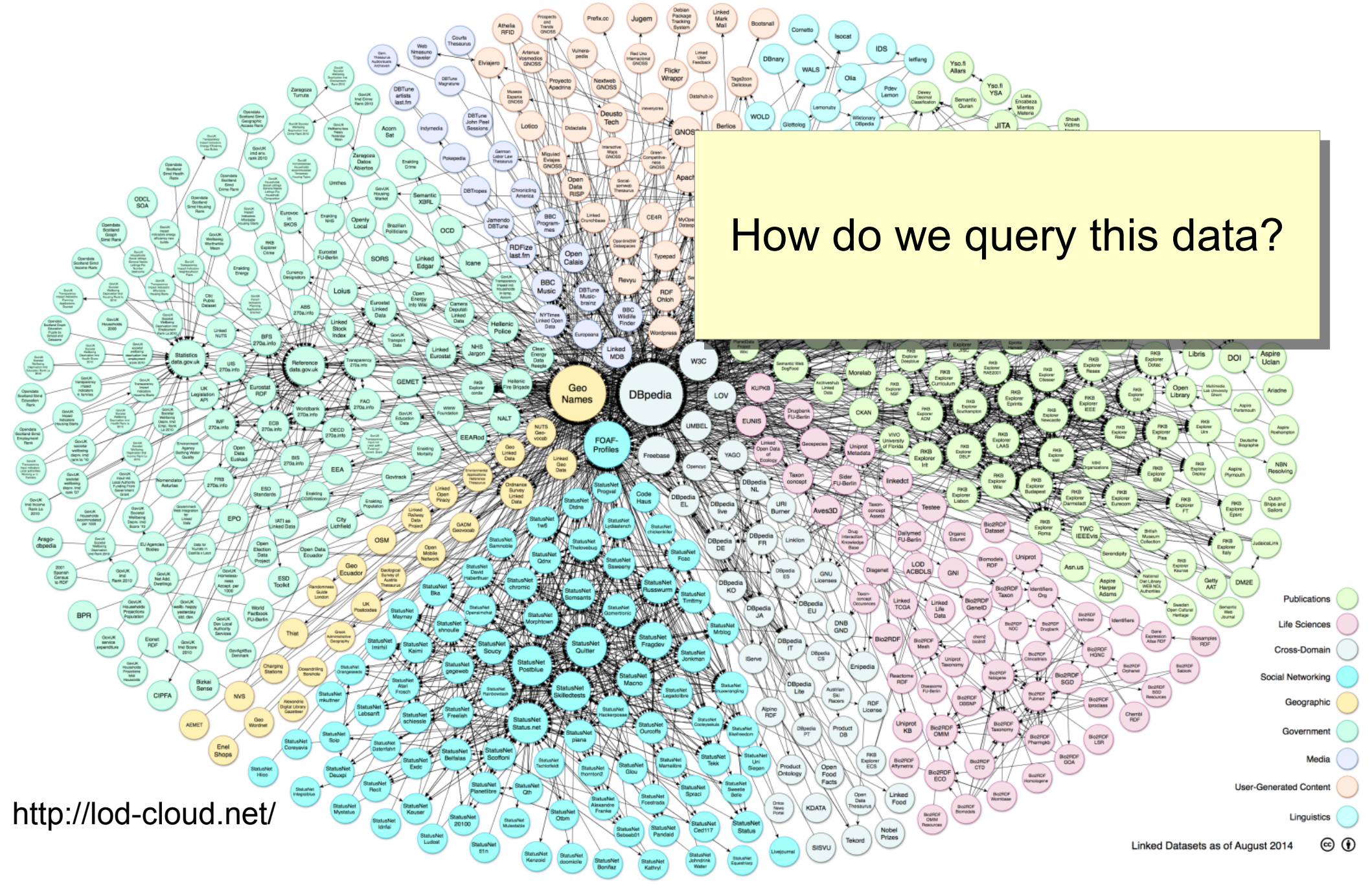
Data model: RDF
Global identifier: URI
Access mechanism: HTTP
Connection: data links

W3C Linking Open Data Project

- **Grassroots community effort**
- **Publish existing, open license datasets as Linked Data**
- **Interlink things between different data sources**

- **Prominent Linked Data publishers today:**
  - Governments (UK, US, I, etc.)
  - The Library of Congress
  - The New York Times
  - Thomson Reuters
  - Renault
  - Best Buy
  - Sears
  - CNET
  - BBC
  - etc.

W3C Linking Open Data Project



http://lod-cloud.net/

Outline

(1) The Foundation: Linked Data on the Web √

(2) Querying Linked Data

- Data Warehousing
- SPARQL Federation
- Linked Data Query Processing

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Remember ...

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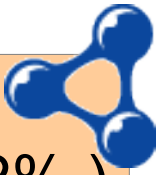
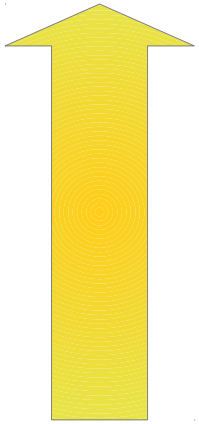
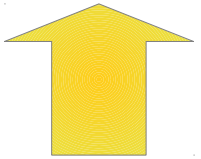
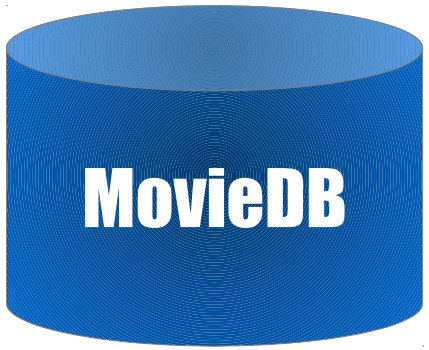
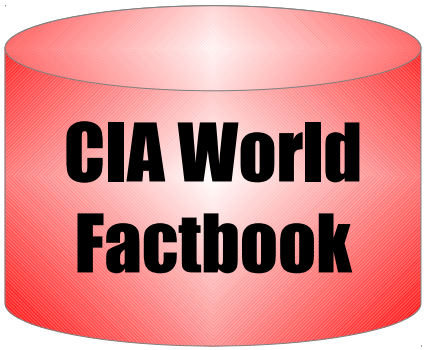






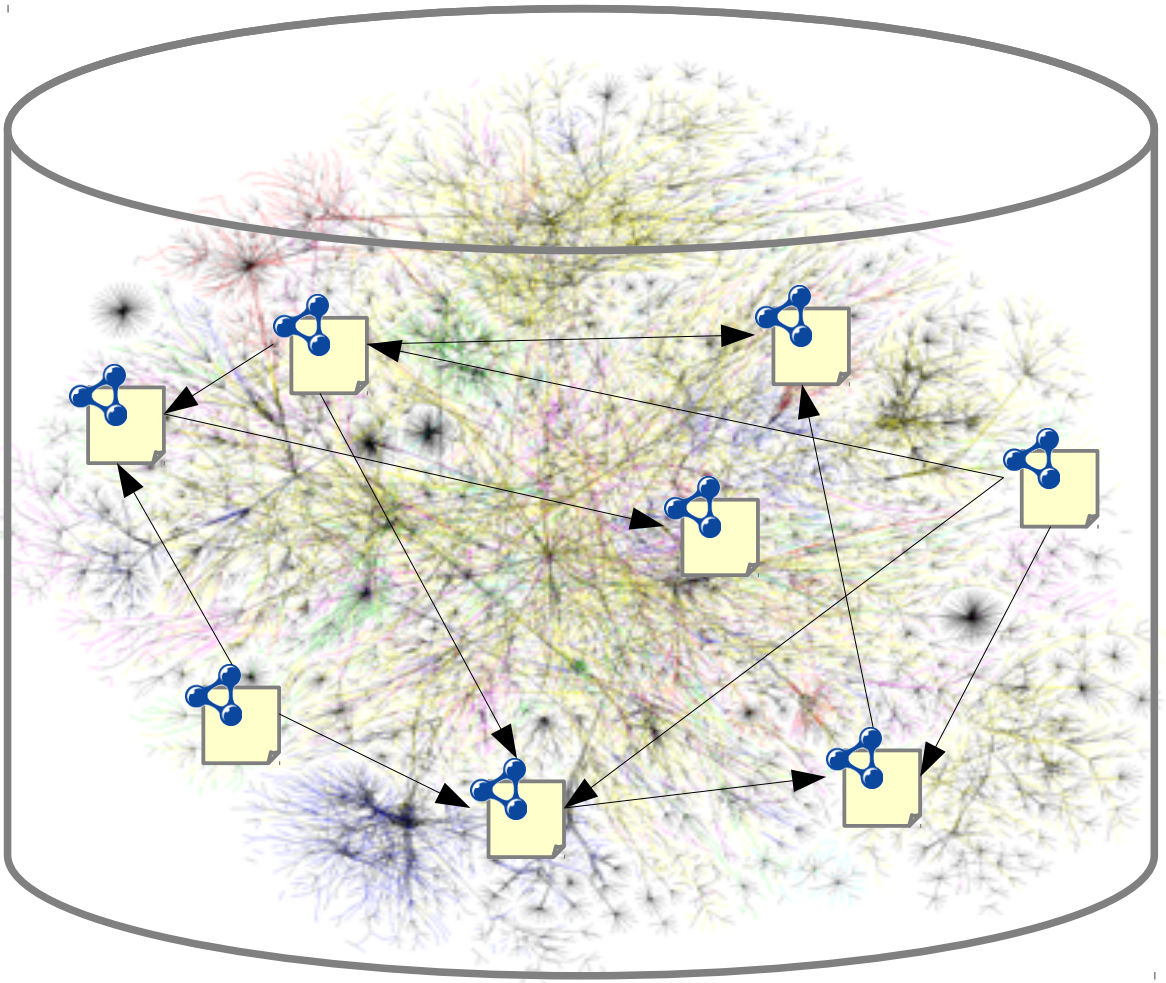


Data model: RDF
Global identifier: URI
Access mechanism: HTTP
Connection: data links



A Globally Distributed Network of Data

...which we understand as a huge distributed database

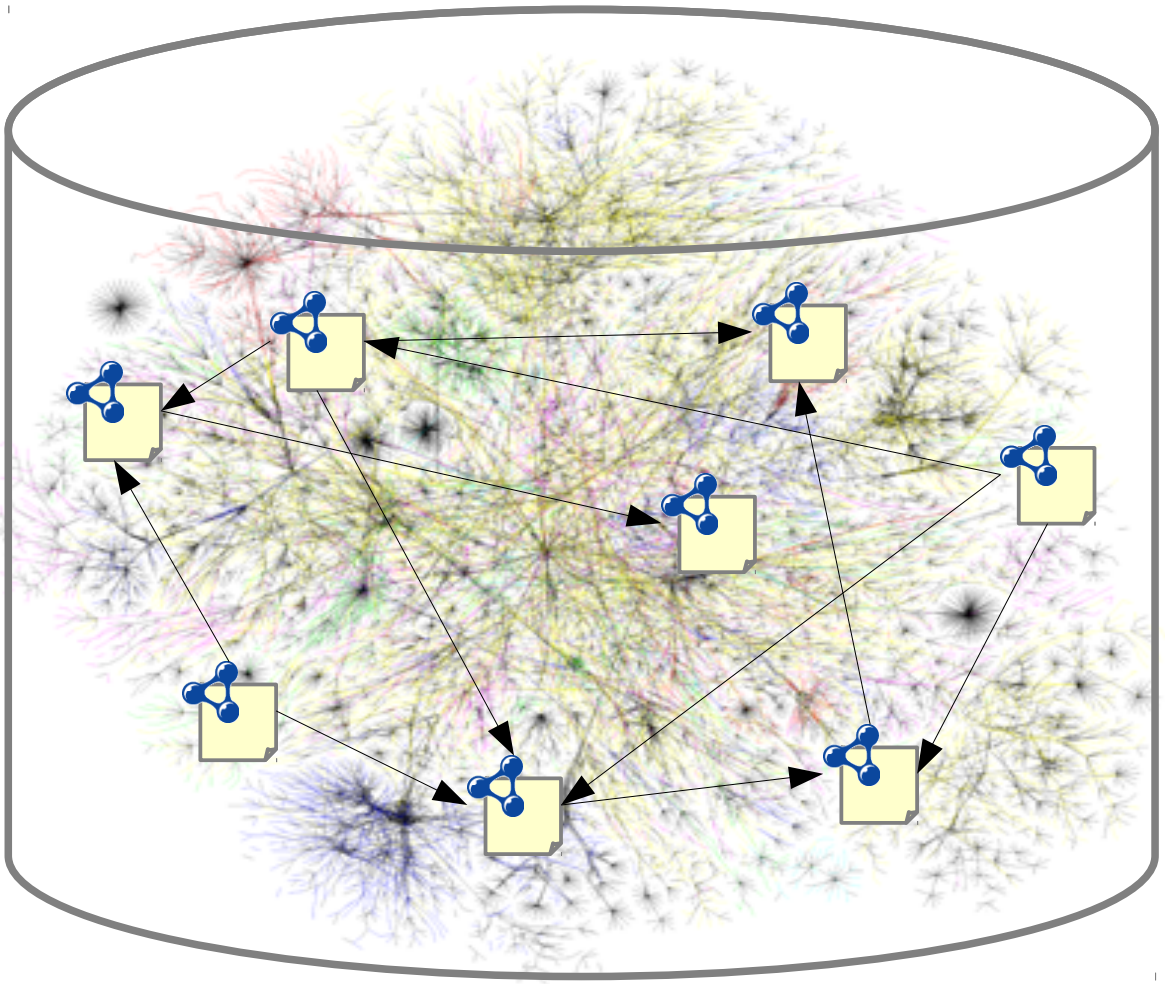


Unusual Characteristics of this DB

- **Data access capabilities of any system that aims to access this DB are inherently limited**
  - HTTP requests only
  - No queries (i.e., we cannot assume that data sources provide a query service)
- **Number of *potential* data sources is infinite**
- **It is impossible to have a DB catalog that is complete or up-to-date (or even both)**

Linked Data Query Processing

… is a new research field that focuses on querying this distributed DB



- **Criteria:**
  - On-line execution
  - Rely only on the Linked Data principles

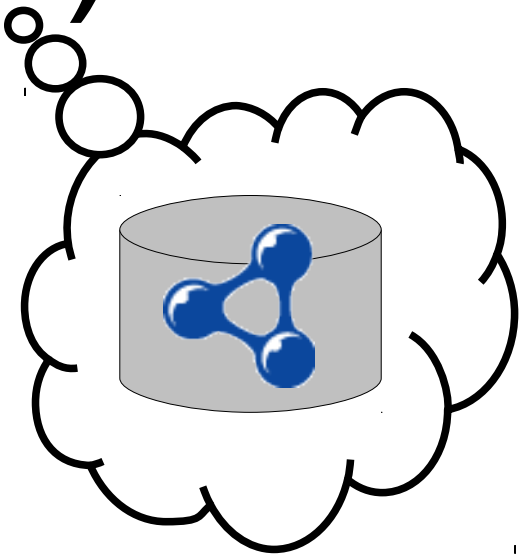
- **Use cases: live querying where freshness and discovery of results is more important than an almost instant answer**

Languages for Linked Data Queries

- **Navigational query languages**
  - Regular expressions to specify paths of data links
  - Query result: end nodes of matching paths
  - NautiLOD, LDPath

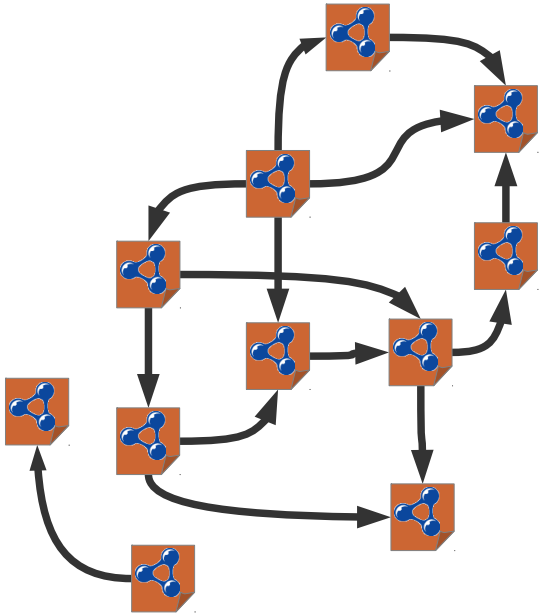
$$Q^{expr}(D) = ?$$

- **SPARQL**
  - Seems to be a natural choice
  - However, standard definition captures queries over a predefined dataset (e.g., stored in an RDF DBMS)



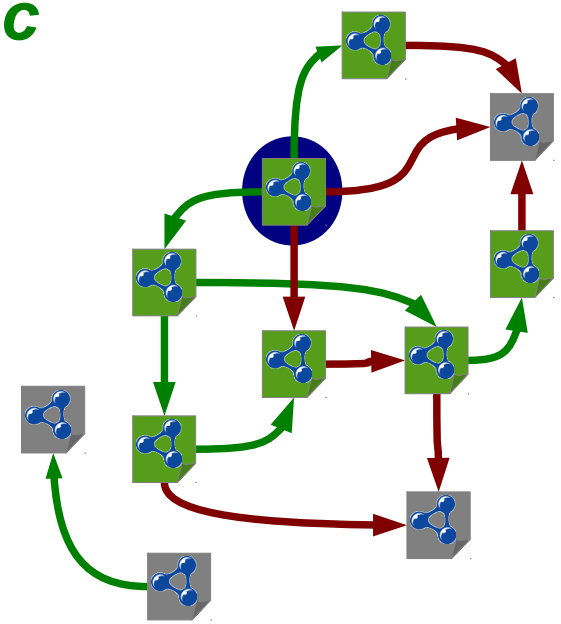
Semantics for SPARQL LD Queries

- **Full-Web query semantics**
  - Scope of evaluating a SPARQL expression is all Linked Data
  - Query result completeness cannot be guaranteed by any (terminating) execution



Semantics for SPARQL LD Queries

- **Full-Web query semantics**
  - Scope of evaluating a SPARQL expression is all Linked Data
  - Query result completeness cannot be guaranteed by any (terminating) execution
- **Reachability-based query semantics**
  - Query consists of a SPARQL expression, a set of seed URIs ***S***, and a reachability condition ***c***
  - Scope: all data along paths of data links that satisfy the condition
  - Computationally feasible



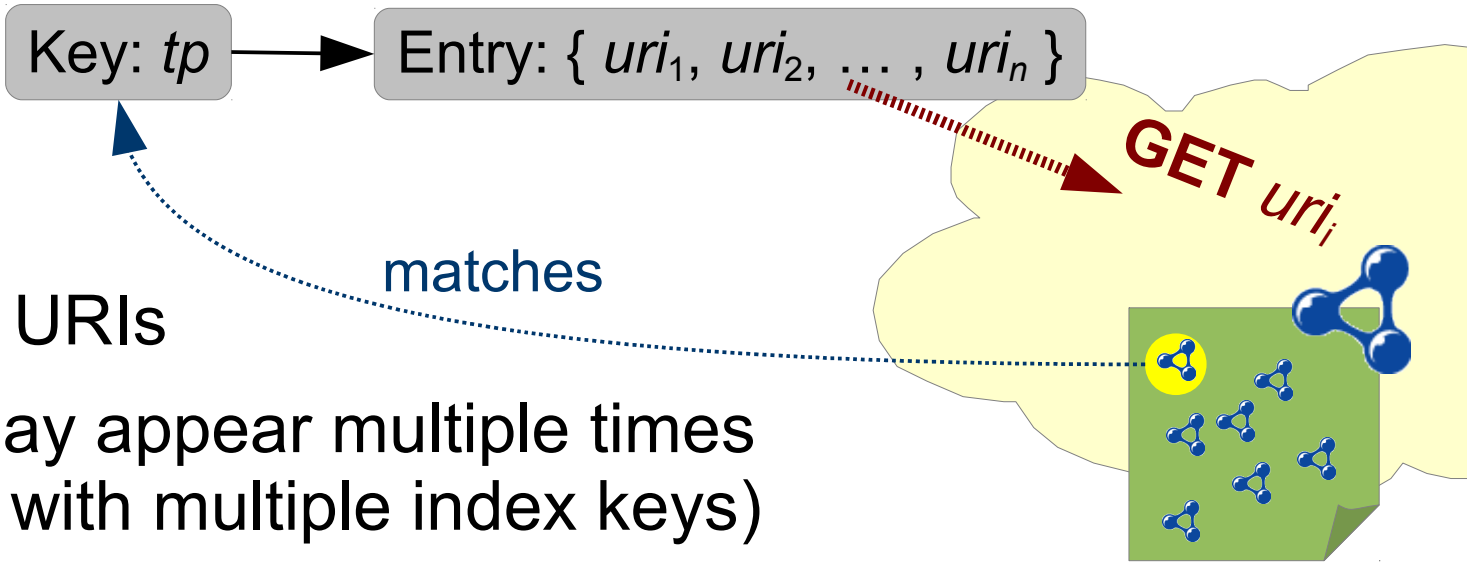
Query Execution

- **Two processes that may be intertwined:**
  - Fetching Linked Data by looking up URIs
  - Constructing the query result

- **Classes of approaches:**
  - Index-based approaches
  - Traversal-based approaches
  - Hybrids

Index-Based Source Selection

- **Idea:** Use pre-populated index to determine relevant URIs (and to avoid as many irrelevant ones as possible)
- **Index keys:**
  - Represent simple summaries of data
  - Different approaches possible; e.g., triple patterns
- **Index entries:**
  - Usually, a set of URIs
  - Indexed URIs may appear multiple times (i.e., associated with multiple index keys)
  - Each URI in such an entry may be paired with a cardinality (utilized for source ranking)



Traversal-Based Query Execution

- **Idea:** Discover relevant URIs recursively by traversing (specific) data links at query execution runtime
  - Natural support of reachability-based query semantics

- **Retrieved data serves two purposes:**

  (1) Discover further URIs

  (2) Construct query result

Traversal-Based – vs. – Index-Based

- **Possibilities for parallelized data retrieval are limited**
  - Data retrieval adds to query execution time significantly
- **Usable immediately**
  - Most suitable for “on-demand” querying scenario
- **Depends on the structure of the network of data links**

- **Data retrieval can be fully parallelized**
  - Reduces the impact of data retrieval on query exec. time
- **Usable only after initialization phase**
- **Depends on what has been selected for the index**
- **May miss new data sources**

None of both strategies is superior over the other w.r.t. result completeness (under full-Web query semantics).

- Both strategies may miss (different) solutions for a query

Summary

- **RDF**
  - Triple-based data model
- **SPARQL**
  - Declarative query language for RDF data
  - Main idea: pattern matching
- **Linked Data**
  - Structured, *interlinked* data on the Web
- **Querying Linked Data**
  - Data warehousing
  - SPARQL federation
  - Linked Data query processing (index-based, traversal-based)