LDIF - A Framework for Large-Scale Linked Data Integration

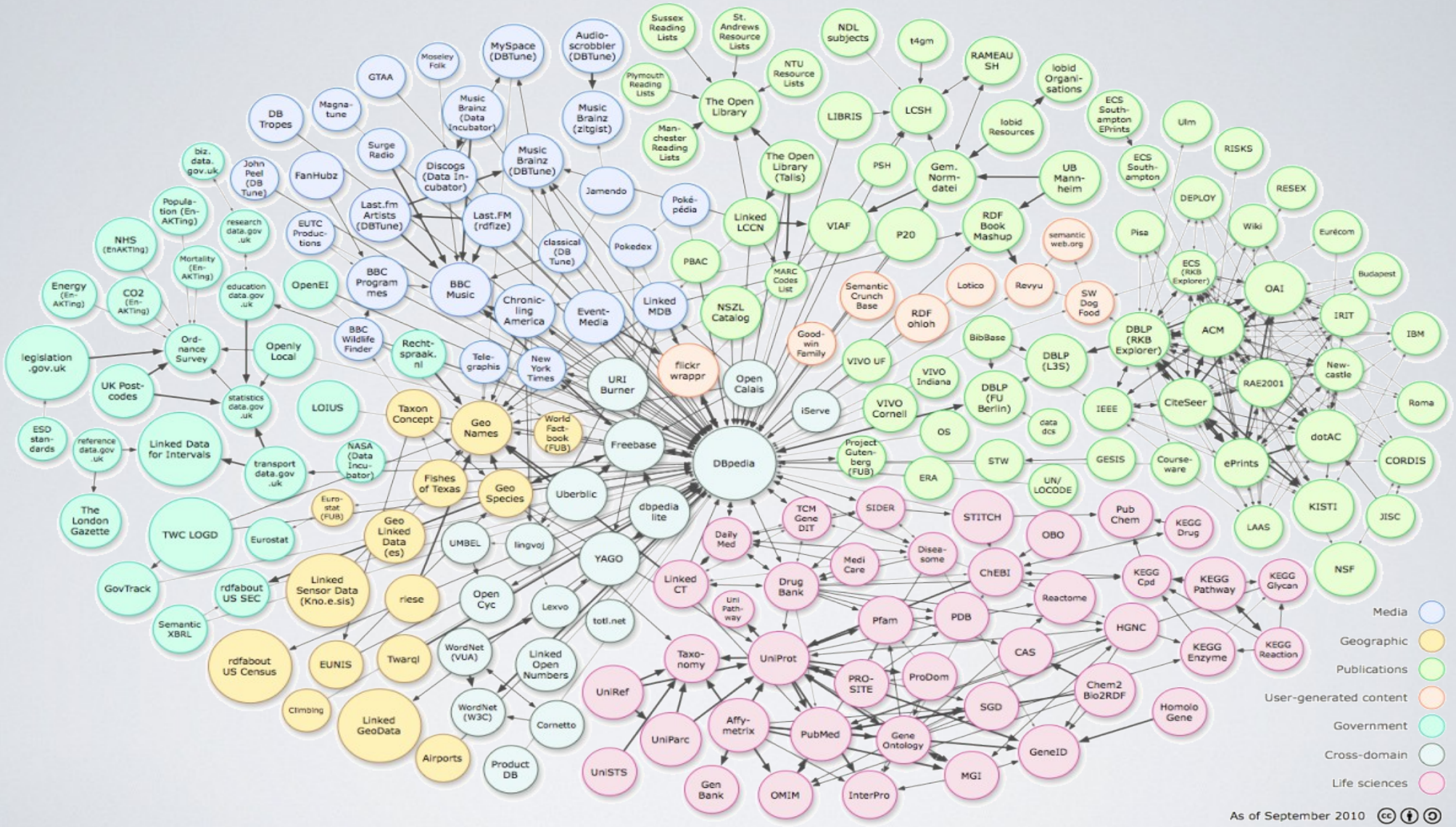
Andreas Schultz, Freie Universität Berlin
Andrea Matteini, mes | semantics
Robert Isele, Freie Universität Berlin
Pablo N. Mendes, Freie Universität Berlin
Christian Bizer, Freie Universität Berlin
Christian Becker, mes | semantics

With contributions from:
Hannes Mühleisen, Freie Universität Berlin

Outline

- Challenges for consuming Linked Data
- LDIF – Linked Data Integration Framework
  - Data Aquisition
  - Data Translation
  - Identity Resolution
  - Quality Assesment and Fusion
  - Output
- Benchmarks

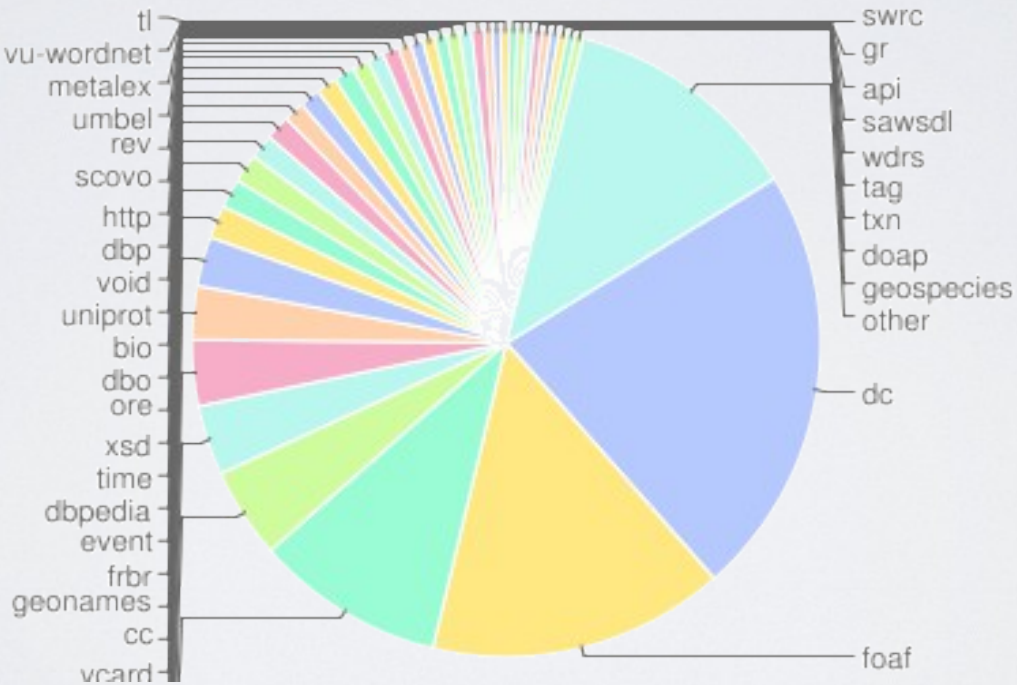
Linked Open Data



Linked Data Challenges

- The Web of Data is heterogeneous
- Many different vocabularies are in use
- Over 60 % of all Linked Data sources use proprietary vocabularies[1]

⇒ Consumer has to normalize the vocabularies



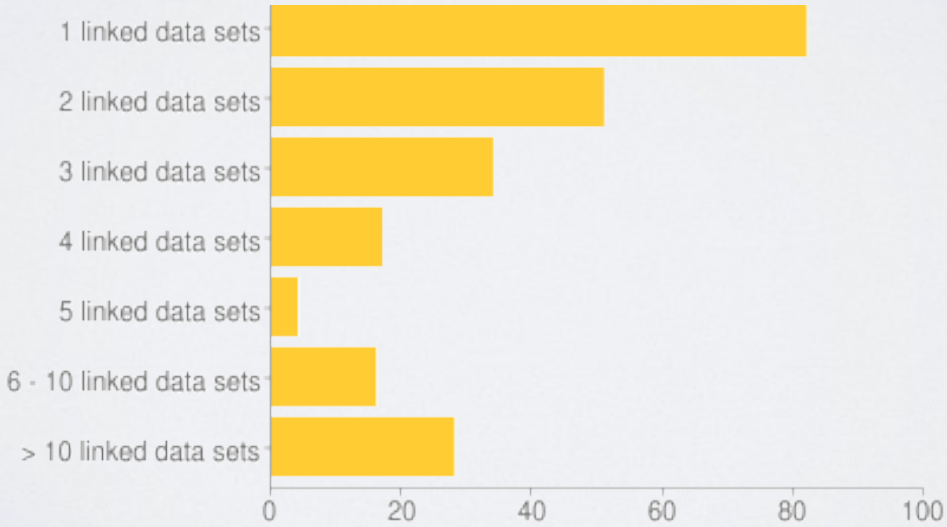
Most widely used vocabularies in the LOD cloud (08/10/2011)

[1]http://www4.wiwiss.fu-berlin.de/lodcloud/state/

Linked Data Challenges

- Over 30 billion triples published as Linked Open Data
  - But only 500 million links
- Many data sources are not sufficiently interlinked
  - Most data sources only link to one other data source

⇒ Consumer needs to generate additional links



LOD data sets by the number of other data sources that are target of outgoing RDF links

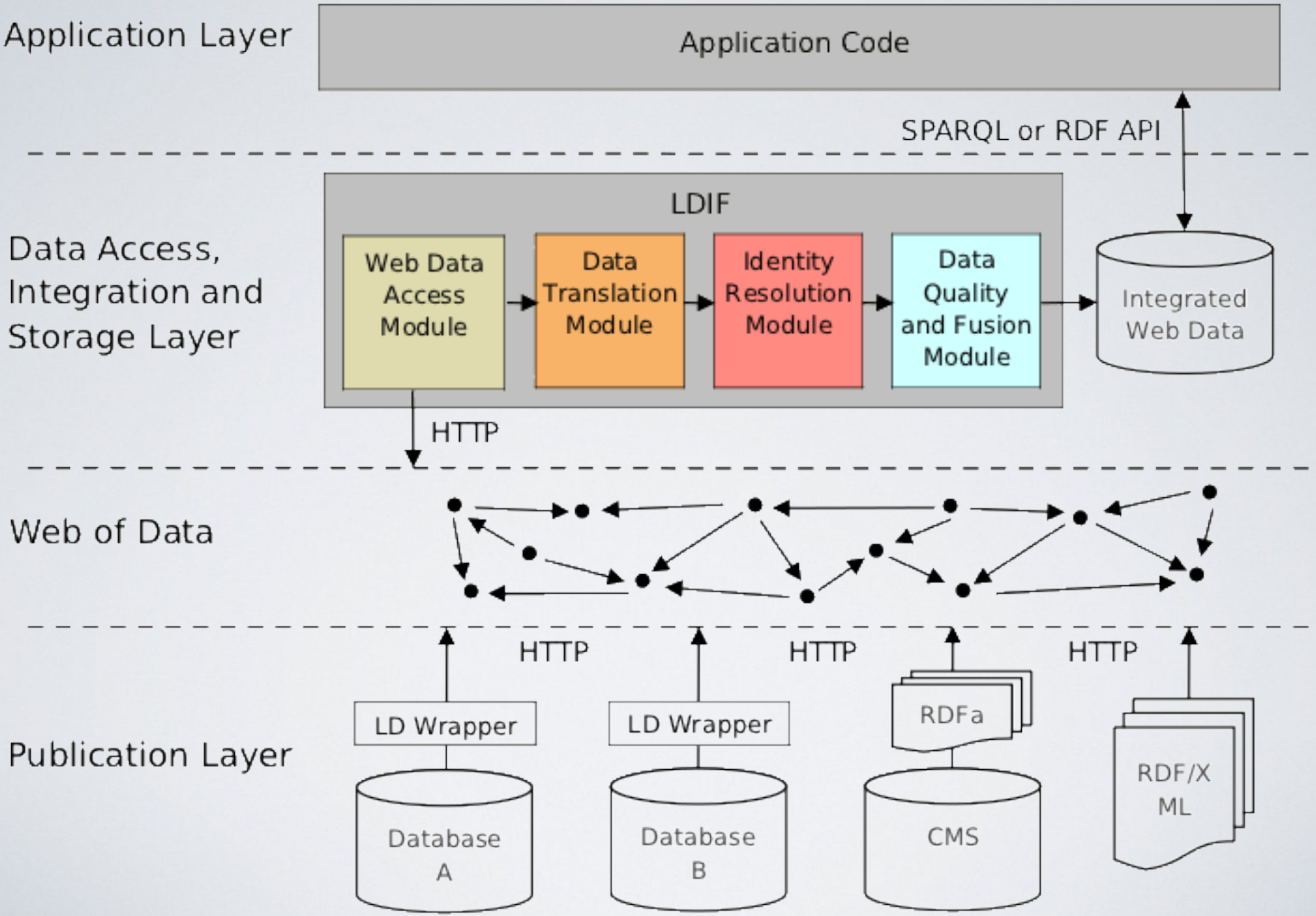
Linked Data Challenges

- The quality of data on the Web is very mixed
- Linked Data Providers differ in:
  - Levels of knowledge
  - Views of the world
  - Different intension
- Information in Linked Data Souces may be:
  - Wrong
  - Biased
  - Inconsistent
  - Outdated

LDIF – Linked Data Integration Framework

- LDIF:
  - Gather Linked Data from the Web
  - Translate the data into a clean local target representation
  - While keeping track of data provenance
- Open source (Apache License, Version 2.0)
- Collaboration between Freie Universität Berlin and mes|semantics
- Available for download at: http://ldif.wbsg.de/

Architecture of Linked Data Applications



LDIF Pipeline

1. Collect data
2. Map to Schema
3. Resolve Identities
4. Quality Assessment & Fusion
5. Output

Data Access

- Data can be loaded from a variety of sources:
  - RDF dumps (various formats)
  - SPARQL Endpoints
  - Crawling Linked Data
- We consider a simple use case:
  - We retrieve and integrate 2 data sources:
  - Freebase using crawling
  - MusicBrainz using SPARQL endpoint
- Complete example with 4 data sources at:
  http://www.assembla.com/code/ldif/git/nodes/master/ldif/examples/music/

Freebase

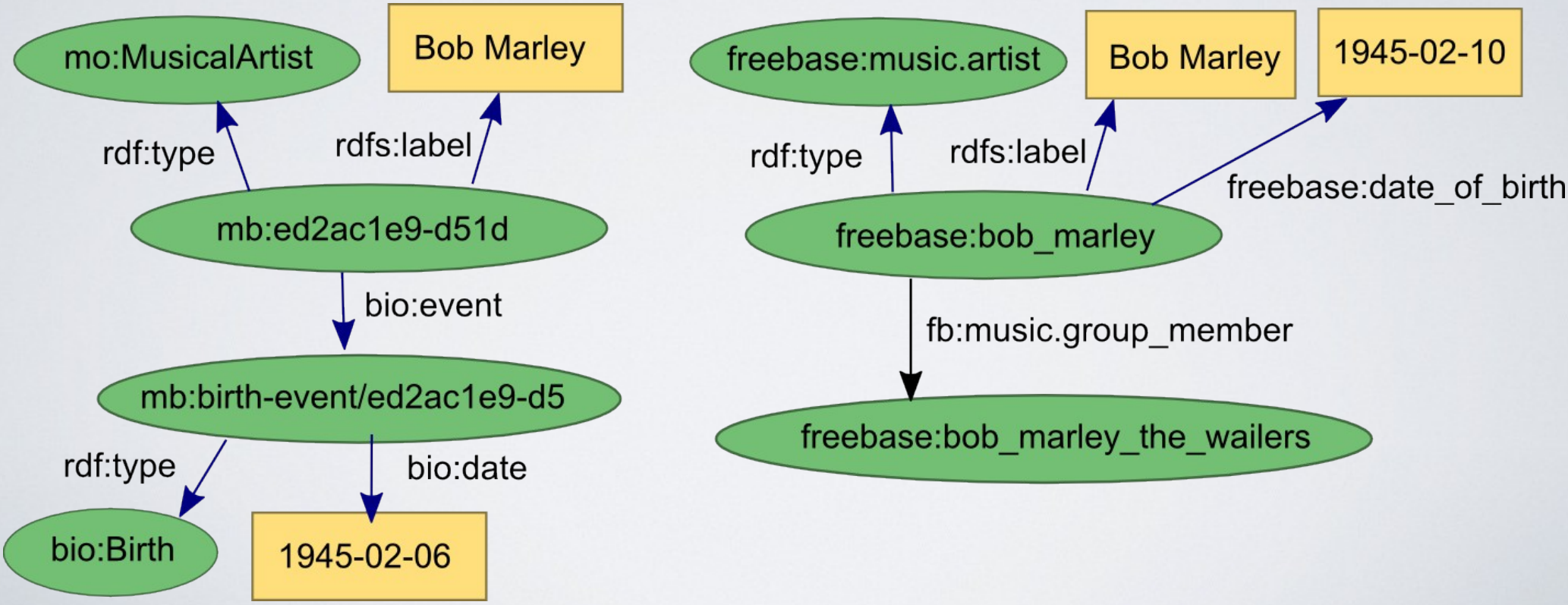
```
<importJob>
    <dataSource>Freebase</dataSource>
    <refresahSchedule>onStartup</refreshSchedule>
    <crawlImportJob>
        <seedURIs>
            <uri>http://rdf.freebase.com/ns/en.bob_marley</uri>
        </seedURIs>
        <predicatesToFollow>
            <uri>http://rdf.freebase.com/ns/music.artist.genre</uri>
            <uri>http://rdf.freebase.com/ns/music.genre.albums</uri>
            <uri>http://rdf.freebase.com/ns/music.genre.artists</uri>
            <uri>http://rdf.freebase.com/ns/music.album.artist</uri>
            <uri>http://rdf.freebase.com/ns/music.artist.album</uri>
        </predicatesToFollow>
        <levels>2</levels>
        <resourceLimit>100000</resourceLimit>
    </crawlImportJob>
</importJob>
```

MusicBrainz

```
<importJob>
   <internalId>musicbrainz.3</internalId>
   <dataSource>MusicBrainz_Talis</dataSource>
   <refreshSchedule>onStartup</refreshSchedule>
   <sparqlImportJob>
      <endpointLocation>
        http://api.talis.com/stores/musicbrainz/services/sparql
      </endpointLocation>
      <tripleLimit>5000</tripleLimit>
      <sparqlPatterns>
         <pattern>?s a
&lt;http://purl.org/ontology/mo/SoloMusicArtist&gt;</pattern>
      </sparqlPatterns>
   </sparqlImportJob>
</importJob>
```

Problems

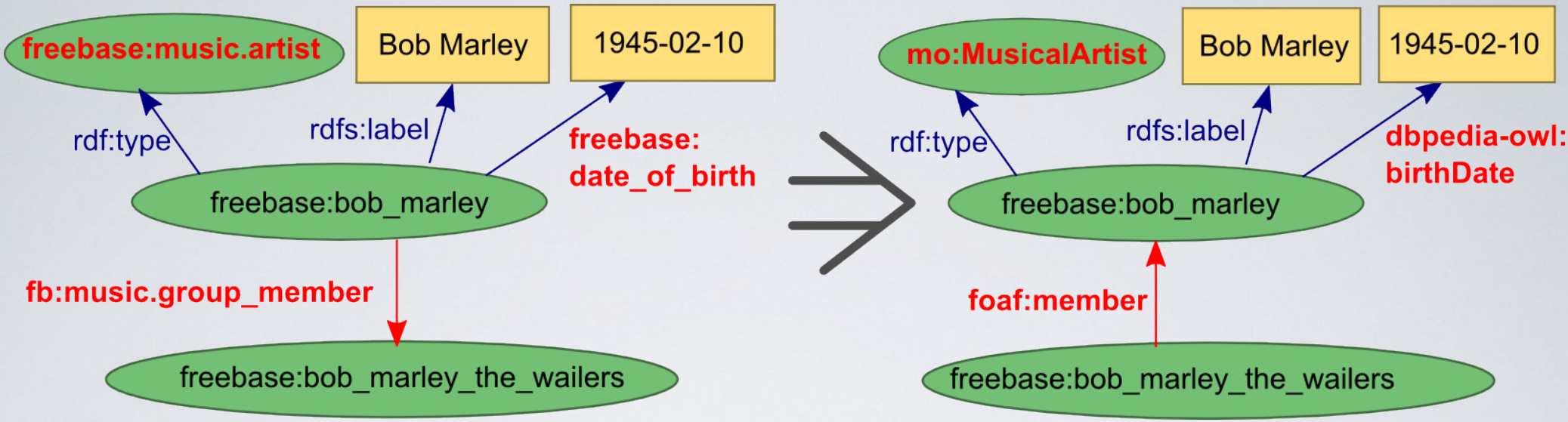
- Different ways to represent the same information
- Different Uris for the same real world object
- Conflicting information



Data Translation

- LDIF uses R2R for vocabulary mapping
- Translates data to a single target vocabulary
- R2R Mapping Language:
  - Mappings expressed in RDF (Turtle)
  - Simple mappings using OWL / RDFs statements (x rdfs:subClassOf y)
  - Complex mappings with SPARQL expressivity
  - Transformation functions

Mapping Freebase

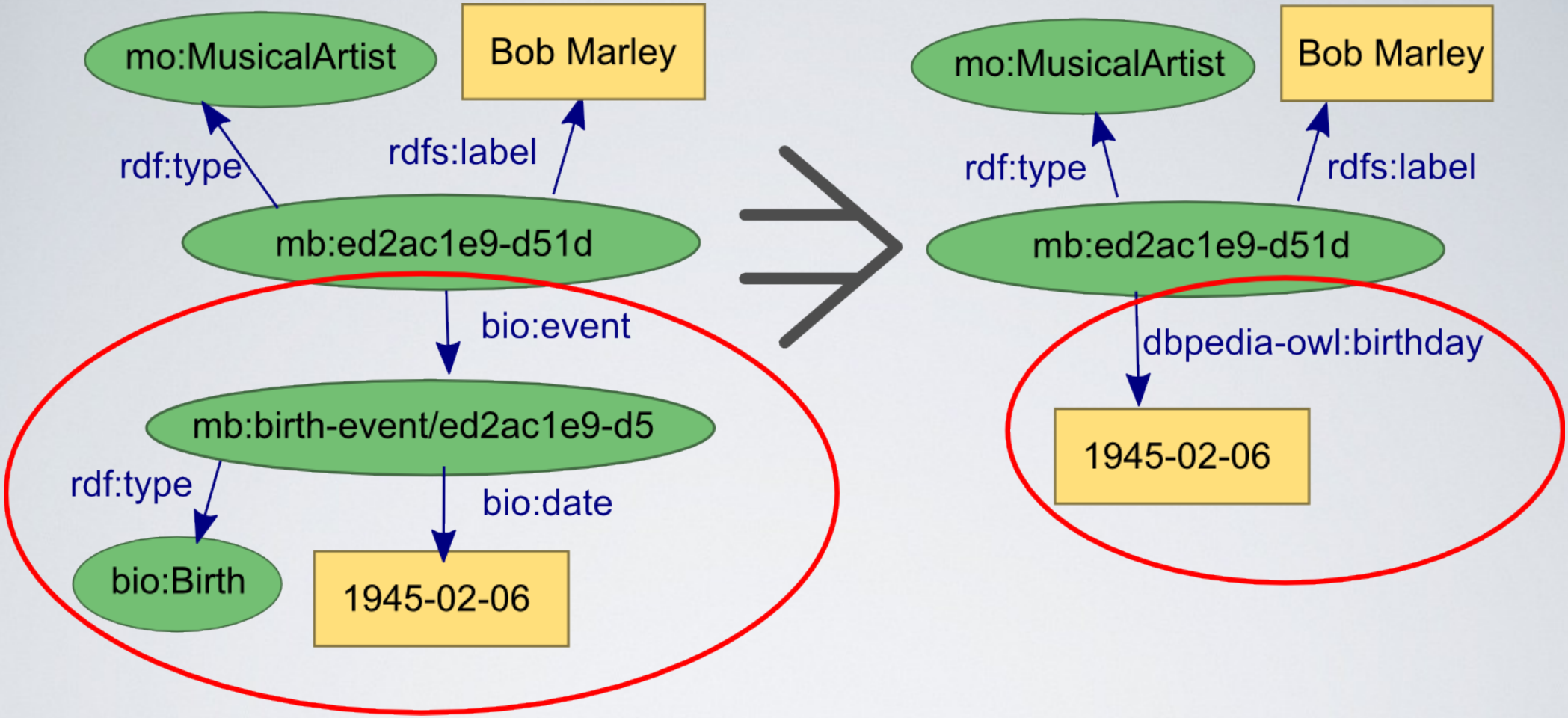



```
<http://rdf.freebase.com/ns/music.artist> rdfs:subClassOf mo:MusicArtist
```

```
freebase:date_of_birth rdfs:subPropertyOf dbpedia-owl:birthDate .
```

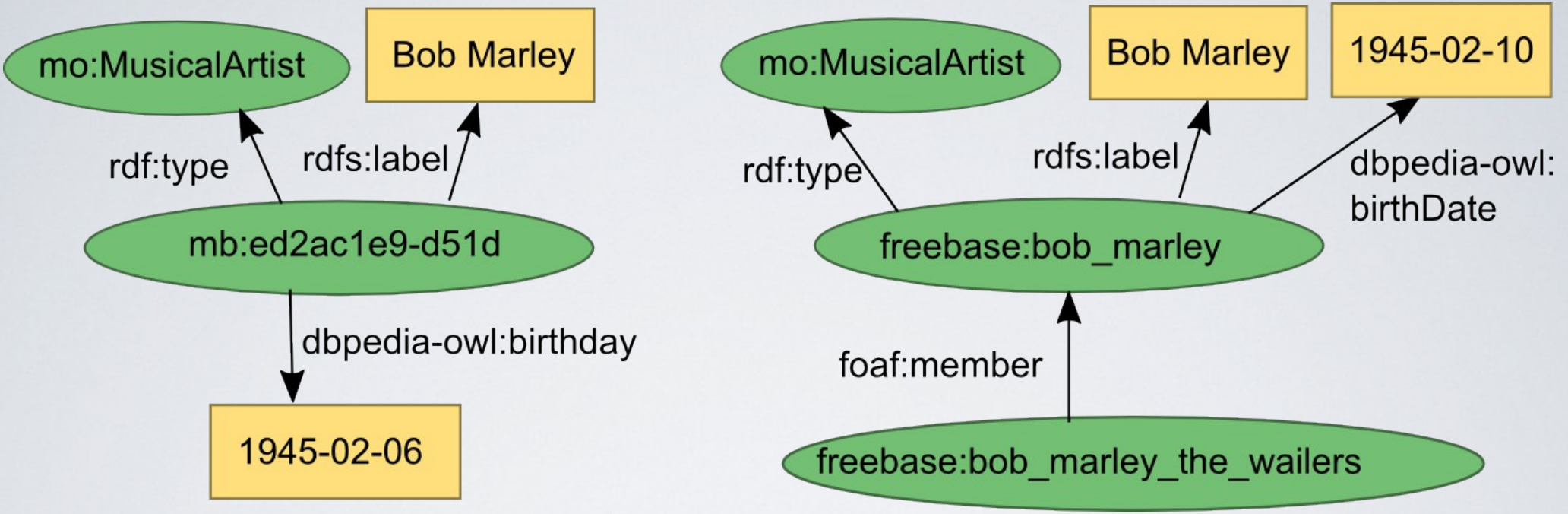
```
mp:mapToFoafMember
  a r2r:Mapping ;
 r2r:sourcePattern "?SUBJ mo:member_of ?o" ;
 r2r:targetPattern "?o foaf:member ?SUBJ " .
```

Mapping MusicBrainz




```
mp:bioToDBpediaBirthDate a r2r:Mapping ;
 r2r:sourcePattern "?SUBJ a foaf:Person . ?SUBJ bio:event ?event .
                    ?event a bio:Birth . ?event bio:date ?o" ;
 r2r:targetPattern "?SUBJ dbpedia-owl:birthDate ?'o'^^xsd:date" .
```

Result


mo:MusicalArtist
Bob Marley
rdf:type
rdfs:label
mb:ed2ac1e9-d51d
dbpedia-owl:birthday
1945-02-06
mo:MusicalArtist
Bob Marley
1945-02-10
rdf:type
rdfs:label
dbpedia-owl:
birthDate
freebase:bob_marley
foaf:member
freebase:bob_marley_the_wailers

Resolve Identities

- LDIF uses the Silk Link Discovery Framework to resolve identities
- Declarative Silk Link Specification Language is used to define linkage rules
- A Linkage Rule defines the conditions that must hold true for two entities to be considered a duplicate

Linkage Rules

A linkage rule is represented as a tree consisting of 4 types of operators:

RDF paths

- Similar to SPARQL 1.1 Property Paths
- Examples:
  - ?movie/dbpedia:director/rdfs:label
  - ?person/label[@lang='en']

Transformations

- Transforms the result set of an RDF paths
- Variety of built-in transformations
- Examples:
  - LowerCase
  - RegexReplace
  - Stem

Similarity Metrics

- Similarity of two inputs based on a user-defined metric.
- Examples:
  - Various string similarity metrics
  - Geographic similarity
  - Date similarity

Aggregations

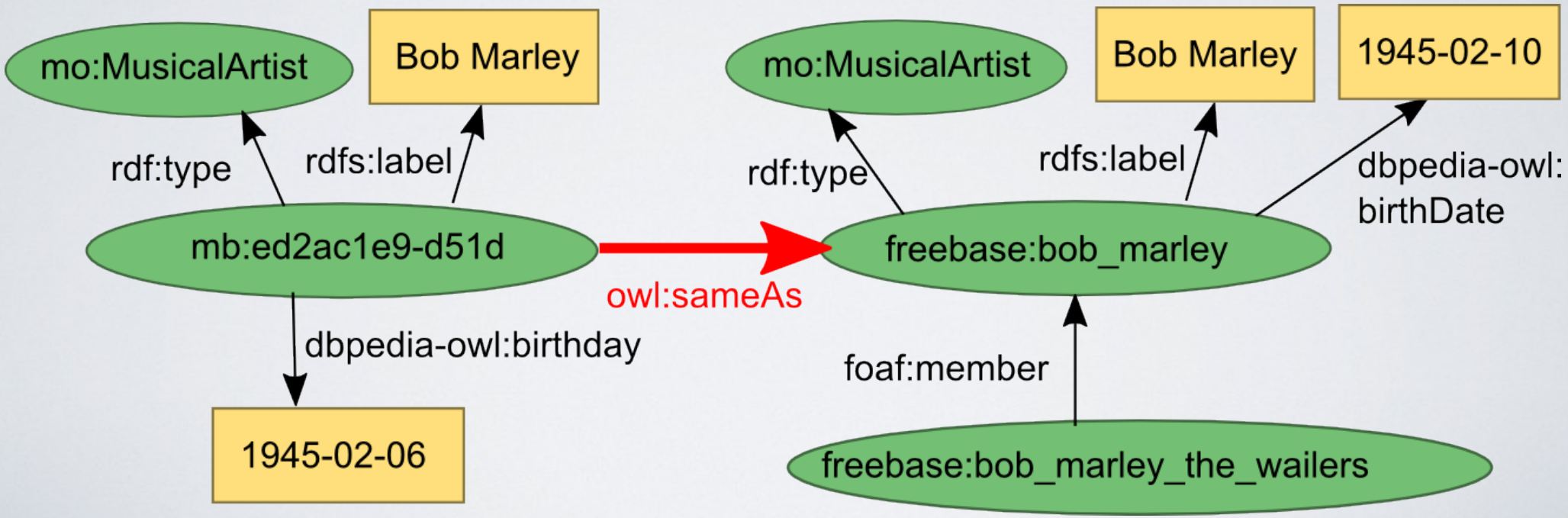
- Aggregates multiple similarity metrics
- Examples:
  - Min, Max, Average
  - Quadratic Mean
  - Geometric Mean

Example Linkage Rule

```
<LinkageRule>
   <Aggregate type="average">
      <Compare metric="equality" >
         <Input path="?a/rdfs:label" />
         <Input path="?b/rdfs:label" />
      </Compare>
      <Aggregate type="max">
         <Compare metric="jaccard" threshold="0.4">
            <Input path="?a\foaf:member/rdfs:label" />
            <Input path="?a\foaf:member/rdfs:label" />
         </Compare>
         <Compare metric="date" threshold="0.0">
            <Input path="?a/dbpediaowl:birthDate" />
            <Input path="?b/dbpediaowl:birthDate" />
         </Compare>
      </Aggregate>
   </Aggregate>
</LinkageRule>
```

Example

- Entities which identify the same real world object are connected using owl:sameAs links
- owl:sameAs links are to be fused into a single entity



Quality Assesment

- LDIF uses Sieve[1] for Quality Assessment
- Quality Assessment Metrics composed by:
  - ScoringFunction (generically applicable to given data types)
  - Quality Indicator as input (adaptable to use case)
- Output describes input within a quality dimension, according to a user's definition of quality.
- We consider a simple example with 2 dimensions:
  - Recency
  - Reputation

[1]http://sieve.wbsg.de

Recency

- Configuration:

```
<QualityAssessment>
   <AssessmentMetric id=”sieve:recency”>
      <ScoringFunction class=”TimeCloseness”>
         <Param name=”timeSpan”” value=”7” />
         <Input path=”?GRAPH/provenance:lastUpdated” />
      </ScoringFunction>
   </AssessmentMetric>
</QualityAssessment>
```

- Example:

```
freebase:bob_marley  sieve:recency  “0.4”
mb:ed2ac1e9-d51d     sieve:recency  “0.8”
```

Reputation

- Configuration:

```
<QualityAssessment>
   <AssessmentMetric id=”sieve:reputation”>
      <ScoringFunction class=”ScoredList”>
         <Param name=”priority”””
           Value=”http://musicbrainz.dataincubator.org
                    http://rdf.freebase.com/ns” />
      </ScoringFunction>
   </AssessmentMetric>
</QualityAssessment>
```

- Example:

```
freebase:bob_marley  sieve:reputation  “0.45”
mb:ed2ac1e9-d51d     sieve:reputation  “0.9”
```

Data Fusion

"fusing multiple records representing the same real-world object into a single, consistent, and clean representation"

(Bleiholder & Naumann, 2008)

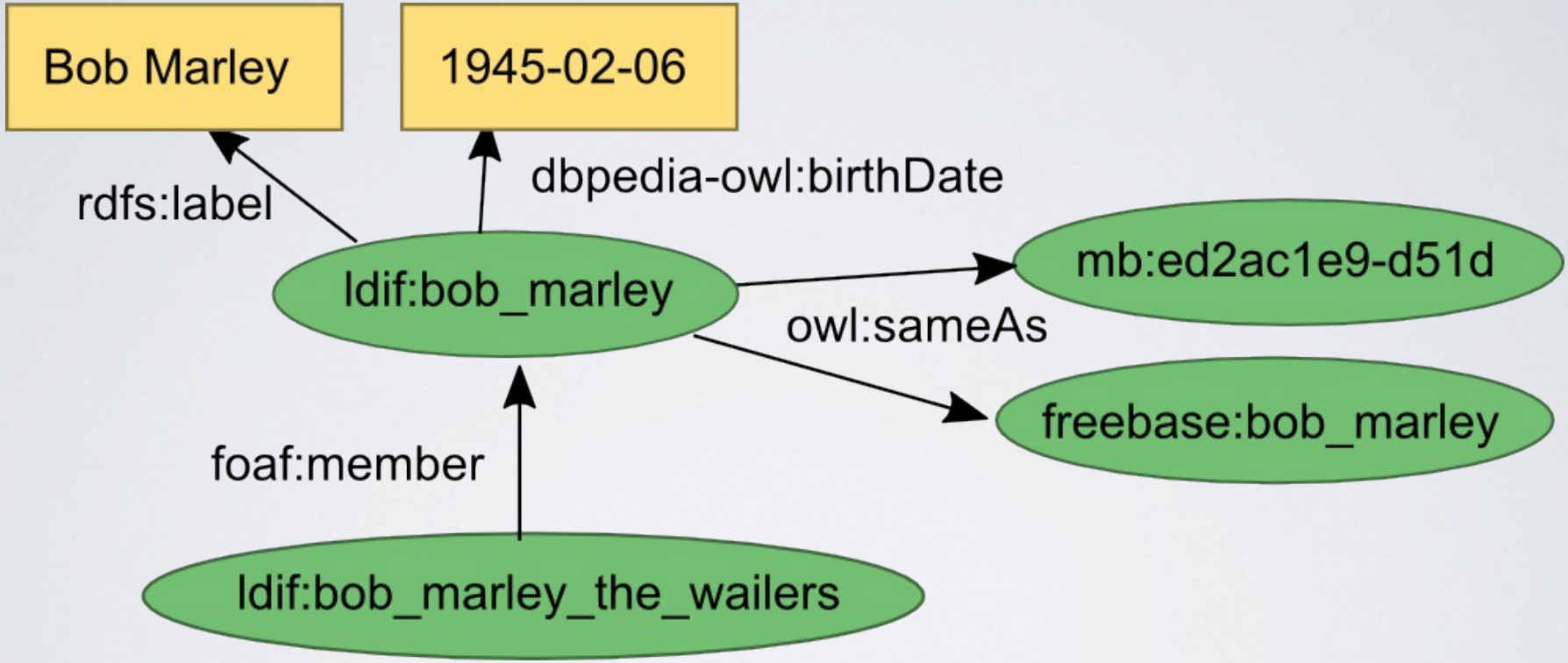
- Input:
  - (Potentially) conflicting data
  - Quality metadata describing input
- Execution:
  - Use existing or custom FusionFunctions
- Output:
  - Clean data, according to user's definition of clean

Fusion Example

- Configuration:

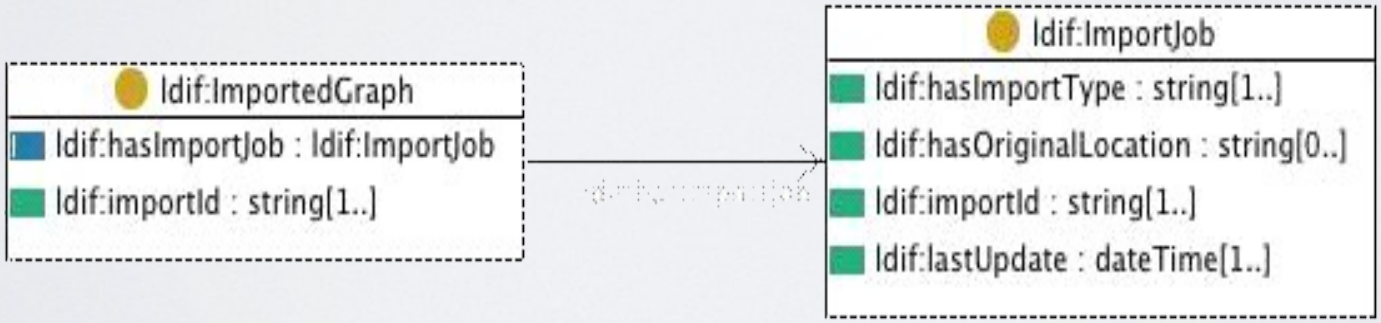
```
<Fusion>
   <Class name=”mo:MusicalArtist”>
      <Property name=”rdfs:label”>
         <FusionFunction  class=”PassItOn” />
      </Property>
      <Property name=”dbpedia-owl:birthDate”>
         <FusionFunction class=”KeepSingleValueByQualityScore”
                                 metric=”sieve:reputation”>
      </Property>
      ...
   </Class>
</Fusion>
```

Result


Bob Marley
1945-02-06
rdfs:label
dbpedia-owl:birthDate
ldif:bob_marley
mb:ed2ac1e9-d51d
owl:sameAs
freebase:bob_marley
foaf:member
ldif:bob_marley_the_wailers

Data Output

- Output options:
  - N-Quads
  - N-Triples
  - SPARQL Update Stream
- Provenance tracking using Named Graphs



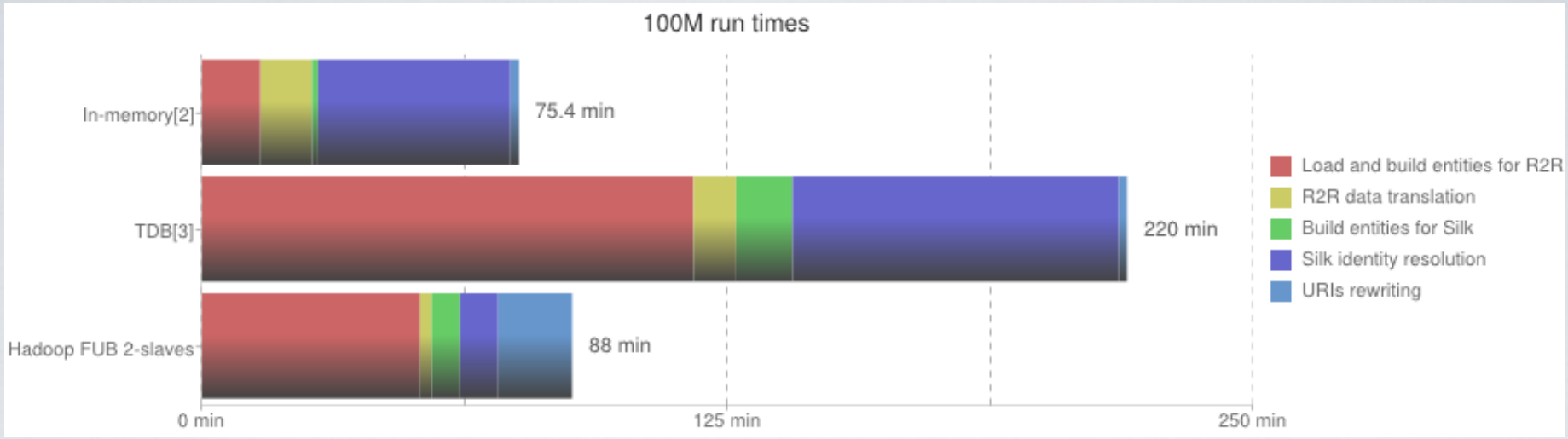
Versions

- In-memory
  - keeps all intermediate results in memory
  - fast, but scalability limited by local RAM
- RDF Store (TDB)
  - stores intermediate results in a Jena TDB RDF store
  - can process more data than In-memory but scalability is limited by the RDF store
- Cluster (Hadoop)
  - scales by parallelizing work across multiple machines using Hadoop
  - can process a virtually unlimited amount of data

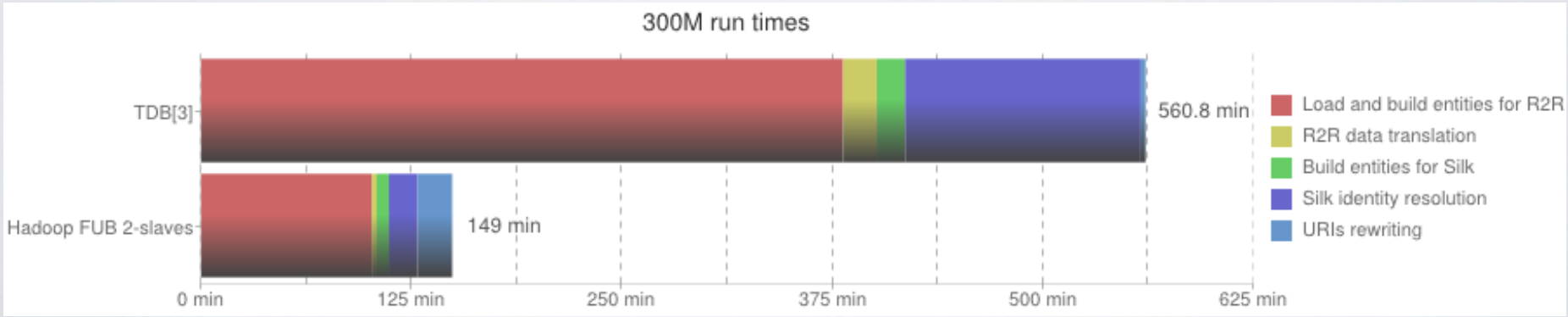
Benchmarks

KEGG GENES VS. UNIPROT (SINGLE MACHINE)

100M Triples:



300M Triples:

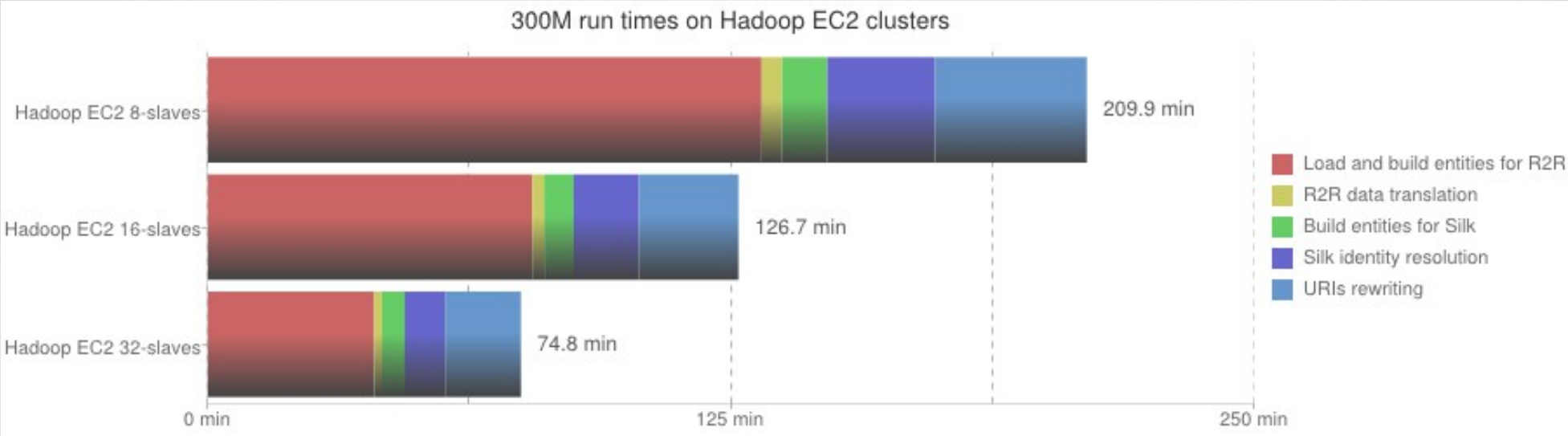


Machine: Intel i7 950, 3.07GHz (quadcore), 24GB

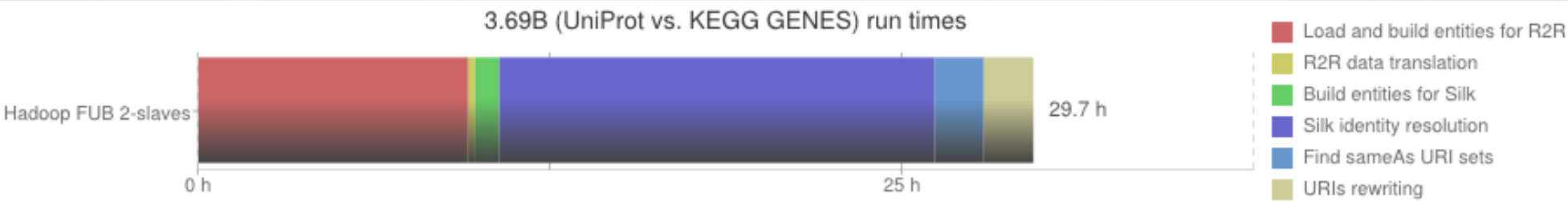
Benchmarks

KEGG GENES VS. UNIPROT (CLUSTER)

300M Triples:



3.6B Triples:



Machines: Amazon EC2 c1.medium instances

Thank You!

- Get LDIF at: http://ldif.wbsg.de
- Development of LDIF has been supported in part by:
  - Vulcan Inc. as part of its Project Halo
  - LOD2 - Creating Knowledge out of Interlinked Data
  - PlanetData - A European Network of Excellence on Large-Scale Data Management