Linked Open Data Aggregation: Conflict Resolution and Aggregate Quality

Tomáš Knap, Jan Michelfeit, Martin Nečaský
{tomas.knap@mff.cuni.cz, jan.michelfeit@seznam.cz}
XML and Web Engineering Research Group (XRG)
Department of Software Engineering
Charles University, Prague, Czech Republic

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Outline

Linked Data Framework and Project ODCleanStore

Data Aggregation Algorithm

Computation of the Aggregate Quality

Experiments & Conclusion

Motivation

- Journalist: “Give me suppliers of public contracts for the Ministry of Finance from the region Prague with just one offer; for each public contract show me the list of payments, links to budget and the person responsible for that contract. Show me the results in the iPhone application”
- Questions:
  - Where to get the data (more sources)
  - How to get the data (different formats, retrieval methods)
  - How to merge and link the data together
  - How to show the data in the iPhone application
- To address the needs of (not just) the journalist: an OpenData.cz initiative with the goals to:
  - Open governmental data in Czech Republic
  - Clean and connect the data
  - Enable exploration of the data

Linked Data

Set of best practises for publishing structured data on the Web, Tim Berners-Lee presented four principles:

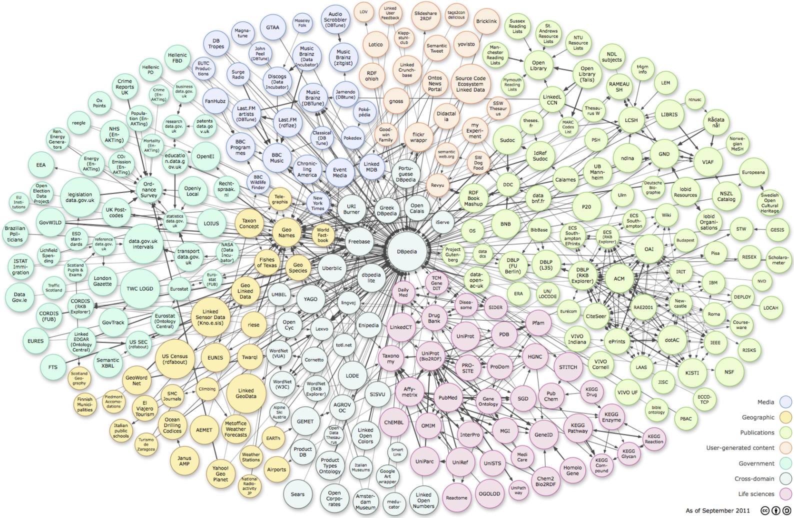
- Use URIs as names for things
- Use HTTP URIs so that people can look up those names.
- When someone looks up a URI, provide useful information, using the standards (RDF)
- Include links to other URIs. so that they can discover more things.

See: `http://www.w3.org/DesignIssues/LinkedData.html`

RDF

- Sample RDF statement (triple):
  - (http://dbpedia.org/resource/Izmir http://dbpedia.org/ontology/populationTotal ”3450889”)
  - (http://dbpedia.org/resource/Izmir http://www.w3.org/2002/07/owl#sameAs http://rdf.freebase.com/ns/en.izmir)
- RDF data are represented as typed statements – *triples* $(s, p, o) \in U^3$ – consisting of a *subject s*, a *predicate (property) p* and an *object (value) o*.
  - U = all possible nodes, URI resources or literals (optionally typed)
- A triple may be part of a *named graph* – a set of triples identified by an URI
  - Triples can be then extended to *quads* $(s, p, o, g) \in Q$ where $g \in G$ is the named graph (its URI) to which the data belongs.
- The RDF data model can be viewed as a directed graph where edges, labeled with a predicate, lead from a subject to an object.

Linked Data Cloud

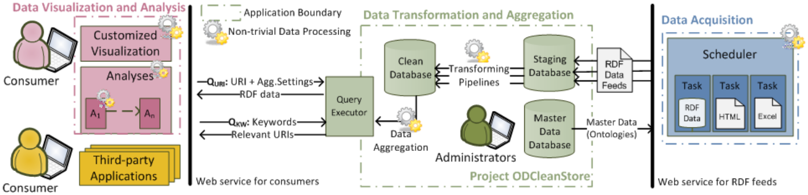


Obrázek: Linked Data Cloud, `http://linkeddata.org/`

Linked Data Framework

- Is built as part of OpenData.cz initiative and LOD2 project

- Data acquisition
- Data transformation and aggregation = ODCleanStore project
- Data visualization and analysis



Obrázek: Linked Data Framework

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Motivational Scenario

- Suppose we have in the clean database data about the city Izmir coming from multiple sources – DBpedia, GeoNames, and Freebase
  - `http://dbpedia.org/resource/Izmir`
  - `http://sws.geonames.org/311046/`
  - `http://rdf.freebase.com/ns/en.izmir`

  .
- Consumer would like to get data about the resource `http://dbpedia.org/resource/Izmir`
- Tasks:
  - Discover and follow `owl:sameAs` links between resources representing the same concepts
  - Discover that meaning of the predicates `geo:lat` and `fb:location.geocode.latitude` is the same
  - Compute average value for the values of the properties `geo:long` and `geo:lat`
  - Select the best value (with the highest aggregate quality) for `rdfs:label`
  - Select the maximum (latest) value from the values of the property `dbpedia:populationTotal`

Data Aggregation - Basics

- Schema mapping
  - Enabled by proper mappings between ontologies in the master data database
- Duplicate detection
  - Enabled by proper linker
- Data fusion
  - Instance level conflicts (data conflicts)

J. Bleiholder and F. Naumann. Data fusion. ACM Comput. Surv., 2009.

Data Fusion Algorithm - Inputs/Outputs

- Inputs:
  - A collection of quads from the clean database to be fused – e.g. the quads (x,*,*,*),(*,*,x,*), where *x* is the requested URI in a URI query
  - Data fusion settings (e.g. a selected conflict resolution policies – global or per property)
  - `owl:sameAs` links between URI resources occurring in the quads
    - result of deduplication and schema mapping
  - Quality scores for named graphs of the quads.
- Outputs:
  - Collection of aggregated triples enriched with the aggregate quality and source named graphs for each quad.

Phase 1 of Data Fusion Algorithm – an Overview

Step 1.1) Replace URIs of resources representing the same entity (i.e. connected by the `owl:sameAs` links) with a single URI. Prefer URI in the consumer's query.

Step 1.2) Remove duplicate quads.

Step 1.3) Group quads to sets of o-conflicting quads.

- Suppose $g_1, g_2 \in G$; quads (s, p, o_1, g_1) and (s, p, o_2, g_2) are called *o-conflicting quads* if $o_1 \neq o_2$

Phase 2 of Data Fusion Algorithm – an Overview

Step 2.1) Choose and apply a conflict resolution policy

Step 2.2) Compute aggregate quality for the conflict resolved quads

- Note: Phase 2 of the algorithm is applied to each set of *o-conflicting quads*

Conflict Resolution Policies

- Deciding - selects one or more values
  - ANY,MIN,MAX,SHORTEST,LONGEST – an arbitrary value, minimum, maximum, shortest, or longest is selected from the conflicting values V
  - BEST – the value with the highest aggregate quality is selected
  - LATEST – the value with the newest time is selected
- Mediating - computes new values
  - AVG, MEDIAN, CONCAT – computes the average, median, or concatenation of conflicting values
- Ignoring
  - ALL – ignores conflicts, fuses equal triples
  - NONE – ignores conflicts, no fusion

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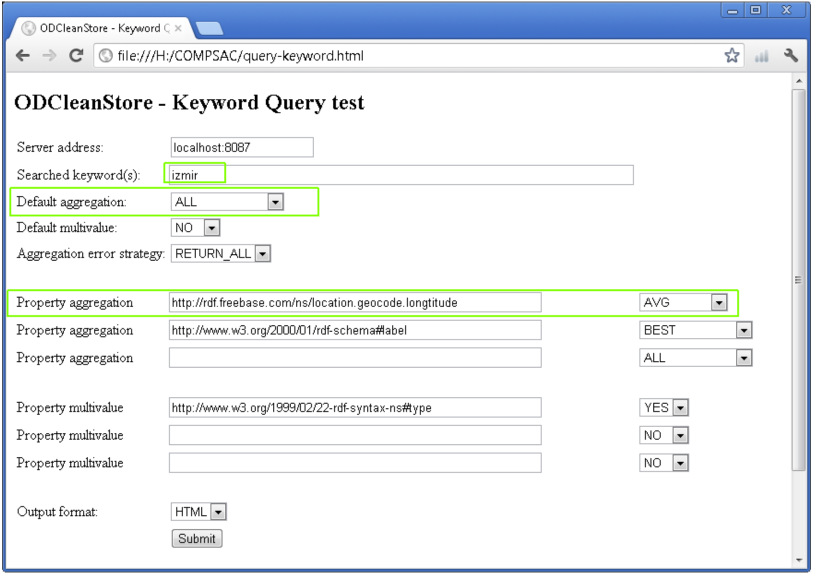
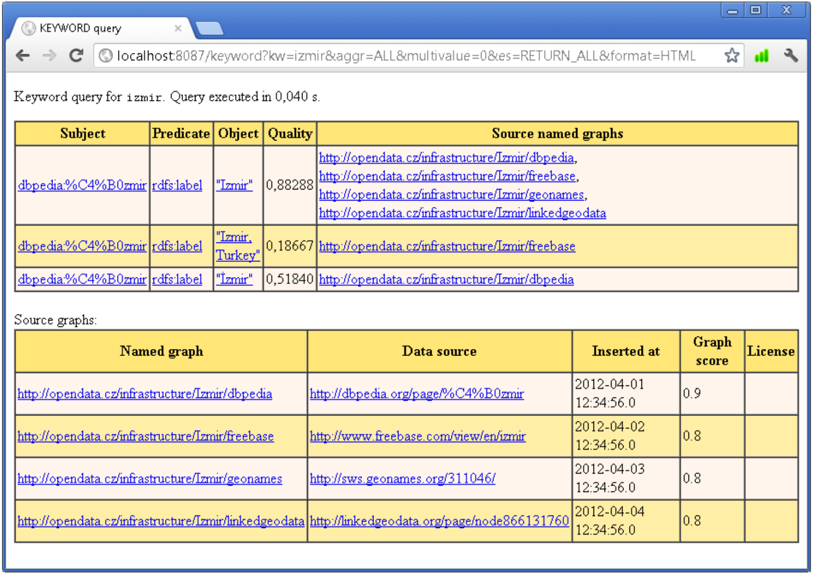
Computation of the Aggregate Quality - Overview

- Several factors based on real-world examples
- Let’s show it on Izmir!



ODCleanStore - Keyword Query test

Server address:	localhost:8087	
Searched keyword(s):	izmir	
Default aggregation:	ALL	
Default multivalue:	NO	
Aggregation error strategy:	RETURN_ALL	
Property aggregation	http://rdf.freebase.com/ns/location.geocode.longtitude	AVG
Property aggregation	http://www.w3.org/2000/01/rdf-schema#label	BEST
Property aggregation		ALL
Property multivalue	http://www.w3.org/1999/02/22-rdf-syntax-ns#type	YES
Property multivalue		NO
Property multivalue		NO
Output format:	HTML	


KEYWORD query
localhost:8087/keyword?kw=izmir&aggr=ALL&multivalue=0&es=RETURN_ALL&format=HTML

Keyword query for `izmir`. Query executed in 0,040 s.

Subject	Predicate	Object	Quality	Source named graphs
dbpedia:%C4%B0zmir	rdfs:label	"Izmir"	0,88288	http://opendata.cz/infrastructure/Izmir/dbpedia, http://opendata.cz/infrastructure/Izmir/freebase, http://opendata.cz/infrastructure/Izmir/geonames, http://opendata.cz/infrastructure/Izmir/linkedgeodata
dbpedia:%C4%B0zmir	rdfs:label	"Izmir, Turkey"	0,18667	http://opendata.cz/infrastructure/Izmir/freebase
dbpedia:%C4%B0zmir	rdfs:label	"İzmir"	0,51840	http://opendata.cz/infrastructure/Izmir/dbpedia

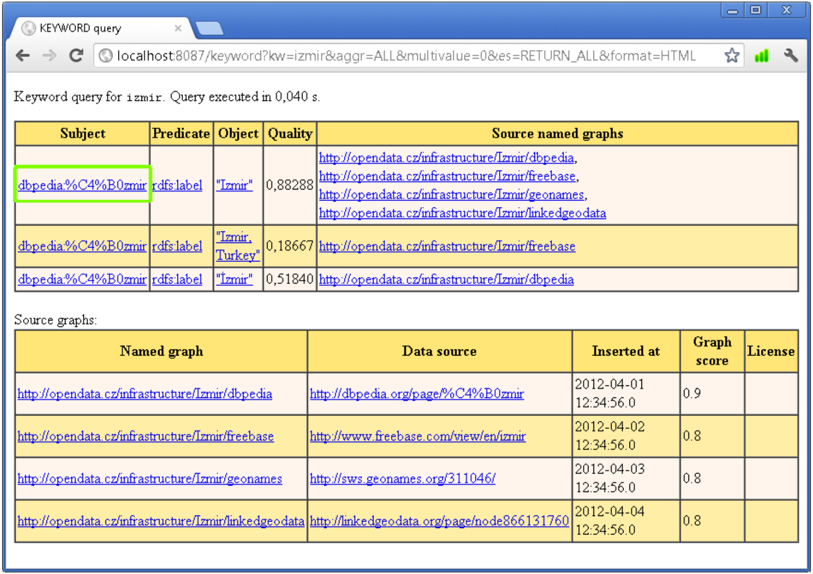
Source graphs:

Named graph	Data source	Inserted at	Graph score	License
http://opendata.cz/infrastructure/Izmir/dbpedia	http://dbpedia.org/page/%C4%B0zmir	2012-04-01 12:34:56.0	0.9	
http://opendata.cz/infrastructure/Izmir/freebase	http://www.freebase.com/view/en/izmir	2012-04-02 12:34:56.0	0.8	
http://opendata.cz/infrastructure/Izmir/geonames	http://sws.geonames.org/311046/	2012-04-03 12:34:56.0	0.8	
http://opendata.cz/infrastructure/Izmir/linkedgeodata	http://linkedgeodata.org/page/node866131760	2012-04-04 12:34:56.0	0.8	

First Quality Factor - Scores of Source Named Graphs

- A value $v \in A$ may
  - (a) be calculated from all the sources (in case of conflict resolution policies AVG, MEDIAN, CONCAT)
  - (b) come from named graphs containing a quad (s, p, v, g_i) (in case of other conflict resolution policies)

$$q_1(v) = \begin{cases} \mathrm{avg}\,\{s(g) \mid g \in \{g_1, \ldots, g_n\}\} & \text{(a)} \\ \max\,\{s(g) \mid g \in agree(v)\} & \text{(b)} \end{cases}$$

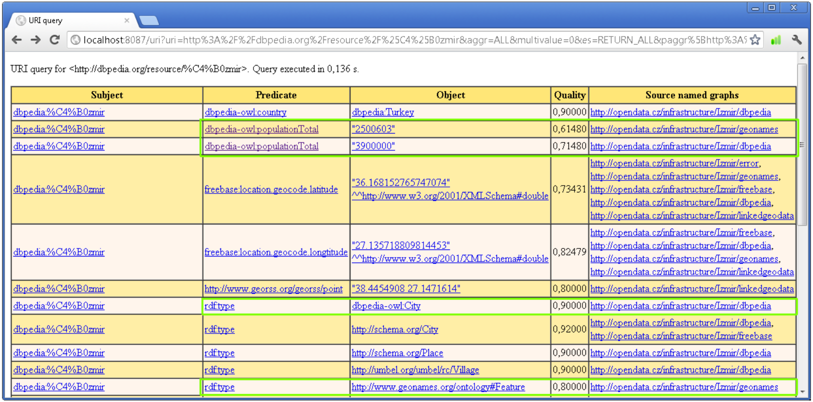

KEYWORD query
localhost:8087/keyword?kw=izmir&aggr=ALL&multivalue=0&es=RETURN_ALL&format=HTML

Keyword query for `izmir`. Query executed in 0,040 s.

Subject	Predicate	Object	Quality	Source named graphs
dbpedia:%C4%B0zmir	rdfs:label	"Izmir"	0,88288	http://opendata.cz/infrastructure/Izmir/dbpedia, http://opendata.cz/infrastructure/Izmir/freebase, http://opendata.cz/infrastructure/Izmir/geonames, http://opendata.cz/infrastructure/Izmir/linkedgeodata
dbpedia:%C4%B0zmir	rdfs:label	"Izmir, Turkey"	0,18667	http://opendata.cz/infrastructure/Izmir/freebase
dbpedia:%C4%B0zmir	rdfs:label	"İzmir"	0,51840	http://opendata.cz/infrastructure/Izmir/dbpedia

Source graphs:

Named graph	Data source	Inserted at	Graph score	License
http://opendata.cz/infrastructure/Izmir/dbpedia	http://dbpedia.org/page/%C4%B0zmir	2012-04-01 12:34:56.0	0.9	
http://opendata.cz/infrastructure/Izmir/freebase	http://www.freebase.com/view/en/izmir	2012-04-02 12:34:56.0	0.8	
http://opendata.cz/infrastructure/Izmir/geonames	http://sws.geonames.org/311046/	2012-04-03 12:34:56.0	0.8	
http://opendata.cz/infrastructure/Izmir/linkedgeodata	http://linkedgeodata.org/page/node866131760	2012-04-04 12:34:56.0	0.8	



localhost:8087/uri?uri=http%3A%2F%2Fdbpedia.org%2Fresource%2F%25C4%25B0zmir&aggr=ALL&multivalue=0&es=RETURN_ALL&paggr%5Bhttp%3A%

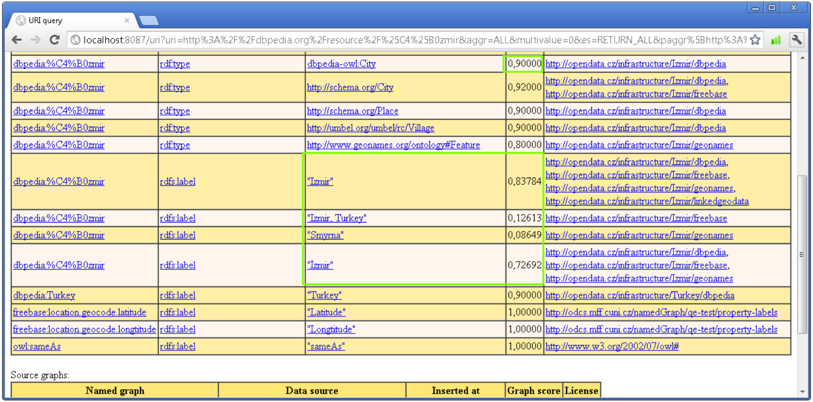
URI query for <http://dbpedia.org/resource/%C4%B0zmir>. Query executed in 0,136 s.

Subject	Predicate	Object	Quality	Source named graphs
dbpedia:%C4%B0zmir	dbpedia-owl:country	dbpedia:Turkey	0,90000	http://opendata.cz/infrastructure/Izmir/dbpedia
dbpedia:%C4%B0zmir	dbpedia-owl:populationTotal	"2500603"	0,61480	http://opendata.cz/infrastructure/Izmir/geonames
dbpedia:%C4%B0zmir	dbpedia-owl:populationTotal	"3900000"	0,71480	http://opendata.cz/infrastructure/Izmir/dbpedia
dbpedia:%C4%B0zmir	freebase:location.geocode.latitude	"36.168152765747074"^^http://www.w3.org/2001/XMLSchema#double	0,73431	http://opendata.cz/infrastructure/Izmir/error, http://opendata.cz/infrastructure/Izmir/geonames, http://opendata.cz/infrastructure/Izmir/freebase, http://opendata.cz/infrastructure/Izmir/dbpedia, http://opendata.cz/infrastructure/Izmir/linkedgeodata
dbpedia:%C4%B0zmir	freebase:location.geocode.longtitude	"27.135718809814453"^^http://www.w3.org/2001/XMLSchema#double	0,82479	http://opendata.cz/infrastructure/Izmir/freebase, http://opendata.cz/infrastructure/Izmir/dbpedia, http://opendata.cz/infrastructure/Izmir/geonames, http://opendata.cz/infrastructure/Izmir/linkedgeodata
dbpedia:%C4%B0zmir	http://www.georss.org/georss/point	"38.4454908 27.1471614"	0,80000	http://opendata.cz/infrastructure/Izmir/linkedgeodata
dbpedia:%C4%B0zmir	rdf:type	dbpedia-owl:City	0,90000	http://opendata.cz/infrastructure/Izmir/dbpedia
dbpedia:%C4%B0zmir	rdf:type	http://schema.org/City	0,92000	http://opendata.cz/infrastructure/Izmir/dbpedia, http://opendata.cz/infrastructure/Izmir/freebase
dbpedia:%C4%B0zmir	rdf:type	http://schema.org/Place	0,90000	http://opendata.cz/infrastructure/Izmir/dbpedia
dbpedia:%C4%B0zmir	rdf:type	http://umbel.org/umbel/rc/Village	0,90000	http://opendata.cz/infrastructure/Izmir/dbpedia
dbpedia:%C4%B0zmir	rdf:type	http://www.geonames.org/ontology#Feature	0,80000	http://opendata.cz/infrastructure/Izmir/geonames

Second Quality Factor - Differences between Conflicting Values

- We use a metric $d : U \times U \to [0, 1]$ for each type of values (numbers, strings, dates, ...).
- Different values reduce score increasingly with their distance and their scores (weighted average)).
- Can be turned off by the *multivalue* parameter.

$$q_2(v) = q_1(v) \cdot \left(1 - \frac{\sum_{i=1}^{n} s(g_i)d(v, v_i)}{\sum_{i=1}^{n} s(g_i)}\right)$$



localhost:8087/uri?uri=http%3A%2F%2Fdbpedia.org%2Fresource%2F%25C4%25B0zmir&aggr=ALL&multivalue=0&es=RETURN_ALL&paggr%5Bhttp%3A9

dbpedia:%C4%B0zmir	rdf:type	dbpedia-owl:City	0,90000	http://opendata.cz/infrastructure/Izmir/dbpedia
dbpedia:%C4%B0zmir	rdf:type	http://schema.org/City	0,92000	http://opendata.cz/infrastructure/Izmir/dbpedia, http://opendata.cz/infrastructure/Izmir/freebase
dbpedia:%C4%B0zmir	rdf:type	http://schema.org/Place	0,90000	http://opendata.cz/infrastructure/Izmir/dbpedia
dbpedia:%C4%B0zmir	rdf:type	http://umbel.org/umbel/rc/Village	0,90000	http://opendata.cz/infrastructure/Izmir/dbpedia
dbpedia:%C4%B0zmir	rdf:type	http://www.geonames.org/ontology#Feature	0,80000	http://opendata.cz/infrastructure/Izmir/geonames
dbpedia:%C4%B0zmir	rdfs:label	"Izmir"	0,83784	http://opendata.cz/infrastructure/Izmir/dbpedia, http://opendata.cz/infrastructure/Izmir/freebase, http://opendata.cz/infrastructure/Izmir/geonames, http://opendata.cz/infrastructure/Izmir/linkedgeodata
dbpedia:%C4%B0zmir	rdfs:label	"Izmir, Turkey"	0,12613	http://opendata.cz/infrastructure/Izmir/freebase
dbpedia:%C4%B0zmir	rdfs:label	"Smyrna"	0,08649	http://opendata.cz/infrastructure/Izmir/geonames
dbpedia:%C4%B0zmir	rdfs:label	"Izmir"	0,72692	http://opendata.cz/infrastructure/Izmir/dbpedia, http://opendata.cz/infrastructure/Izmir/freebase, http://opendata.cz/infrastructure/Izmir/geonames
dbpedia:Turkey	rdfs:label	"Turkey"	0,90000	http://opendata.cz/infrastructure/Turkey/dbpedia
freebase:location.geocode.latitude	rdfs:label	"Latitude"	1,00000	http://odcs.mff.cuni.cz/namedGraph/qe-test/property-labels
freebase:location.geocode.longtitude	rdfs:label	"Longtitude"	1,00000	http://odcs.mff.cuni.cz/namedGraph/qe-test/property-labels
owl:sameAs	rdfs:label	"sameAs"	1,00000	http://www.w3.org/2002/07/owl#

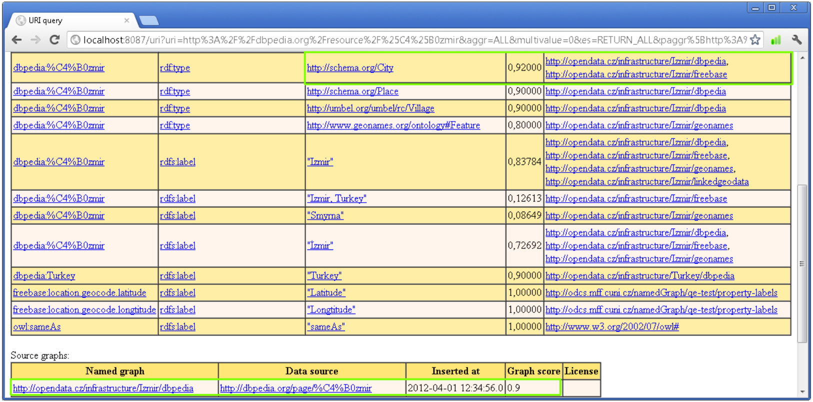
Source graphs:

Named graph	Data source	Inserted at	Graph score	License

Third Quality Factor - Confirmation by Multiple Sources

- Agreement on a single value by multiple sources increases its value.
- Weighted by scores of the sources.

$$q_3(v) = q_2(v) + \\ + (1 - q_2(v)) \cdot \min\left(\frac{-q_1(v) + \sum_{g \in agree(v)} s(g)}{C}, 1\right)$$



localhost:8087/uri?uri=http%3A%2F%2Fdbpedia.org%2Fresource%2F%25C4%25B0zmir&aggr=ALL&multivalue=0&es=RETURN_ALL&paggr%5Bhttp%3A9

dbpedia:%C4%B0zmir	rdf:type	http://schema.org/City	0,92000	http://opendata.cz/infrastructure/Izmir/dbpedia, http://opendata.cz/infrastructure/Izmir/freebase
dbpedia:%C4%B0zmir	rdf:type	http://schema.org/Place	0,90000	http://opendata.cz/infrastructure/Izmir/dbpedia
dbpedia:%C4%B0zmir	rdf:type	http://umbel.org/umbel/rc/Village	0,90000	http://opendata.cz/infrastructure/Izmir/dbpedia
dbpedia:%C4%B0zmir	rdf:type	http://www.geonames.org/ontology#Feature	0,80000	http://opendata.cz/infrastructure/Izmir/geonames
dbpedia:%C4%B0zmir	rdfs:label	"Izmir"	0,83784	http://opendata.cz/infrastructure/Izmir/dbpedia, http://opendata.cz/infrastructure/Izmir/freebase, http://opendata.cz/infrastructure/Izmir/geonames, http://opendata.cz/infrastructure/Izmir/linkedgeodata
dbpedia:%C4%B0zmir	rdfs:label	"Izmir, Turkey"	0,12613	http://opendata.cz/infrastructure/Izmir/freebase
dbpedia:%C4%B0zmir	rdfs:label	"Smyrna"	0,08649	http://opendata.cz/infrastructure/Izmir/geonames
dbpedia:%C4%B0zmir	rdfs:label	"İzmir"	0,72692	http://opendata.cz/infrastructure/Izmir/dbpedia, http://opendata.cz/infrastructure/Izmir/freebase, http://opendata.cz/infrastructure/Izmir/geonames
dbpedia:Turkey	rdfs:label	"Turkey"	0,90000	http://opendata.cz/infrastructure/Turkey/dbpedia
freebase:location.geocode.latitude	rdfs:label	"Latitude"	1,00000	http://odcs.mff.cuni.cz/namedGraph/qe-test/property-labels
freebase:location.geocode.longtitude	rdfs:label	"Longtitude"	1,00000	http://odcs.mff.cuni.cz/namedGraph/qe-test/property-labels
owl:sameAs	rdfs:label	"sameAs"	1,00000	http://www.w3.org/2002/07/owl#

Source graphs:

Named graph	Data source	Inserted at	Graph score	License
http://opendata.cz/infrastructure/Izmir/dbpedia	http://dbpedia.org/page/%C4%B0zmir	2012-04-01 12:34:56.0	0.9	

Computation of the Aggregate Quality - Summary

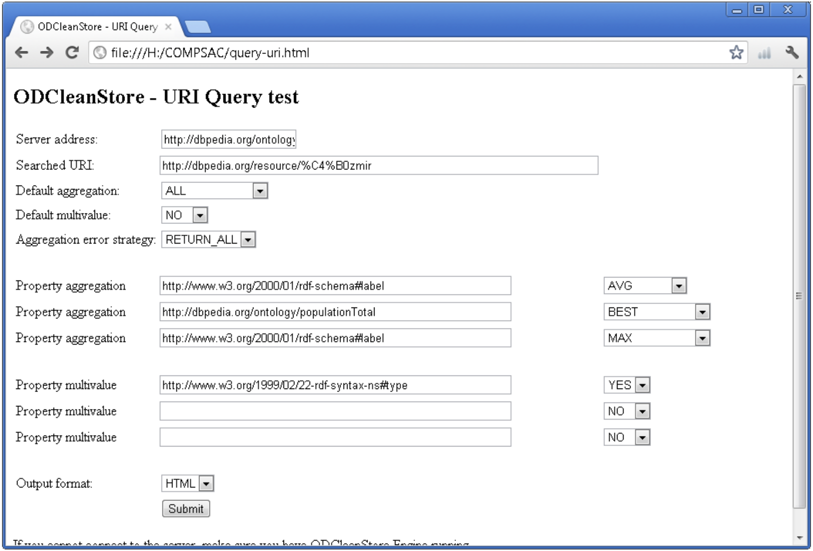
- The result $q(v) = q_3(v)$ is the aggregate quality.
- The second or the third step of the quality computation may be omitted when its use doesn’t make sense (e.g. CONCAT).

The quality satisfies the following constraints:

- If there is a named graph g asserting a non-conflicting value v, the aggregate quality (based just on the value v) should be at least $s(g)$.
- $q(v)$ is increasing with quality scores of source named graphs v was selected from or calculated from.
- $q(v)$ is decreasing with difference of other values $v_i \in V$, taking their quality scores $s(g_i)$ into consideration.
- If multiple sources agree on the same value, the aggregate quality is increased.

Other Interesting Features of the Data Aggregation Algorithm

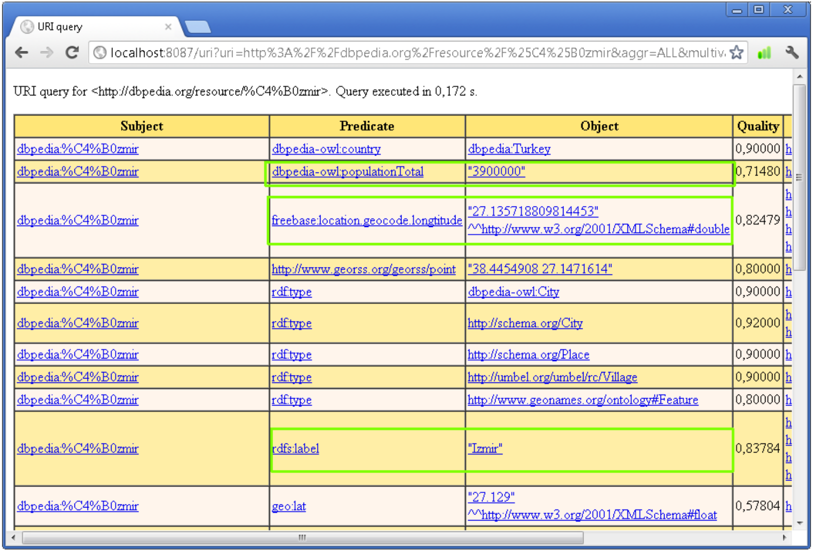
- Automatic translation of URIs:
  - `http://dbpedia.org/resource/Izmir` vs. `http://rdf.freebase.com/ns/en.izmir`
  - `http://www.w3.org/2003/01/geo/wgs84_pos#long` vs. `http://rdf.freebase.com/ns/location.geocode.longtitude`
  - preference given implicitly
- Various aggregation methods - BEST, AVG, conflict tolerating ALL
  - again URI translation



ODCleanStore - URI Query test

Server address:	http://dbpedia.org/ontology	
Searched URI:	http://dbpedia.org/resource/%C4%B0zmir	
Default aggregation:	ALL	
Default multivalue:	NO	
Aggregation error strategy:	RETURN_ALL	
Property aggregation	http://www.w3.org/2000/01/rdf-schema#label	AVG
Property aggregation	http://dbpedia.org/ontology/populationTotal	BEST
Property aggregation	http://www.w3.org/2000/01/rdf-schema#label	MAX
Property multivalue	http://www.w3.org/1999/02/22-rdf-syntax-ns#type	YES
Property multivalue		NO
Property multivalue		NO
Output format:	HTML	

If you cannot connect to the server, make sure you have ODCleanStore Engine running



URI query
localhost:8087/uri?uri=http%3A%2F%2Fdbpedia.org%2Fresource%2F%25C4%25B0zmir&aggr=ALL&multiv

URI query for <http://dbpedia.org/resource/%C4%B0zmir>. Query executed in 0,172 s.

Subject	Predicate	Object	Quality	
dbpedia:%C4%B0zmir	dbpedia-owl:country	dbpedia:Turkey	0,90000	h
dbpedia:%C4%B0zmir	dbpedia-owl:populationTotal	"3900000"	0,71480	h
dbpedia:%C4%B0zmir	freebase:location.geocode.longtitude	"27.135718809814453"^^http://www.w3.org/2001/XMLSchema#double	0,82479	h h h h
dbpedia:%C4%B0zmir	http://www.georss.org/georss/point	"38.4454908 27.1471614"	0,80000	h
dbpedia:%C4%B0zmir	rdf:type	dbpedia-owl:City	0,90000	h
dbpedia:%C4%B0zmir	rdf:type	http://schema.org/City	0,92000	h h
dbpedia:%C4%B0zmir	rdf:type	http://schema.org/Place	0,90000	h
dbpedia:%C4%B0zmir	rdf:type	http://umbel.org/umbel/rc/Village	0,90000	h
dbpedia:%C4%B0zmir	rdf:type	http://www.geonames.org/ontology#Feature	0,80000	h
dbpedia:%C4%B0zmir	rdfs:label	"Izmir"	0,83784	h h h h
dbpedia:%C4%B0zmir	geo:lat	"27.129"^^http://www.w3.org/2001/XMLSchema#float	0,57804	h

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Data Aggregation Algorithm

Computation of the Aggregate Quality

Experiments & Conclusion

Experiments

- Data fusion execution times for various conflict resolution policies

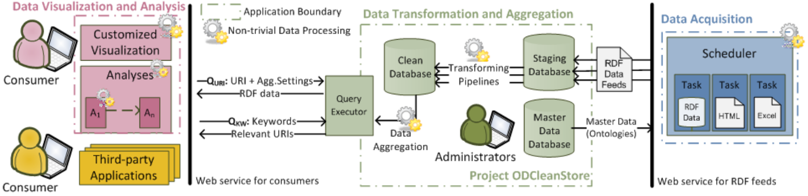
Tabulka: DBpedia evaluation – Execution times

Triples	Conflict resolution	Multivalue	Time
100,000	ALL	no	1.75 s
100,000	ANY	no	1.02 s
100,000	ALL	yes	1.01 s
100,000	CONCAT	yes	0.96 s
100,000	ANY	yes	0.83 s

- Plus time for RDF store query
- Current prototype queries under 0.5 s even on larger dataset

Conclusions

- Linked Data Framework
  - Data Aggregation - Data Fusion



Obrázek: Linked Data Framework

Thank You!