Integration of Geological Data as a Knowledge Graph

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Problem statement

Integration the collected geological data so they can be

- easily accessed
- of a standardized representation
- integrated with the data sources of the similar structure (access way and data representation paradigm)
- thus, reuse the existing data sources for the domain modeling
- processed within Big Data paradigm
- represented as cartographical work (map) dynamically with/without need of GIS software installation

The requested requirements are fulfilled with the present Semantic Web technologies.

Semantic web technologies & Knowledge graphs

Semantic Web (WEB 3.0) is characterized with

- Technological basis, oriented to the web
- Standardized data formats, storage, and processing
- Open principles of data publishing
- Services for data storage and access provision
- Generalized and special user interfaces are used for data presentation

For the Knowledge Graphs (KG), the following is of interest.

- Converged notions **data** and **knowledge** as something is **known**
- Contain data, relations, and metadata (vocabularies)
- Distinguished **node filling in** and **processing** graph triples, *e.g.*, withing SPARQL queries with UPDATEs
- Allow **postpone** the formal definition of a schema
- Three types of graph schemata: **semantic** (aimed at generalization), **validating** (**e.g.** semantics, **completeness** w.r.t. sets of relations), and **emergent** (infer a set of generalized structures and re-represent the KG).

Knowledge graph: Validating semantic example

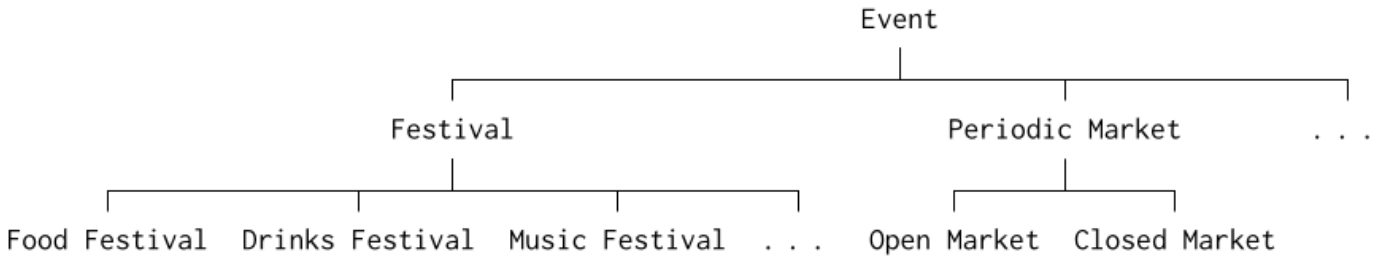


Fig. 10. Example class hierarchy for Event

Table 2. Definitions for sub-class, sub-property, domain and range features in semantic schemata

Feature	Definition	Condition	Example
SUBCLASS	(c) –subc. of→ (d)	(x) –type→ (c) implies (x) –type→ (d)	(City) –subc. of→ (Place)
SUBPROPERTY	(p) –subp. of→ (q)	(x) –p→ (y) implies (x) –q→ (y)	(venue) –subp. of→ (location)
DOMAIN	(p) –domain→ (c)	(x) –p→ (y) implies (x) –type→ (c)	(venue) –domain→ (Event)
RANGE	(p) –range→ (c)	(x) –p→ (y) implies (y) –type→ (c)	(venue) –range→ (Venue)

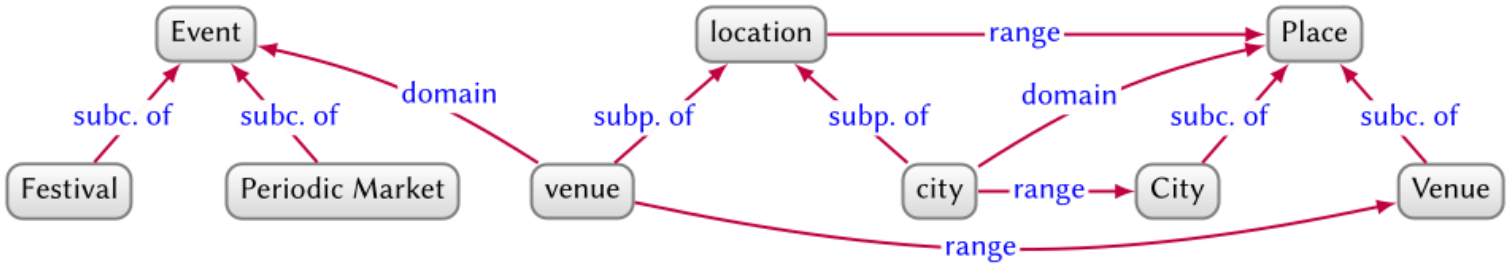


Fig. 11. Example schema graph describing sub-classes, sub-properties, domains, and ranges

Linked Open Data (LOD) star evaluation

Data are available in

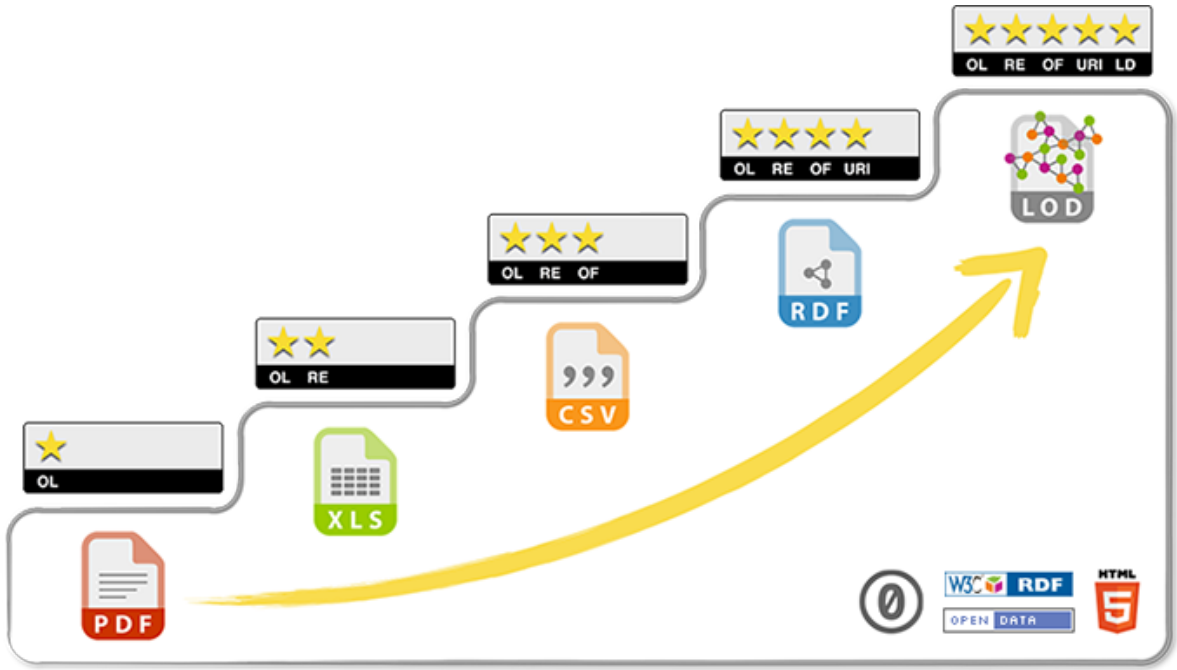
1* any format **openly**

2* a **structured format**, such as Microsoft Excel file format (.xls)

3* a **non-proprietary structured format**, such as .csv

4* **W3C standards**, like using RDF and employing URIs

5* a hypercontent form **having links to other Linked Open Data sources**



The Aim and the plan

The **aim of the project** is to represent geological data accumulated at IEC SB RAS and other institutes into the Semantic Web infrastructure.
The **main problems** to be solved are

1. Design a web-based GIS system, representing data from SPARQL endpoints
2. Convert the existing data into RDF adhering LOD
3. Implement natural language query interface using GeoBase (© Borland) with a conversion into a SPARQL query
4. Bidirectional versioned data transfer between user GIS (QGIS, OSM Mapnik) and the SW storage
5. Implement various analytical functionality for domain problem solving

Related works: **LinkedGeoData** project

The project [?] was to represent OpenSteetMap (OSM) data as a KG,

- Resembles the DBPedia project formalizing Wikipedia data but over the OSM database
- Converts SM data into RDF adhering LOD
- Designed an ontology for object georeferencing (nodes)
- Related the object to DBpedia, GeoNames, icon sets
- Developed a taxonomy of the objects on a various levels (Road $\longrightarrow$ Way (list of nodes))
- Stated the relations between nodes and ways defining complex objects
- Implemented REST and SPARQL (does not work now) endpoints for actual data
- Had a live updates services from OSM changesets.

Related works: LinkedGeoData project

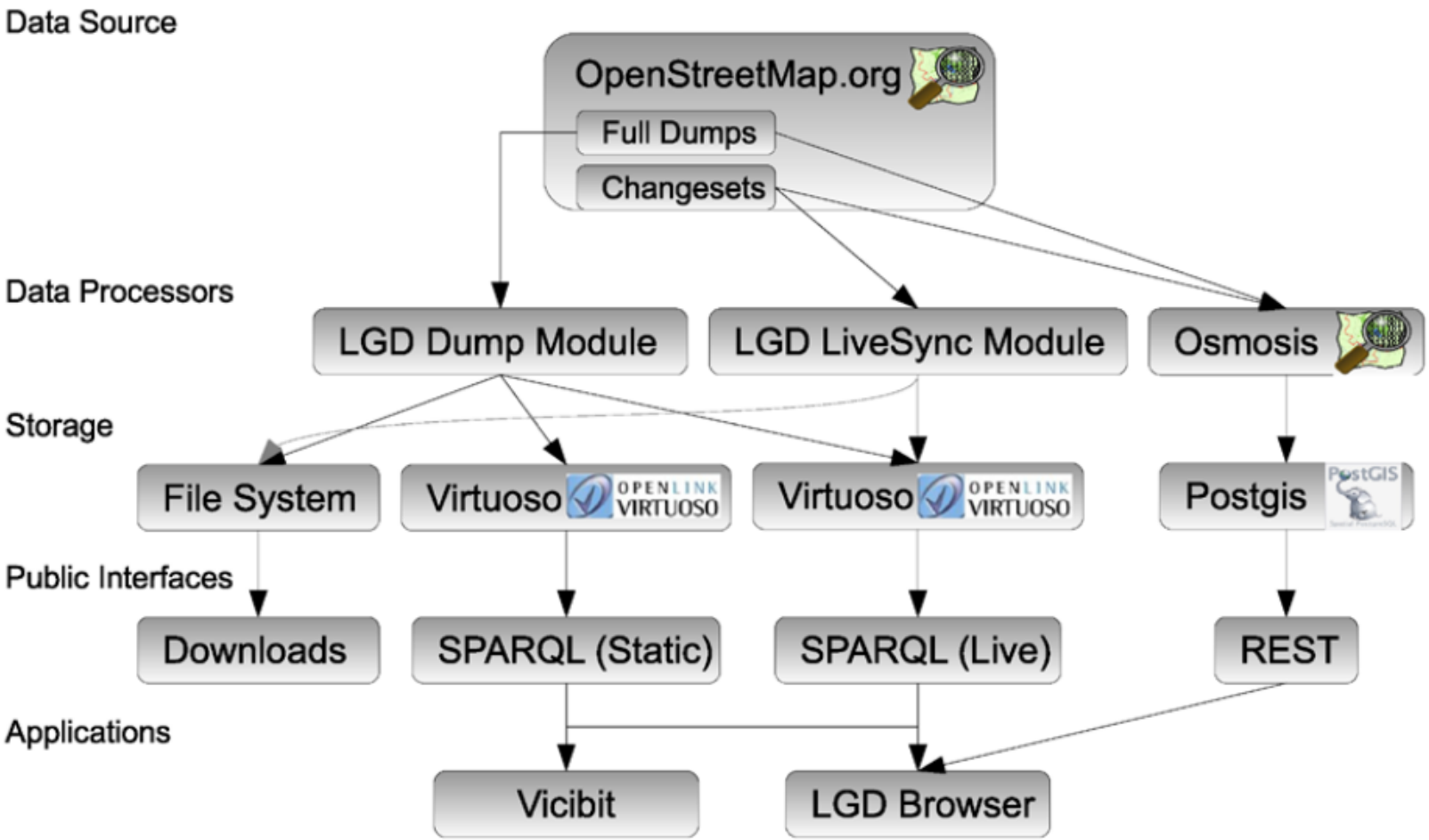


Fig. 2. Overview of LinkedGeoData's architecture.

Related works: LinkedGeoData project

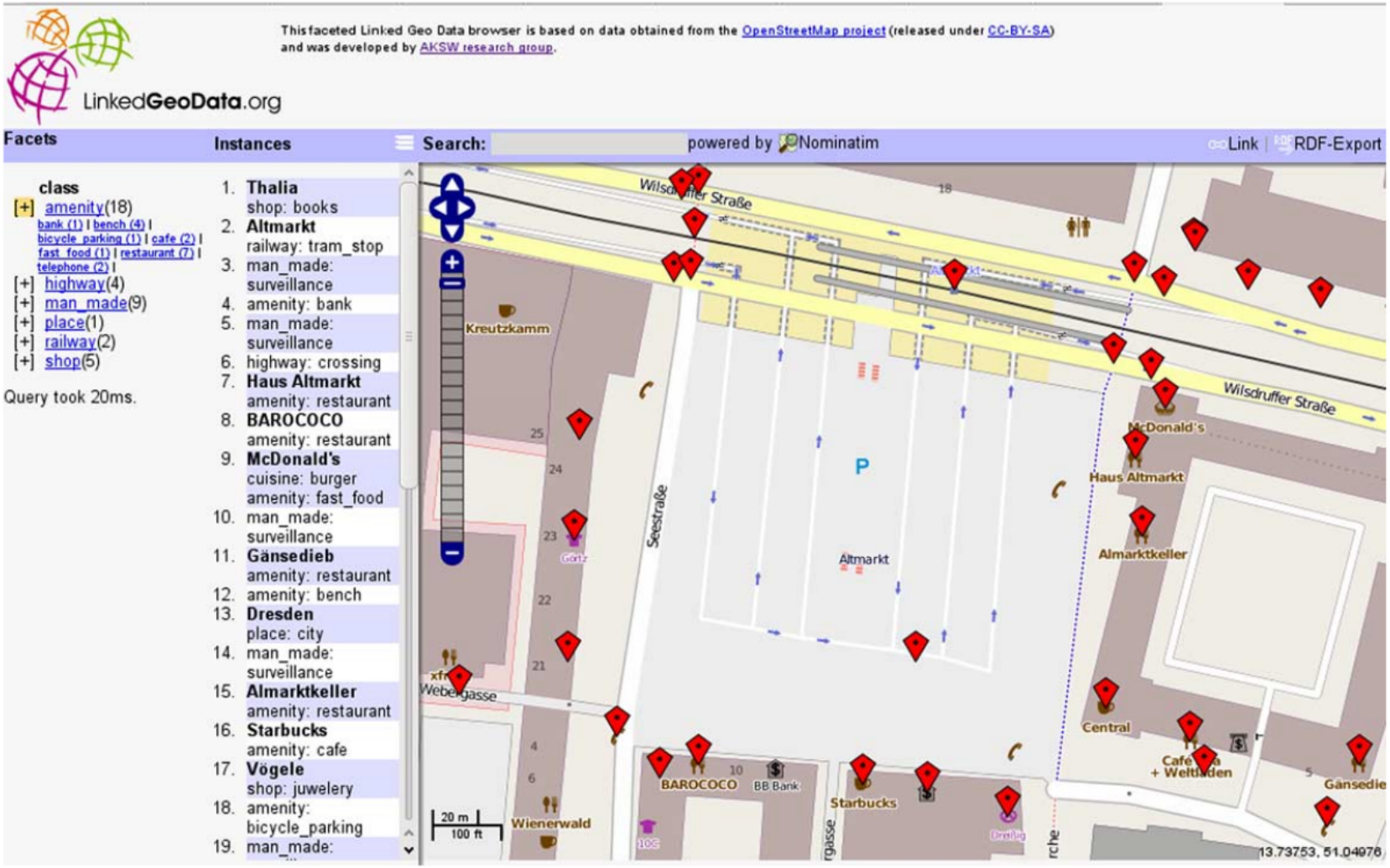


Fig. 6. LinkedGeoData Browser.

Related Works: GeoLink Knowledge graph

GeolLink KG [?]

- Includes diverse information as port calls made by oceanographic cruises, physical sample metadata, research project funding and staffing, and authorship of technical reports
- Implements LOD (4 of 5 stars) and federated SPARQL integration
- Contains 45 millions RDF triples with ontologies and geo-visualization tools
- Describes interlinked **R2R**, expeditions, **BCO-DMO**, oceanography, **IODP**, ocean floor microbiome, **MBLWHOI**, marine life papers, **SESAR**, rock samples, **DataONE**, metadata of external research, **AGU-NSF**, projects & conferences, **NGDB**, sediment geochemy, **USAP**, Antarctica ice.

In the project, an update procedure (harvesting) is implemented to ensure the consistence of the KG w.r.t. the geo-base ontology (GBO).

Related Works: GeoLink Knowledge graph

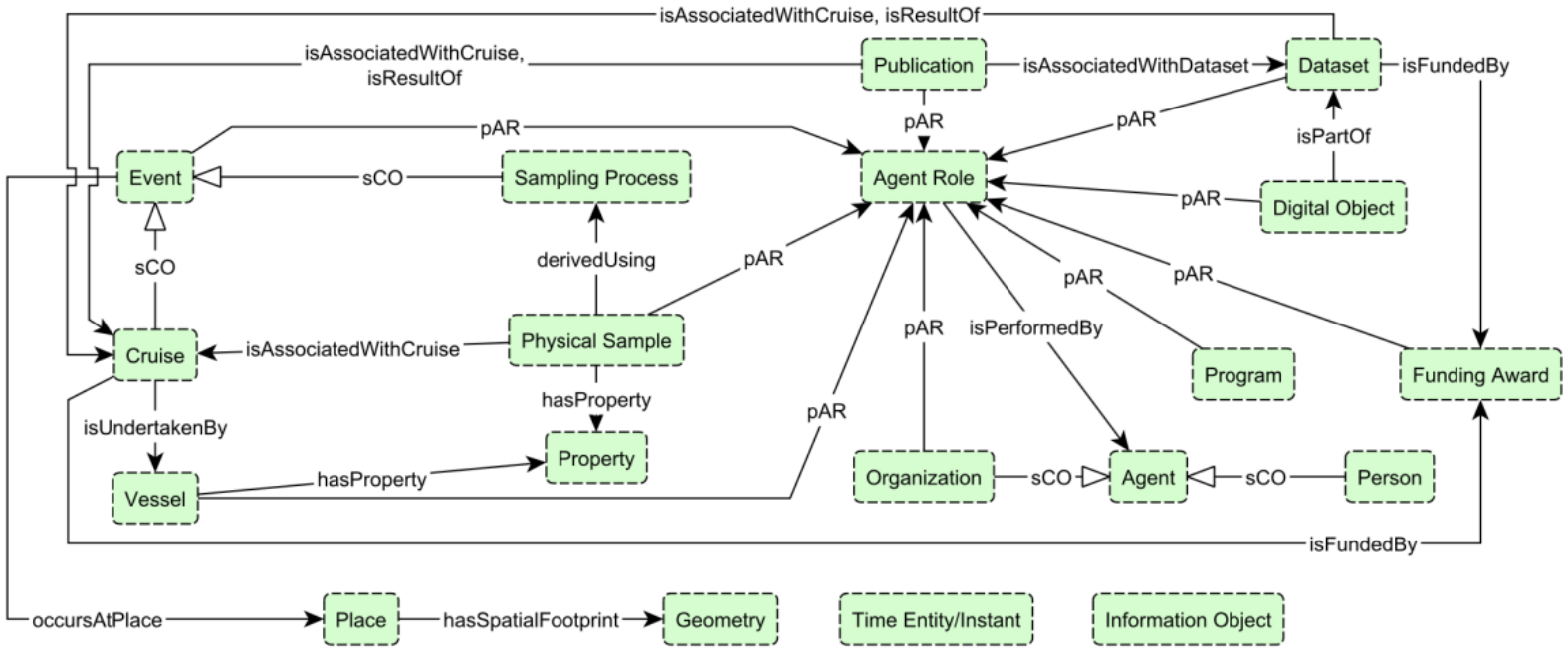


Figure 1. Schema diagram containing (almost) all patterns in the GeoLink ontology and their main links. All patterns have links to Time Entity/Instant and Information Object, but they have been omitted for clarity. sCO=subClassOf; pAR=providesAgentRole; each box is a pattern, represented by its main class.

The GeoLink knowledge graph is deployed at `http://data.geolink.org`.

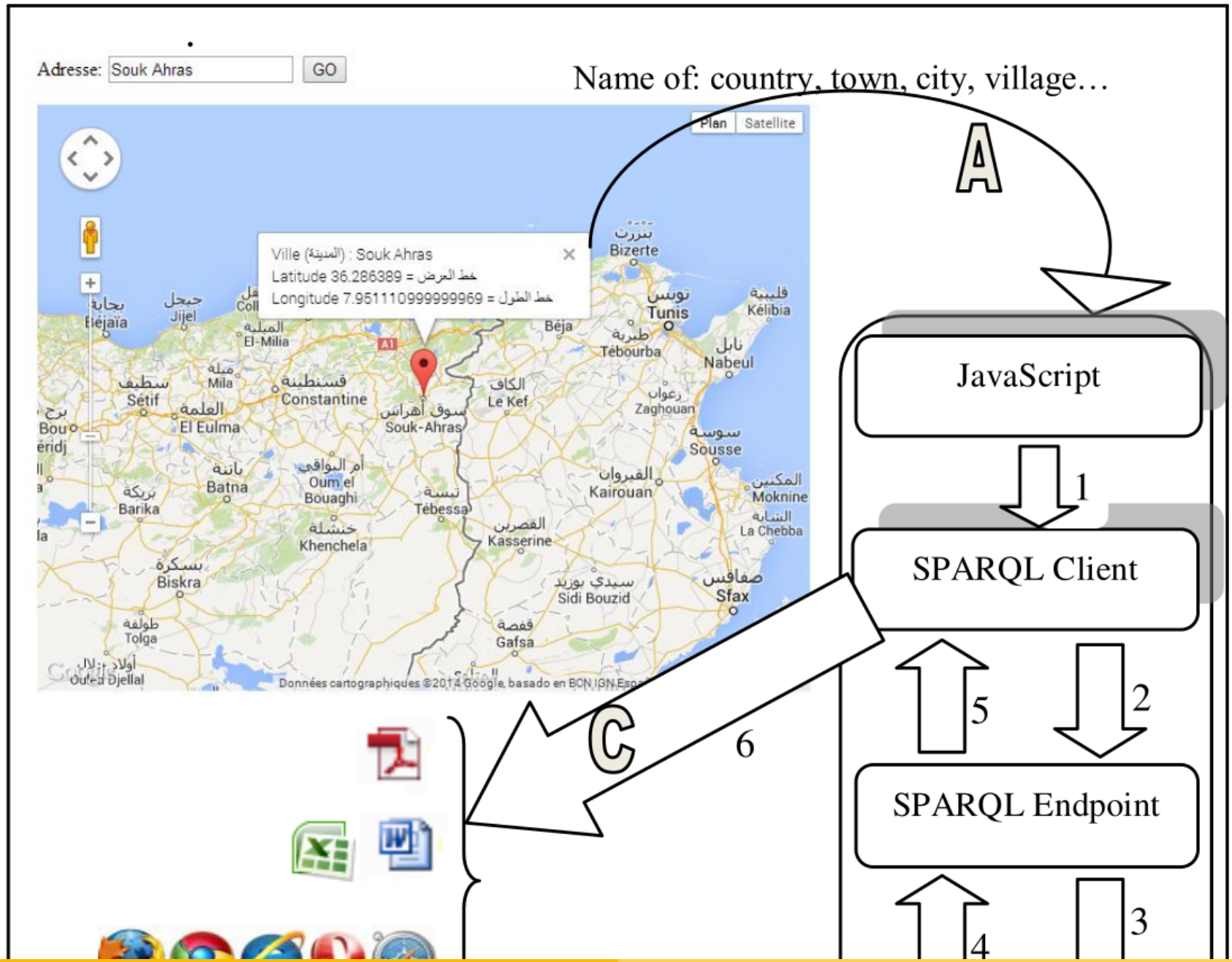
Related Works: Integrating LOD into GIS

The project[1] deals with developing a web GIS automatically publishing DBPedia data.

- LOD resembles Open Government Data principles
- Modules are
  - GIS is Google Map API v3
  - SPARQL used to query DBPedia
  - Viewing DBPedia data with Data Table plug-in of JQuery
- Test application allows user querying celebrities by their home town/city pointed by mouse on the Google Map.

[1] Tarek Abid, Hafed Zarzour. Integrating Linked Open Data in Geographical Information System. International Conference on Information Technology for Organization Development. 2014.

Related Works: Integrating LOD into GIS



Related Works: Integrating LOD into GIS

```
PREFIX dbo: http://dbpedia.org/ontology/
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX foaf: <http://xmlns.com/foaf/0.1/>
PREFIX : http://dbpedia.org/resource/
SELECT ?name  ?birth  ?death  ?person
WHERE {
?person dbo: birthPlace :Souk Ahras .
?person dbo:birthDate ?birth .
?person foaf:name ?name .
?person dbo:deathDate ?death .
}
ORDER BY ?name
```

Related Works: Publishing Geodata LOD in context dependent pages

The project[2] goal is to convert existing GIS data into explicit knowledge, thus, forming a Spatial Data Infrastructure (SDI).

- Integrate existing geoportal data into a KB, including dynamic data
- Geoportal data must be LOD, *e.g.*, HTML is enriched with RDFa
- Relation interpreters implemented as Expert systems ("building near forest")
- Semantic enrichment of raw data to make it more usable/discoverable
- Targeting to GeoSPARQL (sfIntersects, sfOverlaps, sfTouches, sfWithin, sfContains))
- Metadata inference from the data source properties
- Test application is to integrate public services data in Mazowieckie Voivodeship of Poland, queries are realized by a limited set of keywords

[2] Adam Iwaniak, Marta Leszczuk, Marek Strzelecki, Francis Harvey, Iwona Kaczmarek. A Novel Approach for Publishing Linked Open Geodata from National Registries with the Use of Semantically Annotated Context Dependent Web Pages. International Journal of Geo-Information. 6, 252, 2017. doi:10.3390/ijgi6080252

Publishing Geodata LOD in context dependent pages

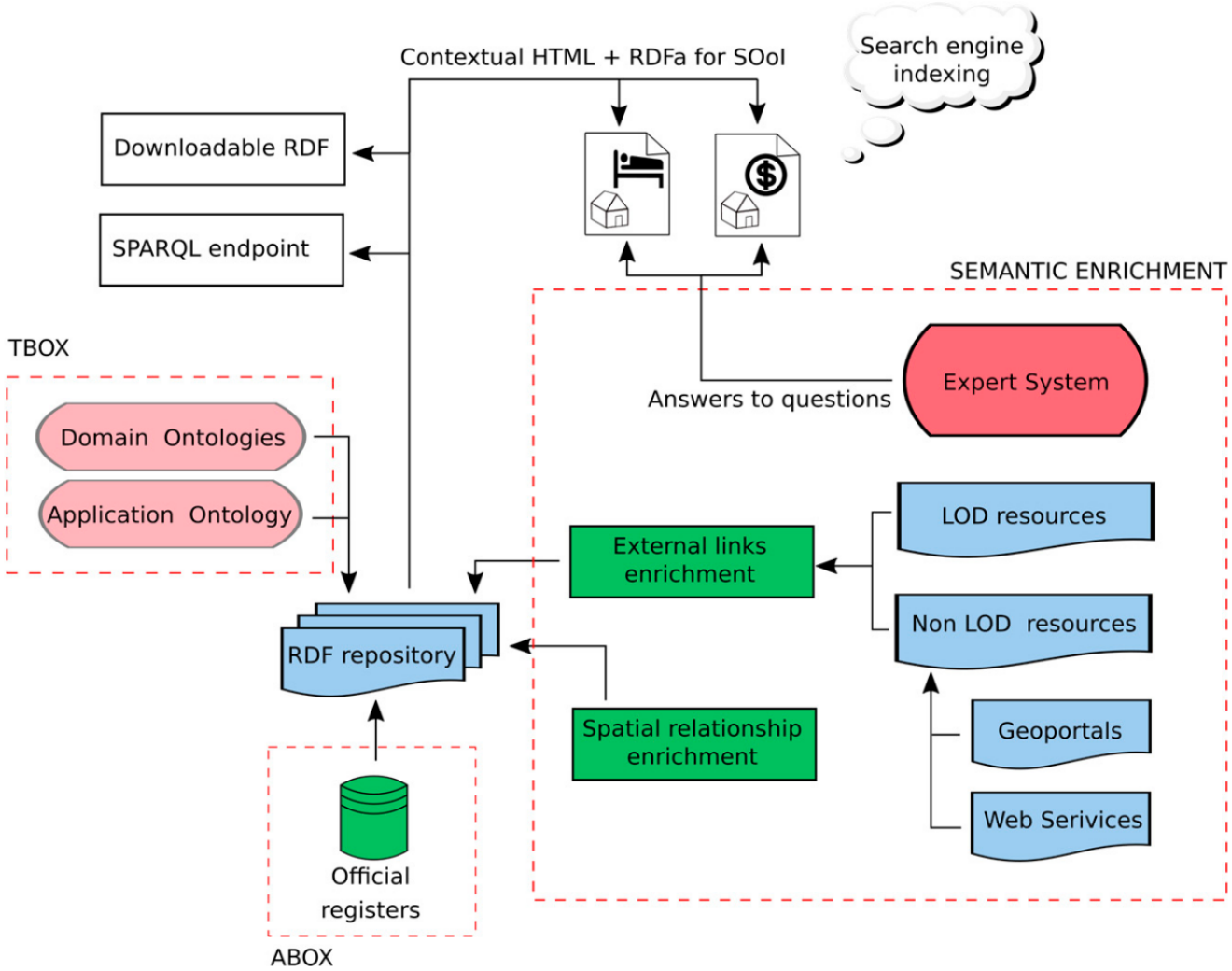


Figure 1. Concept of system architecture.

Enriching and improving the quality of linked data with GIS

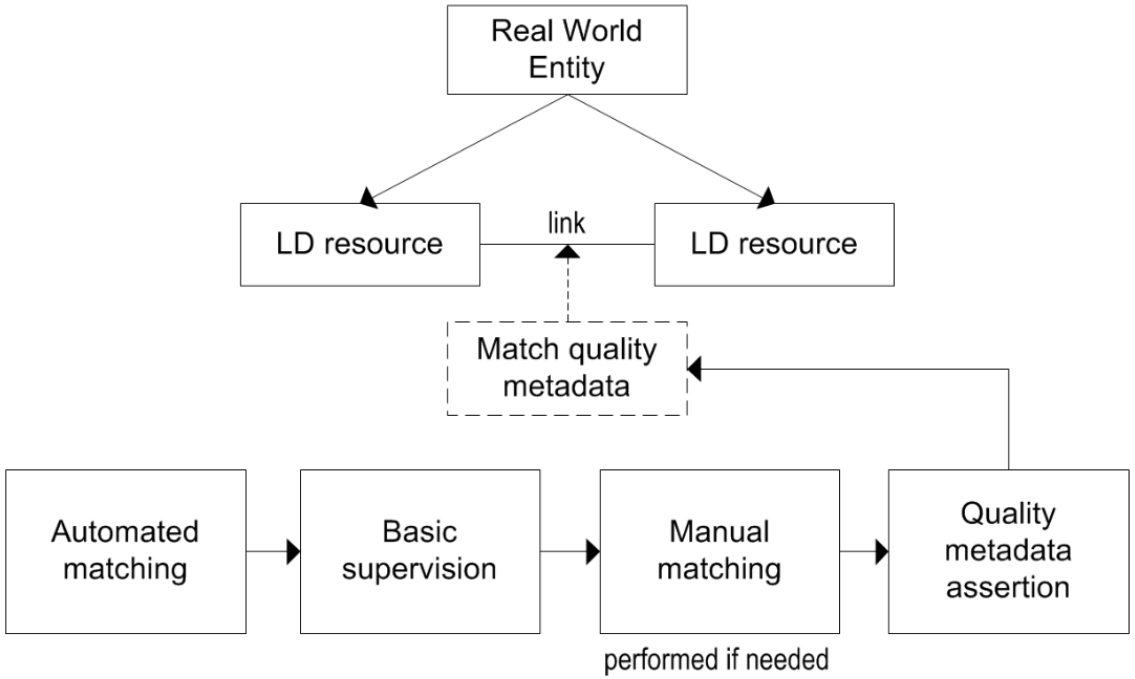


Figure 9: Basic supervision of linked data resources location quality with the use of Desktop GIS map visualization.

From an early work[3].

[3] Adam Iwaniak, Iwona Kaczmarek, Marek Strzelecki, Jaromar Lukowicz, Piotr Jankowski. Enriching and improving the quality of linked data with GIS. doi:10.1515/geo-2016-0020

Publishing Geodata LOD in context dependent pages

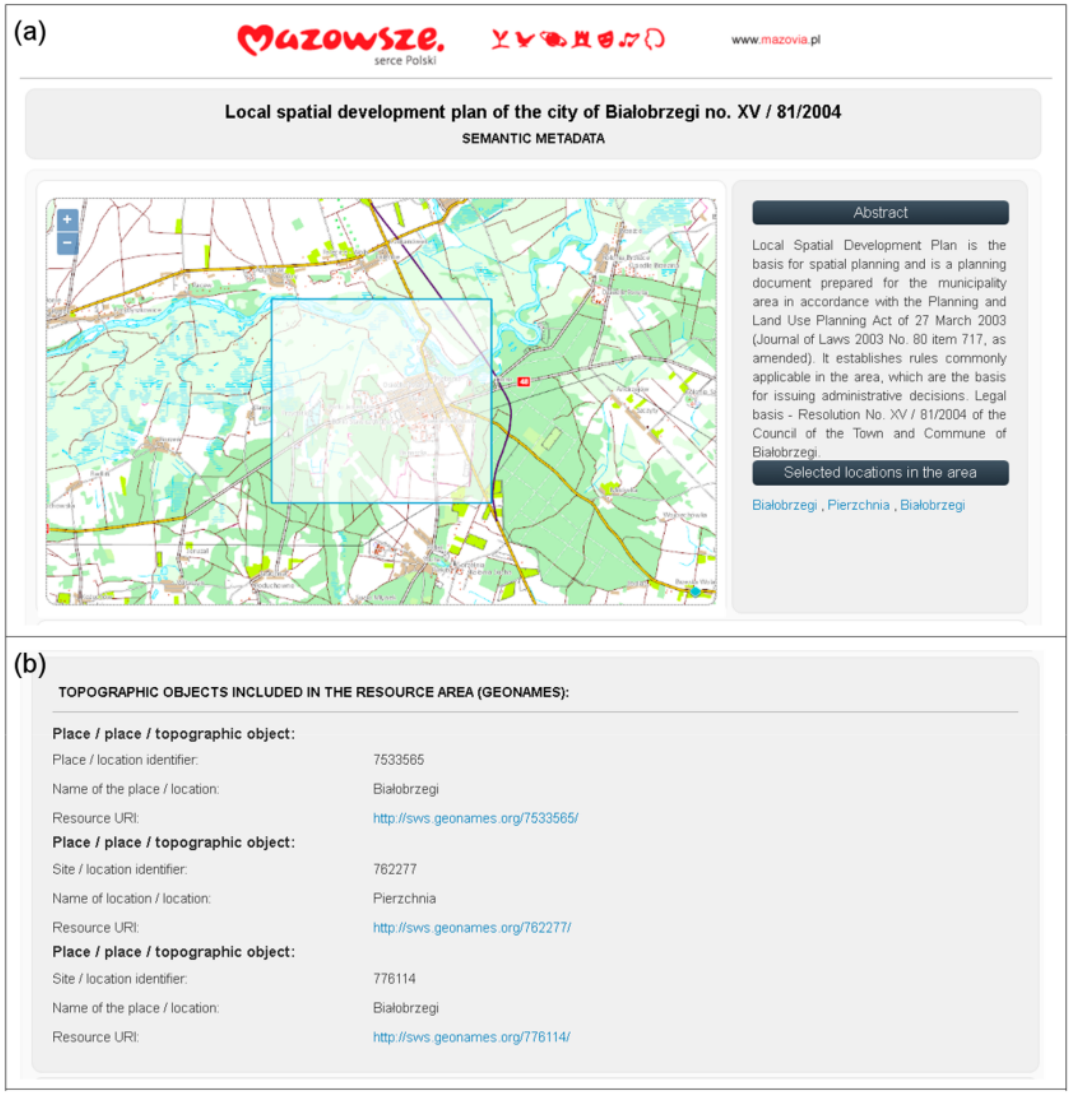
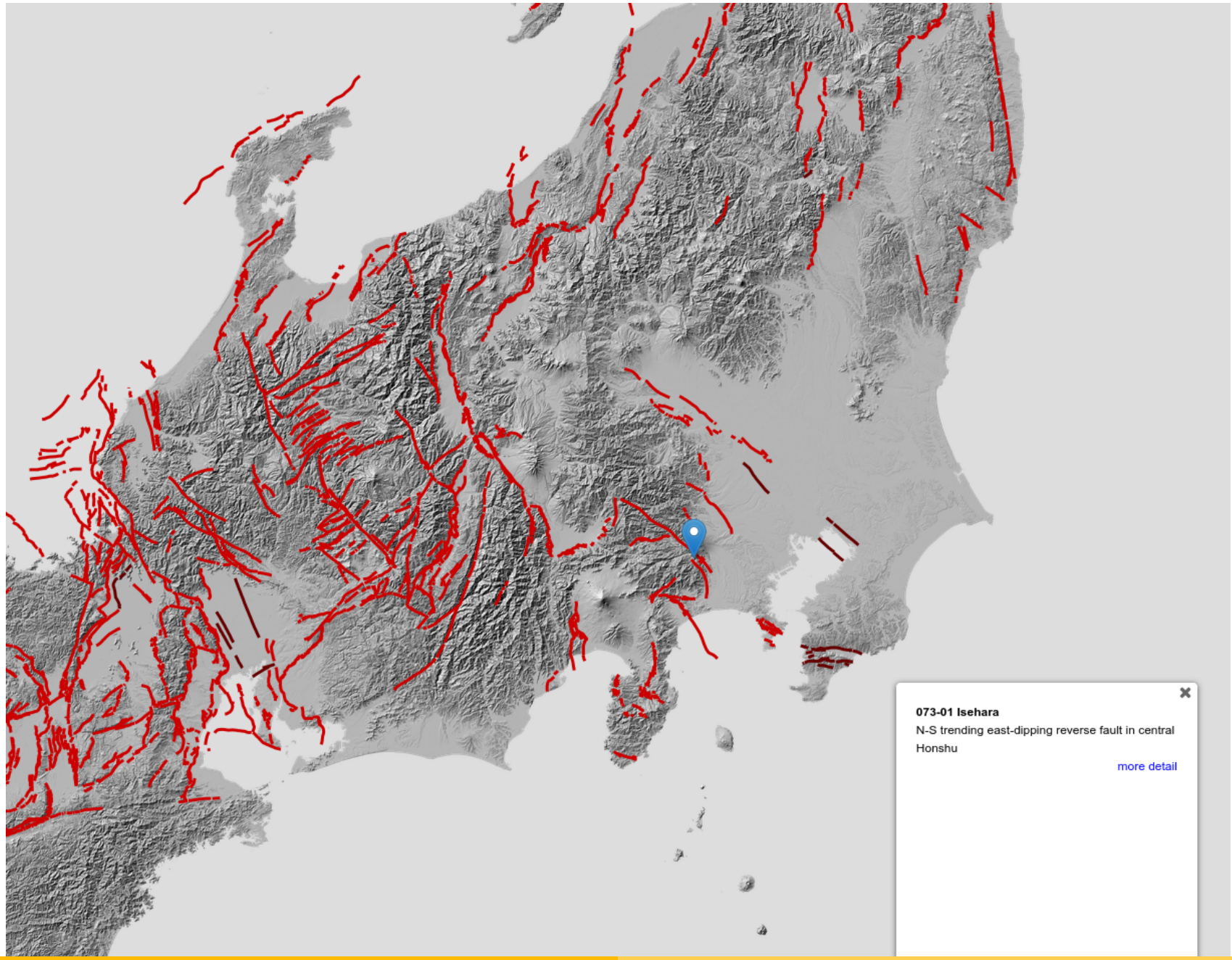


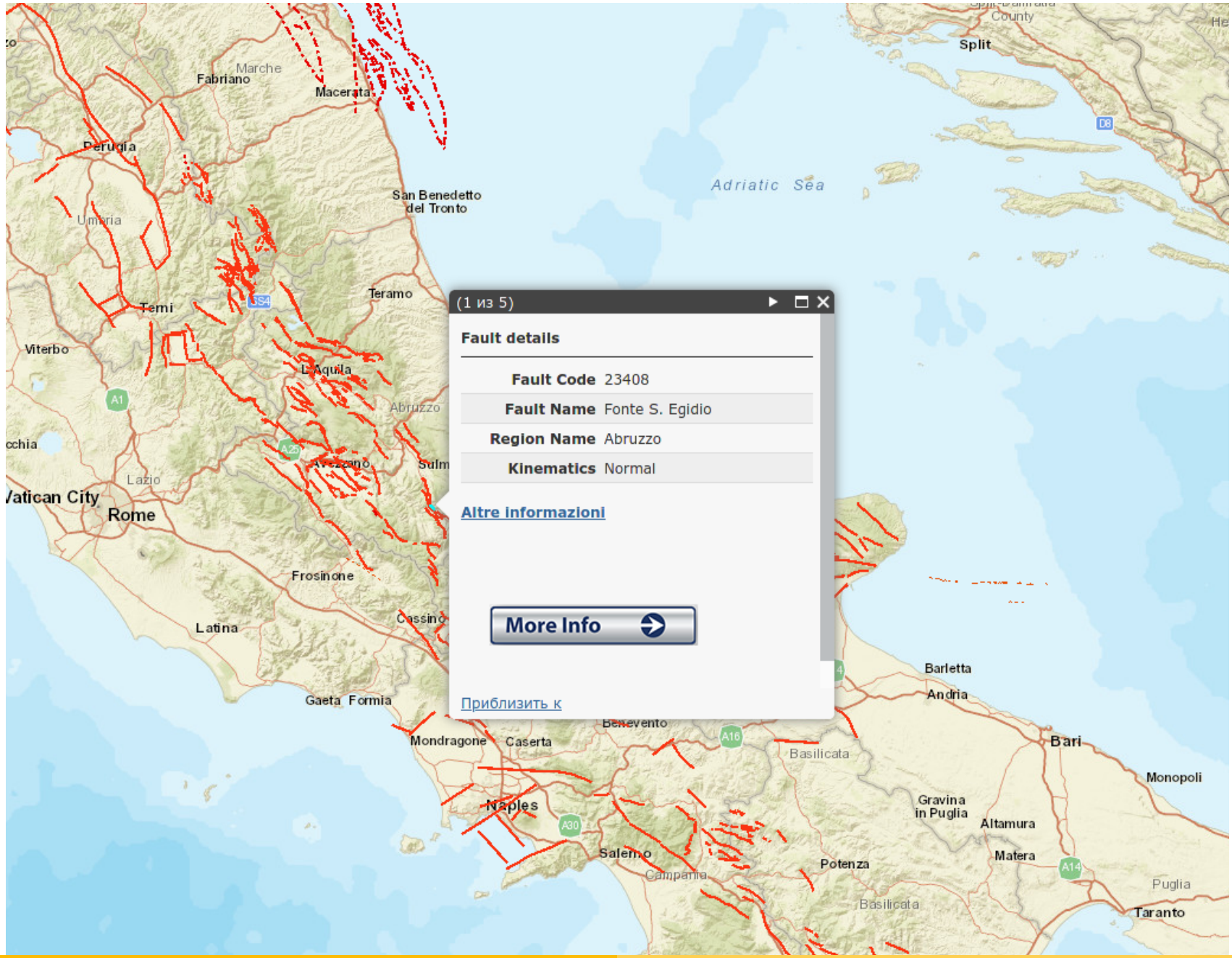
Figure 6. Fragments of HTML document, containing metadata for local spatial development plan: (**a**) title, basic information and bounding box of data; (**b**) links to Geonames features, included in the resource area.

Related Works: Publishing Geodata LOD in context dependent pages

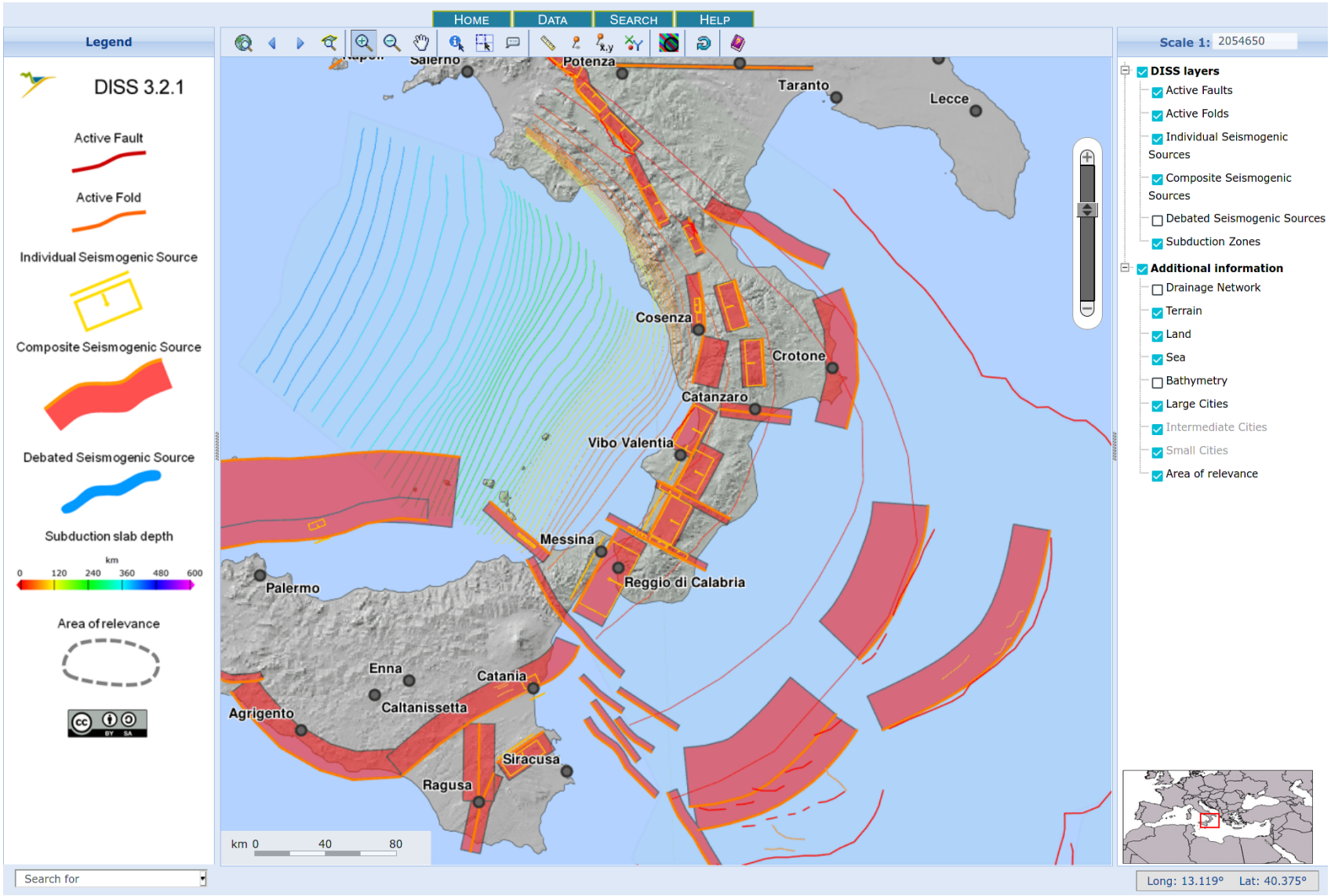
Existing resources



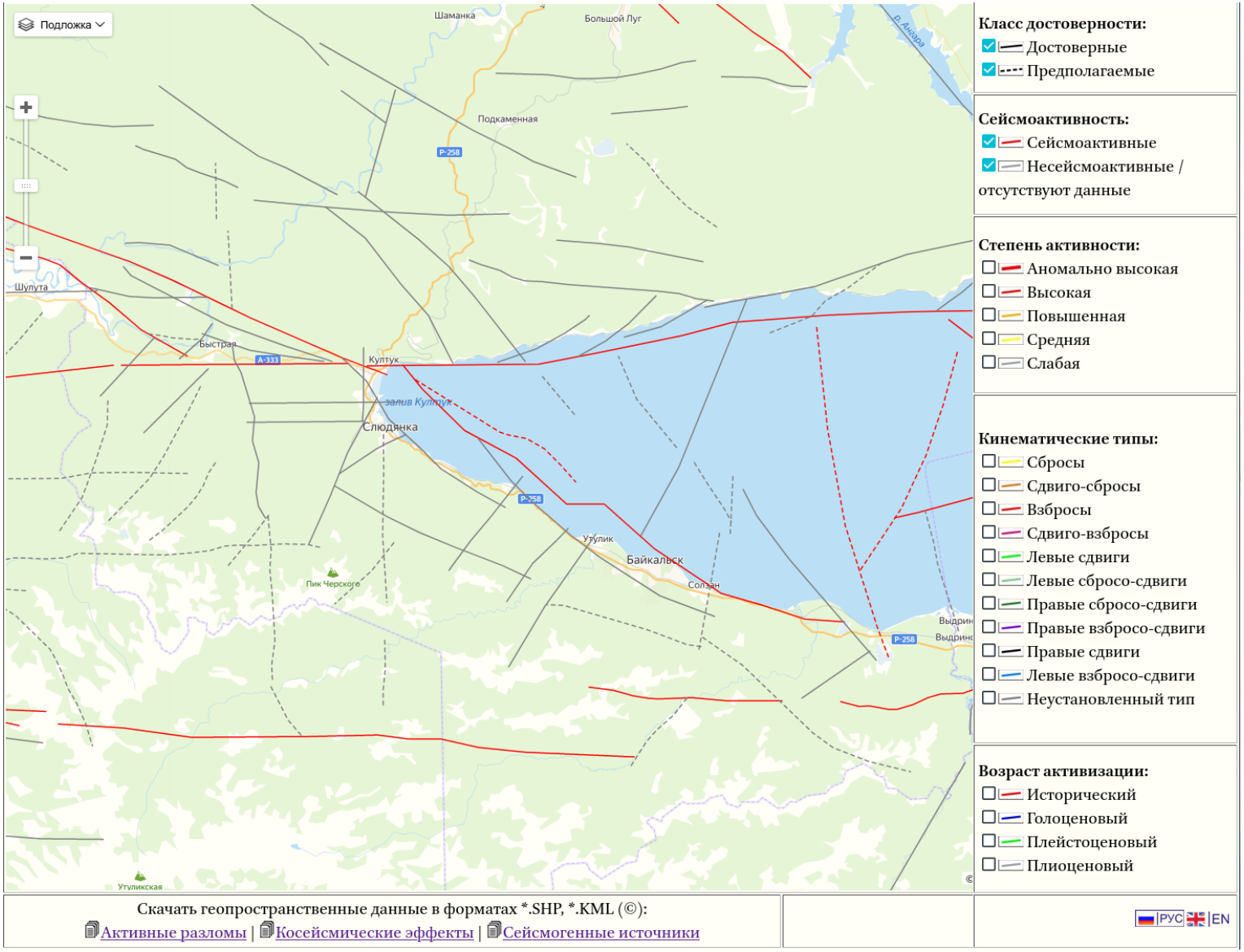
Existing resources



Existing resources



Resources to be presented: Active faults of the South of East Siberia



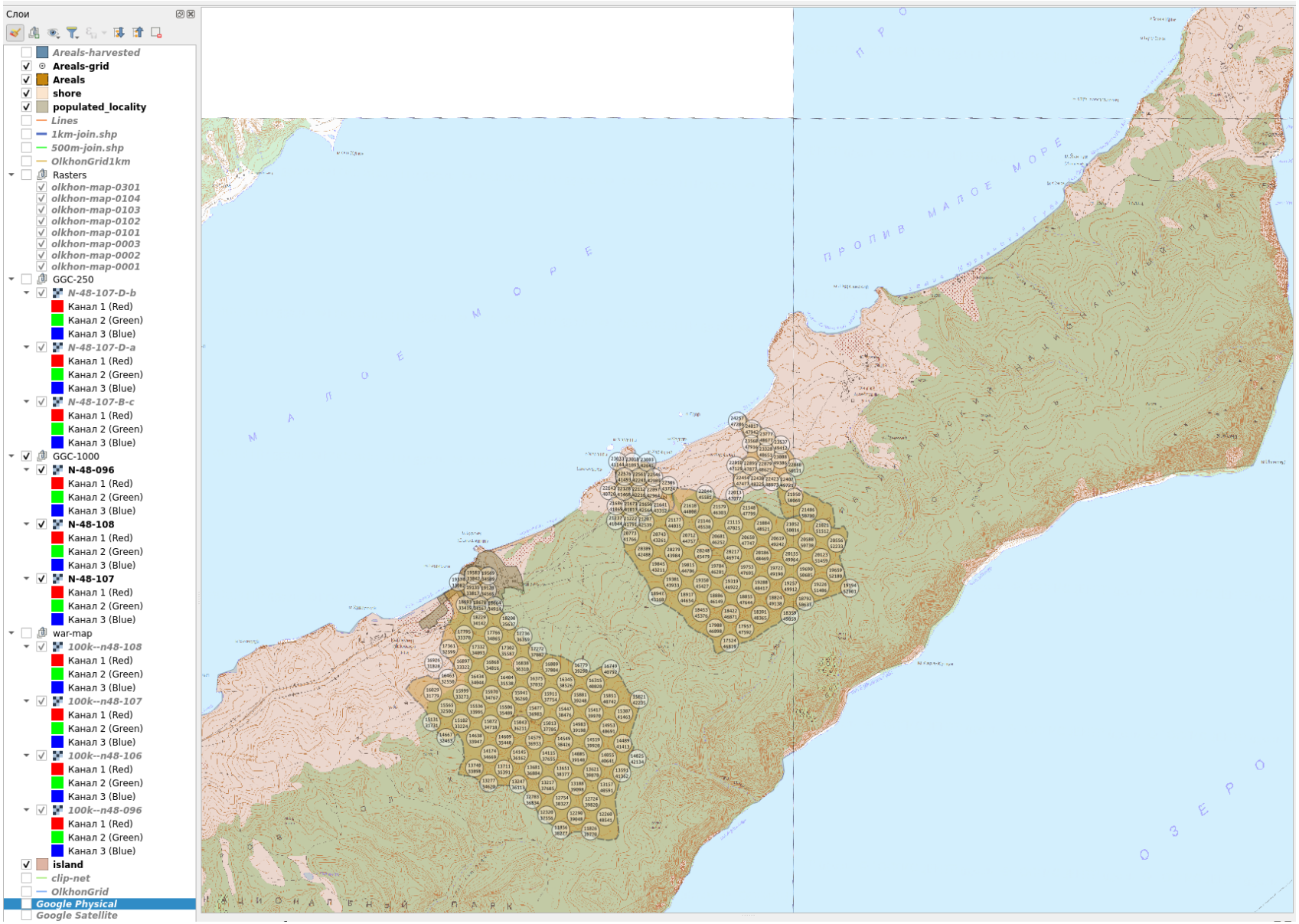
Resources to be presented: Active faults of the South of East Siberia

The fault data[4] have the following properties:

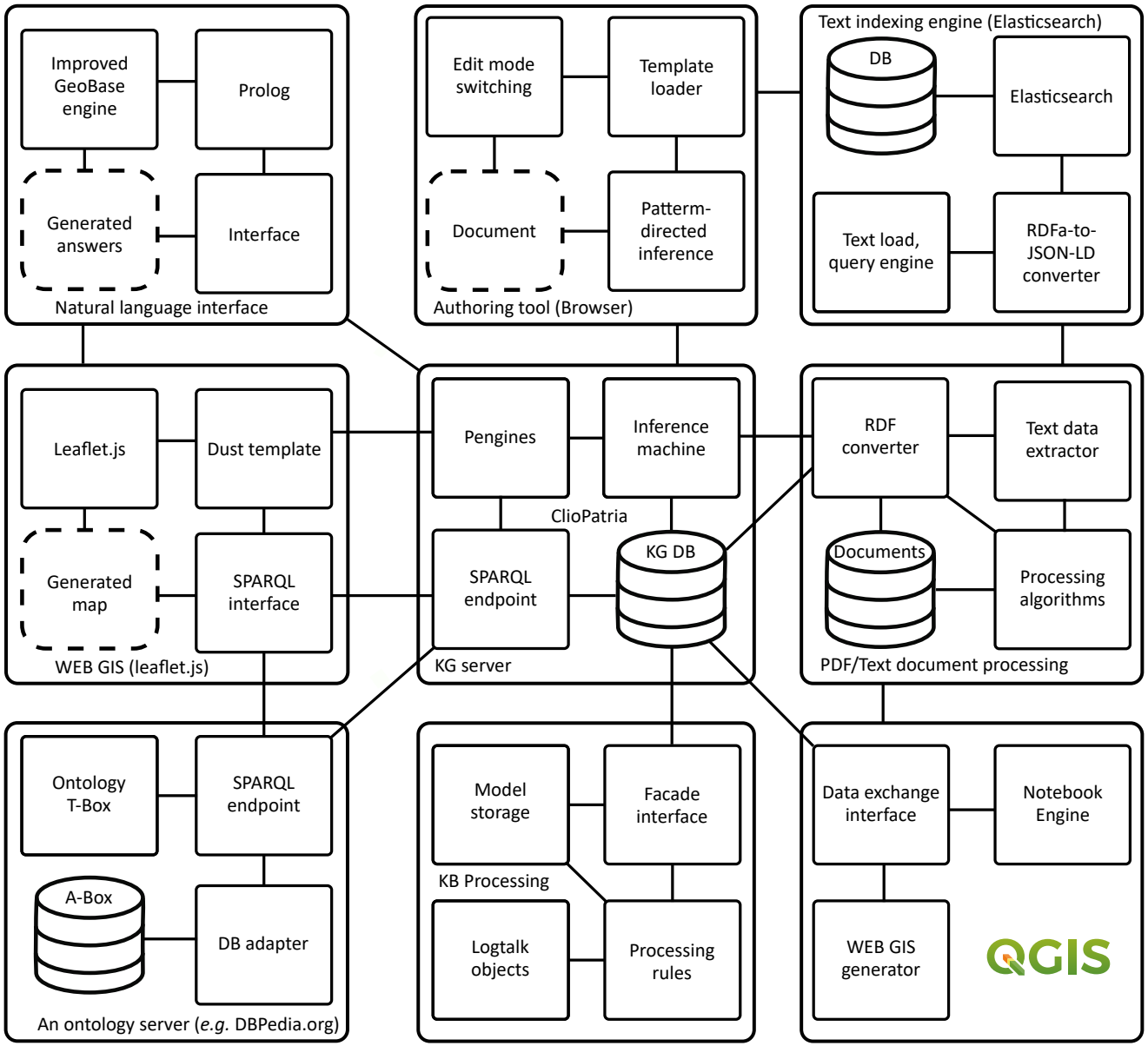
- Faults are the objects having linear projection on the surface, and a depth and a slope in the lithosphere
- Various geological events are also subjects of presentation
- Any object accompanied with various valued characteristics having also characteristics, *e.g.*, unit name, measurement precision and related publications
- Images, tables, expedition trails are a also used as auxiliary materials.

[4] Oksana V. Lunina. The digital map of the pliocene quaternary crustal faults in the southern east siberia and the adjacent northern Mongolia. Geodynamics & Tectonophysics. 2016. 7(3):407-434. doi:10.5800/GT-2016-7-3-0215

Resources to be presented: the Olkhon Island



System architecture



Conclusion

[[[]]]The following results have been obtained as for today:

- Biologists' activities are mastered, investigated and regular patterns are described.
- A technique for interpretation of Mothur interfaces has been developed, implemented, refined and extended.
- Transformation tools are tested in application areas and no significant technical problems were detected.
- A technique of document authoring is being developed and adapted to the domain.
- Integration with Galaxy project is the primary aim of the future development.

The source codes are available at
https://github.com/isu-enterprise/icc.xmitransform,
https://github.com/eugeneai/icc.mothurpim.
This research is supported by Irkutsk scientific center of SB RAS, project No 4.2;

External links

The presentation URL

https://raw.githubusercontent.com/eugeneai/paper-2021-iwci/main/talk-IWCI-2021-03-30.pdf

Oksana V. Lunina. The digital map of the pliocene quaternary crustal faults in the southern east siberia and the adjacent northern Mongolia. Geodynamics & Tectonophysics. 2016. 7(3):407-434. doi:10.5800/GT-2016-7-3-0215

Aidan Hogan, Eva Blomqvist, Michael Cochez, Claudia D'Amato *et al.* Knowledge Graphs. https://arxiv.org/abs/2003.02320v5

Thanks for Your interest in our project!

Auxiliary materials

Technologies used (open source)

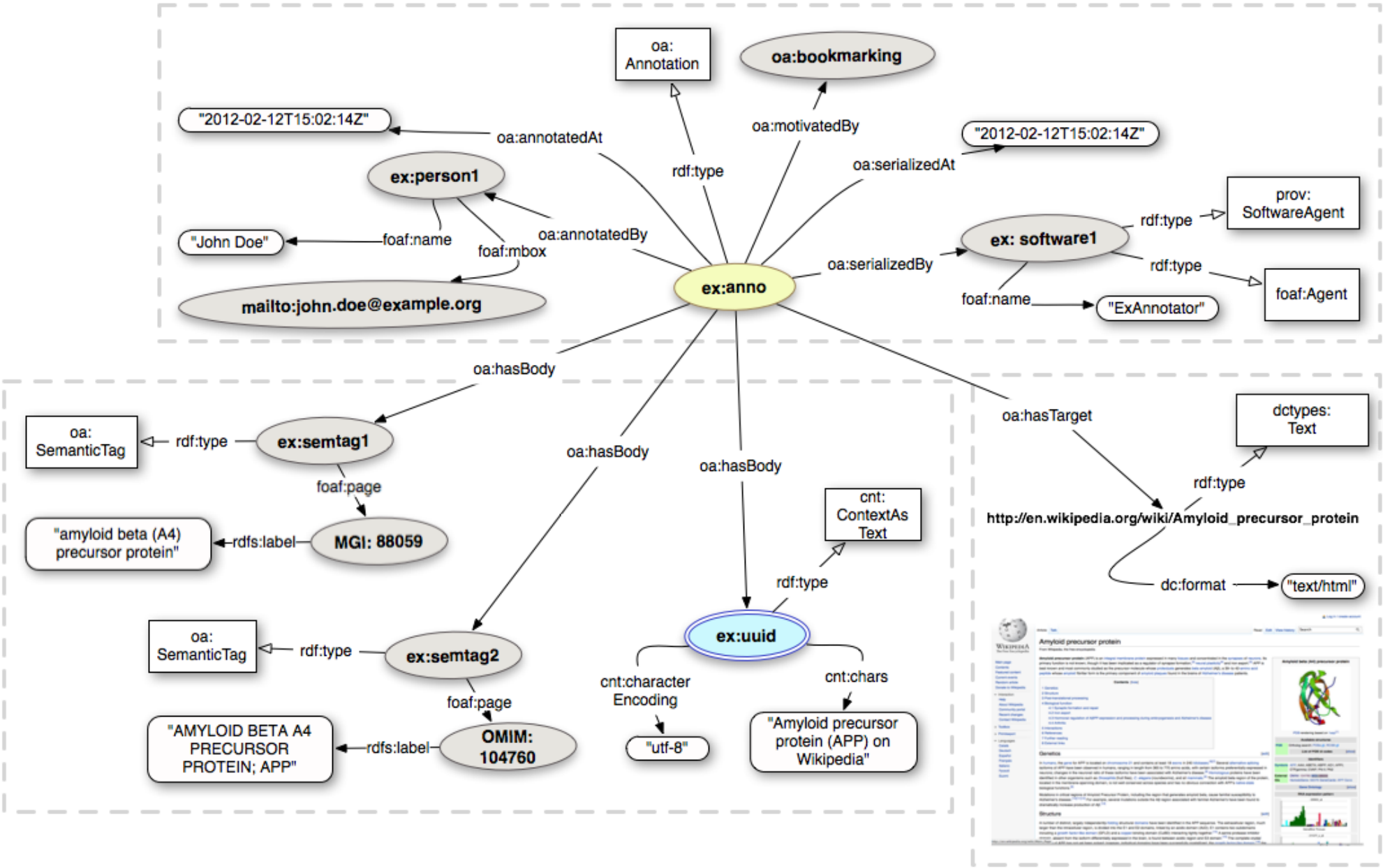
Python-3.x.x (http://python.org)
ZCA (https://muthukadan.net/docs/zca.html)
SWIG (http://swig.org/)
SWI-Prolog (https://www.swi-prolog.org/)
Logtalk (https://logtalk.org/)
ClioPatria (https://cliopatria.swi-prolog.org/home)
Virtuoso Open Source Edition (http://vos.openlinksw.com/owiki/wiki/VOS)
Pengines (https://pengines.swi-prolog.org/docs/index.html)
LOV (https://lov.linkeddata.es/dataset/lov/)
Elastic Search (https://www.elastic.co/)
Kyotocabinet (https://fallabs.com/kyotocabinet/)
DBPedia (https://wiki.dbpedia.org/)
Dust.js (https://akdubya.github.io/dustjs/)
QGIS (https://qgis.org/ru/site/)
TabbyDOC (http://td.icc.ru/)
GeoBase (https://github.com/eugeneai/geobase)
Authoring Tool (https://github.com/isu-enterprise/isu.college)

Used ontologies

Standardized ontologies

- Friend-of-a-friend (**foaf**) for agent information: individuals, legal entities, program agents
- Provenance (**prov**) for making references between documents
- Dublin Core (**dc**) for published resource metadata mark up
- DBPedia resource (**dbr**) to refer external classes and instance objects
- Schema.org (**schema**) for Google, Yandex, Yahoo, *etc.* searchable objects, structural elements
- The Bibliographic Ontology (**bibo**) used for literature reference
- Open annotation (**oa**) as an "bookmark" ontology
- LinkedGeoData A-Box (**lgd**)
- LinkedGeoData T-Box (**lgdo**)
- Coordinate system (**wgs84**)
- the Ontology WEB Language (**owl**)
- XML Schema (**xsd**)

Open Annotation (oa)



Document authoring and storage

In most cases documents are created as a result of

- creative activity of a person with a text processors (authoring);
- printing a digital copy or a data record in a database;
- aggregation operation over database records (report).

Then it is stored either as a physical paper and/or a digital document (PDF, DOCX, HTML).
Since 2000-th, Semantic Web and Linked Open Data (LOD) is being developed, allowing

- structural storage of data within published documents;
- processing stored data computationally;
- integration of data structures and data objects globally.

The **aim of this research** is to develop technologies, software and services allowing construction of digital archives supporting document data inclusion and inference from existing documents.

Logtalk as transformation definition language

We have chosen Logtalk as it

- inherits widely known Prolog language syntax and runtime
- implemented as macro package, performance penalties are about 1.5%
- has flexible semantics: we can define transformations and constraints within the same syntax
- implement object-oriented knowledge (rules) structuring, encapsulation and replacement
- compositional way of transformation implementation
- powerful engine to post constraints on object-to-object messages (events)
- has implementation for many Prolog engines.

The «regular» language allow us to use its libraries not directly related to MDA transformations.