Building Remote Sensing Applications Using Semantic Web Technologies

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Outline

- Motivation
- State of the art in Earth Observation data centers
- The Fire Monitoring Service of the National Observatory of Athens
- Demo
- Evaluation
- Conclusions
Motivation

N. of Earth Observation satellites launched

<table>
<thead>
<tr>
<th>Year</th>
<th>Count</th>
<th>USA (NASA, NOAA)</th>
<th>China</th>
<th>India</th>
<th>Russia</th>
<th>ESA</th>
<th>Other single State Agencies (RoW)</th>
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<tbody>
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<td>1967-1980</td>
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<td>4</td>
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<td>17</td>
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<td>27</td>
<td>26</td>
<td>8</td>
<td>19</td>
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</tbody>
</table>

Total: 246

1. RoW: Rest of the World
2. South Korea

Disaster 2.0
Building Remote Sensing Applications Using Semantic Web Technologies
Motivation (cont’d)

Evolution of ESA’s EO Data Archives between 1986-2007 and future estimates (up to 2020)

- Future Data Estimates
- LANDSAT 2-4 MSS (75-Dec 93)
- AQA Modis (April 03-today)
- ENVISAT LR (March 02-today)
- ENVISAT HR (March 02-today)
- TERRA Modis (June 01-today)
- QUICK SCATT (01-today) / PROBA (May 02-today)
- LANDSAT 7 ETM (April 99-Dec 03)
- SEA STAR SeaWifs (Apr 98-today)
- ERS 2 HR (May 95-today)
- ERS 2 LBR (May 95-today)
- JERS SAR/OPS VNIR (92-Sep 98)
- ERS 1 HR (Jul 91-Mar 00)
- ERS 1 LBR (Jul 91-Mar 00)
- SPOT 1-4 HRV (87-today)
- MOS 1, 1b MESSR (87-Oct 93)
- NOAA 9-17 AVHRR (86-today)
- LANDSAT 5 TM (April 84-today)
- NIMBUS 7 (Nov 78-May 86), SEASAT (Jun-Oct 78)

~20 PB

Big Data!
Motivation (cont’d)

Estimated directly affected inhabitants Japan, Honshu 2011

ANTARCTICA - Bransfield Strait - Oil Spill Situation on November 29, 2007

Disaster 2.0
Building Remote Sensing Applications Using Semantic Web Technologies
State of the Art in EO Data Centers

Disaster 2.0
Building Remote Sensing Applications Using Semantic Web Technologies
Example

- Can I pose the following query using EOWEB?

Find images taken by the SEVIRI satellite on August 25, 2007 which contain fire hotspots in areas which have been classified as forests according to Corine Land Cover, and are located within 2km from an archaeological site in the Peloponnese.
Example (cont’d)

- Well, only partially.

Find images taken by the SEVIRI satellite on August 25, 2007 which contain fire hotspots in areas which have been classified as forests according to Corine Land Cover, and are located within 2km from an archaeological site in the Peloponnese.
Example (cont’d)

• But why?

• All this information is available in the satellite images and other auxiliary data sources of EO data centers or on the Web.

• However, EO data centers today do not allow:
  • the mining of satellite image content and
  • its integration with other relevant data sources so the previous query can be answered.
The TELEIOS Earth Observatory: Concept View

- **Linked Geospatial Data**
- **Semantic Annotations**
- **Ontologies**
- **Knowledge Discovery and Data Mining**

**Rapid Mapping**

**Web Portals**

**Scientists**

**Emergency Response Managers**

**Raw Data**

**Ingestion**

**GIS Data**

**Derived Products**

**Metadata**

**Processing**

**Cataloguing**

**Archiving**

**DATA**

**KNOWL-EDGE**
Wildfire Monitoring and Burnt Area Mapping (NOA)
Fire monitoring application
Pre-TELEIOS practice

System users (Civil Protection Authorities etc.)

Eumetsat @ 9.5° East

Disk Array

Manage SEVIRI data stream in real time:
- Describe & store raw file metadata
- Filter & dispatch raw MSG products
- Remotely trigger processing chain
- Dispatch processed products

Raw data are decoded and stored temporary as wavelet compressed images @...

SQLite

PostGIS

METEOSAT Ground Station

SEVIRI Monitor

MSG-1 Seviri (5 mins)
MSG-2 Seviri (15 mins)

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Building Remote Sensing Applications Using Semantic Web Technologies
Fire monitoring application
Advancements - Integration of the TELEIOS technologies

Eumetsat @ 9.5°East

External Sources

Data Vault

Raw Data

HotSpots

Processing Chain (SciQL based)

Cataloguing Service & Metadata Creation

Geospatial Ontology

Linked Geospatial Data Semantic technologies

Web access based on Semantics

Front End: GUI

Map Element

• Search & Display
• Search for raw & Processing
• Real-time Fire Monitoring
• Refinement (Post-Processing)
• Linked Data

Eumetsat @ 9.5°East
High Level Data Modeling

- Need for representing
  - Standard product metadata
  - Standard product semantic annotations
  - Geospatial information
  - Temporal information

- Need to link to other data sources
  - GIS data
  - Other information on the Web
Semantics-Based Representation and Querying of EO Data

- The data model **stRDF** and the query language **stSPARQL**

- The system **Strabon**

strabon.di.uoa.gr
The Data Model stRDF

- stRDF stands for spatial/temporal RDF.

- It is an extension of the W3C standard RDF for the representation of geospatial data that may change over time.

- stRDF extends RDF with:
  - **Spatial literals** encoded in OGC standards Well-Known Text or GML
  - **New datatypes** for spatial literals (strdf:WKT, strdf:GML and strdf:geometry)
  - **Valid time of triples** (ignored in this talk)
W3C recommendation

RDF is a graph data model (+ XML syntax + semantics)

- For representing metadata
- For describing the semantics of information in a machine-accessible way
- Resources are described in terms of properties and property values using RDF statements
- Statements are represented as triples, consisting of a subject, predicate and object. [S, P, O]

```
x:BurntArea1 noa:hasArea "23.7636"^^xsd:double
```
stRDF: An example
stRDF: An example

noa:BurntArea

ex:BurntArea1

rdf:type

noa:hasID

"1"^^xsd:int

noa:hasArea

"23.7636"^^xsd:double

g:geometry

"POLYGON(( 38.16 23.7, 38.18 23.7, 38.18 23.8, ..., 38.16 23.8, 38.16 3.7));
<http://spatialreference.org/ref/epsg/4121/>"^^strdf:WKT

Spatial Literal (OpenGIS Simple Features)
stSPARQL: An example

- Find all burned forests within 10kms of a city

```sparql
select ?BA ?BAGEO
where {
  ?R rdf:type noa:Region ;
  geo:geometry ?RGEO ;
  noa:hasCorineLandCoverUse ?F .
  ?CITY rdf:type dbpedia:City ;
  geo:geometry ?CGEO .
  ?BA rdf:type noa:BurntArea ;
  geo:geometry ?BAGEO .
  filter( strdf:Intersect(?RGEO,?BAGEO) && strdf:Distance(?BAGEO,?CGEO) < 10000 )
}
```

Spatial Functions (OGC Simple Feature Access)
stSPARQL: An example
Strabon: A Scalable Geospatial RDF Store

WKT  GML

stRDF graphs

stSPARQL/GeoSPARQL queries

Sesame
Query Engine
- Parser
- Optimizer
- Evaluator
- Transaction Manager

Storage Manager
- Repository
- SAIL
- RDBMS

GeneralDB

PostGIS

http://www.strabon.di.uoa.gr/
Fire monitoring application

- Improving the fire monitoring service using Semantic Web technologies
  - **Representing** fire related products using ontologies
  - **Enriching products** with linked geospatial data
  - **Improving accuracy** with respect to:
    - Underlying land cover/land use
    - Persistence in time

http://papos.space.noa.gr/fend_static/
NOA Ontology
Linked Geospatial Data

- Datasets that we developed and published as linked data:
  - Corine Land Use / Land Cover
  - Coastline of Greece
  - Greek Administrative Geography
- Portal: http://www.linkedopendata.gr/
- Datasets from Linked Open Data Cloud
  - LinkedGeoData
  - GeoNames
GeoNames
GeoNames

Disaster 2.0
Building Remote Sensing Applications Using Semantic Web Technologies
OpenStreetMap
Linked Open Data (2/5)
Corine Land Use / Land Cover
Linked Open Data (4/5)

Greek Administrative Geography

Legend
- rdfs:subClassOf
- gag:belongsTo

Administrative Area
- gag:hasOfficialName
- gag:hasCode
- gag:hasPopulation
- gag:hasGeometry
- xsd:string
- xsd:integer
- strdf:WKT

Country
  - Decentralized Administration
  - Region
  - Regional Unit
  - Municipality
  - Municipality Unit
  - Municipal Community
  - Local Community
Linked Open Data (4/5)

Greek Administrative Geography
Greek Coastline
Greek Coastline
Improvements

Using ontologies and stRDF to model knowledge extracted from satellite images, metadata of satellite images and auxiliary geospatial data can improve tasks like:

- **Generated maps** combining diverse information sources
- **Increase hotspot accuracy** correlating them with auxiliary data
Fire monitoring application

- **Generating maps** combining diverse information sources
- **Semantic Enrichment for Hotspots**
- **Fire monitoring application**

DEMO!
Get all hotspots detected in Peloponnese on 24/08/2007.

```
WHERE { 
  ?h rdf:type noa:Hotspot ;
  noa:hasGeometry ?hGeo ;
  noa:hasAcquisitionTime ?hAcqTime ;
  noa:hasConfidence ?hConfidence ;
  noa:isProducedBy ?hProvider ;
  noa:hasConfirmation ?hConfirmation ;
  noa:isDerivedFromSensor ?hSensor ;
  noa:isDerivedFromSatellite ?hSatellite .
FILTER("2007-08-24T00:00:00"^^xsd:dateTime <= ?hAcqTime &&
FILTER(strdf:contains("POLYGON((21.027 38.36, 23.77 38.36,
  23.77 36.05, 21.027 36.05, 21.027 38.36))"^^strdf:WKT, ?hGeo) ) . }
```
Discovering EO data

Get all hotspots detected in Peloponnese on 24/08/2007.

WHERE { ?h rdf:type noa:Hotspot ;
  noa:hasGeometry ?hGeo ;
  noa:hasAcquisitionTime ?hAcqTime ;
  noa:hasConfidence ?hConfidence ;
  noa:isProducedBy ?hProvider ;
  noa:hasConfirmation ?hConfirmation ;
  noa:isDerivedFromSensor ?hSensor ;
  noa:isDerivedFromSatellite ?hSatellite .
FILTER("2007-08-24T00:00:00"^^xsd:dateTime <= ?hAcqTime &&
FILTER(strdf:contains("POLYGON((21.027 38.36, 23.77 38.36,
  23.77 36.05, 21.027 36.05, 21.027 38.36))"^^strdf:WKT, ?hGeo) ) .}
Get all coniferous forests in Peloponnese

```
SELECT  ?a ?aGeo
WHERE{ ?a rdf:type clc:Area;
    clc:hasLandUse ?aLandUse;
    noa:hasGeometry ?aGeo.
    ?aLandUse rdf:type ?aLandUseType.
    FILTER(?aLandUseType =
    clc:ConiferousForest).

    FILTER(strdf:contains("POLYGON((21.027
    38.36, 23.77 38.36, 23.77 36.05,
    21.027 36.05, 21.027 38.36))")
    ^^strdf:WKT,?aGeo)).
}
```
Get all coniferous forests in Peloponnese

```sparql
SELECT ?a ?aGeo
WHERE { ?a rdf:type clc:Area;
  clc:hasLandUse ?aLandUse;
  noa:hasGeometry ?aGeo.
  ?aLandUse rdf:type ?aLandUseType.
  FILTER(?aLandUseType = clc:ConiferousForest).
  FILTER(strdf:contains("POLYGON((21.027 38.36, 23.77 38.36, 23.77 36.05, 21.027 36.05, 21.027 38.36))"^^strdf:WKT, ?aGeo)).
}
```
Get all primary roads in Pelloponnese

SELECT ?r ?rGeo
WHERE{ ?r a ?rType ;
    noa:hasGeometry ?rGeo .
    FILTER(?rType = lgdo:Primary) .
    FILTER(strdf:contains("POLYGON((
        21.027 38.36, 23.77 38.36, 
        23.77 36.05, 21.027 36.05, 
        21.027 38.36)\"^^strdf:WKT,
    ?rGeo) ).
}
Get all primary roads in Pelloponnese

$$\text{SELECT} \ ?r \ ?rGeo$$
$$\text{WHERE} \{ \ ?r \ \text{a} \ ?rType \ ;$$
$$\text{noa:hasGeometry} \ ?rGeo .$$
$$\text{FILTER}(\text{?rType} = \text{lgdo:Primary}) .$$
$$\text{FILTER(\text{strdf:contains("POLYGON((21.027 38.36, 23.77 38.36, 23.77 36.05, 21.027 36.05, 21.027 38.36))"^^\text{strdf:WKT}, \ ?rGeo) )}) .$$

$$\}$$
Get all capitals of prefectures of the Peloponnese.

SELECT ?feature ?fName ?fGeo
WHERE{ ?feature rdf:type gn:Feature;
    noa:hasGeography ?fGeo;
    gn:name ?fName;
    FILTER(?fCode = gn:P.PPLA
            || ?fCode = gn:P.PPLA2 ) .
    FILTER(strdf:contains("POLYGON((21.51 36.41, 22.83 36.41, 22.83 37.69, 21.51 37.69, 21.51 6.41 ))")
            ^^^strdf:WKT, ?fGeo)).
}
Retrieving a map layer (3/3)

Get all capitals of prefectures of the Peloponnese.

```
SELECT ?feature ?fName ?fGeo
WHERE { ?feature rdf:type gn:Feature;
  noa:hasGeography ?fGeo;
  gn:name ?fName;
  FILTER(strdf:contains("POLYGON((21.51 36.41, 22.83 36.41, 22.83 37.69, 21.51 37.69,
  21.51 6.41 ))"^^strdf:WKT, ?fGeo)).
}
```
Semantic Enrichment for Hotspots

- **Enrich** hotspot products
  1. Connect each hotspot with a municipality that it is located

- **Improve accuracy** with respect to **underlying area**
  2. Eliminate false alarms in sea
  3. Eliminate false alarms in inconsistent land cover areas
  4. Keep land part of the polygon

- **Improve accuracy** with respect to **temporal persistence** of each hotspots
  5. Remove “Christmas tree” effects

"Christmas tree effect": some hotspots appear in a timestamp, in the next timestamp they disappear, then they re-appear again, and so on.
Fire monitoring application

- Generating maps combining diverse information sources
- Semantic Enrichment for Hotspots
- Fire monitoring application

DEMO!

http://test.strabon.di.uoa.gr/NOA
Improve the accuracy of EO data

Correlate fire products with auxiliary data to increase their thematic accuracy e.g., delete the parts of the polygons that fall into the sea.

```
DELETE {?h noa:hasGeometry ?hGeo}
INSERT {?h noa:hasGeometry ?dif}
WHERE {
  SELECT DISTINCT ?h ?hGeo
  (strdf:intersection(?hGeo, strdf:union(?cGeo)) AS ?dif)
WHERE {
  ?h rdf:type noa:Hotspot.
  ?h strdf:hasGeometry ?hGeo.
  ?c rdf:type coast:Coastline.
  ?c strdf:hasGeometry ?cGeo.
  FILTER( strdf:anyInteract(?hGeo, ?cGeo))
GROUP BY ?h ?hGeo
HAVING strdf:overlap(?hGeo, strdf:union(?cGeo))}
```
Improve the accuracy of EO data

HAVING strdf:overlap(?hGeo, strdf:union(?cGeo))
Fire monitoring application

- Generating maps combining diverse information sources
- Semantic Enrichment for Hotspots
- Fire monitoring application

DEMO!

http://papos.space.noa.gr/fend_static
Fire monitoring service

Validation

- The fire monitoring service was used **operationally** during the **fire season** of 2012

- Used in a **daily basis** by the
  - Greek civil protection agency
  - Greek fire brigade
  - Greek army

- Initial user feedback very encouraging!
## Fire monitoring service
### Preliminary evaluation – Thematic accuracy

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Total No of FIRMS hotspots</th>
<th>Total No of MSG hotspots</th>
<th>No of FIRMS detected by MSG</th>
<th>Omission error (%)</th>
<th>No of MSG detected by FIRMS</th>
<th>False alarm rate (%)</th>
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<td>41</td>
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<td>18</td>
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<td>84</td>
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<td>8.70</td>
<td>83</td>
<td>28.45</td>
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<td>99</td>
<td>94</td>
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<td>87</td>
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<td>126</td>
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<td>8</td>
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<td></td>
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<td><strong>1916</strong></td>
<td><strong>1897</strong></td>
<td><strong>25.37</strong></td>
<td><strong>1460</strong></td>
<td><strong>23.80</strong></td>
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</tbody>
</table>

### Static thresholds

### Dynamic thresholds

---

**Disaster 2.0**

Building Remote Sensing Applications Using Semantic Web Technologies
Product ingestion, processing and refinement is completed in less than 12 seconds

More refinement operations to be added later given the five minutes time frame
Conclusions

- General architecture for EO applications enriched with semantic web technologies
- The Fire Monitoring Service of the National Observatory of Athens
  - Architecture
  - Improving the service using semantic technologies
Discussion

- Use **higher-level languages**, stop worrying about how to store and manage metadata, just **focus** on the actual **processing**

- Express common earth observation operations easily using the **stSPARQL/GeoSPARQL queries** instead of using a lengthy **C** program

- **Rapid prototyping** and new refinement modules without the need to recompile everything
Thank you for your attention!

Real-time fire monitoring application

http://papos.space.noa.gr/fend_static/

Examples of stSPARQL queries:

http://test.strabon.di.uoa.gr/NOA/

More information about TELEIOS:

http://www.earthobservatory.eu/

Linked Open Geospatial Data Portal

http://www.linkedopendata.gr/