Part 2: Spatial and Temporal Data in RDF: stRDF/stSPARQL and GeoSPARQL

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Common Approach

- The two proposals (stRDF/stSPARQL and GeoSPARQL) offer constructs for:
  - Developing **ontologies** for spatial and temporal data.
  - Encoding **spatial and temporal data** that use these ontologies **in RDF.**
  - **Extending SPARQL** to query spatial and temporal data.

Two Proposals

- **stRDF/stSPARQL**
- GeoSPARQL

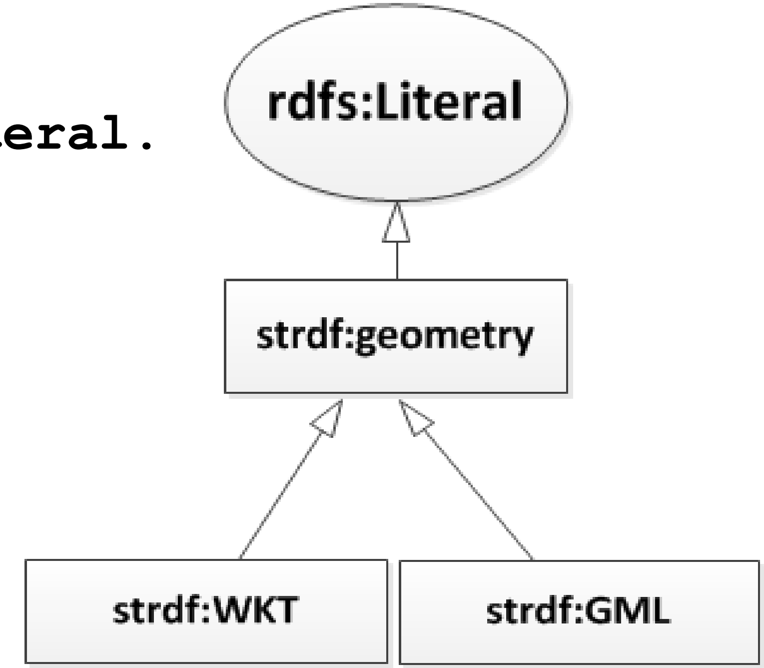
The data model stRDF

[Kyzirakos, Karpathiotakis & Koubarakis 2012]

- An extension of RDF for the representation of **geospatial information that changes over time.**
- **Geospatial dimension:**
  - **Spatial data types** are introduced.
  - Geospatial information is representing using **spatial literals** of these datatypes.
  - **OGC standards WKT and GML** are used for the serialization of spatial literals.
- **Temporal dimension** (later)
- Proposed independently and around the same time as GeoSPARQL (starting with an ESWC 2010 paper by Koubarakis and Kyzirakos).

Spatial Datatypes

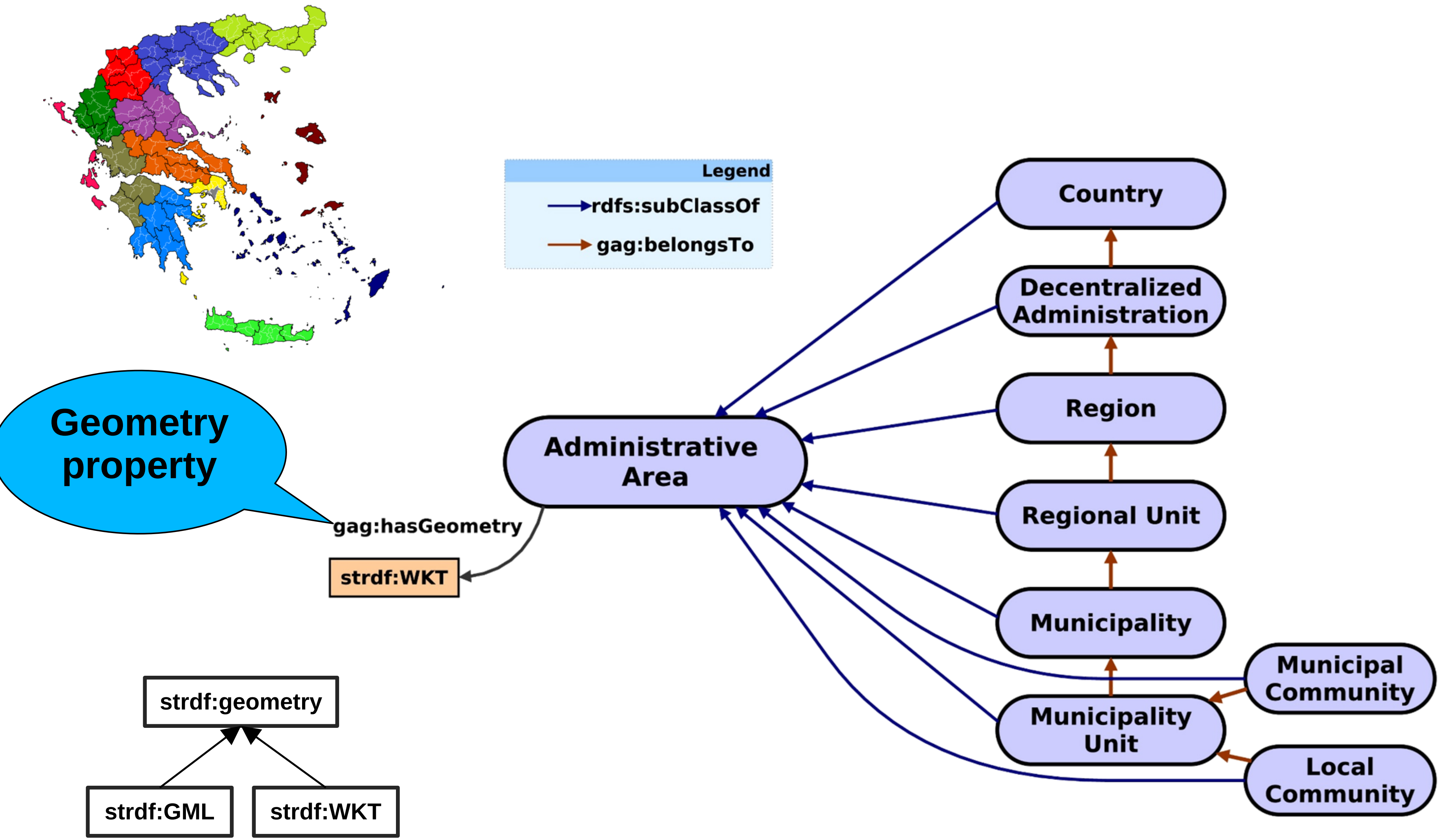
```
strdf:geometry rdf:type rdfs:Datatype;
               rdfs:subClassOf rdfs:Literal.
```



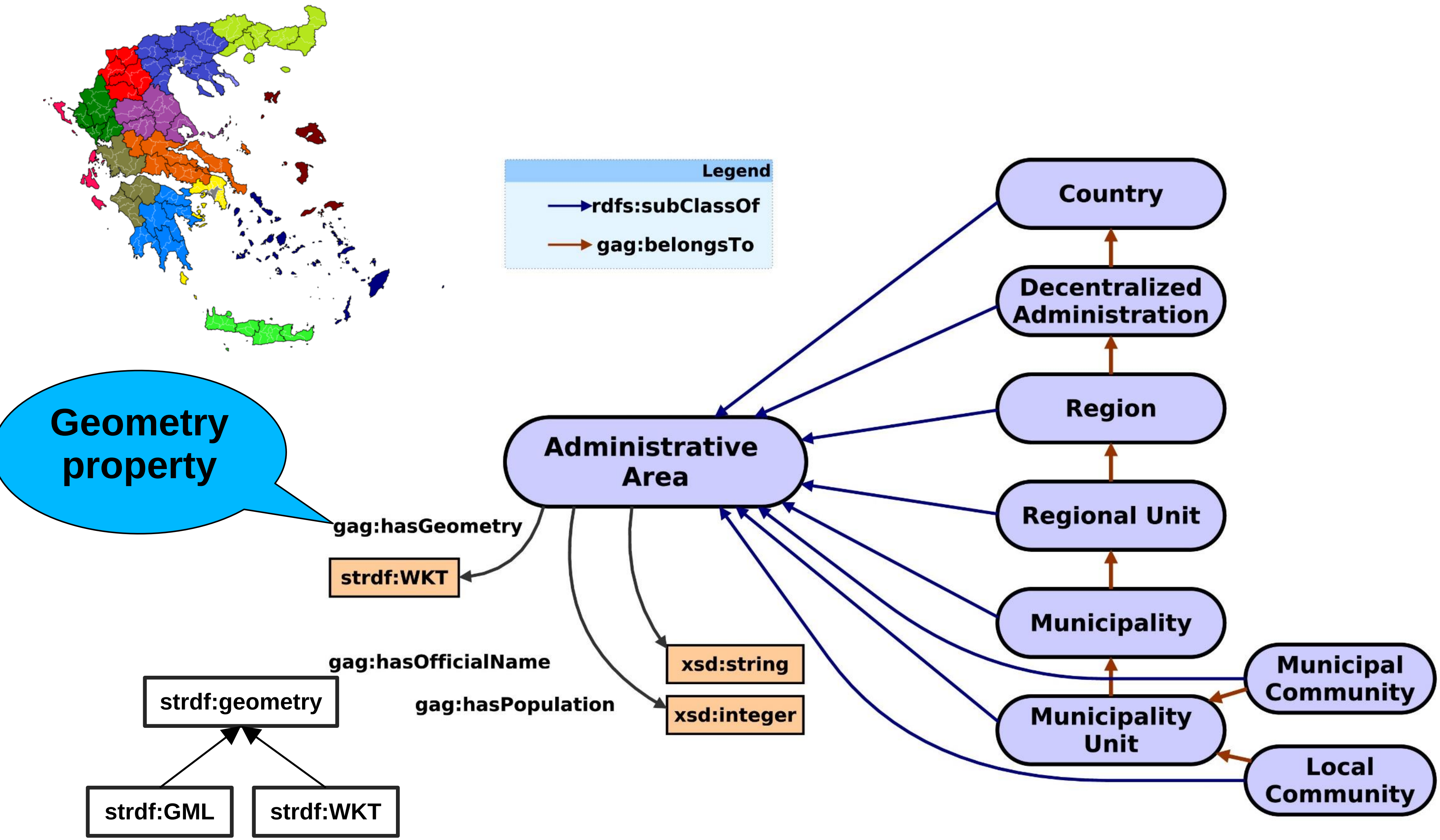

```
strdf:WKT   rdf:type rdfs:Datatype;
            rdfs:subClassOf   strdf:geometry.

strdf:GML   rdf:type rdfs:Datatype;
            rdfs:subClassOf   strdf:geometry.
```

Example Ontology: Administrative Geography of Greece

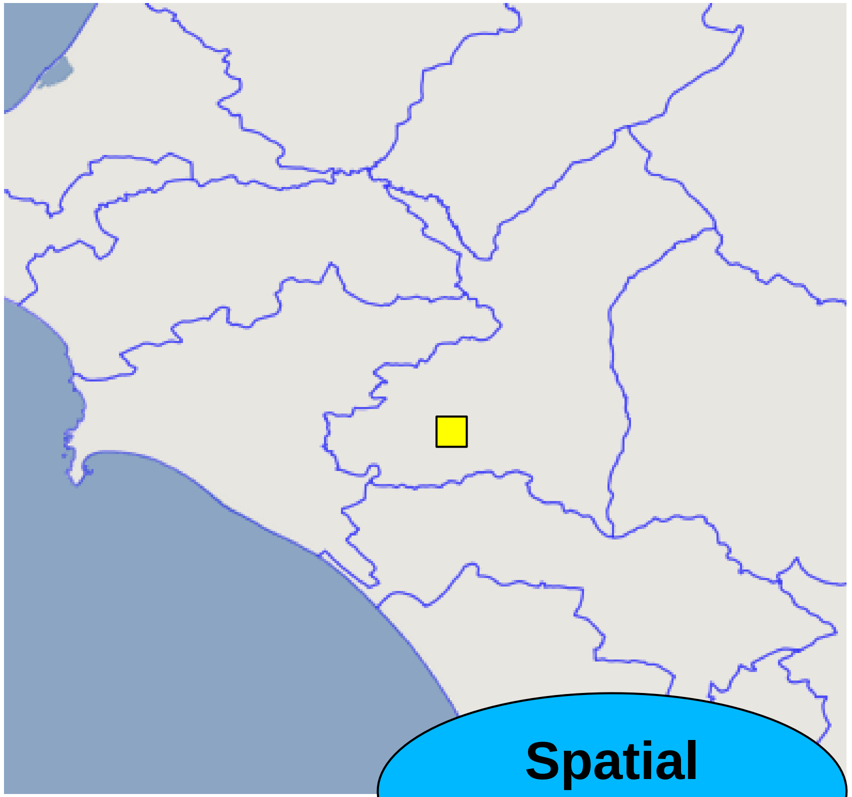


Example Ontology: Administrative Geography of Greece



Example Data in stRDF

```
gag:Olympia
  gag:name "Ancient Olympia";
  rdf:type gag:MunicipalCommunity .
```



Geometry Property

Spatial literal

```
gag:Olympia gag:hasGeometry
          "POLYGON((21.5 18.5, 23.5 18.5,
                    23.5 21, 21.5 21, 21.5 18.5));
  <http://www.opengis.net/def/crs/EPSG/0/4326>"^^
  strdf:WKT .
```

Spatial data type

Coordinate Reference System

Example (cont'd)

```
gag:Olympia
  rdf:type gag:MunicipalCommunity;
  gag:name "Ancient Olympia";
  gag:population "184"^^xsd:int;
  gag:hasGeometry "POLYGON
  (((25.37 35.34,…)))"^^strdf:WKT.

gag:OlympiaMUnit
  rdf:type gag:MunicipalityUnit;
  gag:name "Municipality Unit of
               Ancient Olympia".

gag:OlympiaMunicipality
  rdf:type gag:Municipality;
  gag:name "Municipality of
               Ancient Olympia".

gag:Olympia gag:belongsTo gag:OlympiaMUnit .

gag:OlympiaMUnit gag:belongsTo gag:OlympiaMunicipality.
```

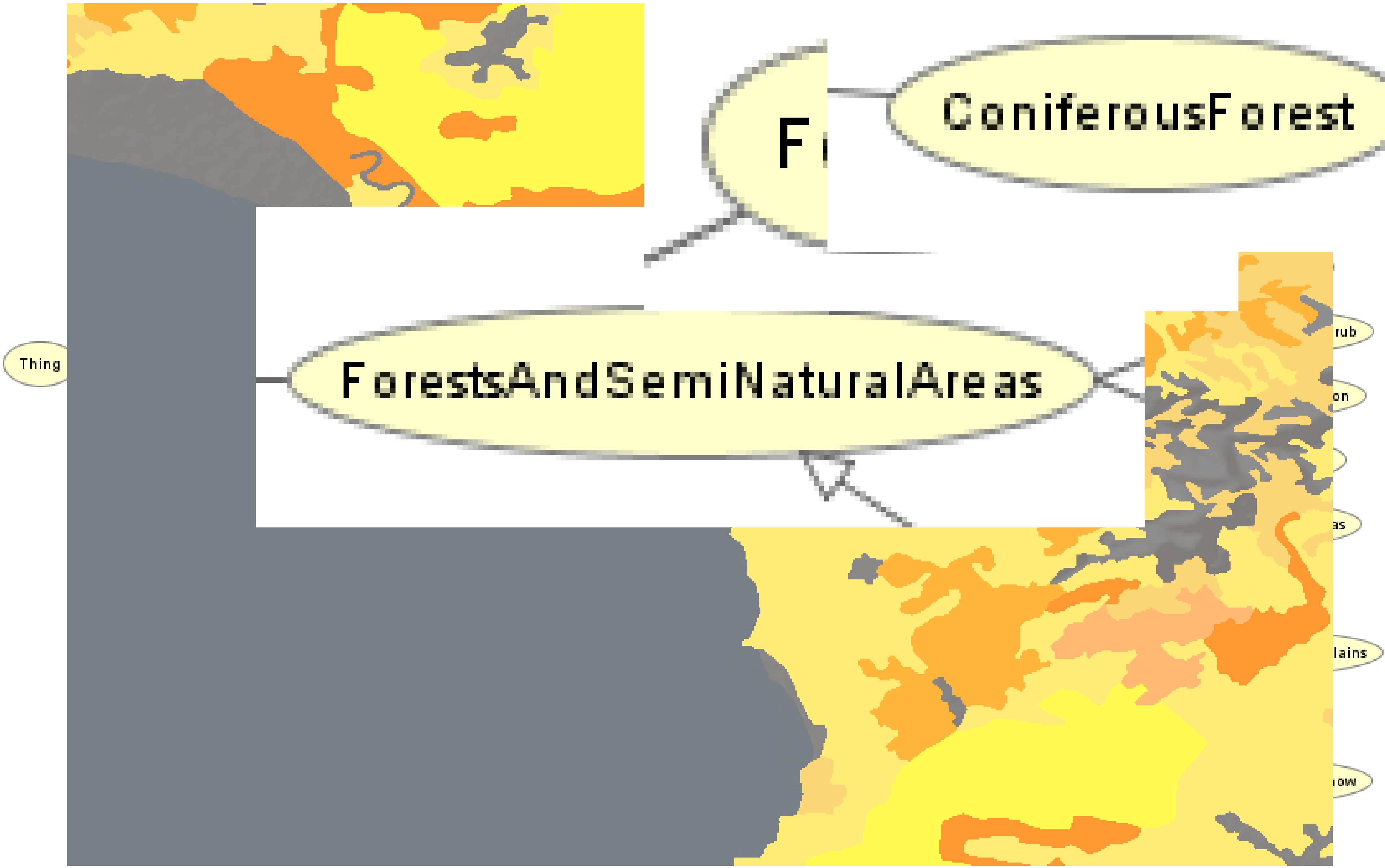
More Examples

- Corine Land Use/Land Cover

  (http://www.eea.europa.eu/publications/COR0-landcover)

- Burnt Area Products (project TELEIOS, http://www.earthobservatory.eu/)

Corine Land Use/Land Cover



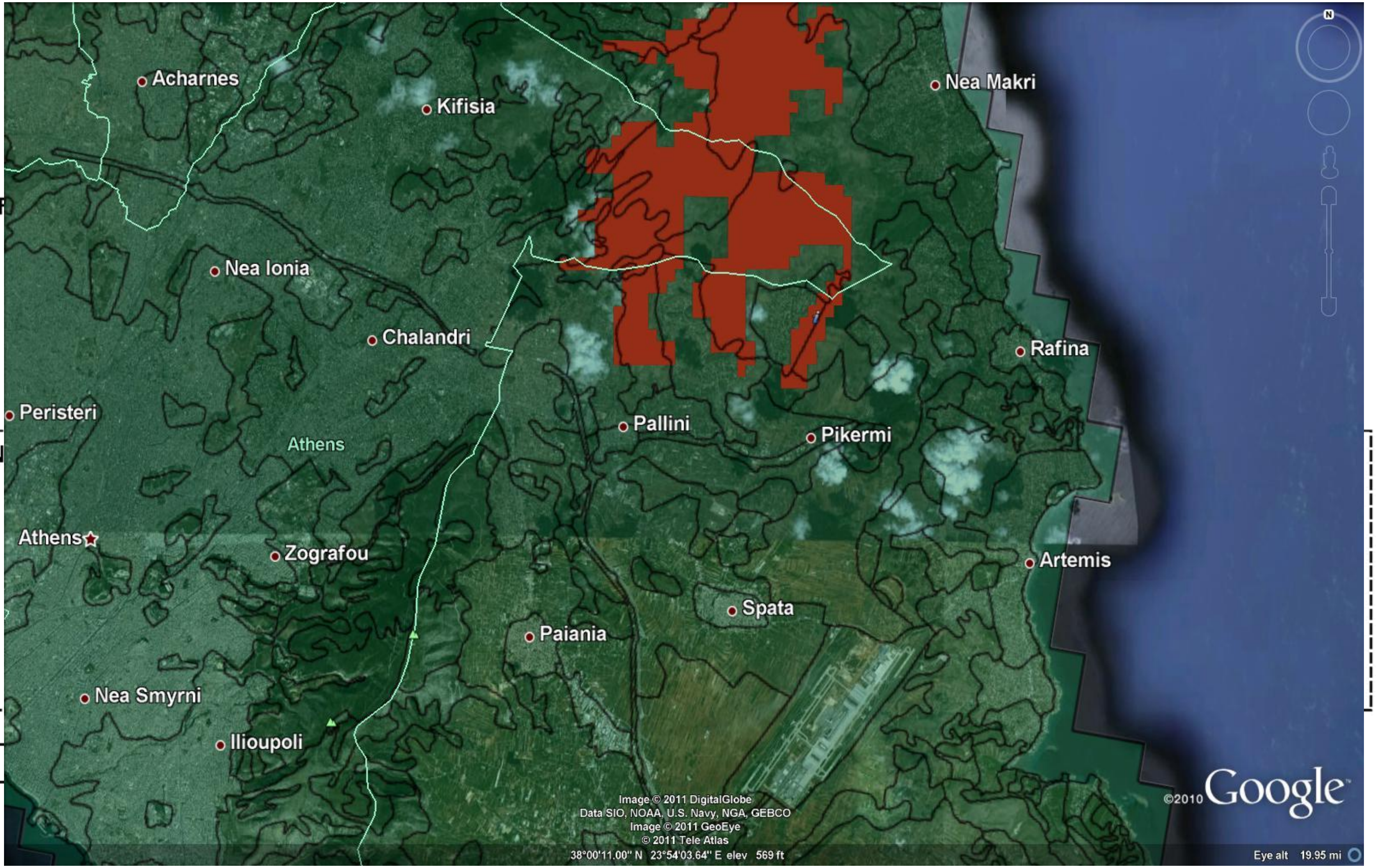
Corine Land Use/Land Cover in stRDF (http://www.linkedopendata.gr)

```
clc:Area_24015134
   rdf:type clc:Area ;
   clc:hasCode "312"^^xsd:decimal;
   clc:hasID "EU-203497"^^xsd:string;
   clc:hasArea_ha "255.5807904"^^xsd:double;
   clc:hasGeometry "POLYGON((15.53 62.54,
                                 …))"^^strdf:WKT;
   clc:hasLandUse clc:ConiferousForest .
```

Geometry Property

Burnt Area Products

(http://www.earthobservatory.eu/ontologies/noaOntology.owl)



Burnt Area Products

```
noa:ba_15
   rdf:type noa:BurntArea;
   noa:isProducedByProcessingChain
            "static thresholds"^^xsd:string;
   noa:hasAcquisitionTime
            "2010-08-24T13:00:00"^^xsd:dateTime;

   noa:hasGeometry "MULTIPOLYGON(((
   393801.42 4198827.92, ..., 393008 424131)));
   <http://www.opengis.net/def/crs/
                      EPSG/0/2100>"^^strdf:WKT.
```

Geometry Property

stSPARQL: Geospatial SPARQL 1.1

We define a SPARQL extension function for each function defined in the OpenGIS Simple Features Access standard

Basic functions

- Get a property of a geometry

```
xsd:int strdf:dimension(strdf:geometry A)
xsd:string strdf:geometryType(strdf:geometry A)
xsd:int strdf:srid(strdf:geometry A)
```

- Get the desired representation of a geometry

```
xsd:string strdf:asText(strdf:geometry A)
xsd:string strdf:asGML(strdf:geometry A)
```

- Test whether a certain condition holds

```
xsd:boolean strdf:isEmpty(strdf:geometry A)
xsd:boolean strdf:isSimple(strdf:geometry A)
```

stSPARQL: Geospatial SPARQL 1.1

Functions for testing topological spatial relationships

- **OGC Simple Features Access**

```
xsd:boolean strdf:equals(strdf:geometry A, strdf:geometry B)
xsd:boolean strdf:disjoint(strdf:geometry A, strdf:geometry B)
xsd:boolean strdf:intersects(strdf:geometry A, strdf:geometry B)
xsd:boolean strdf:touches(strdf:geometry A, strdf:geometry B)
xsd:boolean strdf:crosses(strdf:geometry A, strdf:geometry B)
xsd:boolean strdf:within(strdf:geometry A, strdf:geometry B)
xsd:boolean strdf:contains(strdf:geometry A, strdf:geometry B)
xsd:boolean strdf:overlaps(strdf:geometry A, strdf:geometry B)
xsd:boolean strdf:relate(strdf:geometry A, strdf:geometry B,
                         xsd:string intersectionPatternMatrix)
```

- **Egenhofer**
- **RCC-8**

stSPARQL: Geospatial SPARQL 1.1

Spatial analysis functions

- **Construct new geometric objects from existing geometric objects**

```
strdf:geometry strdf:boundary(strdf:geometry A)
strdf:geometry strdf:envelope(strdf:geometry A)
strdf:geometry strdf:convexHull(strdf:geometry A)
strdf:geometry strdf:intersection(strdf:geometry A, strdf:geometry B)
strdf:geometry strdf:union(strdf:geometry A, strdf:geometry B)
strdf:geometry strdf:difference(strdf:geometry A, strdf:geometry B)
strdf:geometry strdf:symDifference(strdf:geometry A, strdf:geometry B)
strdf:geometry strdf:buffer(strdf:geometry A, xsd:double distance, xsd:anyURI units)
```

- **Spatial metric functions**

```
xsd:float strdf:distance(strdf:geometry A, strdf:geometry B, xsd:anyURI units)
xsd:float strdf:area(strdf:geometry A)
```

- **Spatial aggregate functions**

```
strdf:geometry strdf:union(set of strdf:geometry A)
strdf:geometry strdf:intersection(set of strdf:geometry A)
strdf:geometry strdf:extent(set of strdf:geometry A)
```

stSPARQL: Geospatial SPARQL 1.1

Select clause

- Construction of new geometries (e.g., **`strdf:buffer(?geo, 0.1, uom:metre)`**)
- Spatial aggregate functions (e.g., **`strdf:union(?geo)`**)
- Metric functions (e.g., **`strdf:area(?geo)`**)

Filter clause

- Functions for testing topological spatial relationships between spatial terms (e.g., **`strdf:contains(?G1, strdf:union(?G2, ?G3))`**)
- Numeric expressions involving spatial metric functions (e.g., **`strdf:area(?G1) ≤ 2*strdf:area(?G2)+1`**)
- Boolean combinations

Having clause

- Boolean expressions involving spatial aggregate functions and spatial metric functions or functions testing for topological relationships between spatial terms (e.g., **`strdf:area(strdf:union(?geo))>1`**)

stSPARQL: An example (1/3)

Return the names of local communities that have been affected by fires

```
SELECT   ?name
WHERE {
  ?comm  rdf:type gag:LocalCommunity;
         gag:name ?name;
         gag:hasGeometry ?commGeo .
  ?ba  rdf:type noa:BurntArea;
       noa:hasGeometry ?baGeo .

  FILTER(strdf:overlaps(?commGeo,?baGeo))
}
```

Spatial Function

stSPARQL: An example (2/3)

Find all burnt forests near local communities

```
SELECT ?ba ?baGeom
WHERE {
   ?r rdf:type clc:Region;
      clc:hasGeometry ?rGeom;
      clc:hasCorineLandUse ?f.
   ?f rdfs:subClassOf clc:Forest.
   ?c rdf:type gag:LocalCommunity;
      gag:hasGeometry ?cGeom.
   ?ba rdf:type noa:BurntArea;
       noa:hasGeometry ?baGeom.

   FILTER(  strdf:intersects(?rGeom,?baGeom)  &&

   strdf:distance(?baGeom,?cGeom,uom:metre) < 200)}
```

Spatial Functions

stSPARQL: An example (3/3)

Compute the parts of burnt areas that lie in coniferous forests.

Spatial Aggregate

```
SELECT ?burntArea
(strdf:intersection(?baGeom,
                    strdf:union(?fGeom))
 AS ?burntForest)
WHERE {
   ?burntArea   rdf:type noa:BurntArea;
                noa:hasGeometry ?baGeom.
   ?forest rdf:type clc:Region;
           clc:hasLandCover clc:ConiferousForest;
           clc:hasGeometry ?fGeom.

   FILTER(strdf:intersects(?baGeom,?fGeom))
}
GROUP BY ?burntArea ?baGeom
```

Spatial Function

Time dimensions in Linked Data

User-defined time: A time value (literal) with no special semantics.

Valid time: The time when a fact (represented by a triple) is true in the modeled reality.

Transaction time: The time when the triple is current in the database.

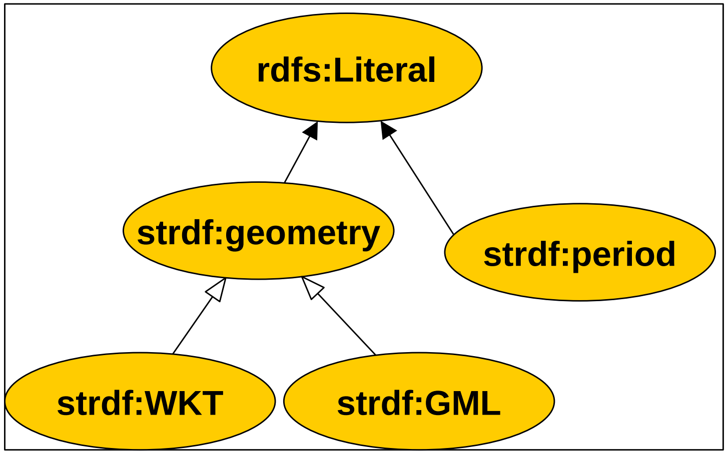
The time dimension of stRDF: The valid time of triples

The following extensions are introduced in stRDF:

- **Timeline:** the (discrete) value space of the datatype `xsd:dateTime` of XML-Schema

- Two kinds of time primitives are supported: **time instants** and **time periods**.
  - A **time instant** is an element of the time line.
  - A **time period** is an expression of the form [B, E) or [B, E] or (B, E] or (B, E) where B and E are time instants called the beginning and ending time of the period.

- The new datatype `strdf:period` is introduced.



The time dimension of stRDF (cont'd)

- **Triples** are extended to **quads**.

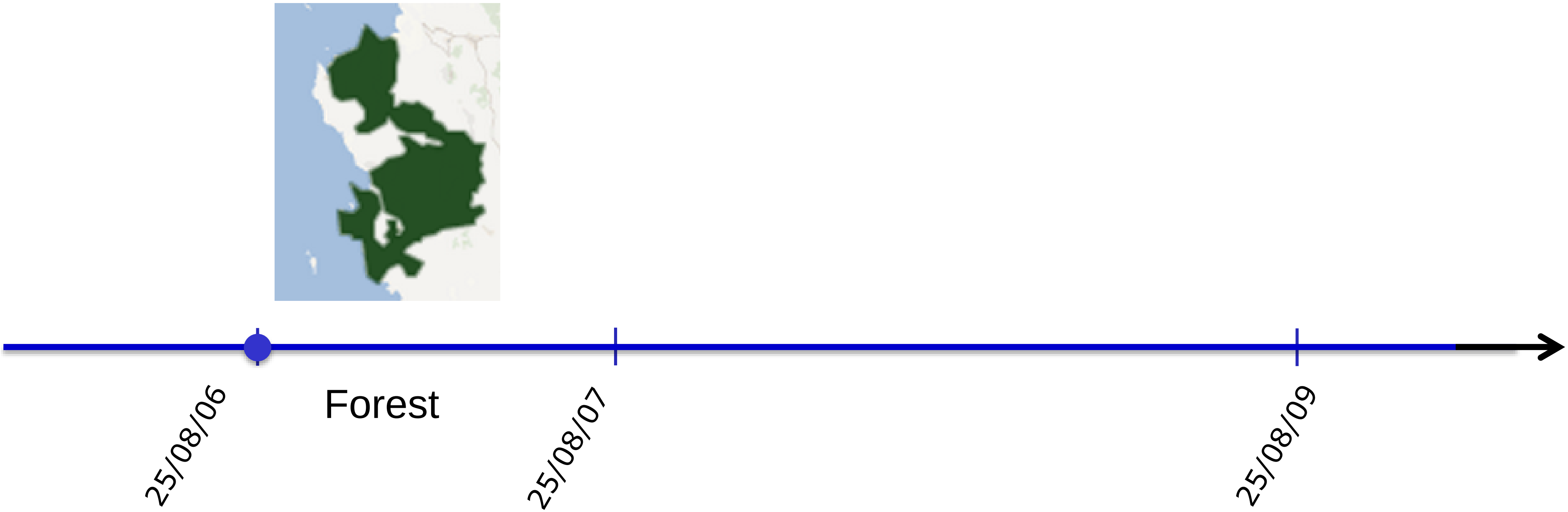
- A **temporal triple (quad)** is an expression of the form

  `s p o t.`

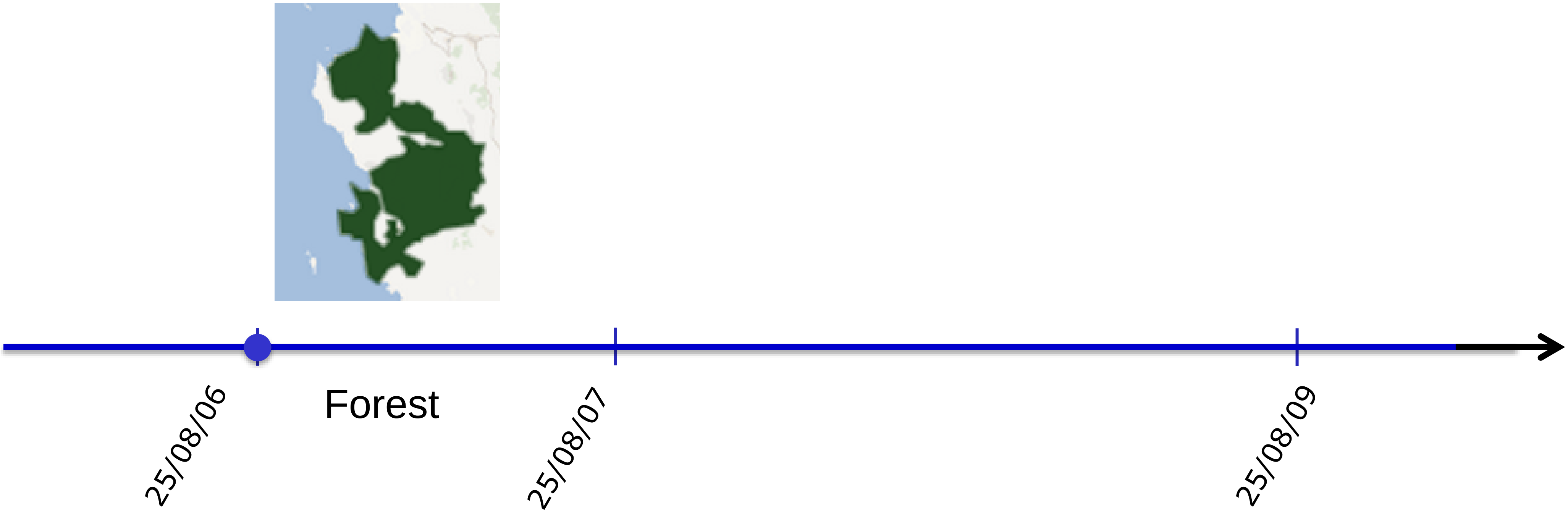
  where `s p o.` is an RDF triple and `t` is a time instant or time period called the **valid time** of the triple.

- The **temporal constants** `NOW` and `UC` ("until changed") are introduced.

An example with valid time

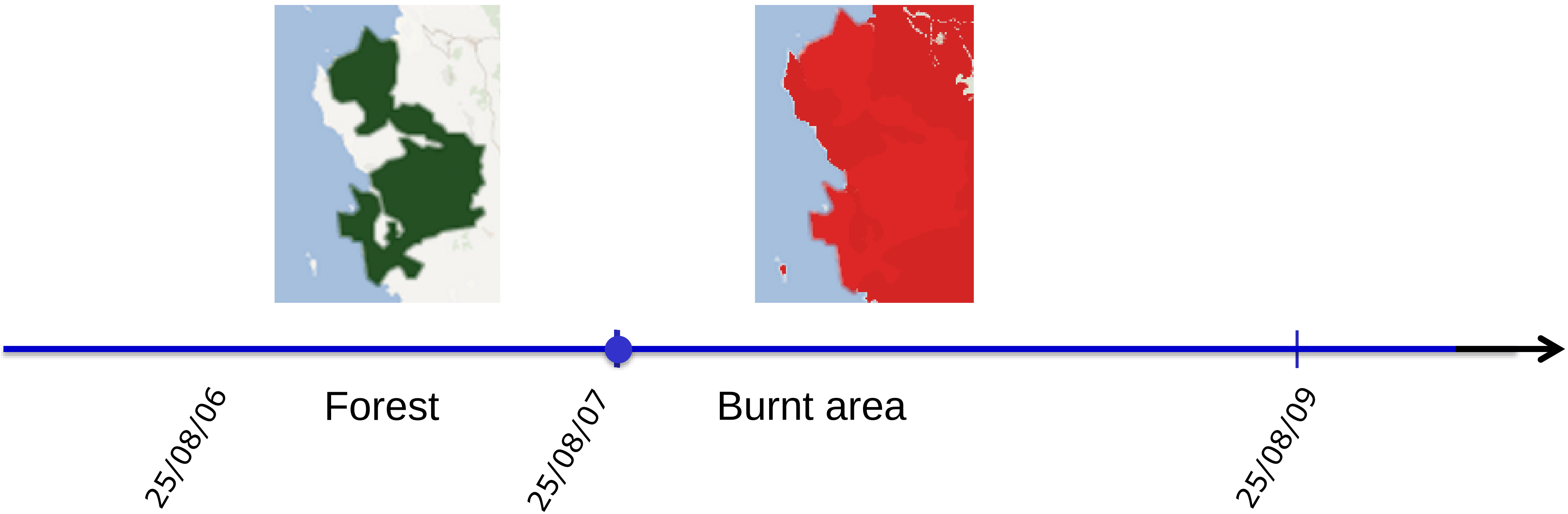


An example with valid time



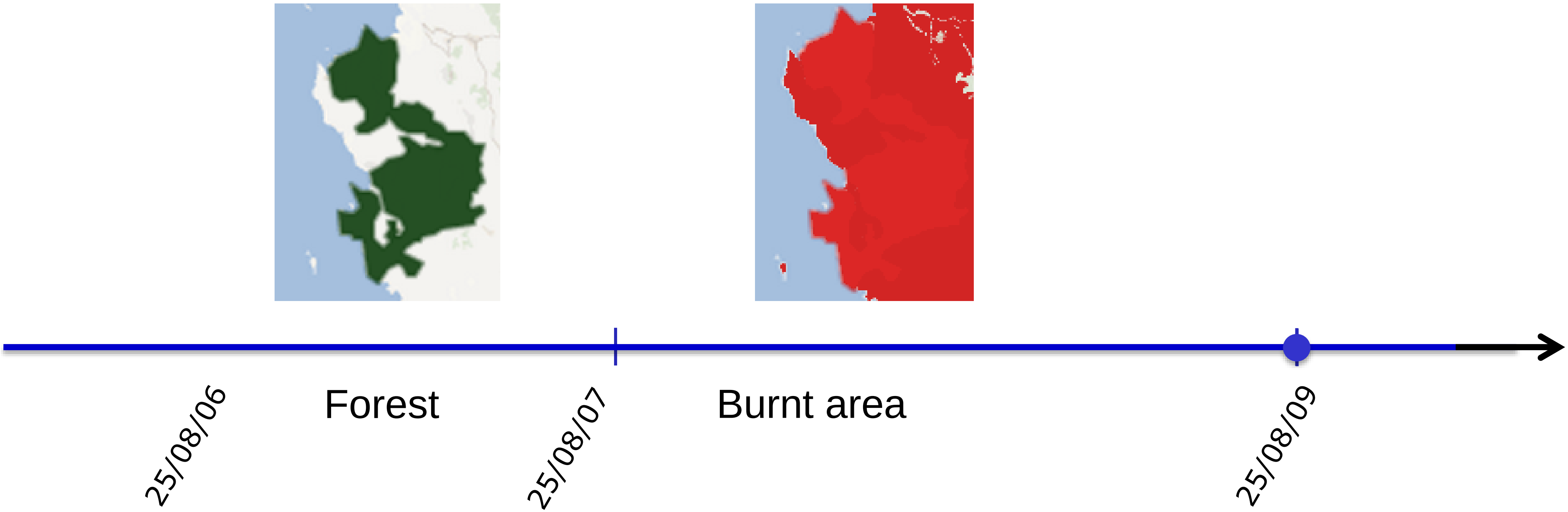

```
clc:region1 clc:hasLandCover clc:Forest
                    "[2006-08-25T11:00:00+02, "UC")"^^strdf:period .
```

An example with valid time




```
clc:region1 clc:hasLandCover clc:Forest
                    "[2006-08-25T11:00:00+02, "UC")"^^strdf:period .
```

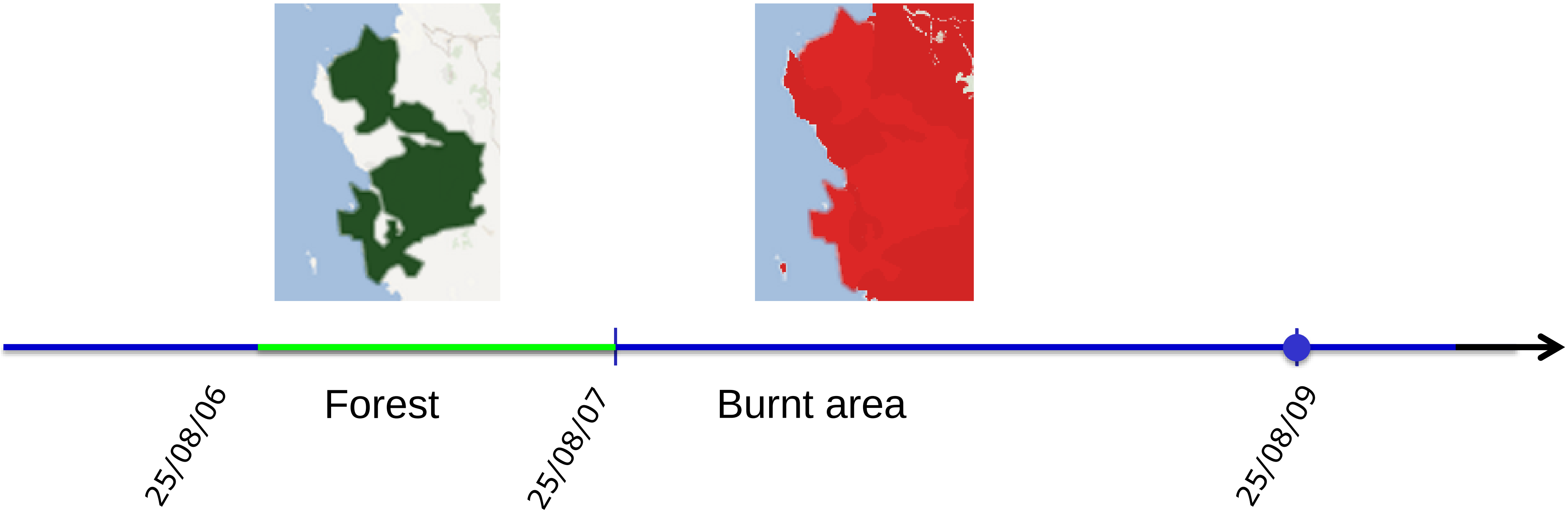
An example with valid time




```
clc:region1 clc:hasLandCover clc:Forest
                        "[2006-08-25T11:00:00+02, "UC")"^^strdf:period .

noa:ba1 rdf:type noa:BurntArea
                        "[2007-08-25T11:00:00+02, "UC")"^^strdf:period .
```

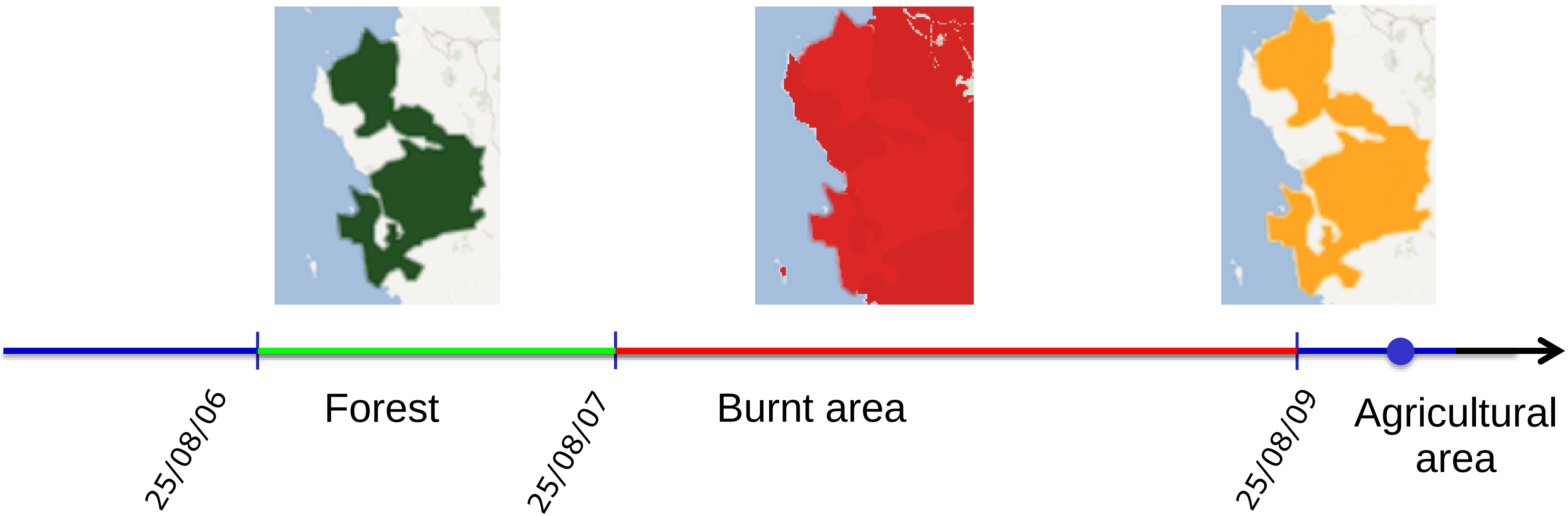
An example with valid time




```
clc:region1 clc:hasLandCover clc:Forest
   "[2006-08-25T11:00:00+02,2007-08-25T11:00:00+02)"^^strdf:period .

noa:ba1 rdf:type noa:BurntArea
                   "[2007-08-25T11:00:00+02, "UC"))"^^strdf:period .
```

An example with valid time




```
clc:region1 clc:hasLandCover clc:Forest
   "[2006-08-25T11:00:00+02,2007-08-25T11:00:00+02)"^^strdf:period .

noa:ba1 rdf:type noa:BurntArea
   "[2007-08-25T11:00:00+02,2009-08-25T11:00:00+02)"^^strdf:period .

clc:region1 clc:hasLandCover clc:AgriculturalArea
                    "[2009-08-25T11:00:00+02, "UC")"^^strdf:period .
```

The time dimension of stSPARQL

The following extensions are introduced:

- **Triple patterns** are extended to **quad patterns** (the last component is a **temporal term**: variable or constant)

- **Temporal extension functions** are introduced:
    - Allen's temporal relations (e.g., `strdf:after`)
    - Period constructors (e.g., `strdf:period_intersect`)
    - Temporal aggregates (e.g., `strdf:maximalPeriod`)

Example Query

- Find the **current** land cover of all areas in the dataset

```
SELECT ?clc
WHERE {
        ?R rdf:type clc:Region .
        ?R clc:hasLandCover ?clc ?t1 .
        FILTER(strdf:during ("NOW", ?t1))
}
```

Quad Pattern

Temporal constant

Temporal extension function

Two Proposals

- stRDF/stSPARQL
- **GeoSPARQL**

GeoSPARQL

GeoSPARQL is an **OGC standard**.

[Perry and Herring, 2012]

Functionalities **similar to stRDF/stSPARQL**:

- Geometries are represented using **literals** of **spatial datatypes**.
- Literals are serialized using **WKT** and **GML**.
- The same families of **functions** are offered for querying geometries.

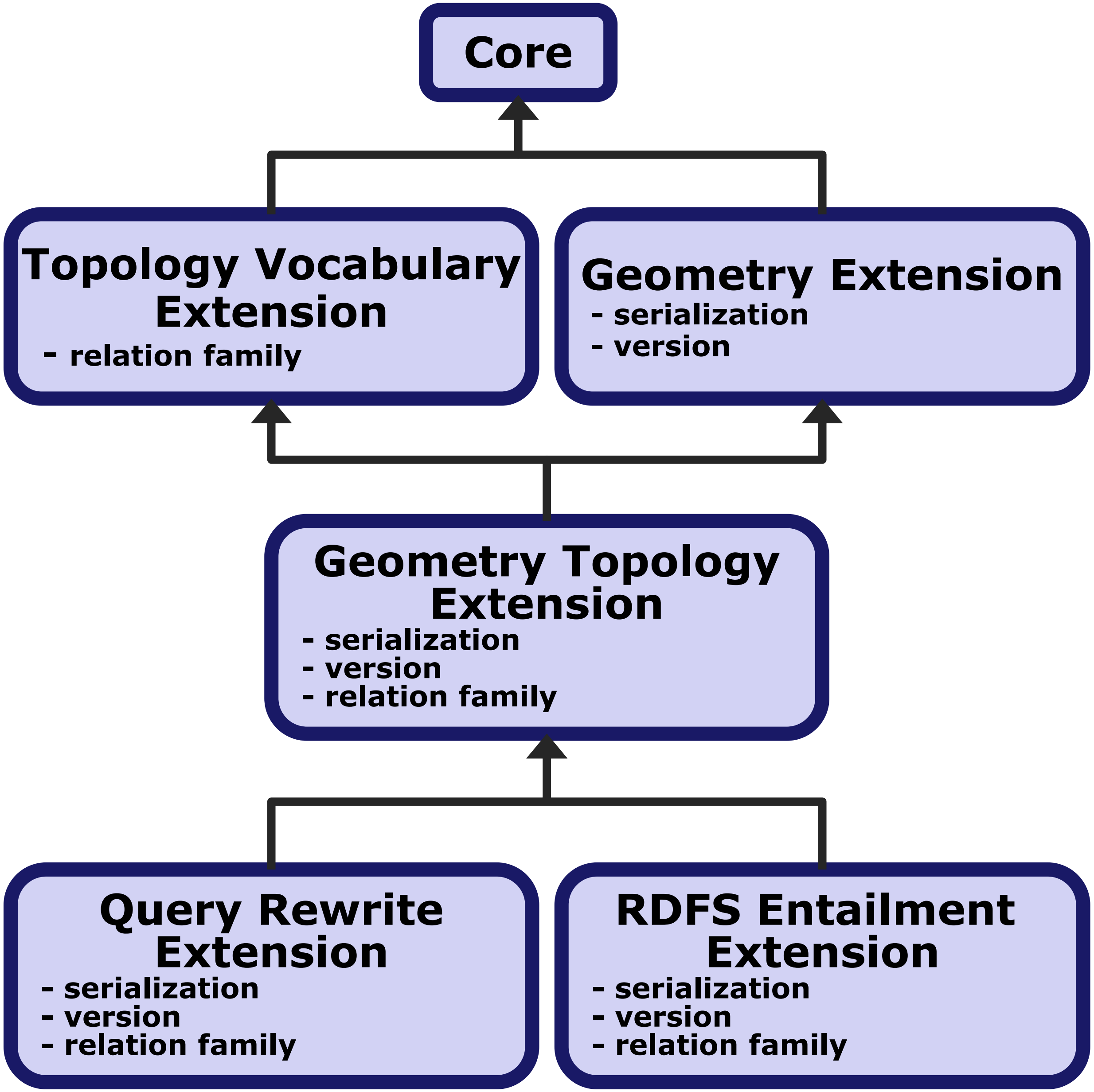
Functionalities **beyond stSPARQL**:

- **High level ontologies** inspired from GIS terminology.
- **Topological relations** can now be **asserted** as well so that reasoning and querying on them is possible.
- A **query rewriting** mechanism.

Functionalities of stSPARQL that are **not included in GeoSPARQL**:

- **Geospatial aggregate functions**
- **Temporal dimension**

GeoSPARQL Components

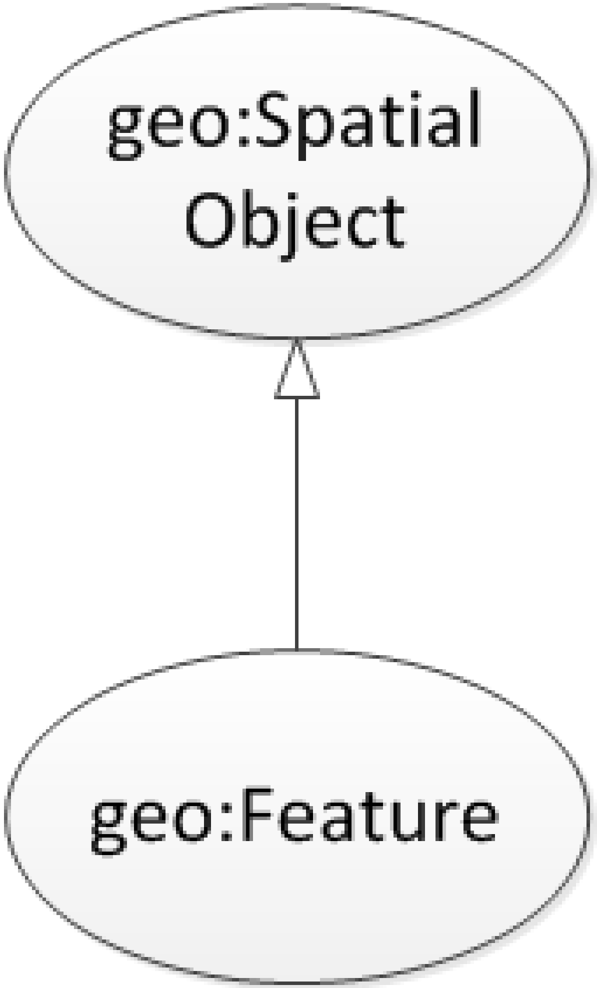


Parameters

- **Serialization**
  - WKT
  - GML
- **Relation Family**
  - Simple Features
  - RCC-8
  - Egenhofer

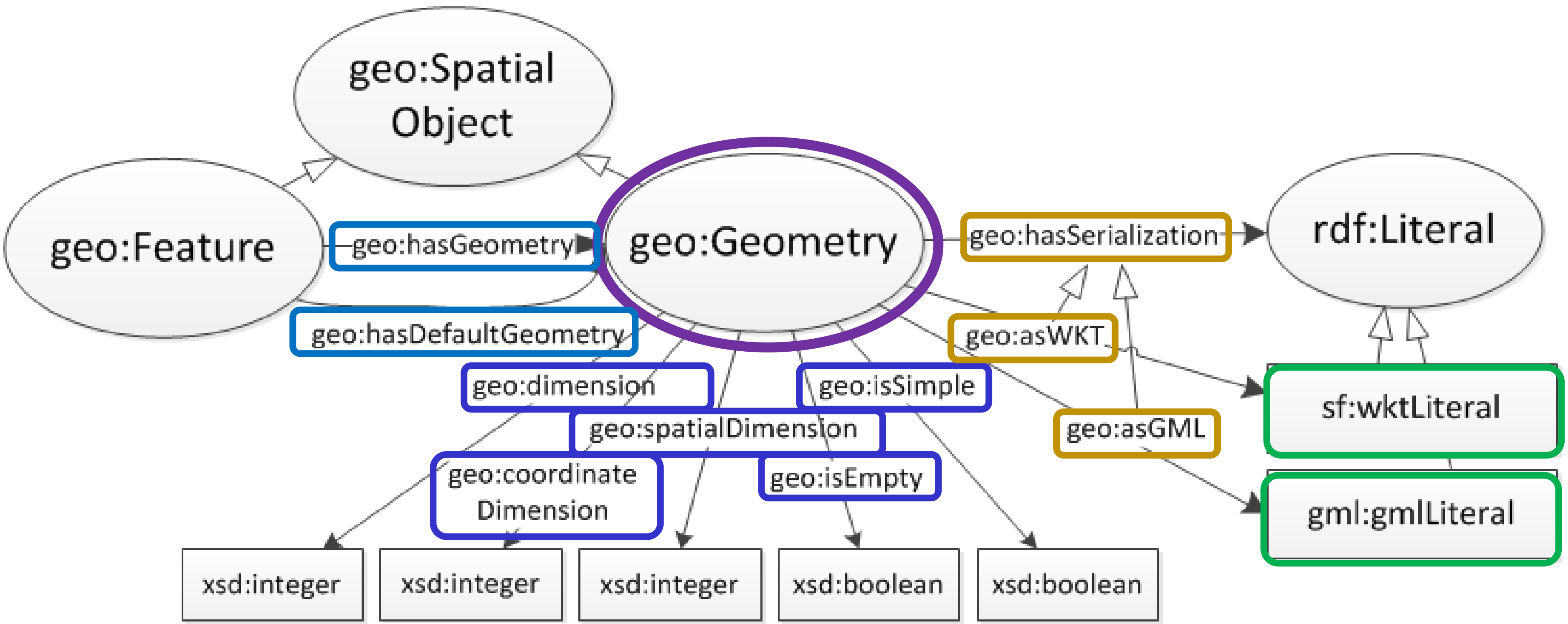
GeoSPARQL Core

Defines two **top level classes** that can be used to organize geospatial data.

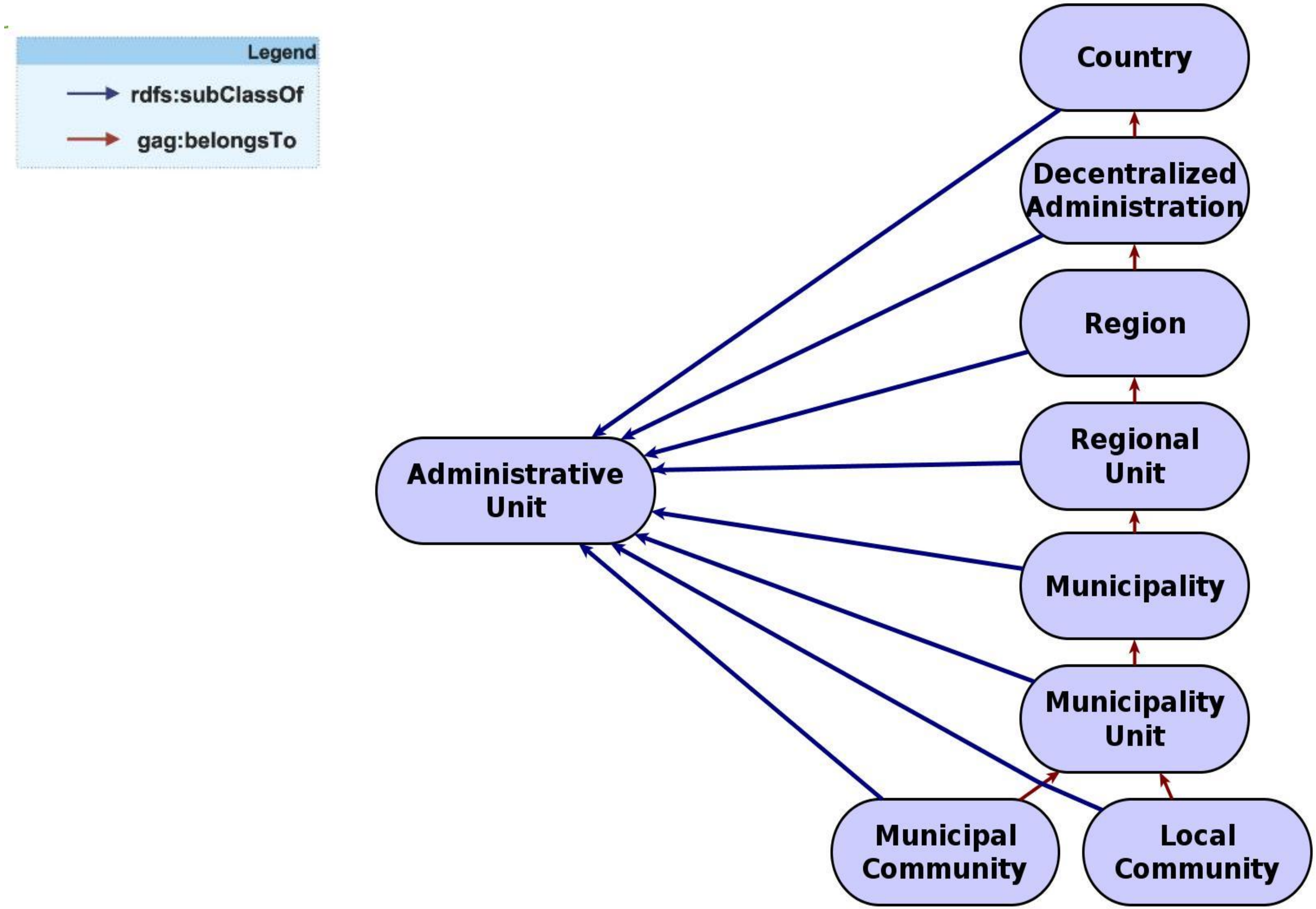


GeoSPARQL Geometry Extension

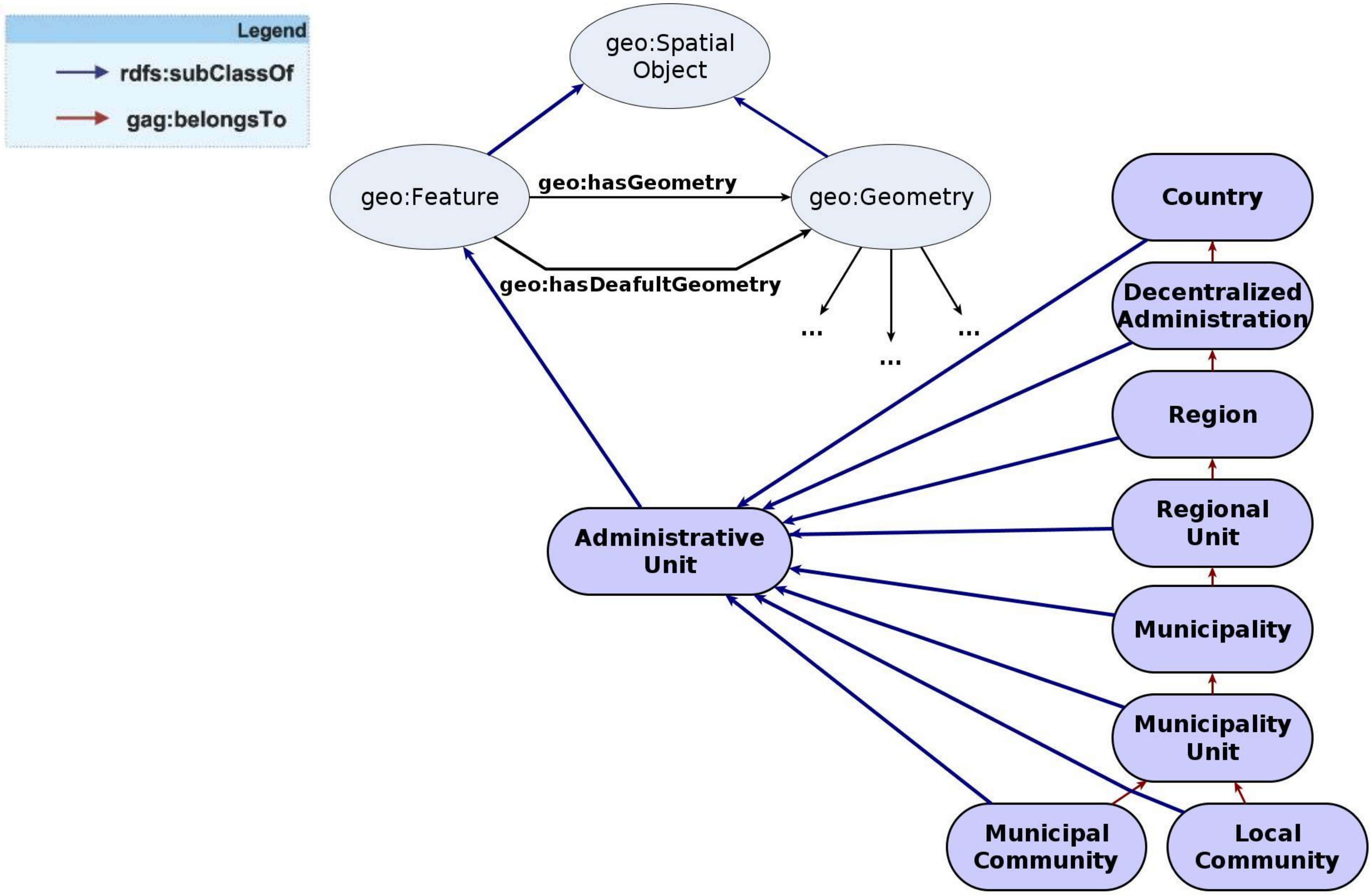
Provides vocabulary for asserting and querying data about the **geometric attributes of a feature.**



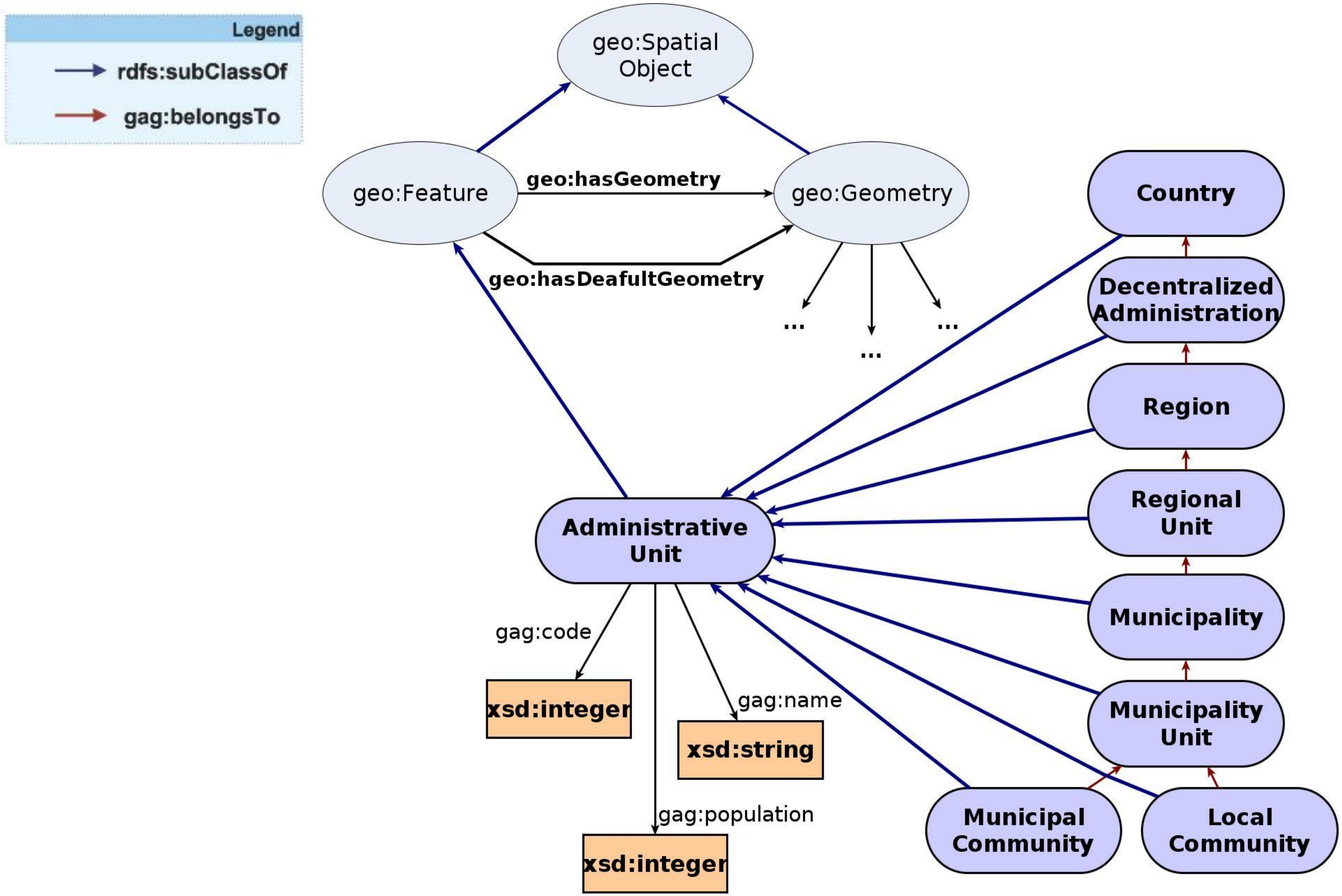
Example Ontology: Greek Administrative Geography



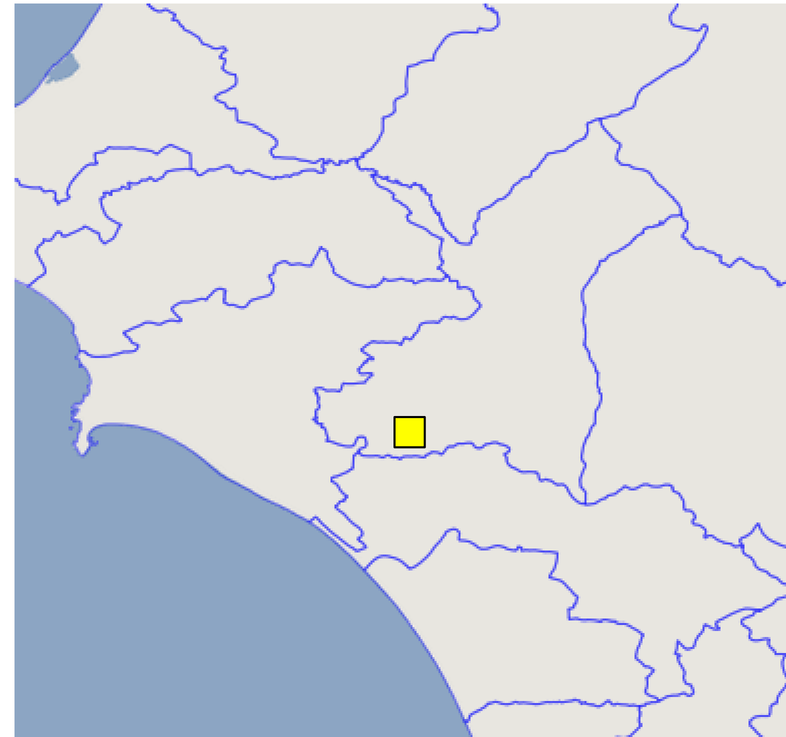
Greek Administrative Geography



Greek Administrative Geography



Example Data



```
gag:Olympia
  rdf:type gag:MunicipalCommunity;
  gag:name "Ancient Olympia";
  gag:population "184"^^xsd:int;
  geo:hasGeometry ex:polygon1.
```

Property from Geometry extension

Class from Geometry extension

```
ex:polygon1
  rdf:type geo:Geometry;
  geo:asWKT "http://www.opengis.net/def/crs/OGC/1.3/CRS84
              POLYGON((21.5 18.5,23.5 18.5,
                        23.5 21,21.5 21,21.5 18.5))"
                ^^sf:wktLiteral.
```

Geometry literal

Property from Geometry extension

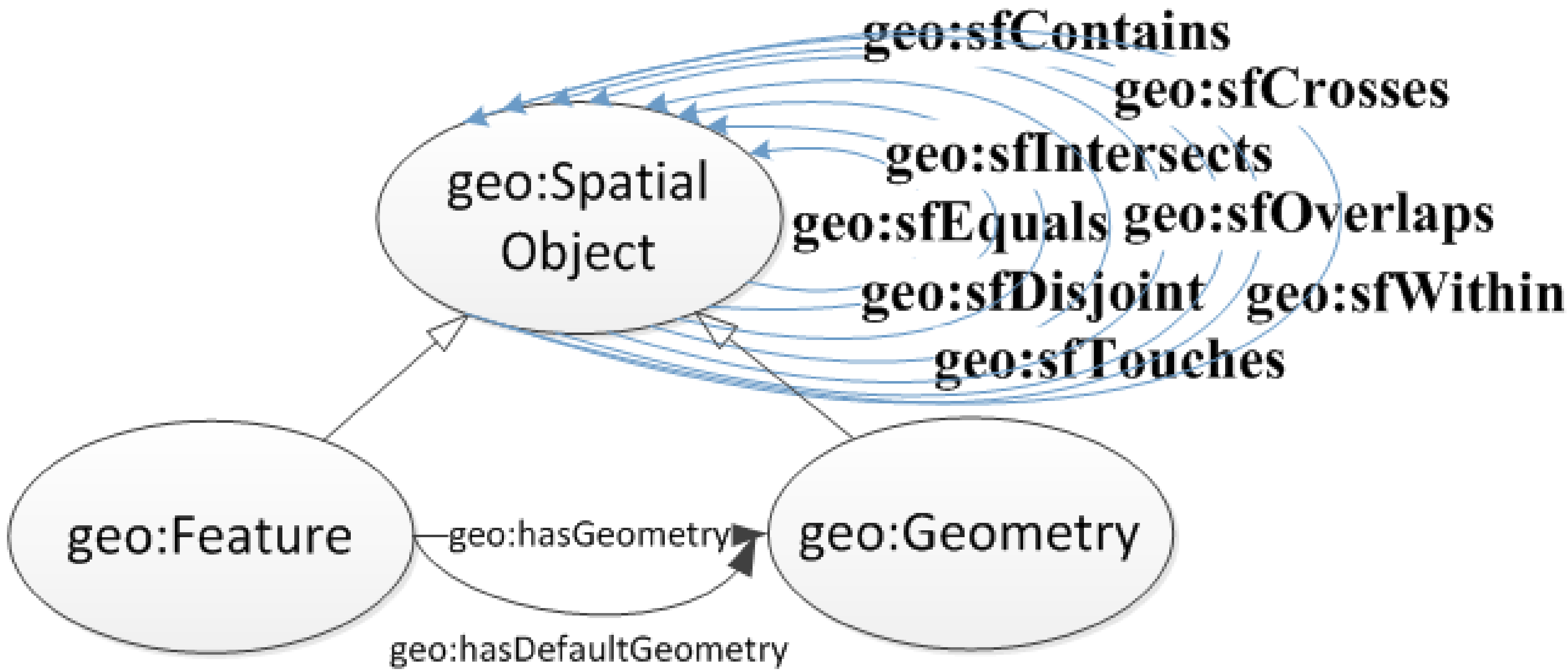
Datatype from Geometry extension

Non-Topological Query Functions of the Geometry Extension

- The following non-topological query functions are also offered:
  - `geof:distance`
  - `geof:buffer`
  - `geof:convexHull`
  - `geof:intersection`
  - `geof:union`
  - `geof:difference`
  - `geof:symDifference`
  - `geof:envelope`
  - `geof:boundary`

GeoSPARQL Topology Vocabulary Extension

- The extension is parameterized by the family of topological relations supported.
  - Topological relations for simple features



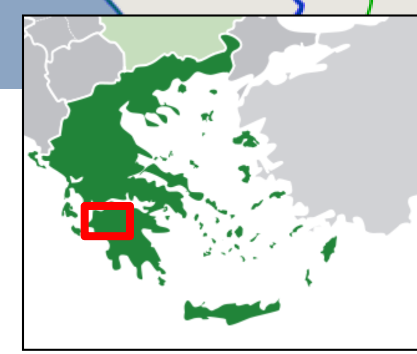
  - The Egenhofer relations e.g., **`geo:ehMeet`**
  - The RCC-8 relations e.g., **`geo:rcc8ec`**

Greek Administrative Geography

```
gag:Olympia
  rdf:type gag:MunicipalCommunity;
  gag:name "Ancient Olympia".

gag:OlympiaMUnit
  rdf:type gag:MunicipalityUnit;
  gag:name "Municipality Unit of
                 Ancient Olympia".

gag:OlympiaMunicipality
  rdf:type gag:Municipality;
  gag:name "Municipal
                 Anc
```



Simple Features topological relation

```
gag:Olympia geo:sfWithin gag:OlympiaMUnit .

gag:OlympiaMUnit geo:sfWithin gag:OlympiaMunicipality.
```

GeoSPARQL: An example

Find the **municipality unit** that contains the community of Ancient Olympia

```
SELECT   ?m
WHERE {
  ?m rdf:type gag:MunicipalityUnit.
  ?m geo:sfContains gag:Olympia.
}
```

Simple Features topological relation

Answer: **?m = gag:OlympiaMUnit**

GeoSPARQL: An example

Find the **municipality** that contains the community of Ancient Olympia

```
SELECT  ?m
WHERE {
 ?m rdf:type gag:Municipality.
 ?m geo:sfContains gag:Olympia.
}
```

Answer?

Example (cont'd)

The answer to the previous query is

`?m = gag:OlympiaMunicipality`

GeoSPARQL does not tell you how to compute this answer which needs **reasoning about the transitivity** of relation **`geo:sfContains`**.

Options:

- Use rules
- Use constraint-based techniques

The Geometry Topology Extension

- Offers vocabulary for **querying topological properties** of geometry literals.

- **Simple Features**
  - `geof:relate`
  - `geof:sfEquals`
  - `geof:sfDisjoint`
  - `geof:sfIntersects`
  - `geof:sfTouches`
  - `geof:sfCrosses`
  - `geof:sfWithin`
  - `geof:sfContains`
  - `geof:sfOverlaps`

- **Egenhofer** (e.g., `geof:ehDisjoint`)
- **RCC-8** (e.g., `geof:rcc8dc`)

Example Query

Return the names of local communities that have been affected by fires

```
SELECT   ?name
WHERE {
   ?comm  rdf:type gag:LocalCommunity;
          gag:name ?name;
          geo:hasGeometry ?commGeo .
   ?ba  rdf:type noa:BurntArea;
        geo:hasGeometry ?baGeo .

   FILTER(geof:sfOverlaps(?commGeo,?baGeo))
}
```

Geometry Extension Property

Geometry Extension Property

Geometry Topology Extension Function

GeoSPARQL Query Rewrite Extension

- Provides a collection of **RIF rules** that use topological extension functions to establish the existence of topological predicates.

- Example: given the RIF rule named **`geor:sfWithin`**, the serializations of the geometries of **`gag:Athens`** and **`gag:Greece`** named **`AthensWKT`** and **`GreeceWKT`** and the fact that

`geof:sfWithin(AthensWKT, GreeceWKT)`

returns true from the computation of the two geometries, we can derive the triple

`gag:Athens geo:sfWithin gag:Greece`

- One possible implementation is to re-write a given SPARQL query.

RIF Rule

Feature - Feature

Feature - Geometry

Geometry - Feature

Geometry - Geometry

```
Forall ?f1 ?f2 ?g1 ?g2 ?g1Serial ?g2Serial
  (?f1[geo:sfWithin->?f2] :-
    Or(
      And (?f1[geo:hasDefaultGeometry->?g1]
           ?f2[geo:hasDefaultGeometry->?g2]
           ?g1[ogc:asGeomLiteral->?g1Serial]
           ?g2[ogc:asGeomLiteral->?g2Serial]
           External(geof:sfWithin (?g1Serial,?g2Serial)))

      And (?f1[geo:hasDefaultGeometry->?g1]
           ?g1[ogc:asGeomLiteral->?g1Serial]
           ?f2[ogc:asGeomLiteral->?g2Serial]
           External(geof:sfWithin (?g1Serial,?g2Serial)))

      And (?f2[geo:hasDefaultGeometry->?g2]
           ?f1[ogc:asGeomLiteral->?g1Serial]
           ?g2[ogc:asGeomLiteral->?g2Serial]
           External(geof:sfWithin (?g1Serial,?g2Serial)))

      And (?f1[ogc:asGeomLiteral->?g1Serial]
           ?f2[ogc:asGeomLiteral->?g2Serial]
           External(geof:sfWithin (?g1Serial,?g2Serial)))
))
```

Example

Find all features that are inside the municipality of Ancient Olympia

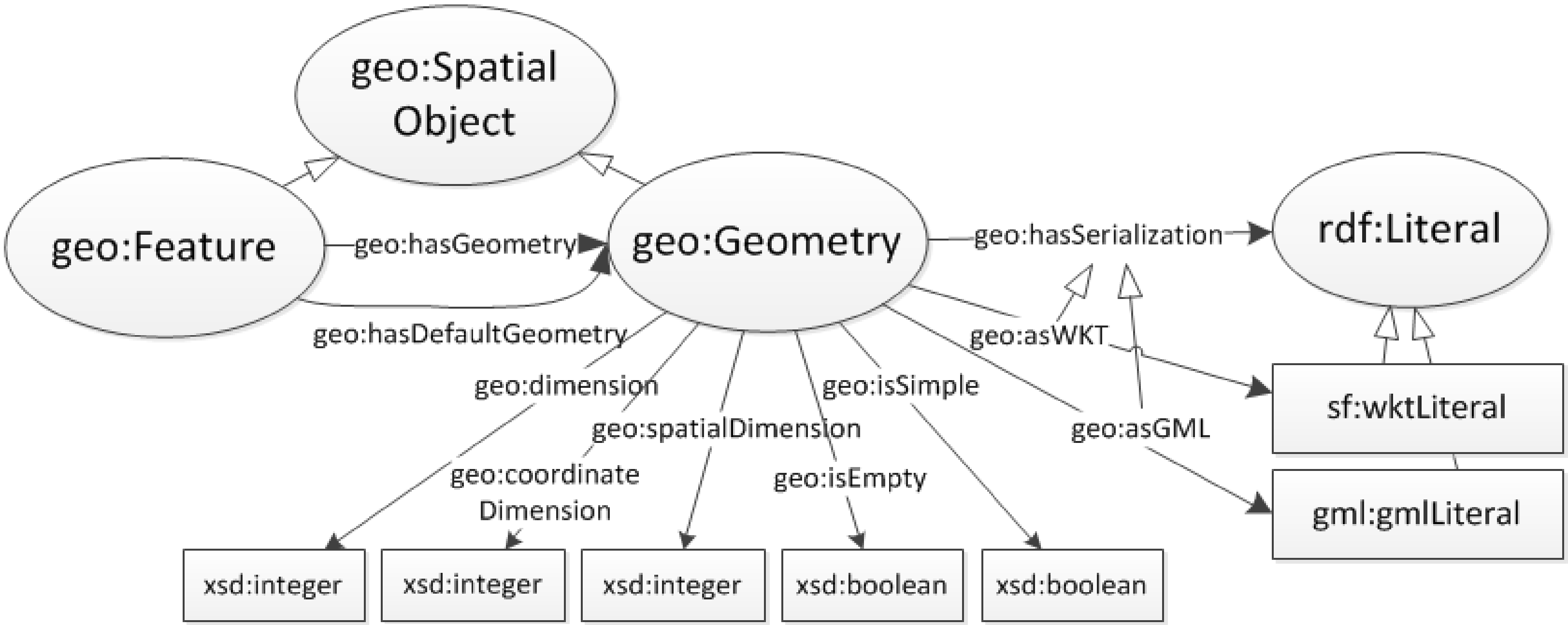
```
SELECT ?feature
WHERE {
?feature geo:sfWithin
             geonames:OlympiaMunicipality.
}
```

Rewritten Query

```
SELECT ?feature
WHERE { {?feature geo:sfWithin geonames:Olympia }
        UNION
        { ?feature geo:hasDefaultGeometry ?featureGeom .
          ?featureGeom geo:asWKT ?featureSerial .
          geonames:Olympia geo:hasDefaultGeometry ?olGeom .
          ?olGeom geo:asWKT ?olSerial .
          FILTER (geof:sfWithin (?featureSerial, ?olSerial)) }
        UNION { ?feature geo:hasDefaultGeometry ?featureGeom .
          ?featureGeom geo:asWKT ?featureSerial .
          geonames:Olympia geo:asWKT ?olSerial .
          FILTER (geof:sfWithin (?featureSerial, ?olSerial)) }
        UNION { ?feature geo:asWKT ?featureSerial .
          geonames:Olympia geo:hasDefaultGeometry ?olGeom .
          ?olGeom geo:asWKT ?olSerial .
          FILTER (geof:sfWithin (?featureSerial, ?olSerial)) }
        UNION {
          ?feature geo:asWKT ?featureSerial .
          geonames:Olympia geo:asWKT ?olSerial .
          FILTER (geof:sfWithin (?featureSerial, ?olSerial)) }
```

GeoSPARQL RDFS Entailment Extension

- Specifies the RDFS entailments that follow from the class and property hierarchies defined in the other components e.g., the Geometry Extension.



- Systems should use an implementation of RDFS entailment to allow the derivation of new triples from those already in a graph.

Example

Given the triples

```
ex:f1 geo:hasGeometry ex:g1 .
geo:hasGeometry rdfs:domain geo:Feature.
```

we can infer the following triples:

```
ex:f1 rdf:type geo:Feature .
ex:f1 rdf:type geo:SpatialObject .
```

Readings

- Material from the Strabon web site (http://strabon.di.uoa.gr).
- The following tutorial paper which introduces to the topic of linked geospatial data:
  M. Koubarakis, M. Karpathiotakis, K. Kyzirakos, C. Nikolaou and M. Sioutis. *Data Models and Query Languages for Linked Geospatial Data*. Reasoning Web Summer School 2012.
  http://strabon.di.uoa.gr/files/survey.pdf
- The following paper which introduces stSPARQL and Strabon:
  K. Kyzirakos, M. Karpathiotakis and M. Koubarakis. Strabon: A Semantic Geospatial DBMS. 11th International Semantic Web Conference (ISWC 2012). November 11-15, 2012. Boston, USA.
  http://iswc2012.semanticweb.org/sites/default/files/76490289.pdf
- The following paper which introduces the temporal features of stSPARQL and Strabon:
  K. Bereta, P. Smeros and M. Koubarakis. Representing and Querying the Valid Time of Triples for Linked Geospatial Data. In the 10th Extended Semantic Web Conference (ESWC 2013). Montpellier, France. May 26-30, 2013.
  http://www.strabon.di.uoa.gr/files/eswc2013.pdf
- The GeoSPARQL standard found at http://www.opengeospatial.org/standards/geosparql

Readings (cont'd)

- The following paper which introduces the RDF^i framework:
  Charalampos Nikolaou and Manolis Koubarakis. Incomplete Information in RDF. In the 7th International Conference on Web Reasoning and Rule Systems (RR 2013). Mannheim, Germany. July 27-29, 2013.
  http://cgi.di.uoa.gr/~koubarak/publications/rr2013.pdf

- The following paper which introduces the benchmark Geographica:
  G. Garbis, K. Kyzirakos and M. Koubarakis. Geographica: A Benchmark for Geospatial RDF Stores. In the 12th International Semantic Web Conference (ISWC 2013). Sydney, Australia. October 21-25, 2013.
  http://cgi.di.uoa.gr/~koubarak/publications/Geographica.pdf