Modeling and Querying Metadata in the Semantic Sensor Web: stRDF and stSPARQL

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Talk Outline

- Motivation
- The Data Model stRDF
- The Query Language stSPARQL
- Implementation
- Future Work

Motivation

- The vision of the **Semantic Sensor Web**: annotate sensor data and services to enable discovery, integration, interoperability etc. (Sheth et al. 2008, SemsorGrid4Env)
- Sensor annotations involve **thematic, spatial** and **temporal metadata.** Examples:
  - The sensor measures temperature. (thematic)
  - The sensor is located in the location represented by point (A, B). (spatial)
  - The sensor measured -3^0 Celsius on 26/01/2010 at 03:00pm. (temporal)
- RDF can represent thematic metadata. How about spatial and temporal metadata?

Previous Work

- Time in RDF (Gutierrez and colleagues, 2005).
- SPARQL-ST (Perry, 2008).
- SPAUK (Kollas, 2007)

Our Approach

- Use ideas from **constraint databases** (Kanellakis, Kuper and Revesz, 1991). **Slogan:** What's in a tuple? Constraints.
- Extend RDF to a constraint database model. **Slogan:** What's in a triple? Constraints.
- Extend SPARQL to a constraint query language.
- Follow exactly the approach of CSQL (Kuper et al., 1998).
- Use **linear constraints** to represent spatial and temporal metadata.

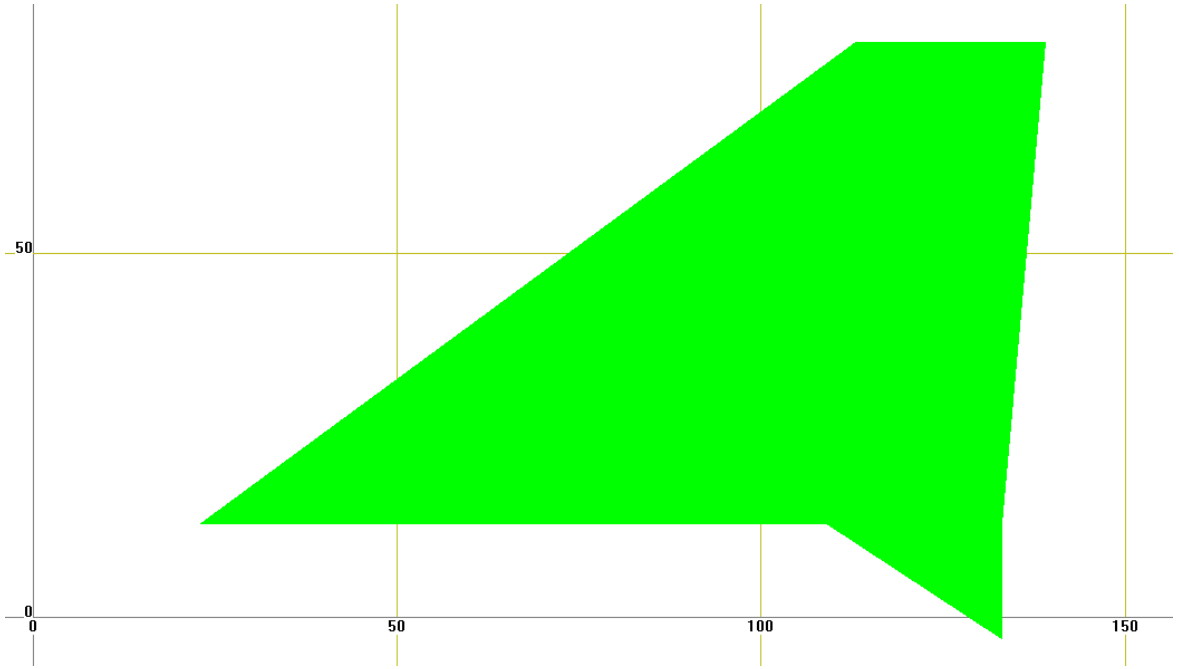
Spatial Metadata

- We start with a FO language $\mathcal{L} = \{\leq, +\} \cup \mathbb{Q}$ over the structure $\mathcal{Q} = \langle \mathbb{Q}, \leq, +, (q)_{q \in \mathbb{Q}} \rangle$.
- Atomic formulae: linear equations and inequalities of the form

$$(\sum_{i=1}^{p} a_i x_i) \Theta a_0$$

  where Θ is one of $=$, $\leq$ or $<$.
- **Semi-linear point sets**: sets that can be defined by quantifier-free formulas of $\mathcal{L}$.

Example



$$(-x + 1.363636y < -5.272576 \wedge x - 0.090909y < 131.818133 \wedge y < 79 \wedge -y < -13) \vee (y < 13 \wedge x < 133 \wedge -x - 1.5y < -128.5)$$

The sRDF data model

- Let I, B and L be the sets of IRIs, blank nodes and literals.
- Let C_k be the set of quantifier-free formulae of $\mathcal{L}$ with k free variables ($k = 1, 2, \ldots$).
- Let C be the infinite union $C_1 \cup C_2 \cup \cdots$.
- An **sRDF triple** is an element of the set $(I \cup B) \times I \times (I \cup B \cup L \cup C)$.
- An **sRDF graph** is a set of sRDF triples.
- sRDF can be realized as an extension of RDF with a new kind of **typed literals**: quantifier-free formulae with linear constraints. The datatype of these literals is `strdf:SemiLinearPointSet`.

Example of sRDF graph

```
ex:s1 rdf:type, ex:Sensor .
ex:s1 ex:has_location "x=40 and y=15"^^strdf:SemiLinearPointSet .
```

Introducing Time

- **Time structure**: the set of rational numbers $\mathbb{Q}$ (i.e., time is assumed to be linear, dense and unbounded).
- Temporal constraints are expressed by quantifier-free formulas of the language $\mathcal{L}$ defined earlier, but their syntax is limited to elements of the set C_1.
- **Atomic temporal constraints**: formulas of $\mathcal{L}$ of the following form: $x \sim c$, where x is a variable, c is a rational number and $\sim$ is $<, \leq, \geq, >, =$ or $\neq$.
- **Temporal constraints**: Boolean combinations of atomic temporal constraints using a single variable.

Example

$$t = 1 \vee (t \geq 5 \wedge t \leq 10) \vee (t \geq 12 \wedge t \leq 15)$$

The stRDF data model

stRDF extends sRDF with the ability to represent the **valid time** of a triple:

- An **stRDF quad** (a, b, c, τ) is an sRDF triple (a, b, c) with a fourth component τ which is a temporal constraint.
- An **stRDF graph** is a set of sRDF triples and stRDF quads.

Example of stRDF graph

```
ex:obs1Result om:uom ex:Celcius .
ex:obs1Result om:value "27"
                    "(10 <= t <= 11)"^^strdf:SemiLinearPointSet .
```

The Query Language stSPARQL

- Syntactic extension of SPARQL
- Formal semantics
- Closure
- Computability
- Low data complexity
- Efficient implementation

Example - Dataset I

Sensor metadata using the SSN ontology:

```
ex:sensor1 rdf:type ssn:Sensor .
ex:sensor1 ssn:measures ex:temperature .
ex:temperature rdf:type ssn:PhysicalQuality .
ex:sensor1 ssn:supports ex:grounding1 .
ex:grounding1 rdf:type ssn:SensorGrounding .
ex:grounding1 ssn:hasLocation ex:location1 .
ex:location1 rdf:type ssn:Location .
ex:location1 strdf:hasGeometry
                    "x=40 and y=15"^^strdf:SemiLinearPointSet .

ex:sensor2 rdf:type ssn:Sensor .
```

Queries - Dataset I

Spatial selection. Find the URIs of the sensors that are inside the rectangle R(0, 0, 100, 100)?

```
select  ?S
where { ?S rdf:type ssn:Sensor .
        ?G rdf:type ssn:SensorGrounding .
        ?L rdf:type ssn:Location .
        ?S ssn:supports ?G .
        ?G ssn:haslocation ?L .
        ?L strdf:hasGeometry ?GEO .
        filter(?GEO inside "0<=x<=100 and 0<=y<=100") }
```

Answer

?S
ex:sensor1

Queries - Dataset I

Spatial selection with OPTIONAL. Find the URIs of the sensors that optionally has a grounding that has a location which is inside the rectangle R(0, 0, 100, 100)?

```
select  ?S ?GEO
where { ?S rdf:type ssn:Sensor .
        optional {
                ?G rdf:type ssn:SensorGrounding .
                ?L rdf:type ssn:Location .
                ?S ssn:supports ?G .
                ?G ssn:haslocation ?L .
                ?L strdf:hasGeometry ?GEO .
                filter(?GEO inside "0<=x<=100 and 0<=y<=100") } }
```

Answer

?S	?GEO
ex:sensor1	"x=40 and y=15"^^strdf:SemiLinearPointSet
ex:sensor2	

Example - Dataset II

Sensor observation metadata using the O&M ontology:

```
ex:sensor1 rdf:type ex:TemperatureSensor .
ex:TemperatureSensor rdfs:subClassOf om:Sensor .
ex:obs1 rdf:type om:Observation .
ex:obs1 om:procedure ex:sensor1 .
ex:obs1 om:observedProperty ex:temperature .
ex:temperature rdf:type om:Property .
ex:obs1 om:observationLocation ex:obslocation1 .
ex:obslocation1 rdf:type om:Location .
ex:obslocation1 strdf:hasGeometry
                    "x=40 and y=15"^^strdf:SemiLinearPointSet .
ex:obs11 om:result ex:obs1Result .
ex:obs1Result rdf:type om:ResultData .
ex:obs1Result om:uom ex:Celcius .
ex:obs1Result om:value "27"
                    "(10 <= t <= 11)"^^strdf:SemiLinearPointSet .
```

Example - Dataset II (cont'd)

Metadata about geographical areas:

```
ex:area1 rdf:type ex:RuralArea .
ex:area1 ex:hasName "Brovallen" .
ex:area1 strdf:hasGeometry
           "(-x+1.363636y<-5.272576 and y<79 and -y<-13 and
              x-0.090909y<131.818133) or (y<13 and x<133 and
             -x-1.5y<-128.5)"^^strdf:SemiLinearPointSet .
```

Queries - Dataset II

Spatial and temporal selection. Find the values of all observations that were valid at time 11 and the rural area they refer to.

```
select  ?V ?RA
where { ?OBS rdf:type om:Observation .
        ?LOC rdf:type om:Location .
        ?R rdf:type om:ResultData .
        ?RA rdf:type ex:RuralArea .
        ?OBS om:observationLocation ?LOC .
        ?LOC strdf:hasGeometry ?OBSLOC .
        ?OBS om:result ?R .
        ?R om:value ?V ?T .
        ?RA strdf:hasGeometry ?RAGEO .
        filter(?T contains "t = 11" && ?RAGEO contains ?OBSLOC) }
```

Answer

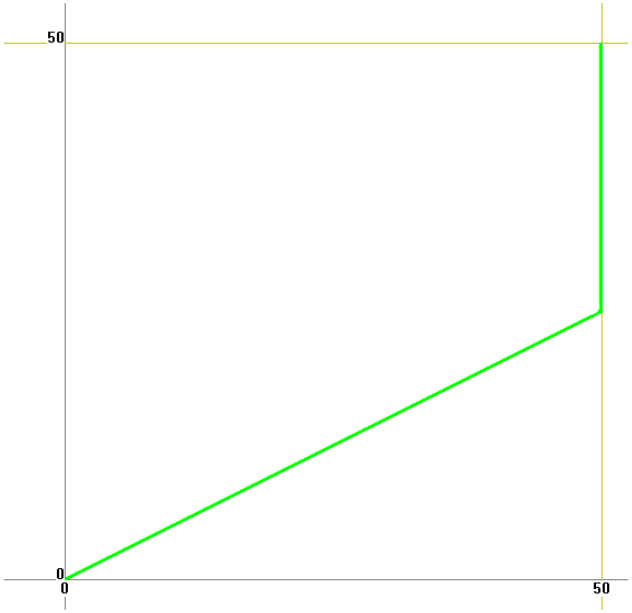
?V	?RA
"27"	ex:area1

Example - Dataset III

Moving sensor metadata using the SSN ontology:

```
ex:sensor2 rdf:type ssn:Sensor .
ex:sensor2 ssn:measures ex:temperature .
ex:sensor2 ssn:supports ex:grounding2 .
ex:grounding2 rdf:type ssn:SensorGrounding .
ex:grounding2 ssn:hasLocation ex:location2 .
ex:location2 rdf:type ssn:Location .
```

Example - Dataset III (cont'd)




```
ex:location2 strdf:hasTrajectory
              "(x=10t and y=5t and 0<=t<=5) or
               (y=5t and x=50 and 25<=y<=50)"^^strdf:SemiLinearPointSet.
```

Example - Dataset III (cont'd)

Metadata about geographical areas:

```
ex:area1 rdf:type ex:RuralArea .
ex:area1 ex:hasName "Brovallen" .
ex:area1 strdf:hasGeometry
           "(-x+1.363636y<-5.272576 and y<79 and -y<-13 and
              x-0.090909y<131.818133) or (y<13 and x<133 and
             -x-1.5y<-128.5)"^^strdf:SemiLinearPointSet .
```

Queries - Dataset III

Intersection of an area with a trajectory. Which areas of Brovallen were sensed by a moving sensor and when?

```
select  (?TR[1,2] INTER ?GEO) as ?SENSEDAREA   ?GEO[3]
where { ?SN rdf:type ssn:Sensor .
        ?Y rdf:type ssn:Location .
        ?X rdf:type  ssn:SensorGrounding .
        ?RA rdf:type ex:RuralArea .
        ?SN ssn:supports ?X .
        ?X ssn:hasLocation ?Y .
        ?Y strdf:hasTrajectory ?TR .
        ?RA ex:hasName "Brovallen" .
        ?RA strdf:hasGeometry ?GEO .
        filter(?TR[1,2] overlap ?GEO) }
```

Answer

?SENSEDAREA	?T1
"((y=0.5x and 0<=x<=50) or (x=50 and 25<=y<=50)) and ((y<79 and -y<-13 and -x+1.363636y<-5.272576 and x-0.090909y<131.818133) or (y<13 and x<133 and -x-1.5y<-128.5))" ^^strdf:SemiLinearPointSet	"0 <= t <= 10" ^^strdf:SemiLinearPointSet.

One More Query

Projection and spatial function application. Find the URIs of the sensors that are north of Brovallen.

```
select   ?SN
where  { ?SN rdf:type ssn:Sensor .
         ?X rdf:type ssn:SensorGrounding .
         ?RA rdf:type ex:RuralArea .
         ?SN ssn:supports ?X .
         ?X ssn:hasLocation ?Y .
         ?Y strdf:hasGeometry ?SN_LOC .
         ?RA ex:hasName "Brovallen".
         ?RA strdf:hasGeometry ?GEO .
         filter(MAX(?GEO[2])<MIN(?SN_LOC[2])) }
```

Answer

?SN

What Else is There in stSPARQL Syntax?

- k-ary spatial terms

  “$(x \geq 1 \wedge x = y) \vee y = 7$”

  $?GEO \cap$ “$(x \geq 1 \wedge x = y) \vee y = 7$”

  $BD(?GEO \cap$ “$(x \geq 1 \wedge x = y) \vee y = 7$”$)$

  “$(x \geq 1 \wedge x \leq 10 \wedge y \geq 0 \wedge x = z)$”$[1, 2] \cap$ “$(z \geq 0 \wedge z \leq 10)$”

- Metric spatial terms

  $AREA($“$(x \geq 1 \wedge x \leq 10 \wedge y \geq 0 \wedge x = y)$”$)$

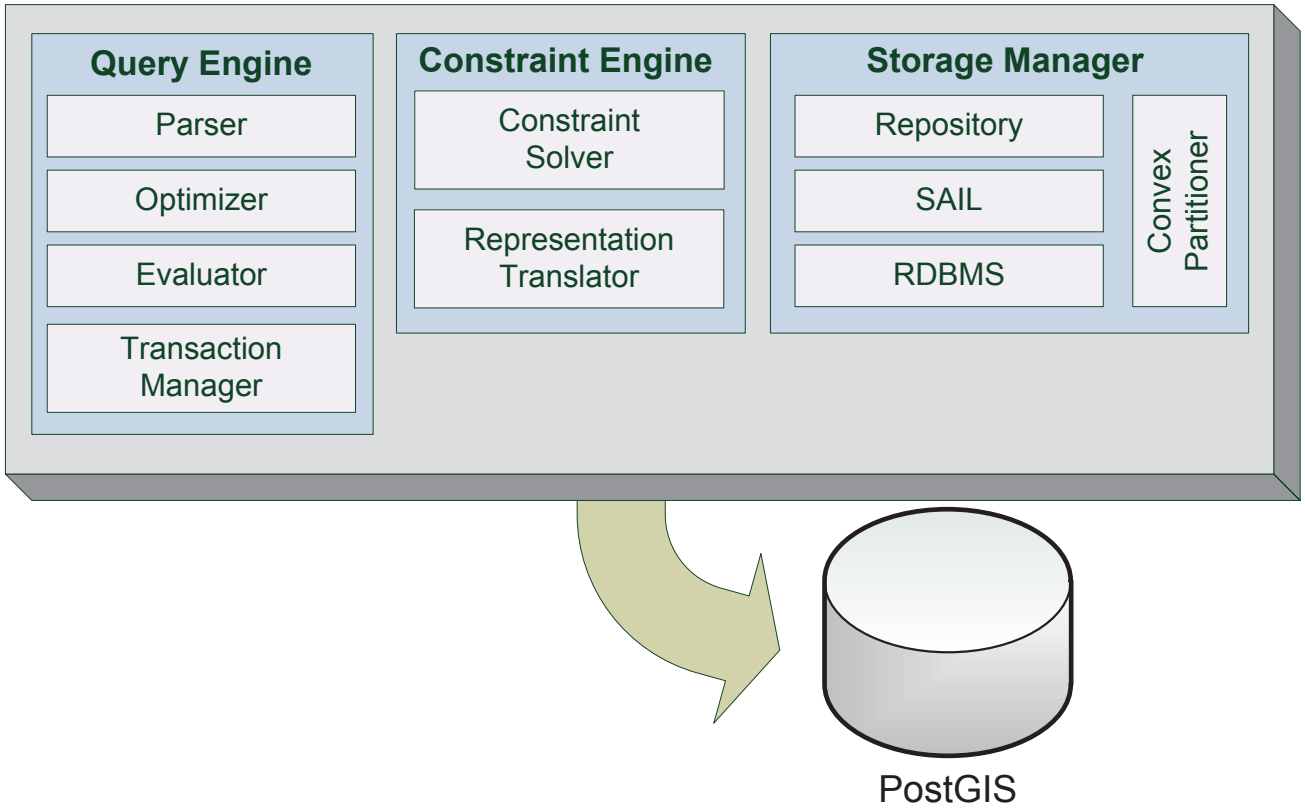
  $MIN($“$(x \geq 1 \wedge x \leq 10 \wedge y \geq 0 \wedge x = y)$”$[1])$

- Spatial and temporal selection predicates

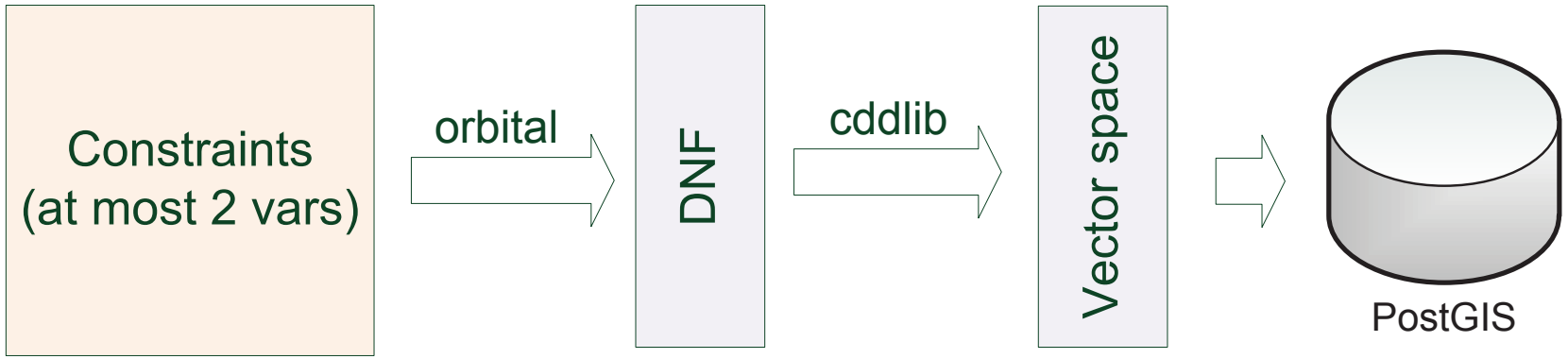
stSPARQL Semantics

- Extension of the SPARQL semantics of (Perez et al., 2006).
  - Extend the concept of mapping.
  - The semantics of AND, OPT, UNION remain the same.
  - We need to define carefully the evaluation of spatial terms and the semantics of spatial and temporal filters.

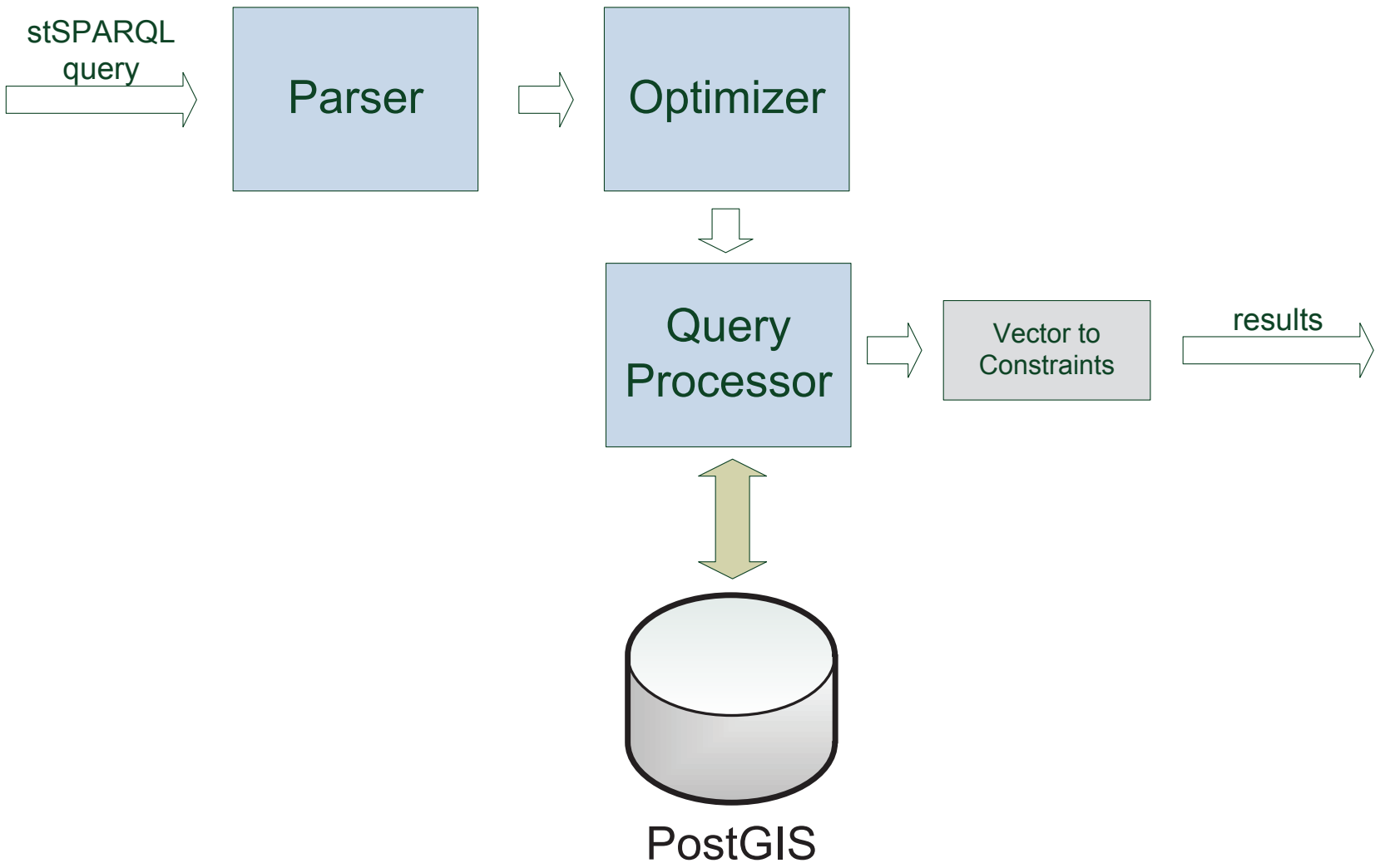
The System Strabon



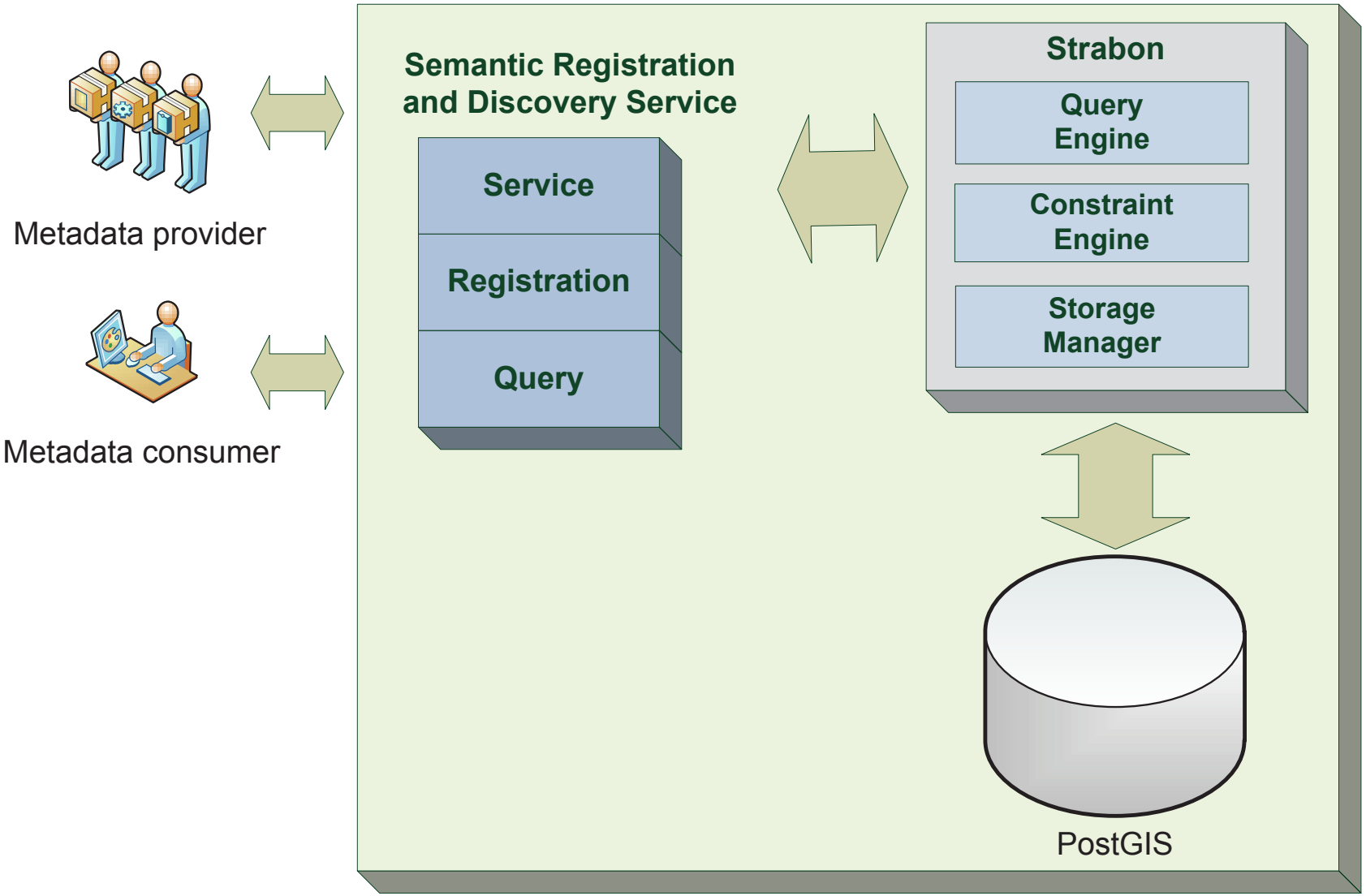
Implementation Details: Store



Implementation Details: Query



Strabon in SemsorGrid4Env



Future Work

- Complete the theory (complexity results).
- Complete the implementation (see demo for what works now).
- Integrate with the rest of SemsorGrid4Env architecture components.
- Incomplete information (use the blank nodes for a bit more than what they are currently used).
- OWL 2 and constraints?