12-17-2008

Semantic Sensor Web

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COLLECTING THE DOTS | CONNECTING THE DOTS

Semantic Sensor Web

Invited Talk
Advancing Digital Watersheds and Virtual Environmental Observatories II
AGU Fall Meeting, San Franscisco, December 17, 2008

Amit Sheth , Cory Henson, K. Thirunarayan
Kno.e.sis Center, Wright State University

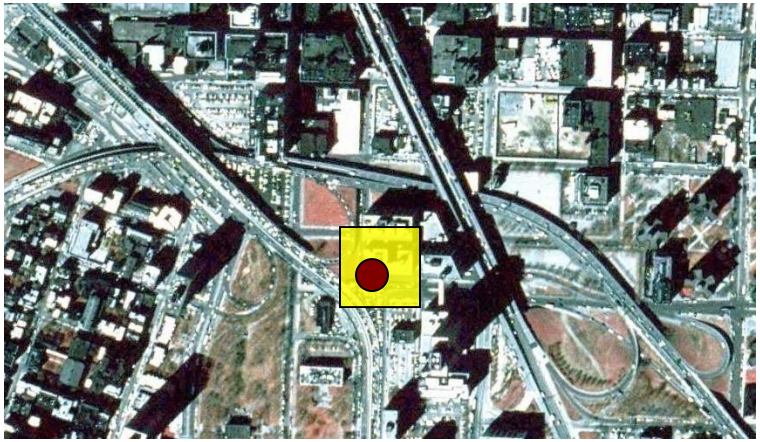
Thanks: Kno.e.sis Semantic Sensor Web team

Presentation Outline

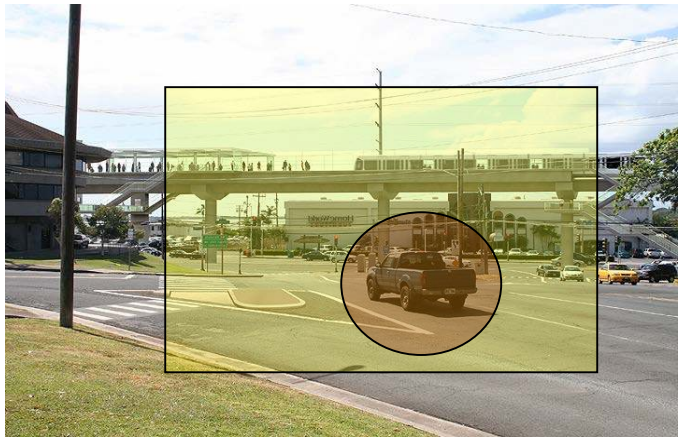
1. Motivating scenario
2. Sensor Web Enablement
3. Semantic Sensor Web
4. Perception as Abduction
5. Spatial, Temporal, and Thematic Analysis
6. Prototype

Motivating Scenario

High-level Sensor



Low-level Sensor



How do we determine if the three images depict …

- the same time and same place?
- same entity?
- a serious threat?

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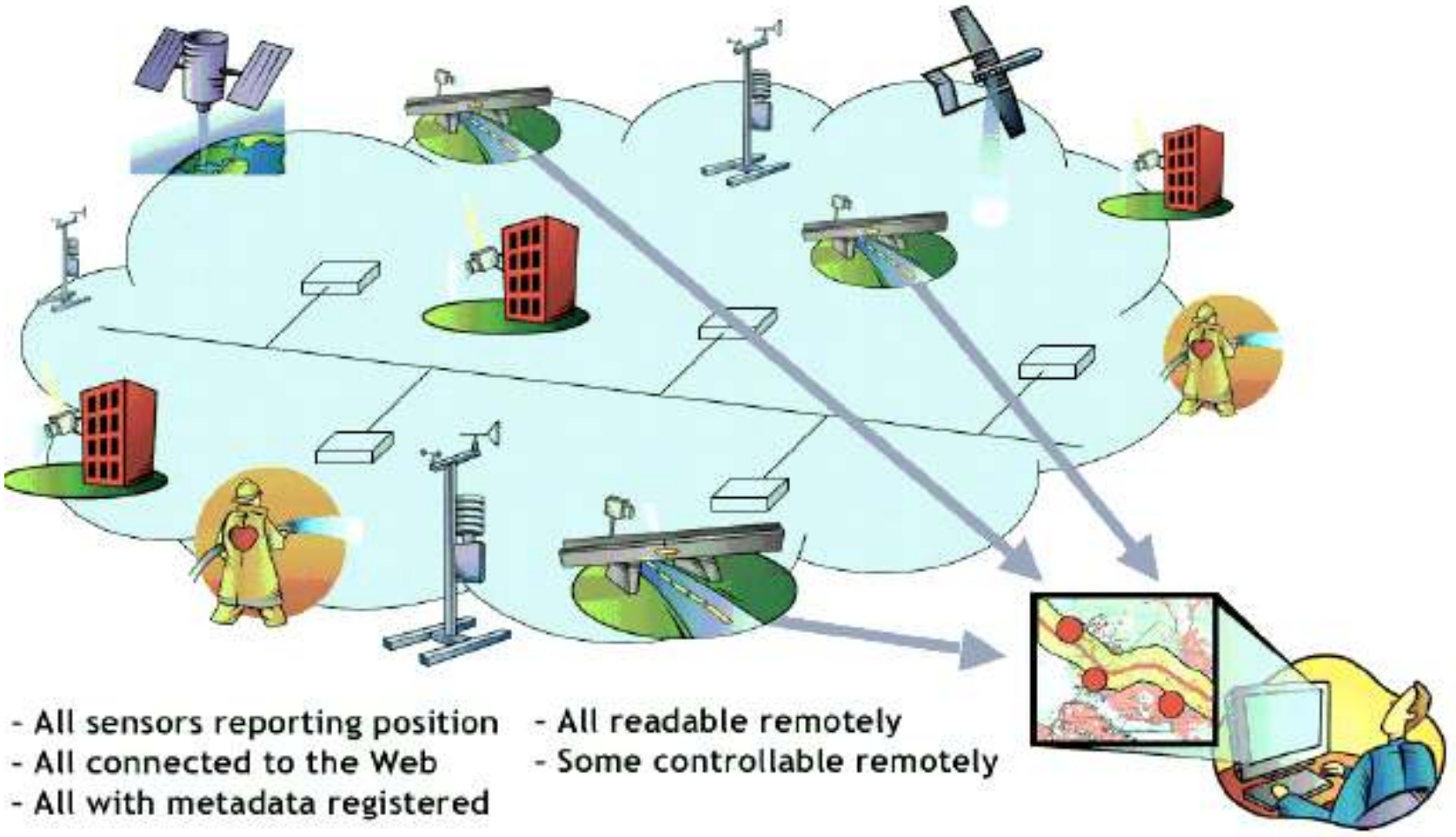
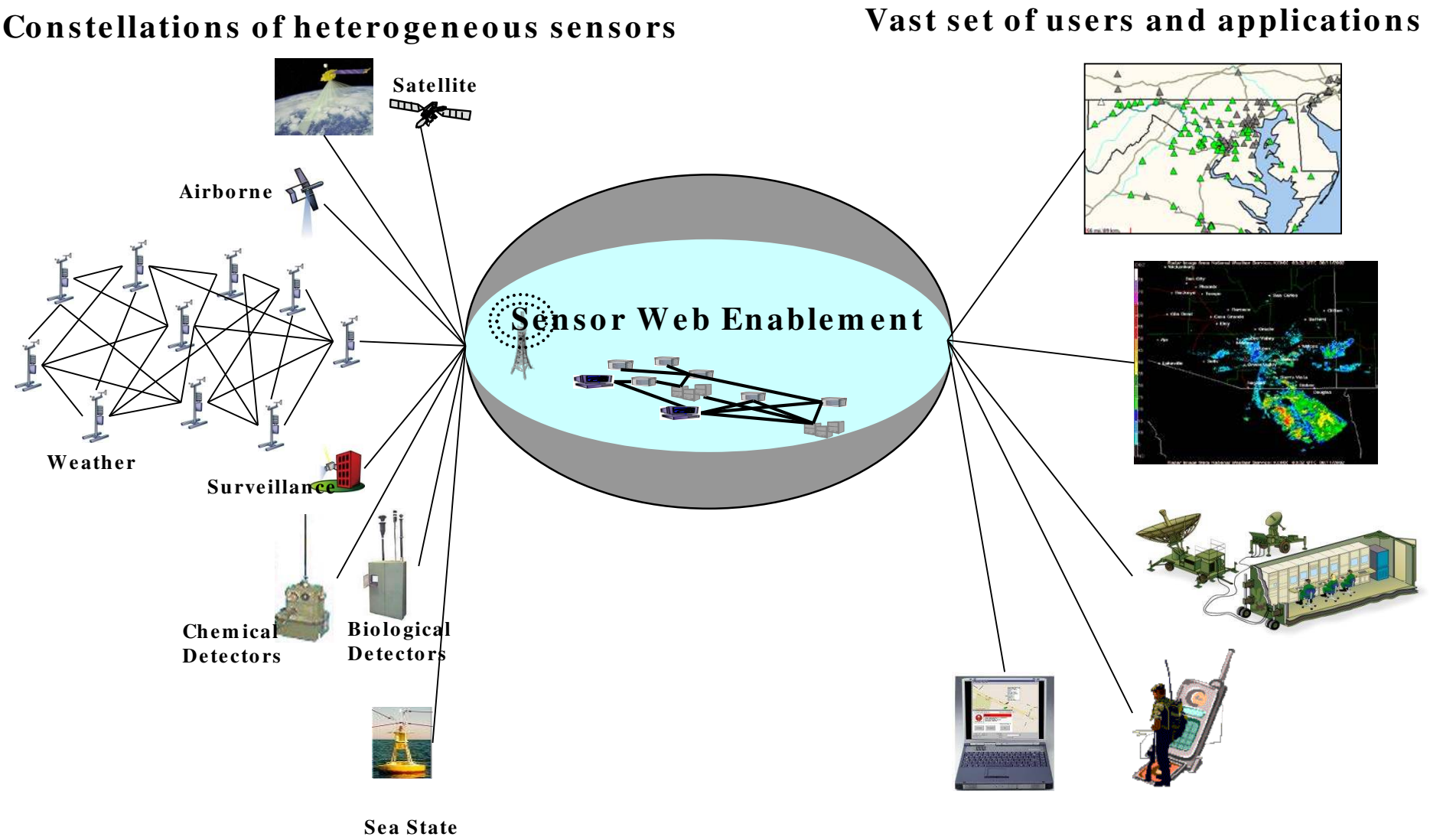
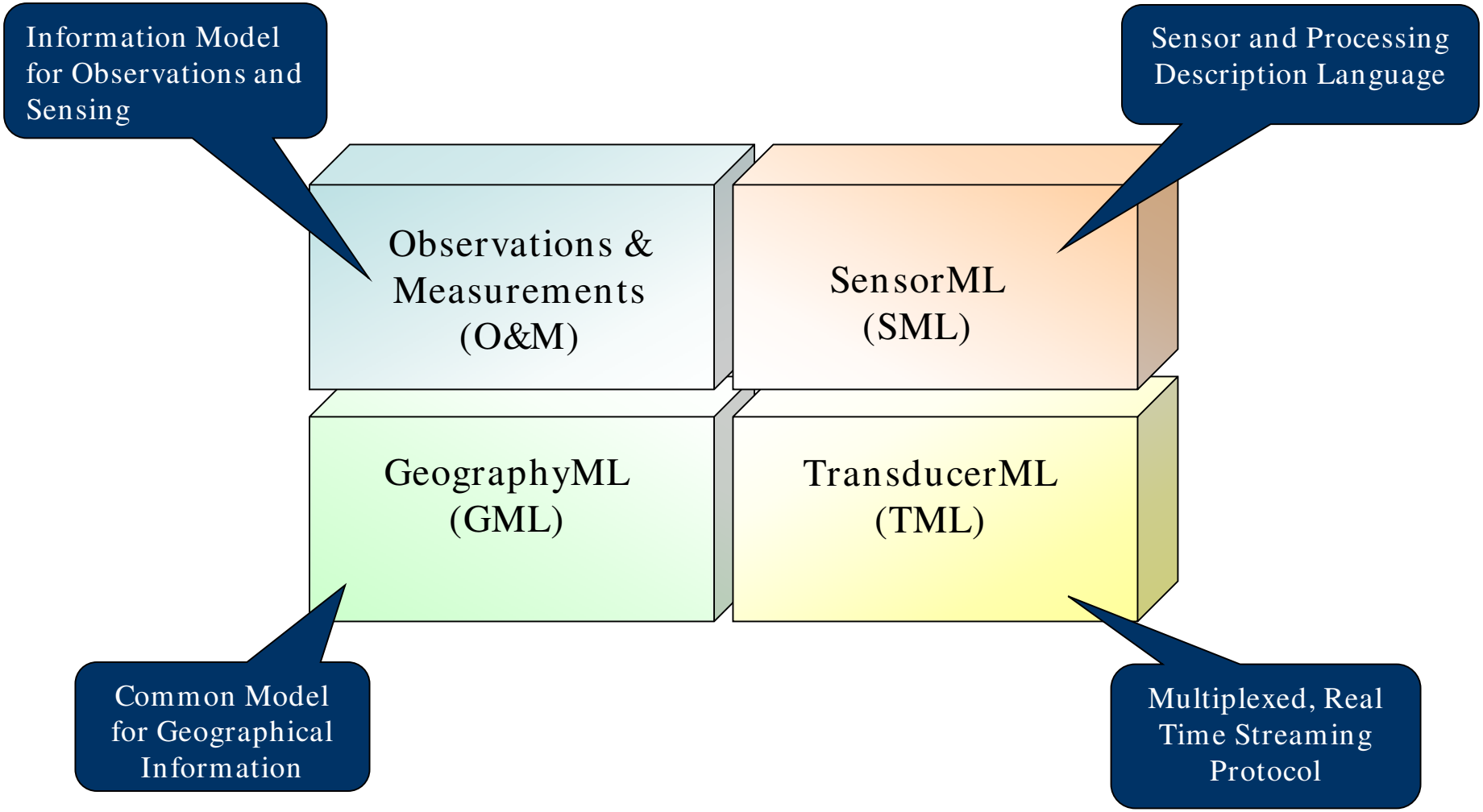
What is Sensor Web Enablement?



OGC Sensor Web Enablement

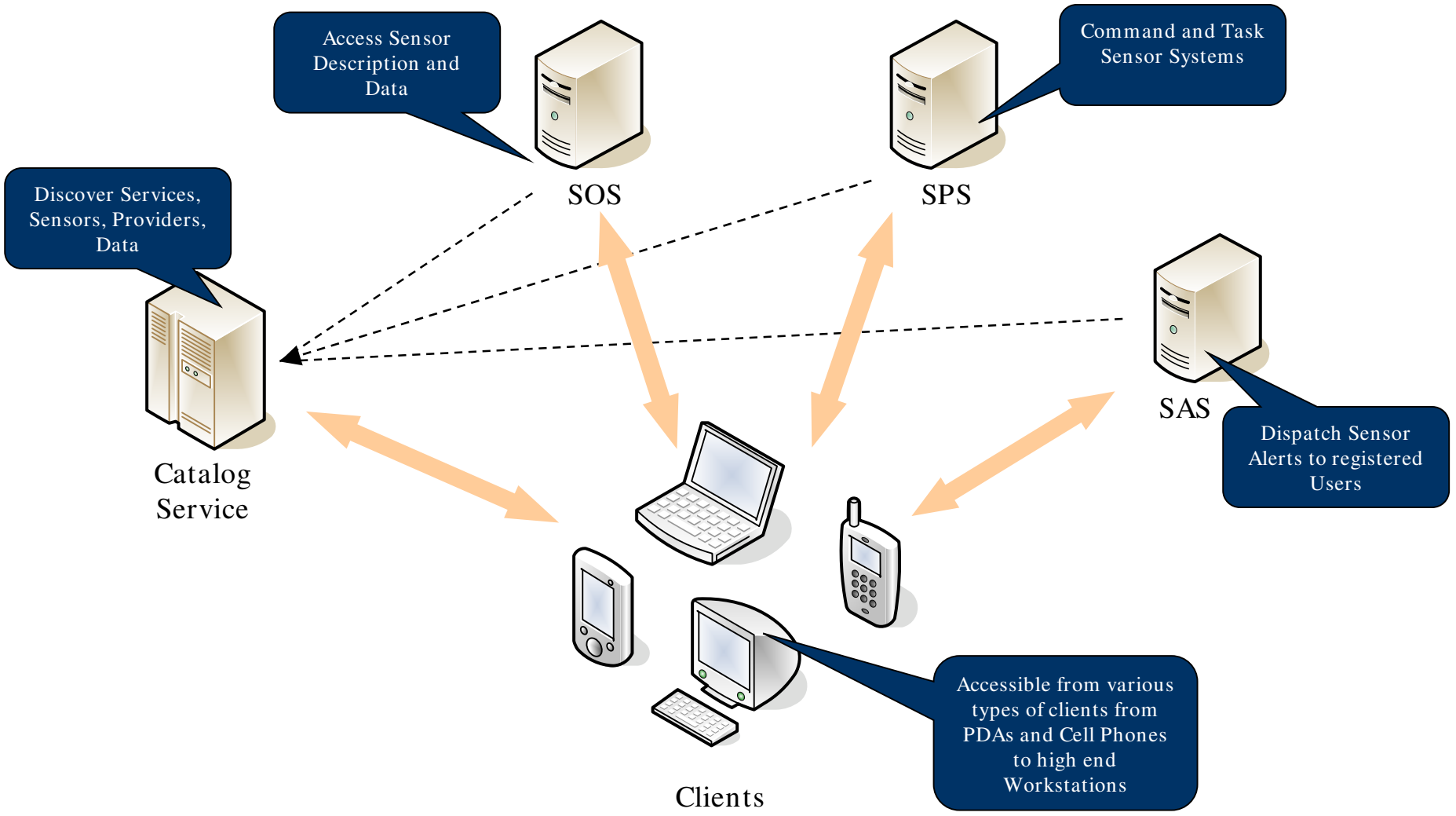


SWE Components - Languages



Sam Bacharach, "GML by OGC to AIXM 5 UGM," OGC, Feb. 27, 2007.

SWE Components – Web Services



Sam Bacharach, "GML by OGC to AIXM 5 UGM," OGC, Feb. 27, 2007.

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What is the Semantic Sensor Web?

- Adding semantic annotations to existing standard Sensor Web languages in order to provide semantic descriptions and enhanced access to sensor data

- This is accomplished with *model-references* to ontology concepts that provide more expressive concept descriptions

What is the Semantic Sensor Web?

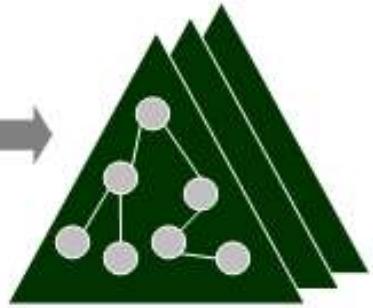
- For example,
  - using model-references to link O&M annotated sensor data with concepts within an OWL-Time ontology allows one to provide temporal semantics of sensor data
  - using a model reference to annotate sensor device ontology enables uniform/interoperable characterization/descriptions of sensor parameters regardless of different manufactures of the same type of sensor and their respective proprietary data representations/formats

Semantic Sensor Web

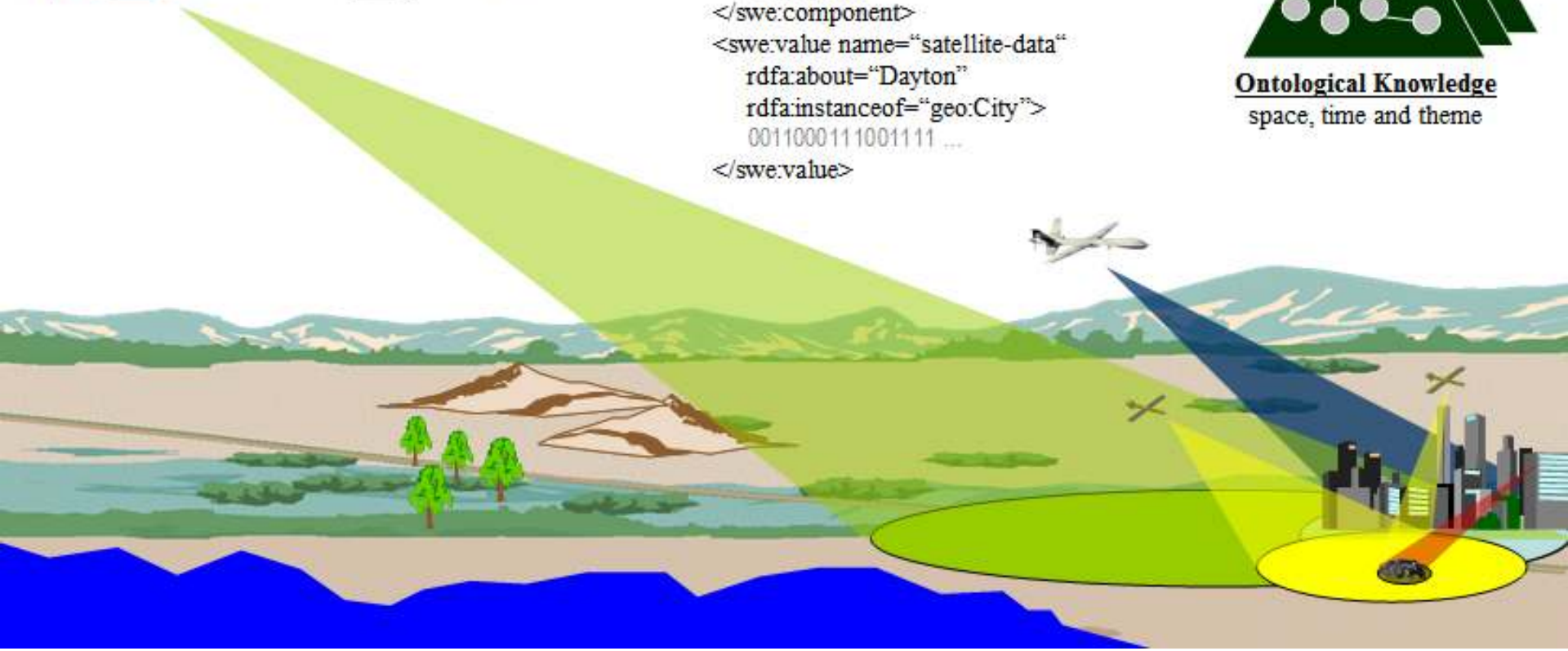
001100011
100111100
0111010...

Semantic annotation of SWE

```
<swe:component rdfa:about="time_1"
    rdfa:intanceof="time:Instant">
    <swe:Time rdfa:property="xs:date-time">
        2008-03-08T05:00:00
    </swe:Time>
</swe:component>
<swe:value name="satellite-data"
    rdfa:about="Dayton"
    rdfa:instanceof="geo:City">
    0011000111001111 ...
</swe:value>
```



Ontological Knowledge
space, time and theme

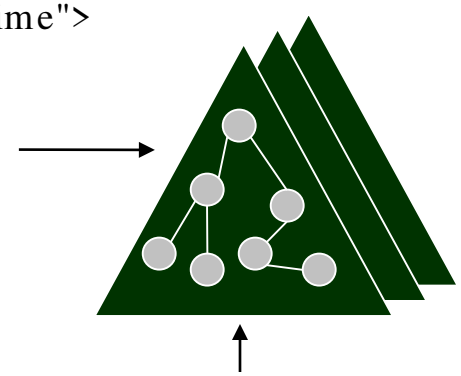


Semantically Annotated O&M

```
<swe:component name="time">
<swe:Time definition="urn:ogc:def:phenomenon:time" uom="urn:ogc:def:unit:date-time">
        <sa:swe rdfa:about="?time" rdfa:instanceof="time:Instant">
                <sa:sml rdfa:property="xs:date-time"/>
        </sa:swe>
</swe:Time>
</swe:component>
<swe:component name="measured_air_temperature">
<swe:Quantity definition="urn:ogc:def:phenomenon:temperature“
        uom="urn:ogc:def:unit:fahrenheit">
        <sa:swe rdfa:about="?measured_air_temperature“
rdfa:instanceof=“senso:TemperatureObservation">
                <sa:swe rdfa:property="weather:fahrenheit"/>
                <sa:swe rdfa:rel="senso:occurred_when" resource="?time"/>
                <sa:swe rdfa:rel="senso:observed_by" resource="senso:buckeye_sensor"/>
        </sa:sml>
</swe:Quantity>
</swe:component>

<swe:value name=“weather-data">
2008-03-08T05:00:00,29.1
</swe:value>
```

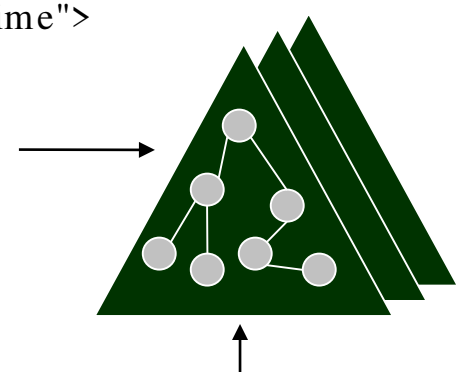
Semantically Annotated O&M

```
<swe:component name="time">
<swe:Time definition="urn:ogc:def:phenomenon:time" uom="urn:ogc:def:unit:date-time">
        <sa:swe rdfa:about="?time" rdfa:instanceof="time:Instant">
                <sa:sml rdfa:property="xs:date-time"/>
        </sa:swe>
</swe:Time>
</swe:component>
<swe:component name="measured_air_temperature">
<swe:Quantity definition="urn:ogc:def:phenomenon:temperature“
        uom="urn:ogc:def:unit:fahrenheit">
        <sa:swe rdfa:about="?measured_air_temperature“
rdfa:instanceof=“senso:TemperatureObservation">
                <sa:swe rdfa:property="weather:fahrenheit"/>
                <sa:swe rdfa:rel="senso:occurred_when" resource="?time"/>
                <sa:swe rdfa:rel="senso:observed_by" resource="senso:buckeye_sensor"/>
        </sa:sml>
</swe:Quantity>
</swe:component>

<swe:value name=“weather-data">
2008-03-08T05:00:00,29.1
</swe:value>
```

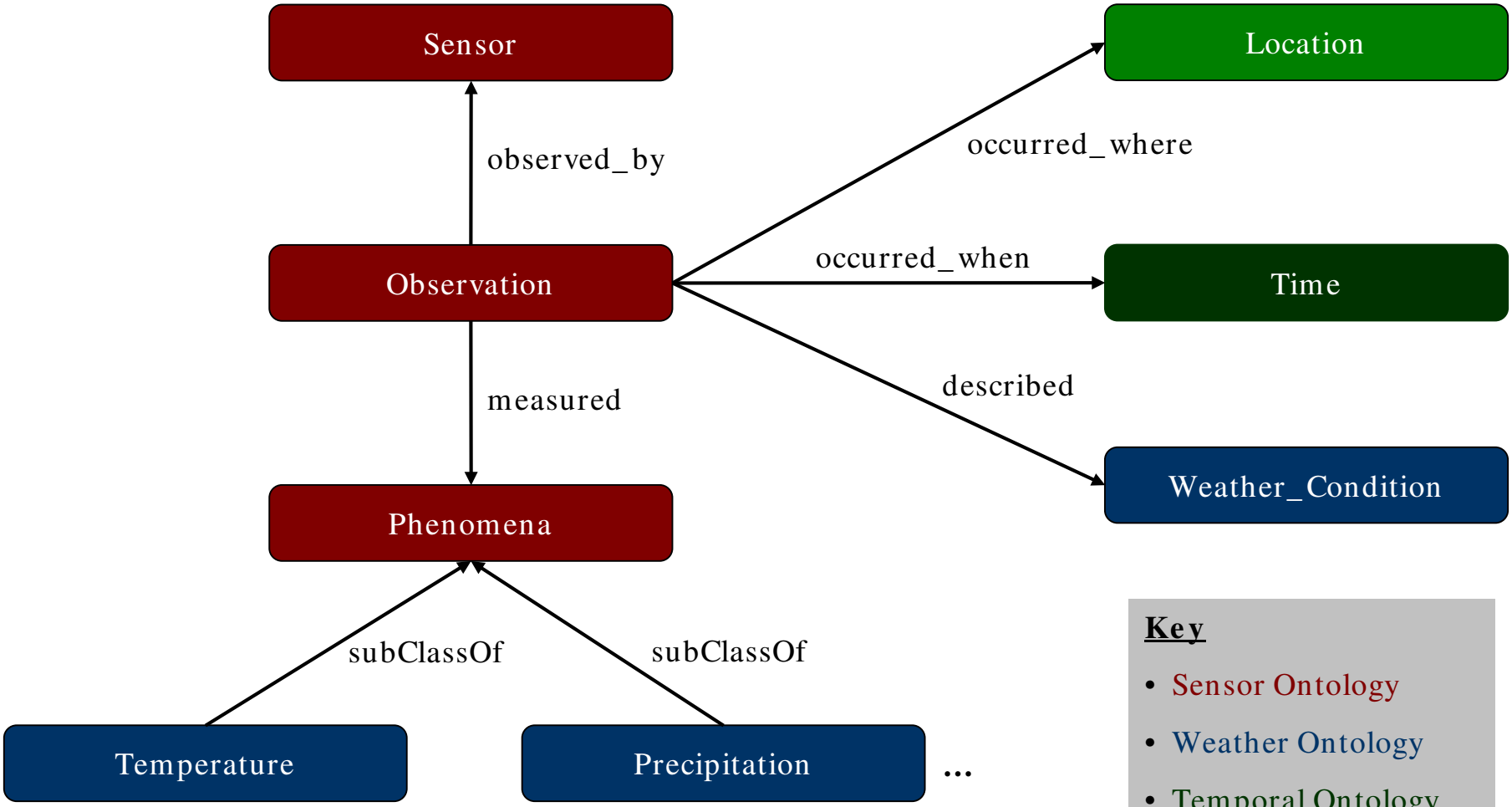


Semantically Annotated O&M

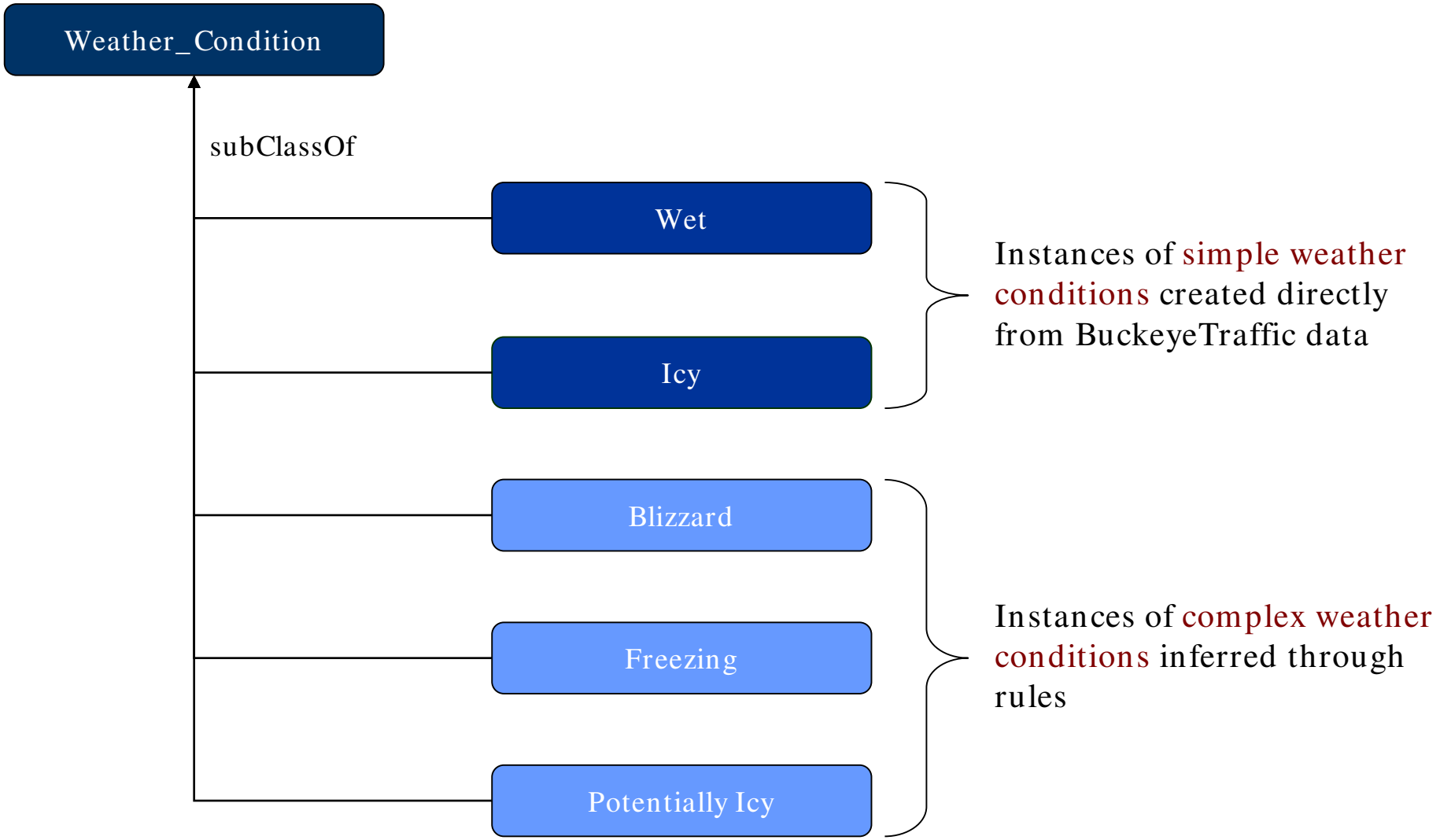
```
<swe:component name="time">
<swe:Time definition="urn:ogc:def:phenomenon:time" uom="urn:ogc:def:unit:date-time">
<
                ?time rdf:type time:Instant
                ?time xs:date-time "2008-03-08T05:00:00"
<
</swe:Time>
</swe:component>
<swe:component name="measured_air_temperature">
<swe:Quantity definition="urn:ogc:def:phenomenon:temperature“
        uom="urn:ogc:def:unit:fahrenheit">
<
rdfa:instanc
                ?measured_air_temperature rdf:type senso:TemperatureObservation
                ?measured_air_temperature weather:fahrenheit "29.1"
                ?measured_air_temperature senso:occurred_when ?time
                ?measured_air_temperature senso:observed_by senso:buckeye_sensor
</sa:sim1>
</swe:Quantity>
</swe:component>

<swe:value name=“weather-data">
2008-03-08T05:00:00,29.1
</swe:value>
```



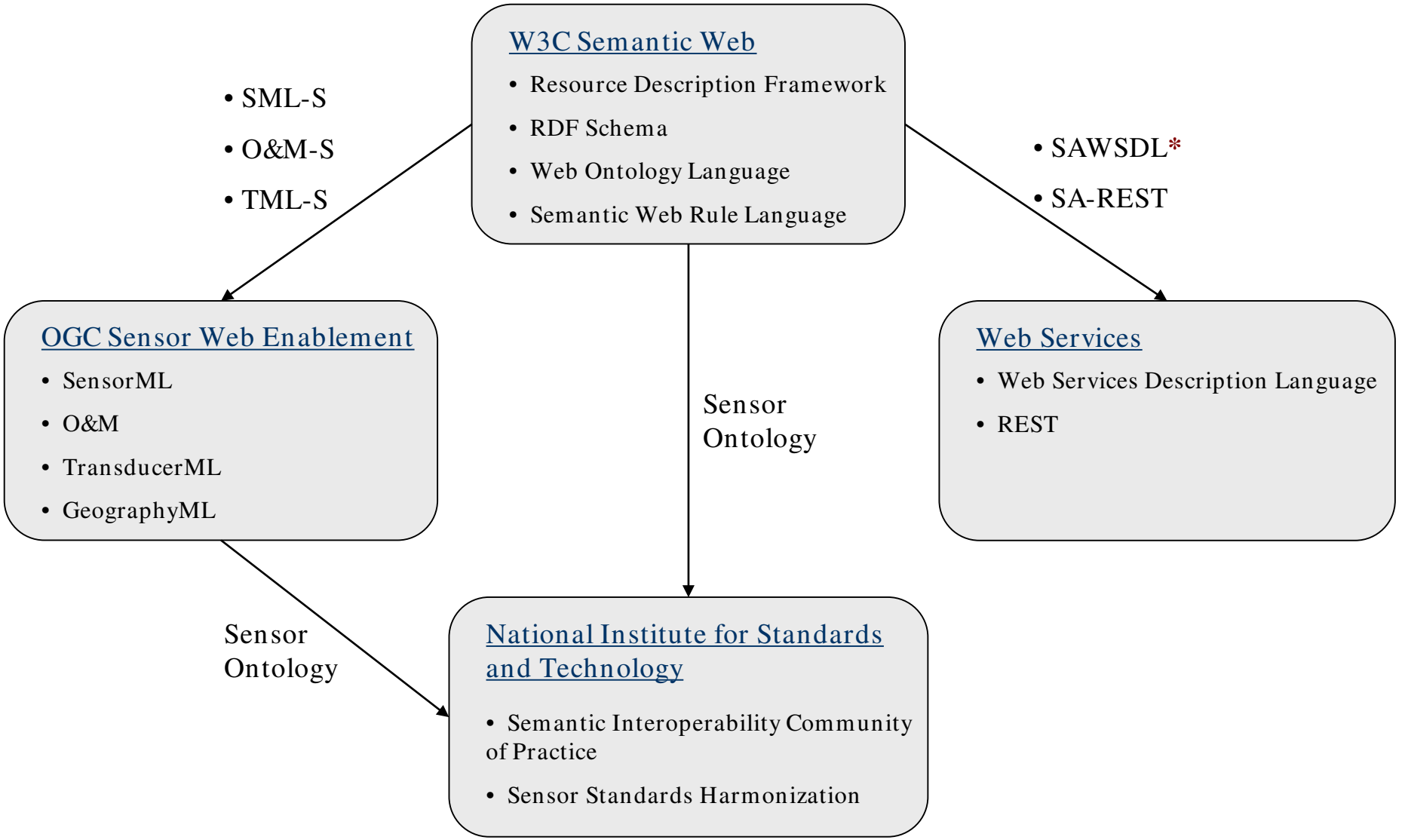
S-SOS Ontology Concepts



S-SOS Ontology Concepts



Standards Organizations



* SAWSDL - now a W3C Recommendation is based on our work.

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Perception as Abduction

- Abduction - A formal model of inference which centers on cause-effect relationships and tries to find the best or most plausible explanations (causes) for a set of given observations (effects).

- The task of abductive perception is to find a consistent set of perceived objects and events (DELTA), given a background theory (SIGMA) and a set of observations (RHO)

$$SIGMA \ \& \ DELTA \models RHO$$

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Active Perception

- In the abductive theory of perception, active perception is accommodated by making use of *explanation, expectation, and attention*.

- explanation - The explanation mechanism turns the resulting raw sensor data into hypotheses about the world (through abductive reasoning).

- expectation - Each explanation will, when conjoined with the background theory, entail a number of other observation sentences that might not have been present in the original sensor data.

- attention - The attention mechanism, directs the sensory apparatus onto the most relevant aspects of the environment.

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- **Data Modeling and Querying:**
  - Thematic relationships can be directly stated but many spatial and temporal relationships (e.g. distance) are implicit and require additional computation
  - Temporal properties of paths aren't known until query execution time …hard to index

- **RDFS Inferencing:**
  - If statements have an associated valid time this must be taken into account when performing inferencing
  - (x, rdfs:subClassOf, y) : [1, 4] AND (y, rdfs:subClassOf, z) : [3, 5] → (x, rdfs:subClassOf, z) : [3, 4]

Work to Date

- **Ontology-based model for spatiotemporal data using temporal RDF** [1]
  - Illustrated benefits in flexibility, extensibility and expressiveness as compared with existing spatiotemporal models used in GIS

- **Definition, implementation and evaluation of corresponding query operators using an extensible DBMS (Oracle)** [2]
  - Created SQL Table Functions which allow SPARQL graph patterns in combination with Spatial and Temporal predicates over Temporal RDF graphs

1. Matthew Perry, Farshad Hakimpour, Amit Sheth. "Analyzing Theme, Space and Time: An Ontology-based Approach", Fourteenth International Symposium on Advances in Geographic Information Systems (ACM-GIS '06), Arlington, VA, November 10 - 11, 2006
2. Matthew Perry, Amit Sheth, Farshad Hakimpour, Prateek Jain. "What, Where and When: Supporting Semantic, Spatial and Temporal Queries in a DBMS", Kno.e.sis Center Technical Report. KNOESIS-TR-2007-01, April 22, 2007

Sample STT Query

```
select * from table (spatial_find(
        '(?sensor :location ?loc)
         (?sensor :generatedObservation ?obs)
         (?obs :featureOfInterest :Blizzard)', 'loc',
        'POINT(-149.40572 61.29302)',
        'GEO_DISTANCE(distance=100 unit=mile)');
```

Scenario (Blizzard Detection): Find all sensors that have observed a Blizzard within a 100 mile radius of a given location.

Query specifies

(1) a relationship between a sensor, observation, blizzard, and location

(2) a spatial filtering condition based on the proximity of the sensor and the defined point

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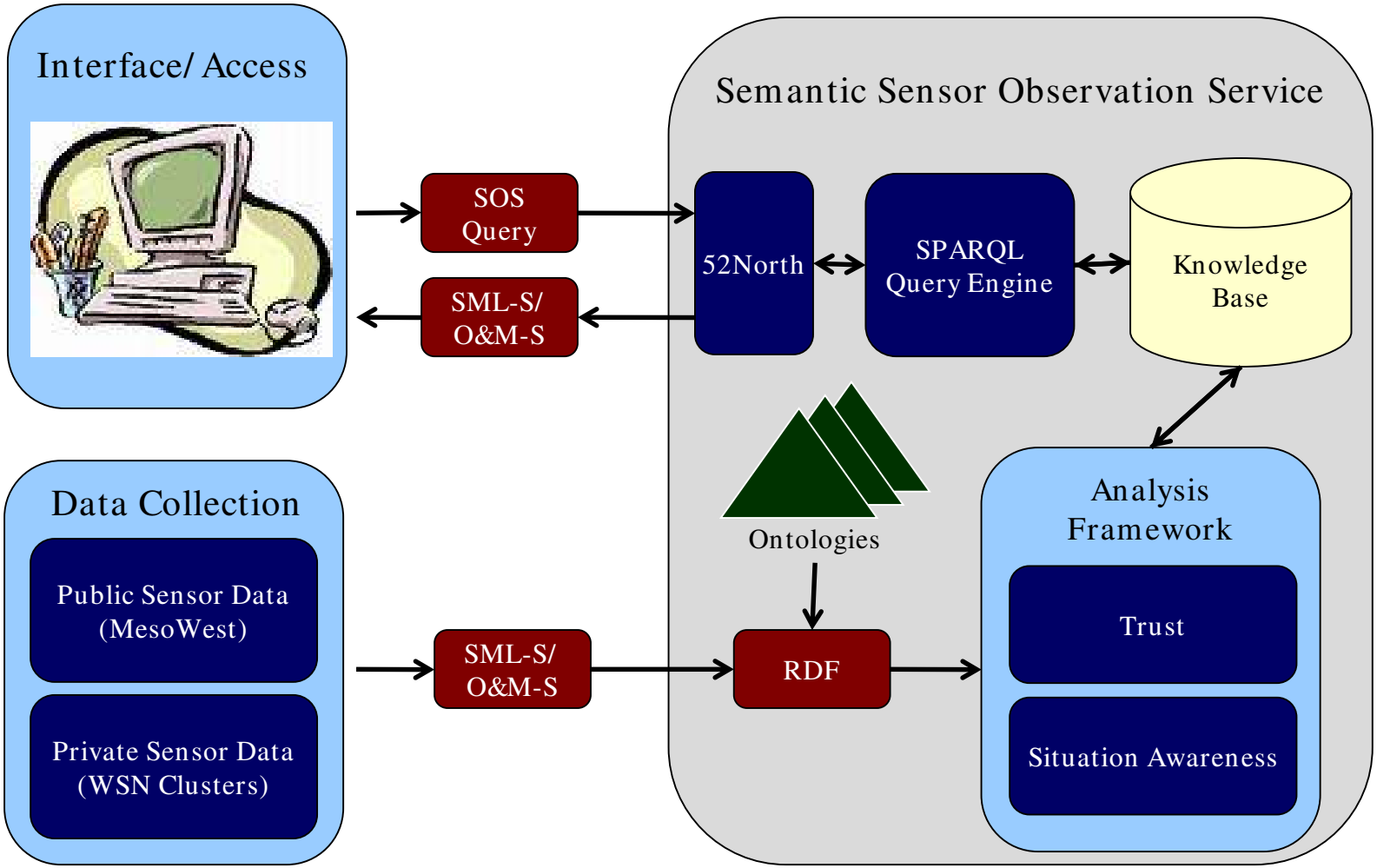
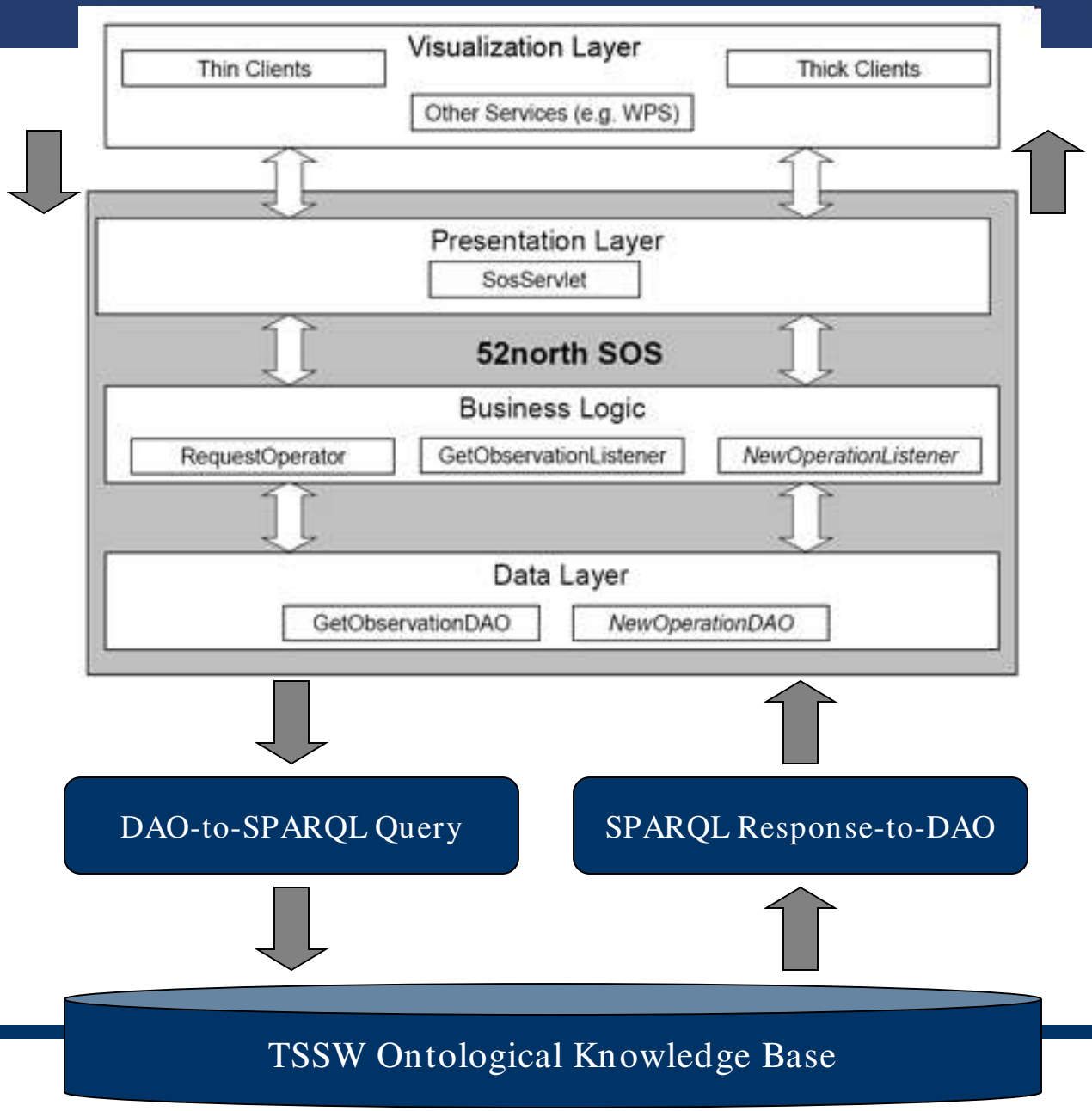
SSW Architecture



Extended 52 North SOS Architecture



SSW-SOS Query and Response

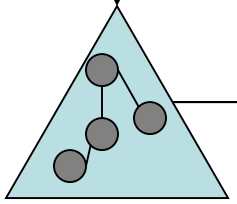
```
<GetObservation>
<offering>BRAU1</offering>
<observedProperty>AirTemperature</observedProperty>
</GetObservation>
```

Request

Response

SOS

```
<om:featureOfInterest>
  FreezingRain1, FreezingRain2,
  Blizzard, FreezingRain3
</om:featureOfInterest>
    ...
<om:result>
    ...
  </swe:Count>
    <swe:value>4</swe:value>
  </swe:Count>
      ...
  <swe:values>
    Value1, Value2, Value3, Value4
  </swe:values>
    ...
</om:result>
```



ID: Value1
Time: 5:00pm
Feature: Freezing Rain
Temp: 9.0 degrees
Belief: 0.43

ID: Value2
Time: 5:15pm
Feature: Freezing Rain
Temp: 2.0 degrees
Belief: 0.41

ID: Value3
Time: 5:30pm
Feature: Blizzard
Temp: 24.0 degrees
Belief: 0.29

ID: Value4
Time: 5:30pm
Feature: Freezing Rain
Temp: 6.0 degrees
Belief: 0.51

SSW-SOS Query and Response (w/ Belief)

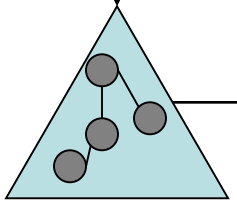
```
<GetObservation>
<offering>BRAU1</offering>
<observedProperty>AirTemperature</observedProperty>
<result>
  <ogc:PropertyIsGreaterThan>
    <ogc:PropertyName>beliefValue</ogc:PropertyName>
    <ogc:Literal>0.40</ogc:Literal>
  </ogc:PropertyIsGreaterThan>
</result>
</GetObservation>
```

Request

Response

SOS

```
<om:featureOfInterest>
  FreezingRain1, FreezingRain2,
  FreezingRain3
</om:featureOfInterest>
    ...
<om:result>
    ...
  </swe:Count>
    <swe:value>4</swe:value>
  </swe:Count>
    ...
  <swe:values>
    Value1, Value2, Value3, Value4
  </swe:values>
    ...
</om:result>
```



ID: Value1
Time: 5:00pm
Feature: Freezing Rain
Temp: 9.0 degrees
Belief: 0.43

ID: Value2
Time: 5:15pm
Feature: Freezing Rain
Temp: 2.0 degrees
Belief: 0.41

ID: Value3
Time: 5:30pm
Feature: Blizzard
Temp: 24.0 degrees
Belief: 0.29

ID: Value4
Time: 5:30pm
Feature: Freezing Rain
Temp: 6.0 degrees
Belief: 0.51

SSW-SOS Query and Response (w/ Features)

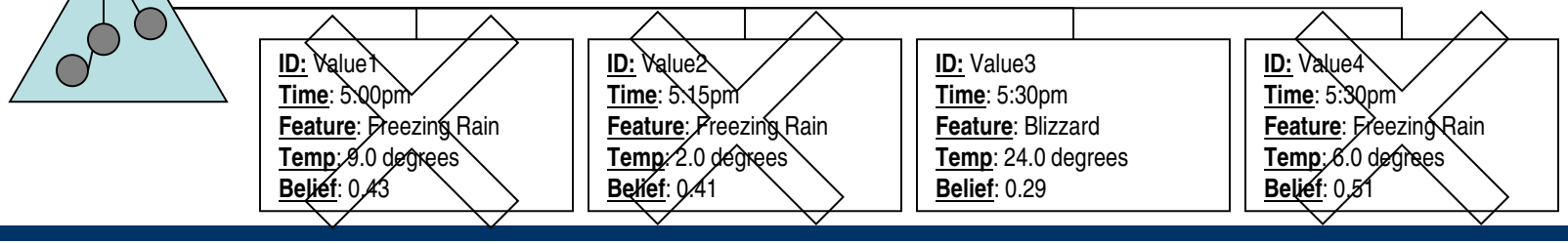
```
<GetObservation>
<offering>BRAU1</offering>
<observedProperty>AirTemperature</observedProperty>
 <featureOfInterest>
     <ObjectID>Blizzard</ObjectID>
  </featureOfInterest>
</GetObservation>
```

Request

Response

SOS

```
<om:featureOfInterest>
   Blizzard
</om:featureOfInterest>
        ...
<om:result>
        ...
   </swe:Count>
      <swe:value>1</swe:value>
   </swe:Count>
        ...
   <swe:values>
      Value3
   </swe:values>
        ...
</om:result>
```

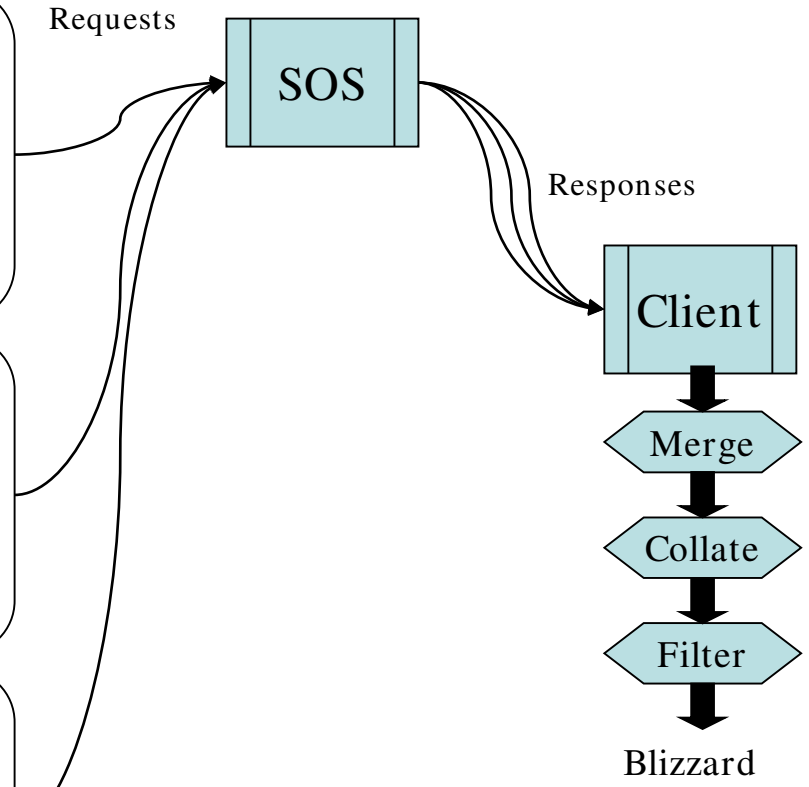


Without Leveraging Semantics

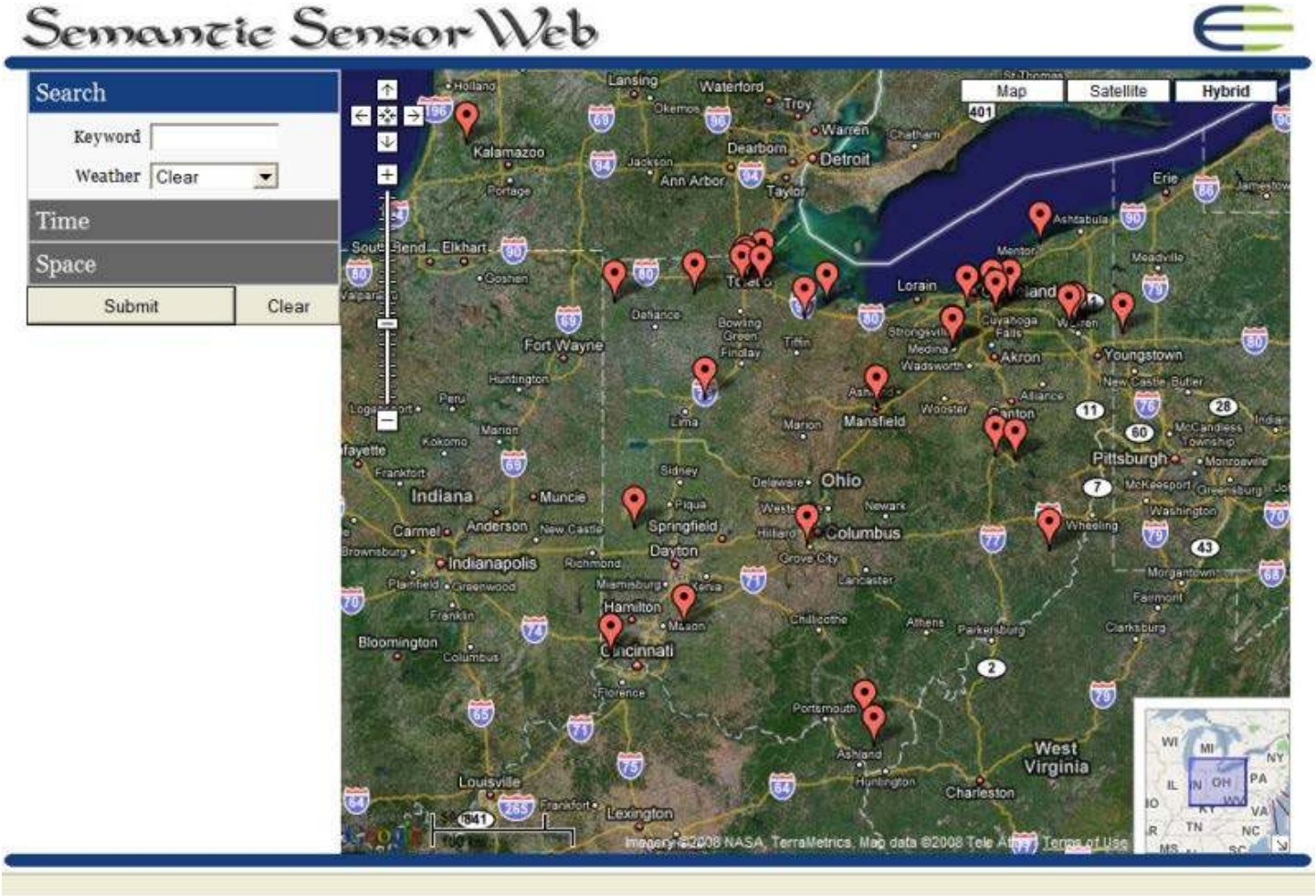
```
<GetObservation>
<offering>BRAU1</offering>
<observedProperty>AirTemperature</observedProperty>
<result><ogc:PropertyIsEqualTo>
      <ogc:PropertyName>Snow</ogc:PropertyName>
      <ogc:Literal>true</ogc:Literal>
</ogc:PropertyIsEqualTo></result>
</GetObservation>
```

```
<GetObservation>
<offering>BRAU1</offering>
<observedProperty>AirTemperature</observedProperty>
<result><ogc:PropertyIsGreaterThan>
      <ogc:PropertyName>WindSpeed</ogc:PropertyName>
      <ogc:Literal>30</ogc:Literal>
</ogc:PropertyIsGreaterThan></result>
</GetObservation>
```

```
<GetObservation>
<offering>BRAU1</offering>
<observedProperty>AirTemperature</observedProperty>
<result><ogc:PropertyIsLessThan>
      <ogc:PropertyName>Visibility</ogc:PropertyName>
      <ogc:Literal>0.25</ogc:Literal>
</ogc:PropertyIsLessThan></result>
</GetObservation>
```



Demo: Semantic Sensor Observation Service



Demos on the project Web site:
http://knoesis.wright.edu/research/semsci/application_domain/sem_sensor/

References

- Amit Sheth, Cory Henson, and Satya Sahoo, "Semantic Sensor Web," IEEE Internet Computing, July/ August 2008, p. 78-83.
- Cory Henson, Amit Sheth, Prateek Jain, Josh Pschorr, Terry Rapoch, "Video on the Semantic Sensor Web," W3C Video on the Web Workshop, December 12-13, 2007, San Jose, CA, and Brussels, Belgium
- Matthew Perry, Amit Sheth, Farshad Hakimpour, Prateek Jain. "Supporting Complex Thematic, Spatial and Temporal Queries over Semantic Web Data," Second International Conference on Geospatial Semantics (GEOS '07), Mexico City, MX, November 29-30, 2007
- Matthew Perry, Farshad Hakimpour, Amit Sheth. "Analyzing Theme, Space and Time: An Ontology-based Approach," Fourteenth International Symposium on Advances in Geographic Information Systems (ACM-GIS '06), Arlington, VA, November 10-11, 2006
- Farshad Hakimpour, Boanerges Aleman-Meza, Matthew Perry, Amit Sheth. "Data Processing in Space, Time, and Semantic Dimensions," Terra Cognita 2006 – Directions to Geospatial Semantic Web, in conjunction with the Fifth International Semantic Web Conference (ISWC '06), Athens, GA, November 6, 2006

References

Semantic Sensor Web projects:
http://knoesis.org/research/semsci/application_domain/sem_sensor/

Spatio-temporal-thematic Query Processing & Reasoning:
http://knoesis.org/research/semweb/projects/stt/

Demos at: http://knoesis.wright.edu/library/demos/

Publications: http://knoesis.wright.edu/library

Rest: http://knoesis.org