From Raw Sensor Data to Semantic Web Triples

Information Flow in Semantic Sensor Networks

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Lecture Outline

- Introduction
- Sensor data
- Semantic web
- Context-awareness
- The GSN middleware
- Exposing sensor data as triples
- Semantic Integration using SPARQL

Introduction

- The Situation
  - Decrease in the value of sensors encourage the shift from Desktop to Ubiquitous Computing
- The Problem
  - Extracting meaning from a network of deployed sensors
- Why is this a problem?
  - Raw sensor data is useless unless properly annotated
  - Limited resources in terms of processing, storage capabilities and bandwidth
- What is the suggested solution?
  - Establish ways to automatically process and manage the data

Concepts involved (1)

- Context-awareness
  - Context-aware systems are able to sense and measure their environment and include these measurements in their behavior
- Data fusion
  - Combine information and data residing at disparate sources, in order to achieve improved accuracies and more specific inferences than could be achieved by the use of a single data source alone
  - Data fusion spans various levels, from signal and object refinement (low level) to situation and threat assessment (high level)

Concepts involved (2)

- Information Integration
  - Unify information originating from various sources in order to allow its processing as a whole
  - Obstacles include
    - Heterogeneity in source schemas and data
    - Various Technical Spaces
    - Semantic and syntactic differences
- *Semantic* Information Integration
  - The resulting integration scheme carries its semantics
- Information Merging
  - Unification of the information at the implementation level

Concepts involved (3)

- Information Aggregation
  - Report the mean value of a set of measurements
  - E.g. the average temperature of a set of temperature sensors
- Information Annotation
  - Inclusion of metadata next or in the actual data
  - E.g. ID3 tags in mp3
- *Semantic* Information Annotation
  - Unambiguously define information
  - Third parties can understand the information

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Sensors and Sensor Data (1)

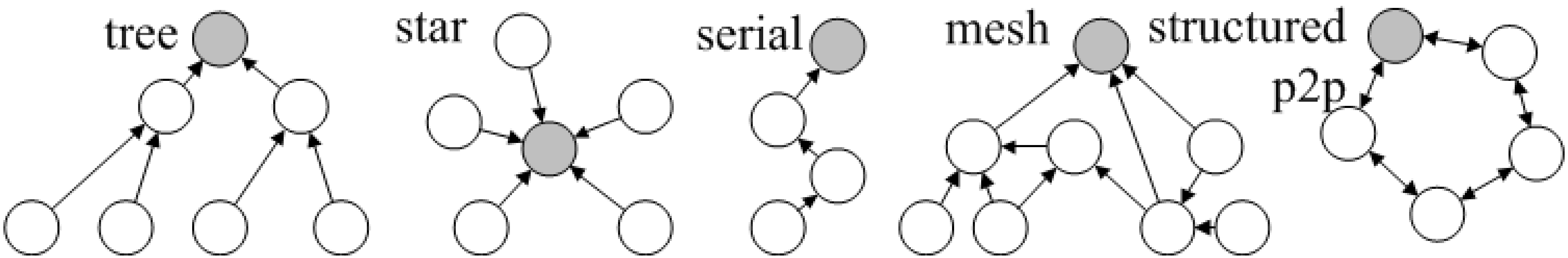
- Sensors are devices that measure physical properties
  - Temperature, motion, light, humidity sensors
  - Also cameras, microphones, GPS-enabled smartphones
- Sensors provide data that can be
  - Streamed data
    - Audio/Video content
  - Event-based
    - Temperature measurement
    - RFID tag read
    - Light curtain interrupt

Sensors and Sensor Data (2)

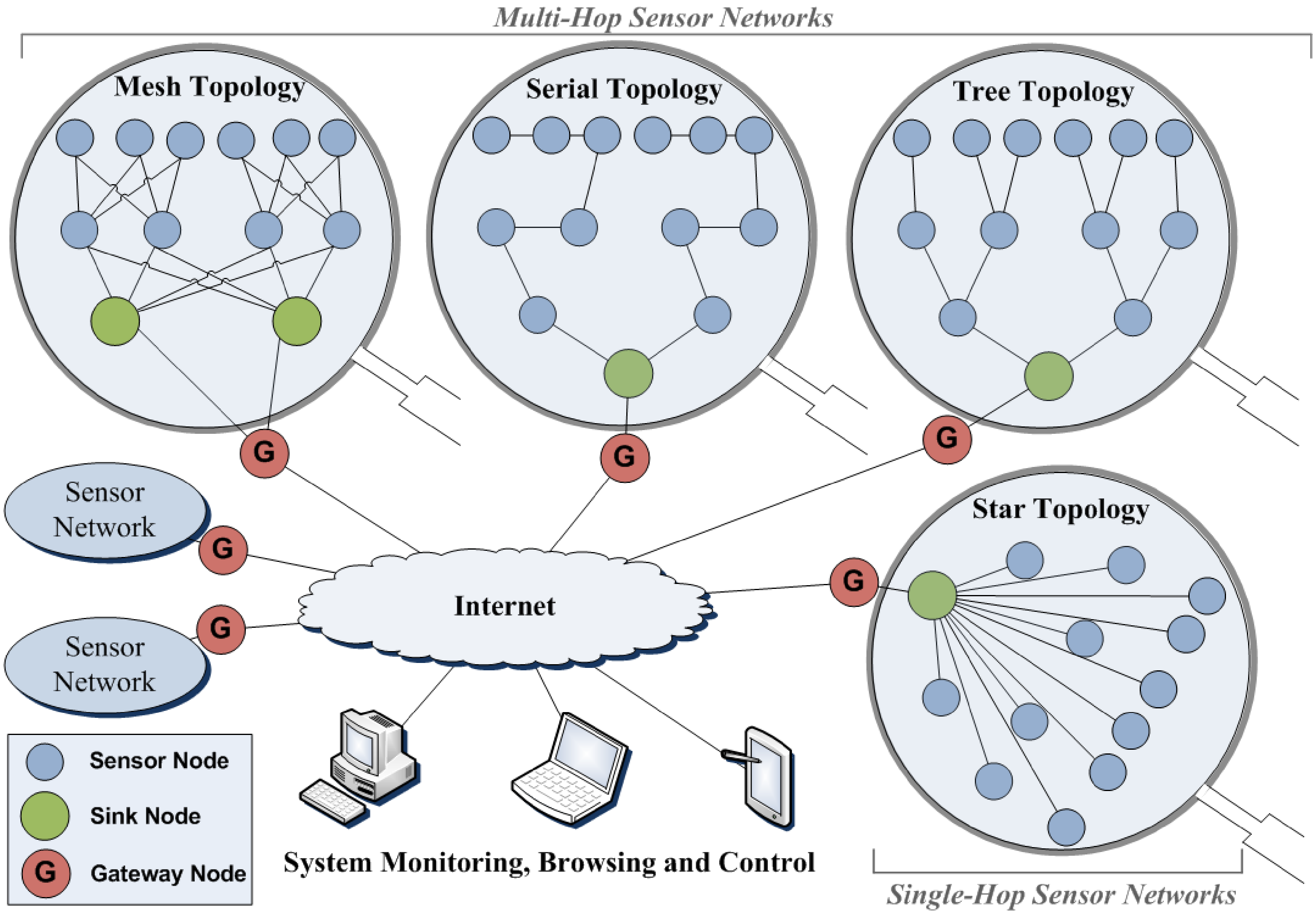
- Why is sensor data any different than other forms of data, e.g. multimedia?
  – Synchronization issues
    - Apply acceptance thresholds
  – Erroneous measurements
    - Apply aggregation
  – Limited resources in the nodes
    - Caution when designing *where* the actual processing takes place
    - Keep a sliding window
    - Heavy process in the Gateway Nodes
  – Streaming may lead to packet losses
    - Reconstruct, or take decisions based on what you have

Sensor Network Topologies (1)

- Sink nodes collect information
  - Higher processing capabilities



Sensor Network Topologies (2)



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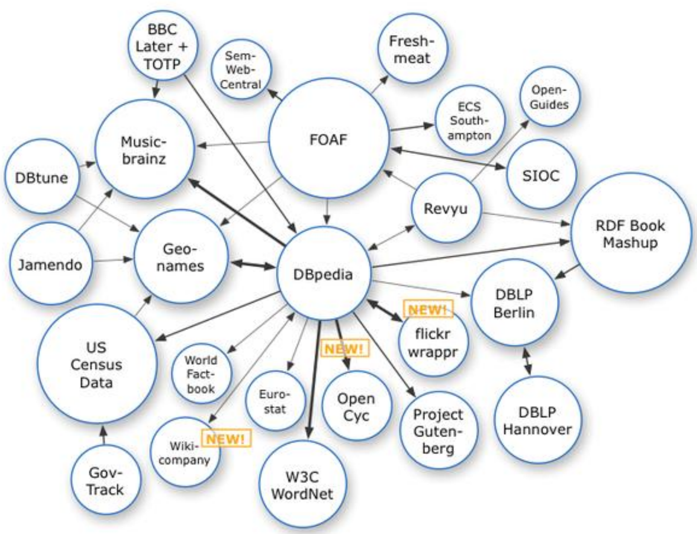
Why Semantic Web (1)

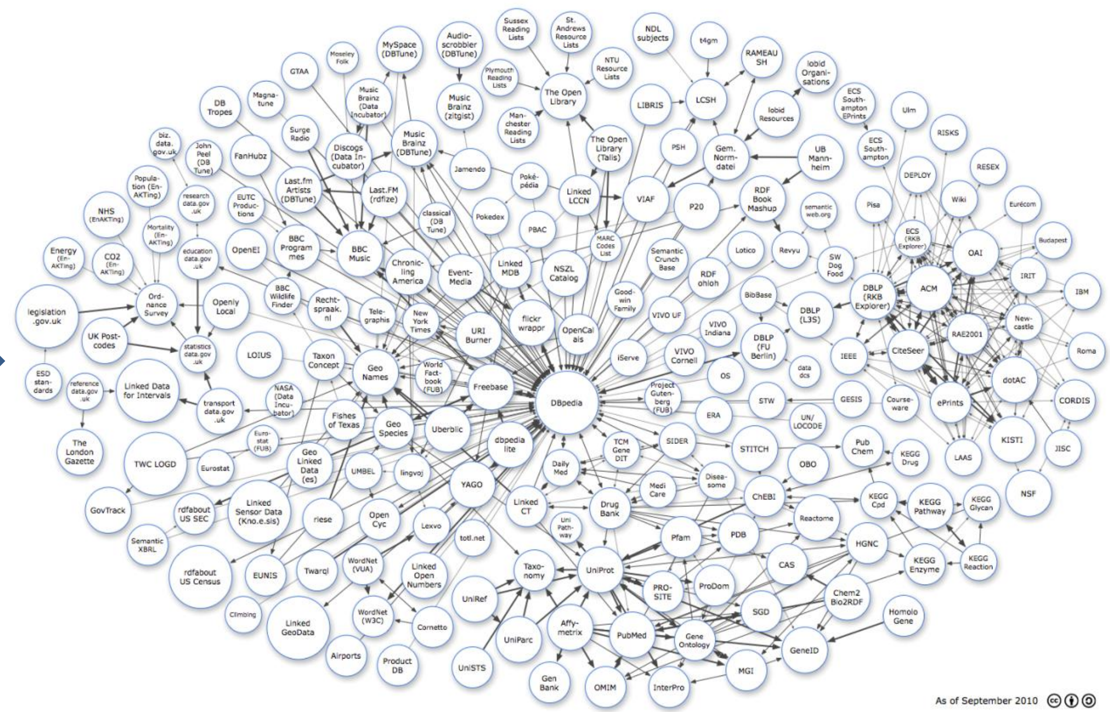
- Knowledge in the form of a graph
  - (subject, property, object)
- Information is assigned an unambiguously defined meaning, its semantics
  - Queries can be posed by any third parties
  - Ontology, a well defined vocabulary
- Numerous ontologies already available and interconnected on the Web
  - Can and should be used when integration is a goal

Why Semantic Web (2)

- Enables semantic annotation and integration
- Enables reasoning
  - Extract implicit information from the explicitly asserted
  - Assure concept consistency and satisfiability
- Open source tools available
  - Protégé, Jena, Virtuoso, …
- Allows information to be exposed as Linked Open Data

The Linked Open Data Cloud





2007

2010

Source: linkeddata.org

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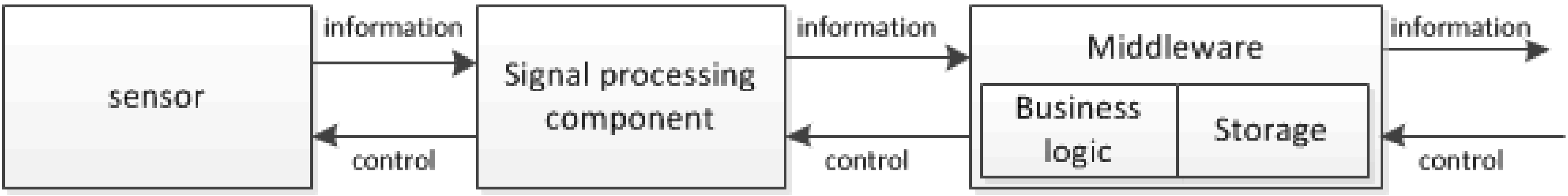
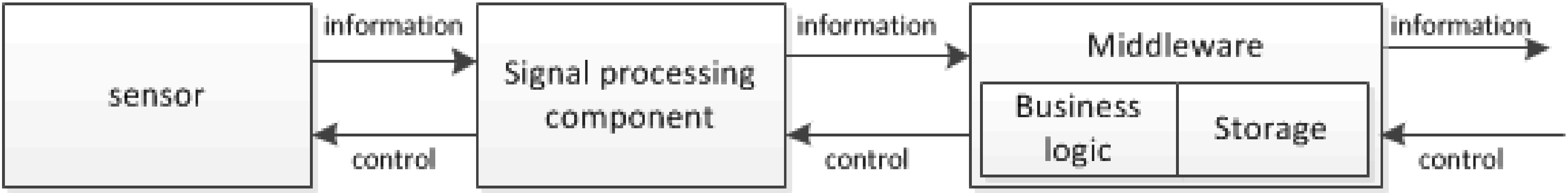
Context-awareness: The big picture (1)



- The sensors capture information from the environment
- The signal processing components produce structured information
  - Face detector, Body Tracker, Vehicle tracker, Smoke detection etc.

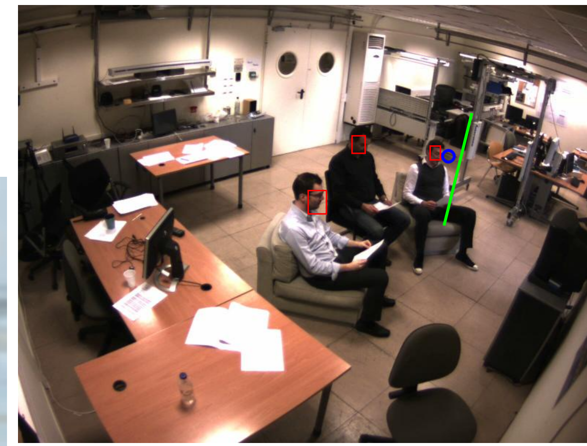
Context-awareness: The big picture (2)



- The middleware
  - Business logic: Program, configure, monitor and control system behavior
  - Storage layer
    - Support database: limited historicity, sliding window
    - Archive database: enables further processing
- Note the Information/Control duality

Signal Processing Components (1)

- Much work carried out in the AGC lab
  - Image Processing
    - Face Detection/Recognition/Tracking
    - Body Tracking
  - Audio Processing
    - A/V Localization
    - Voice activity detection



Signal Processing Components (2)

- Challenges
  - Processing is resource-hungry
  - Heterogeneous technologies must be combined
    - Production Algorithms in C++, prototypes in Matlab
    - Multidisciplinary skills required
    - Well-defined Interfaces need to be developed using RMI/Sockets/Web services/JNA
  - Video processing differs from streaming processing
    - Processing an avi file differs (greatly!) from processing an rtp stream

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Global Sensor Networks (1)

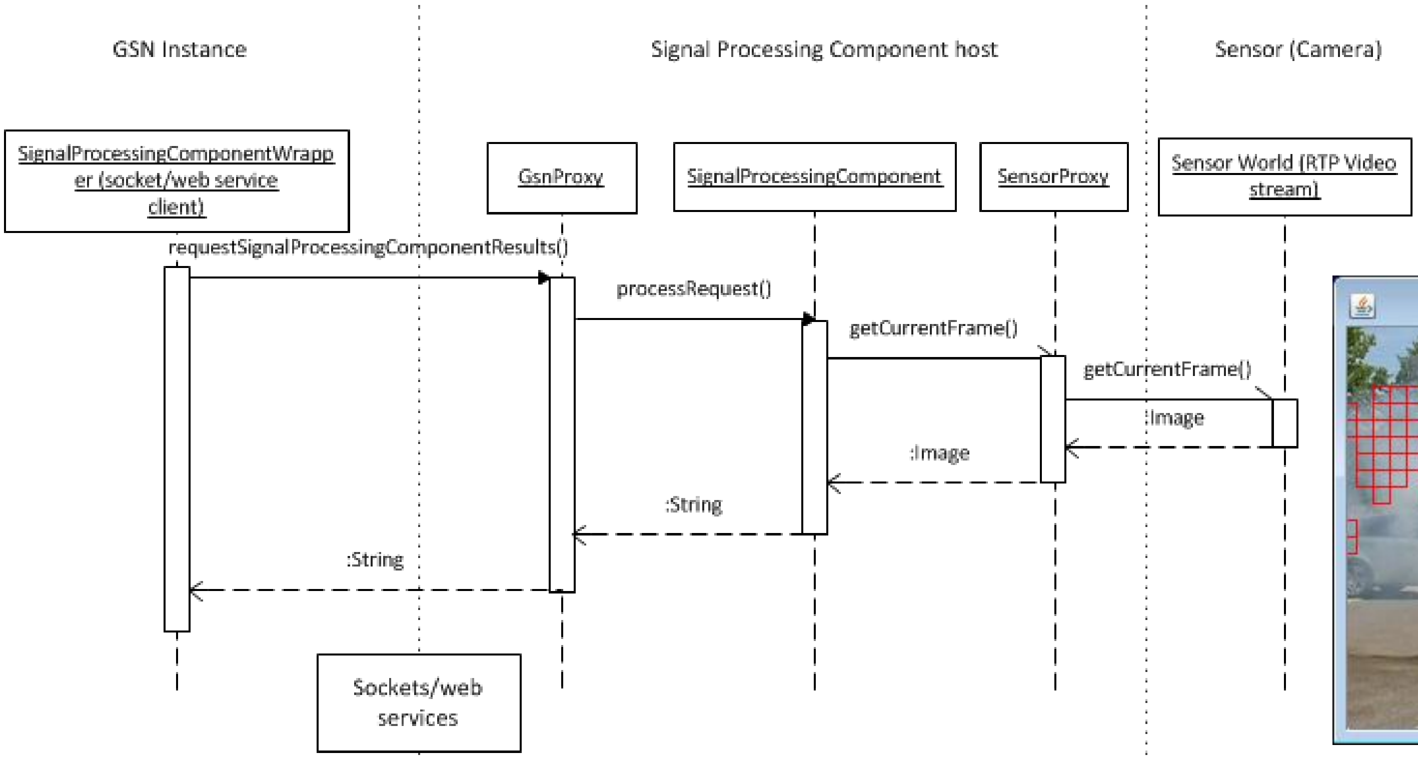
- Open-source, java-based *middleware* solution
- Available online at sf.net/projects/gsn/
- Adaptability
  - Everything is a virtual sensor
  - Virtual sensors rely on wrappers
  - Every data producer can be integrated into the GSN with a virtual sensor and wrapper

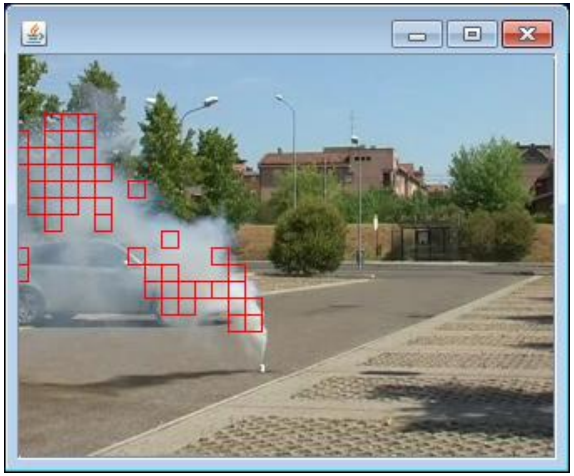
Global Sensor Networks (2)

- Simplicity
  - Configurable without compiling source code
  - Web application for sensor management
- Scalability
  - Allows communication between nodes
  - Allows data aggregation and fusion using an SQL-like declarative language

Global Sensor Networks (3)

- Example
  - Integrating a Signal Processing component (e.g. a Smoke detector) into GSN





Example of data aggregation using GSN

```
<output-structure>
        …
        <field name="TEMPERATURE" type="int" />
        …
</output-structure>
…
<storage history-size="24h" />
…
<streams>
        <stream name="input1">
                <source alias="source1" sampling-rate="1" storage-size="1">
                        <address wrapper="temperature">
                                <predicate key="sampling-rate">10000</predicate>
                        </address>
                        <query>select TEMPERATURE from wrapper</query>
                </source>
                <query>select avg(TEMPERATURE) from source1</query>
        </stream>
</streams>
```

measured properties

sliding window size

data source

aggregated output

Example of data fusion using GSN

```
<storage history-size="1h" />
<streams>
	<stream name="teststream" rate="1000">
		<source name="source1" alias="source1" storage-size="100" slide="0" sampling-rate="1">
				<address wrapper="remote-rest">
				<predicate key="HOST">localhost</predicate><predicate key="PORT">22001</predicate>
				<predicate key="QUERY">select FACE_COUNT from doorwatcher</predicate>
				</address>
				<query>select FACE_COUNT AS S1 from wrapper</query>
		</source>
```

source 1

```
		<source name="source2" alias="source2" storage-size="100" slide="0" sampling-rate="1">
				<address wrapper="remote-rest">
				<predicate key="HOST">localhost</predicate><predicate key="PORT">22002</predicate>
				<predicate key="QUERY">select TAG from touchatag</predicate>
				</address>
				<query>select TAG AS S2 from wrapper</query>
		</source>
```

source 2

```
		<query>
		select source1.S1 as S1OUT, source2.S2 as S2OUT
		from source1, source2
		where source1.S1 > 0 AND source2.S2="04dddcb9232580"
		</query>
```

fused output

```
	</stream>
</streams>
```

The Storage Layer (1)

- Schema according to the Virtual Sensors
  - Virtual Sensor definition example:

```
<virtual-sensor name="temperature" priority="10">
…
<output-structure>
  <field name="ID" type="int" />
  <field name="SENSORTIME" type="time" />
  <field name="TEMPERATURE" type="double" />
  <field name="UNIT" type="varchar(255)" />
</output-structure>
```

The Storage Layer (2)

- Schema according to the Virtual Sensors
  - Schema auto-generated SQL create statement:

```
CREATE TABLE `gsn1`.`temperature` (
  `PK` bigint(20) NOT NULL AUTO_INCREMENT,
  `timed` bigint(20) NOT NULL,
  `ID` int(11) DEFAULT NULL,
  `SENSORTIME` time DEFAULT NULL,
  `TEMPERATURE` double DEFAULT NULL,
  `UNIT` varchar(255) DEFAULT NULL,
  PRIMARY KEY (`PK`),
  UNIQUE KEY `temperature_INDEX` (`timed`)
) ENGINE=MyISAM AUTO_INCREMENT=122 DEFAULT CHARSET=latin1
```

added by GSN

depending on the virtual sensor description

The Storage Layer (3)

- Historical data
  - According to the Virtual Sensor definition
    - Tuple-based: <storage history-size="1" />
    - Time-based: <storage history-size="1m" />
- Out-of-the-box support for
  - Mysql
  - SQL Server
  - Oracle
  - H2
  - Can be extended to support other RDBMS's

gsn1.temperature: 10 rows total (approximately)

PK	timed	ID	TEMPERATURE	UNIT
14983	1301312947745	3612	23	C
15023	1301312959138	3612	23	C
15018	1301312957746	3612	23	C
15013	1301312956379	3612	23	C
15008	1301312954970	3612	23	C
15003	1301312953579	3612	23	C
14998	1301312952170	3612	23	C
14993	1301312950700	3612	23	C
14988	1301312949223	3612	23	C
15028	1301312960725	3612	23	C

The Storage Layer (4)

- Storage Layer can be
  - Centralized (in the Central Control node)
    - Data is pushed to the Central Control node
  - Distributed (in the Gateway nodes)
- Interfaces
  - Legacy (ODBC/JDBC)
  - Web Services (SOAP or RESTful)
  - SPARQL Endpoints
    - Allow Semantic Information Integration

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Exposing sensor data as triples (1)

- OpenLink Virtuoso universal server can be used as
  - A web application server
  - A relational database repository
  - A triplestore
  - A web service server
- Open-source version available at http://virtuoso.openlinksw.com/
- Cluster Configuration
  - Parallel and Horizontal scaling

Exposing sensor data as triples (2)

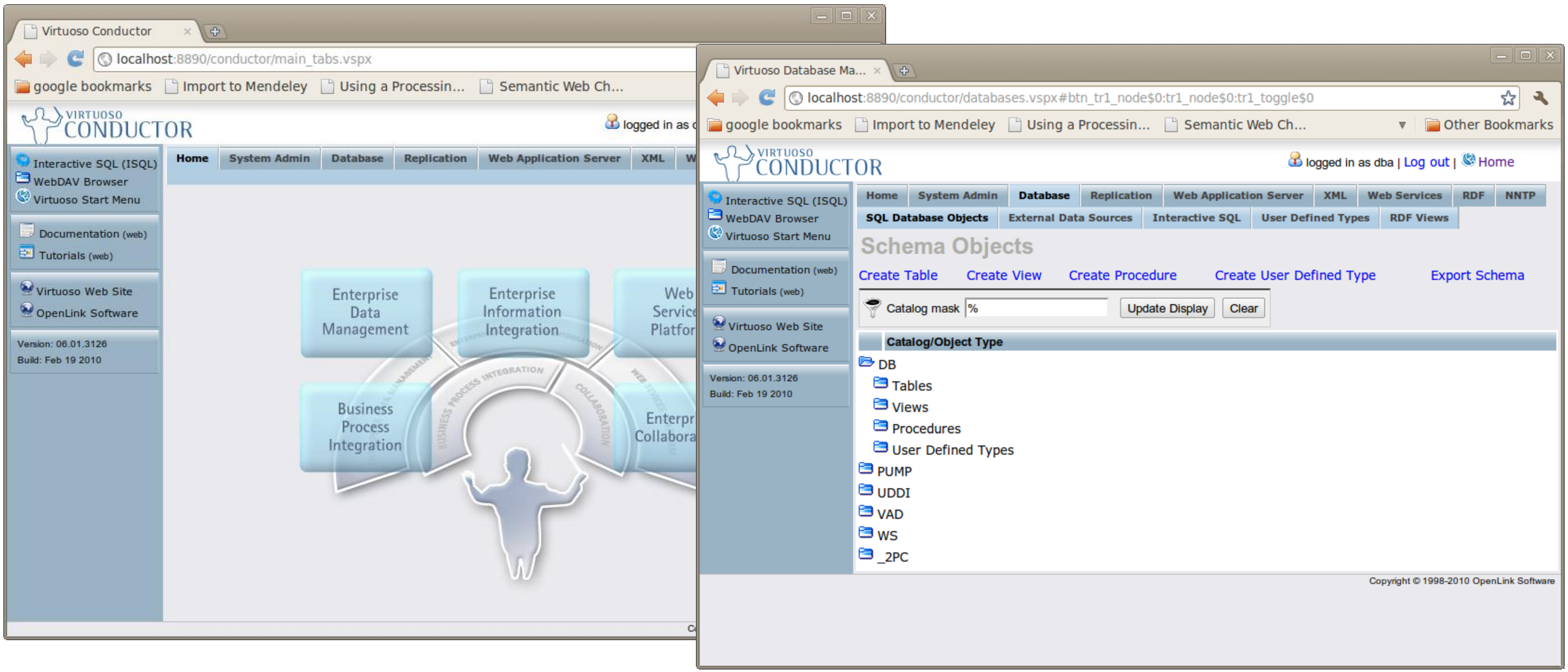
- Virtuoso RDF Views
  - Export relational data as triples
- SPARQL 1.1 support, plus
  - Full Text Queries
  - Geo Spatial Queries
  - Business Analytics and Intelligence
  - SQL Stored Procedure and Built-In Function exploitation from SPARQL
  - Create, Update, and Delete (SPARUL)
- Backward-chaining OWL reasoner

Exposing sensor data as triples (3)

- Using Virtuoso, RDF Data can also be accessible via
  - ODBC/JDBC
  - ADO.NET (Entity Frameworks compatible)
  - OLE DB
  - XMLA (XML for Analysis) data providers / drivers
- Using the “Sponger” RDF-izer, RDF data can be extracted from non-RDF sources (e.g. with XSLT)

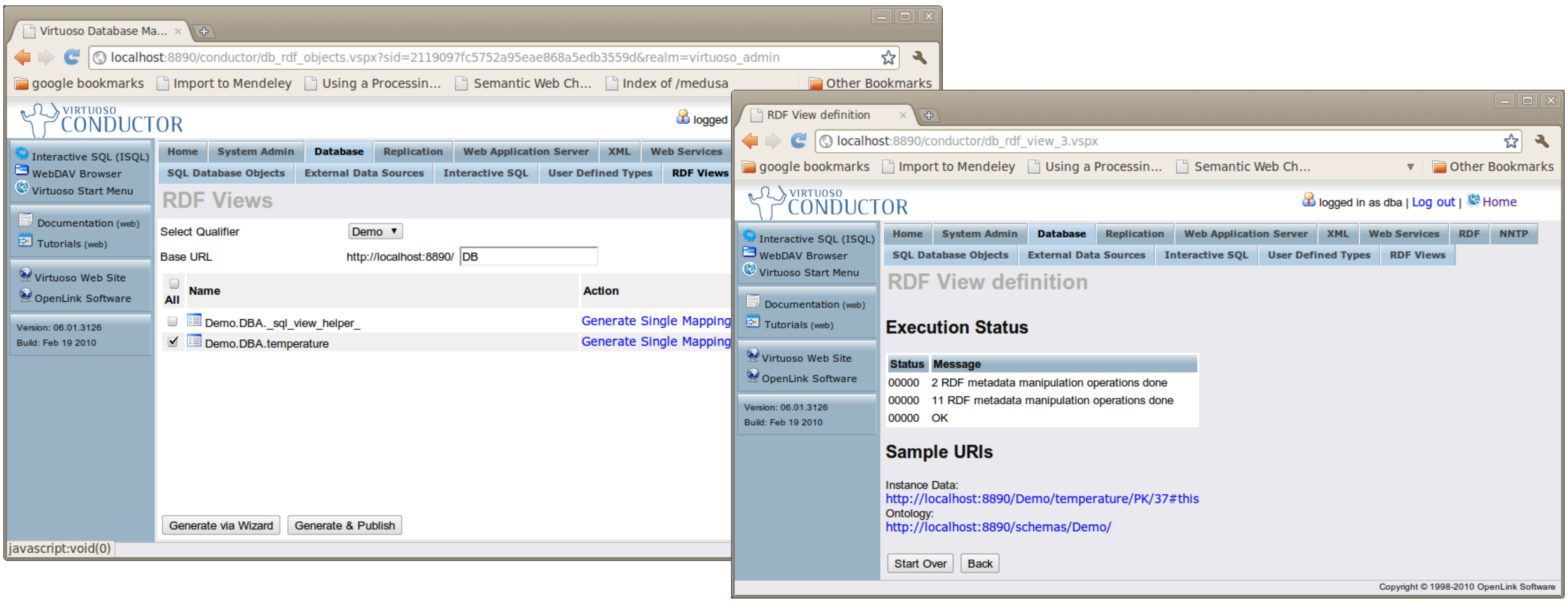
Publishing RDF using Virtuoso (1)

- Conductor: a GUI for server administration
- Virtuoso can be used as a DBMS



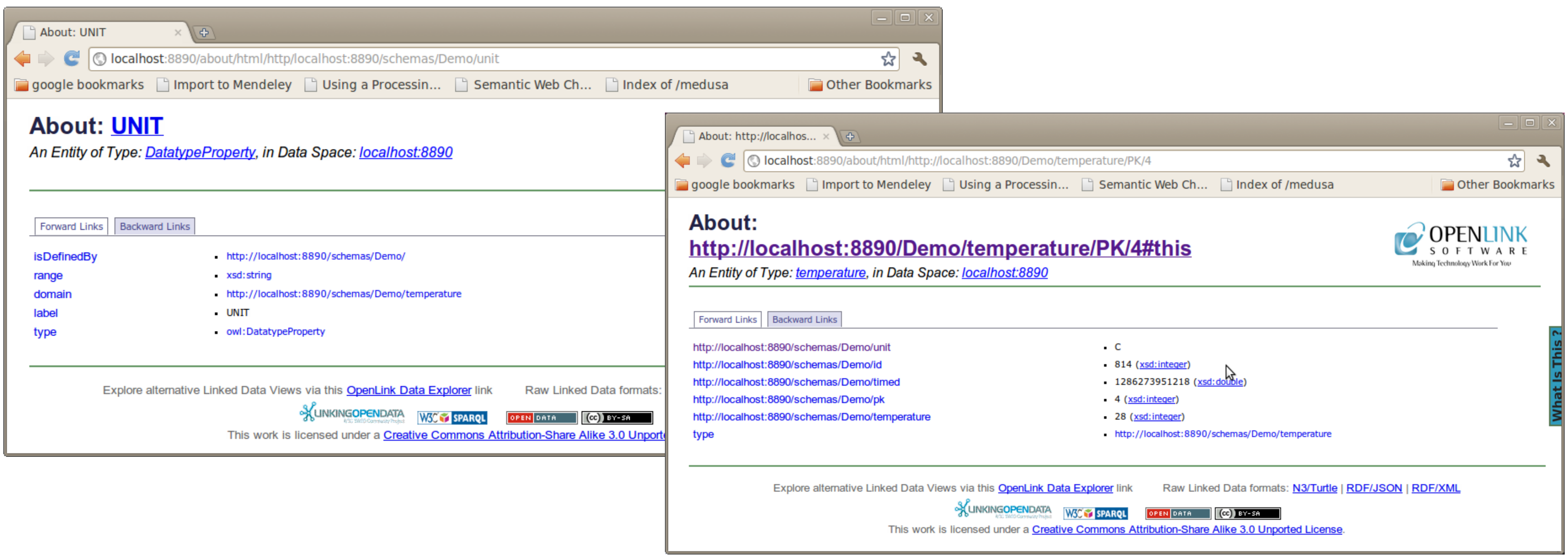
Publishing RDF using Virtuoso (2)

- Can be combined with GSN to process sensor data streams and export them as RDF
- Create RDF Views over the relational data

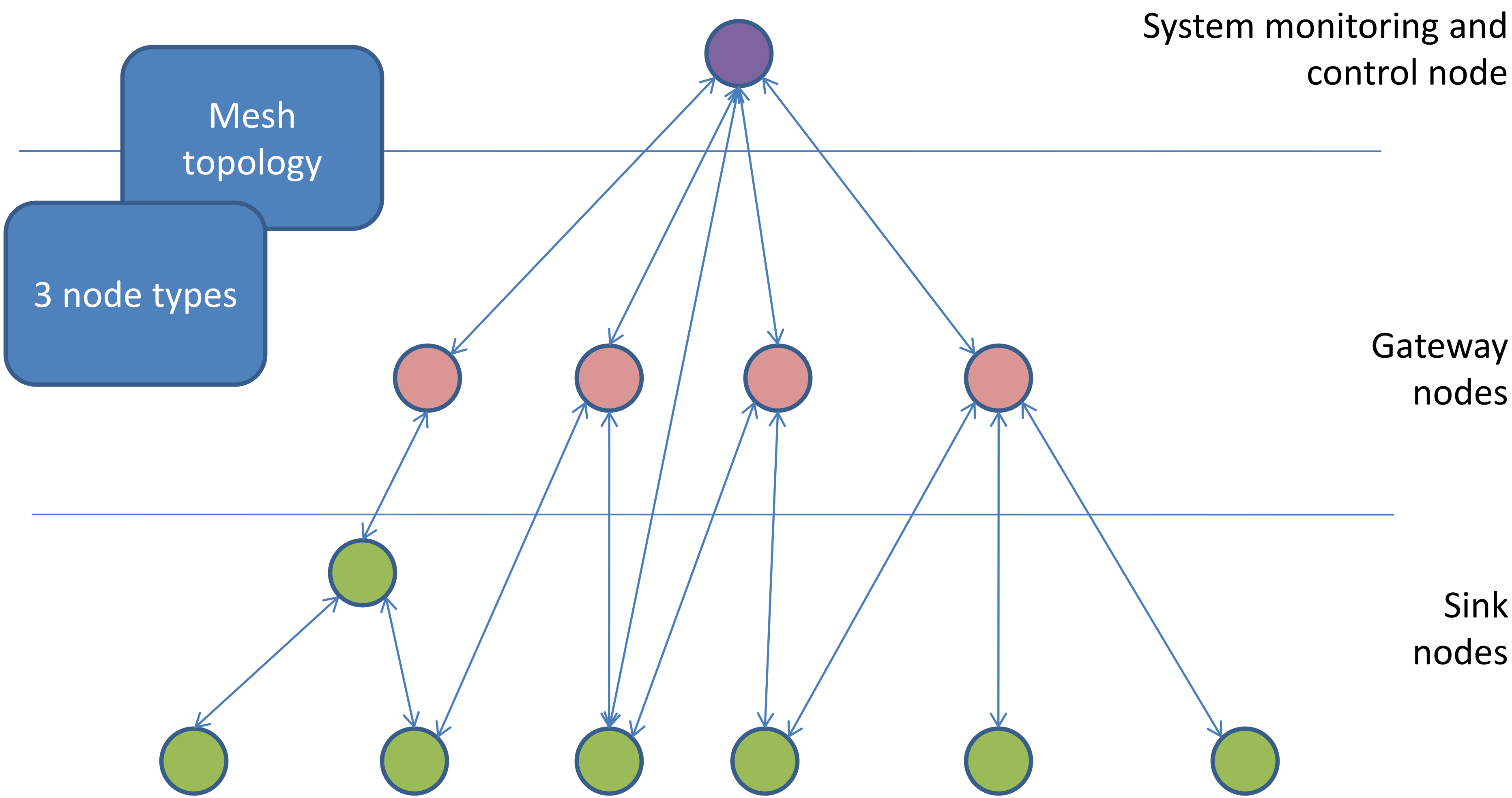


Publishing RDF using Virtuoso (3)

- Browseable repository
- A URI for every resource
- Example: Measurement URI



Semantic Sensor Network Example (1)



Semantic Sensor Network Example (2)

- Sink node
  - Operation relies on a relational database
  - Limited historical data
  - Keep a "sliding window"
    - Based on time or tuples
  - Do not have semantic capabilities
  - One Database per Sink node

Semantic Sensor Network Example (3)

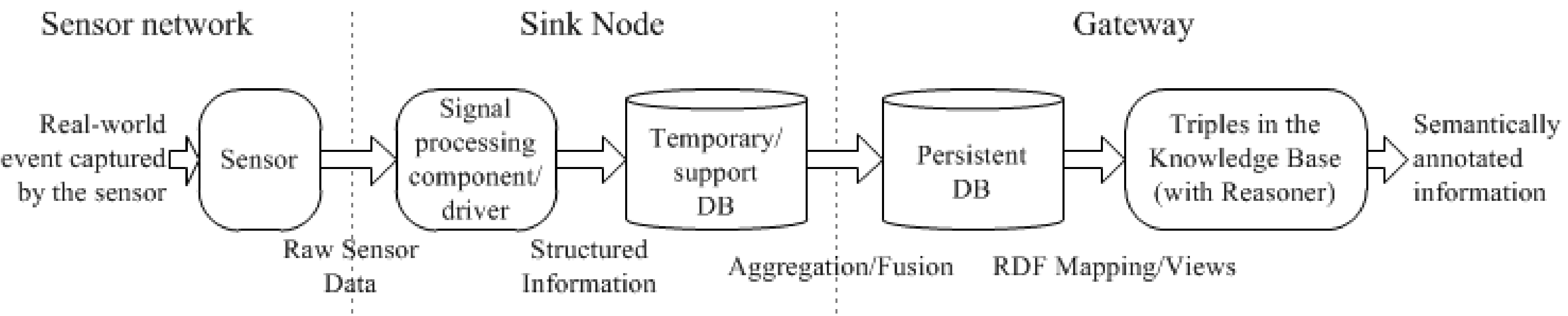
- Gateway Node
  - Operation relies on a semantically-enabled knowledge base
  - Supported by inference procedures
  - Maintains historical/archived information
  - One Knowledge Base per Gateway node
  - Appropriate for Higher Level Fusion (e.g. threats, events)

Semantic Sensor Network Example (4)

- Central Control node
  - Monitors and controls the network
  - Provides system-wide services
    - E.g. directory services, secure authentication
  - Can store its view over the network for intelligence extraction

Information Flow

- An Information flow example in a decentralized Semantic Sensor Network



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Semantic integration using SPARQL (1)

- SPARQL: An SQL-like language for querying RDF graphs
- `SELECT-FROM-WHERE` syntax
- WHERE conditions are triple patterns
- `SELECT ?x ?y ?z`

  `WHERE`

  `{ ?x ?y ?z }`

  returns all the triples in the graph

Semantic integration using SPARQL (2)

- XML over HTTP (RESTful approach)
  - http://demo.openlinksw.com/sparql?default-graph-uri=urn:lsid:ubio.org:namebank:11815&should-sponge=soft&query=SELECT+*+WHERE+{?s+?p+?o}&format=text/html
- No create/update/delete capabilities

Semantic integration using SPARQL (3)

- SPARQL queries can be named and stored
  - A query named *sparql-demo* listens to: http://localhost:8890/DAV/sparql-demo
- Can return results over HTTP (XML by default)
- MIME type of the RDF data
  - 'rdf+xml' (default) | 'n3' | 'turtle' | 'ttl‘

Semantic integration using SPARQL (4)

- SPARQL results example in RDF/XML


```
<ROOT>
<rdf:RDF  xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#” xmlns:rs="http://www.w3.org/2005/sparql-results#"
xmlns:xsd="http://www.w3.org/2001/XMLSchema#">
<rs:results rdf:nodeID="rset">
  <rs:result rdf:nodeID="sol193">
   <rs:binding rdf:nodeID="sol193-0" rs:name="x“><rs:value rdf:resource="http://localhost:8890/Demo/temperature/PK/4#this"/></rs:binding>
   <rs:binding rdf:nodeID="sol193-1" rs:name="y“><rs:value rdf:resource="http://www.w3.org/1999/02/22-rdf-syntax-ns#type"/></rs:binding>
   <rs:binding rdf:nodeID="sol193-2" rs:name="z“><rs:value rdf:resource="http://localhost:8890/schemas/Demo/temperature"/></rs:binding>
  </rs:result>
…
</rs:results>
</rdf:RDF>
</ROOT>
```

Thank you!

Questions?