AGGREGATION OF SEMANTIC SENSOR DATA

Graduation proposal

by

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API application program interface . . . 2
EU european union . . . 1
GIS geographical information system . . . 9
HTTP hypertext transfer protocol . . . 13
INSPIRE infrastructure for spatial information in Europe . . . 1
IoT internet of things . . . 1
IRCEL-CELINE Belgian interregional environment agency . . . 19
IRI international resource identifier . . . 13
ISO international organisation for standardisation . . . 1
LusTRE linked thesaurus framework for the environment . . . 7
OGC open geospatial consortium . . . 1
O&M observations and measurements . . . 1
OWL web ontology language . . . 14
RDF resource description framework . . . 1
REST representational state transfer . . . 5
RIVM Dutch national institute for public health and the environment . . . 2
SEL semantic enablement layer . . . 5
Sem-SOS semantically enabled sos . . . 5
SensorML sensor modelling language . . . 1
SIR sensor instance registry . . . 2
SOR sensor obserable registry . . . 2
SOS sensor observation service . . . 1
SPARQL sparql protocol and rdf query language . . . 1
SSNO semantic sensor network ontology . . . 5
SSW semantic sensor web . . . 2
SWE sensor web enablement . . . 1
UML unified modeling language . . . 14
URI uniform resource identifier . . . 2
URL uniform resource locator . . . 13
W3C world wide web consortium . . . 2
WCS web coverage service . . . 2
WFS web feature service . . . 2
WMS web map service . . . 2
WPS web processing service . . . 8
XML extensible markup language . . . 2

1 INTRODUCTION

From 2020 onwards all member states of the european union (EU) should provide sensor data to the infrastructure for spatial information in Europe (INSPIRE) in order to comply with annex II and III of the INSPIRE directive (INSPIRE, 2015). For this a number of sensor web enablement (SWE) standards are required to be used (INSPIRE, 2014). The sensor web is a relatively new development and there are still many questions on how to structure it. This thesis aims to develop a method to publish and link sensor metadata on the semantic web for discovering, integrating and aggregating sensor data.

1.1 BACKGROUND

In 2008 the open geospatial consortium (OGC) introduced a new set of standards called SWE. These standards make it possible to connect sensors to the internet and retrieve data in a uniform way. This allows users or applications to retrieve sensor data through standard protocols, regardless of the type of observations or the sensor's manufacturer (Botts et al., 2008). Among other standards SWE includes the observations and measurements (O&M) which is a model for encoding sensor data, the sensor modelling language (SensorML) which is a model for describing sensor metadata and the sensor observation service (SOS) which is a service for retrieving sensor data (Botts et al., 2007). O&M has also been adopted by the international organisation for standardisation (ISO) under ISO 19156:2011 (ISO, 2011).

Recently OGC has defined the role which their standards could play in smart city developments (Percivall, 2015). Smart cities can be defined as "enhanced city systems which use data and technology to achieve integrated management and interoperability" (Moir et al., 2014, p. 18). Research on smart cities has shown a great potential for using sensor data in urban areas. Often this is presented in the context of the internet of things (IoT) (Zanella et al., 2014; Wang et al., 2015a). The IoT can be described as "the pervasive presence around us of a variety of *things* or *objects* ... [which] are able to interact with each other and cooperate with their neighbors to reach common goals" (Atzori et al., 2010, p. 2787).

Parallel to the development of the sensor web other research has focused on the semantic web, as proposed by Berners-Lee et al. (2001). This is a response to the traditional way of using the web, where information is only available for humans to read. The semantic web is an extension of the internet which contains meaningful data that machines can understand as well. Rather than publishing documents on the internet the semantic web contains linked data using the resource description framework (RDF), also known as the 'web of data' (Bizer et al., 2009). Data in RDF can be queried using the sparql protocol and rdf query language (SPARQL) at so called SPARQL endpoints. Originally, the semantic web intended to add metadata on the internet (Lassila and Swick, 1999). However, today it is being used for linking any kind of data from one source to another in a meaningful way (Cambridge Semantics, 2015).

Sheth et al. (2008) proposes to use semantic web technologies in the sensor web. This so-called semantic sensor web (SSW) builds on standards by OGC and the world wide web consortium (W3C) ”to provide enhanced descriptions and meaning to sensor data” (Sheth et al., 2008, p.78). W3C responded to this development by creating a standard ontology for sensor data on the semantic web (Compton et al., 2012).

1.2 PROBLEM STATEMENT

Finding sensor data that can be retrieved using a SOS is not easy. The implementation of the sensor web is still in an early stage. At the moment there are only a limited number of SOS implementations available on the web and they contain a limited amount of data. In the Netherlands the SOS by the Dutch national institute for public health and the environment (RIVM) is one of the first ones to be developed. It has only recently been created and contains data on air quality. A number of other organisations still use a custom application program interface (API) to retrieve data from sensors connected to the internet. It has been researched to what extent a catalogue services could be useful for discovering sensor data: the sensor instance registry (SIR) (Jirka and Nüst, 2010) and the sensor obserable registry (SOR) (Jirka and Bröring, 2009). Catalogue services have already been available for example for the web map service (WMS), web feature service (WFS) or web coverage service (WCS) (Nebert et al., 2007). However, for discovering sensor data from the SOS services used in this paper no register or catalogue service has been implemented.

It has been argued that one of the challenges of using sensor data is the difficulty of integrating data from different sources to perform data fusion (Corcho and Garcia-Castro, 2010; Ji et al., 2014; Wang et al., 2015b). Data fusion is ”a data processing technique that associates, combines, aggregates, and integrates data from different sources” (Wang et al., 2015a, p. 2). Even if the sources comply with the SWE standards it is challenging, since the data can be of a different scale, both in time and space.

A question that comes to mind is to what extent the semantic web could be a better solution for publishing sensor data than using a SOS. The geoweb has some very good qualities, such as very structured approaches in which (sensor) data can be retrieved using well defined services. This is different from for example web pages where content can be completely unstructured. The response of a SOS also contains some semantics about sensor data. There can be x-links inside the extensible markup language (XML) with uniform resource identifier (URI)s that point to semantic definitions of objects. Still, the semantic web could be beneficial for the geoweb as it is machine understandable which could be useful for automatic integration and aggregation. It also contains links to other relevant data which could make discovering sensor data more easy.

1.3 SCIENTIFIC RELEVANCE

Sensor data ties together many different fields of research. On the one hand there is research on how to create the most efficient sensor networks that uses the least amount of power to transfer the observed data over long distances. This involves academic fields such as mathematics, physics and electrical engineering. On the other hand there is research that uses sensor data to gain insights into real world phenomenon. This involves academic fields such as geography, environmental studies and urbanism. In order to connect these scientific fields, research has been focused on the use of computer science and standardisation for transferring sensor data over the internet.

In the future more sensor data is expected to be produced, on the one hand by experts because of European legislation (INSPIRE). However, on the other hand also non-experts will be involved more often via smart cities and IoT developments where users or consumer electronics produce sensor data. This vast amount of data could be very useful for academic research, provided researchers are able to find the data they need online and are able to integrate and aggregate data from heterogeneous sources. Publishing sensor metadata on the semantic web could make it easier to find what you need through related data on the internet. A SOR or SIR is only useful for users if it is already known in advance where to find a specific catalogue service, as content inside the service cannot be linked to from other parts of the web. It is also dependent on whether people producing data have invested time and effort to register their sensors to such a service.

1.4 RESEARCH QUESTION

This thesis aims to develop a method that uses the semantic web to improve sensor data discovery as well as the integration and aggregation of sensor data from heterogeneous sources. The following question will be answered in this research: *How can the semantic web improve the discovery, integration and aggregation of distributed sensor data?*

2 RELATED WORK

A number of research topics are relevant for this thesis: how to use existing standards for publishing sensor data to the semantic web, developing ontologies that are suitable for many different kinds of sensor data and how to aggregate sensor data based on features-of-interest and time. This chapter discusses the recent relevant literature on these topics.

2.1 SENSOR DATA CATALOGUE SERVICE

Jirka and Bröring (2009), Jirka and Nüst (2010)

2.2 SEMANTIC SENSOR DATA MIDDLEWARE

Henson et al. (2009) and Pschorr (2013) suggest adding semantic annotations to a SOS which they call semantically enabled sos (Sem-SOS). In Sem-SOS the raw sensor data goes through a process of semantic annotating before it can be requested with a SOS service. The retrieved data is still an XML document, but with embedded semantic terminology as defined in an ontology model. The data retrieved from Sem-SOS is therefore semantically enriched.

Janowicz et al. (2013) has specified a method that uses a representational state transfer (REST)ful proxy as a façade for SOS. When a specific URI is requested the so-called semantic enablement layer (SEL) translates this to a SOS request, fetches the data and translates the results back to RDF. In this method the sensor data is converted to RDF on-the-fly. This allows the data to be interpreted by both humans and machines.

Atkinson et al. (2015) have identified that "distributed heterogeneous data sources are a necessary reality in the case of widespread phenomena with multiple stakeholder perspectives" (Atkinson et al., 2015, p.129). Therefore, they propose that methods should be developed to move away from the traditional dataset centric approaches and towards using linked data for cataloguing. This has the potential to bring together data and knowledge from different areas of research about the same (or similar) features-of-interest. It is also argued that using both linked data services and data-specific services could ease the transition into the linked data world.

2.3 SENSOR DATA ONTOLOGIES

SEMANTIC SENSOR NETWORK ONTOLOGY

W3C has developed an ontology for sensors and observations called the semantic sensor network ontology (SSNO). This ontology aims to address semantic interoperability on top of the syntactic operability that the SWE standards provide. To accommodate different definitions of the same con-

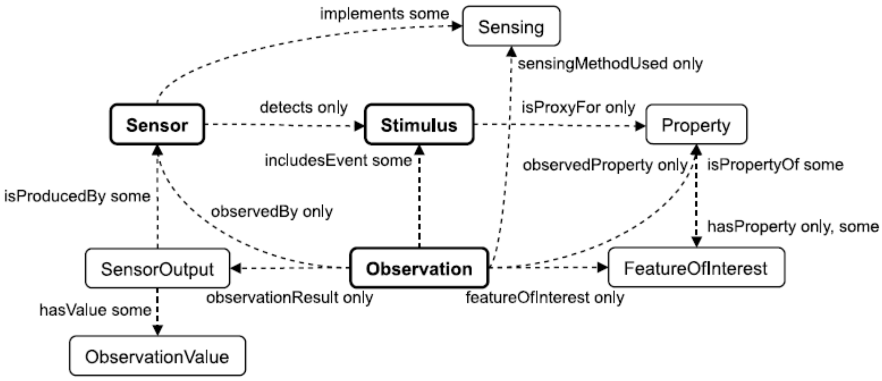

Figure 2.1: The stimulus–sensor–observation pattern (Compton et al., 2012, p. 28)

cepts the broadest definitions have been used. Depending on the interpretation these can be further defined with subconcepts. The SSNO is based on the stimulus-sensor-observation pattern, describing the relations between a sensor, a stimulus and observations (figure 2.1). Sensors are defined as "physical objects ... that observe, transforming incoming stimuli ... into another, often digital, representation", stimuli are defined as "changes or states ... in an environment that a sensor can detect and use to measure a property" and observations are defined as "contexts for interpreting incoming stimuli and fixing parameters such as time and location" (Compton et al., 2012, p 28). The ontology can be used to model sensor networks from four different perspectives (sensor, observation, system, and feature & property), which have been discussed together with additional relevant concepts.

OBSERVATION CAPABILITY METADATA MODEL

Hu et al. (2014) have reviewed a number of metadata models (including SensorML and SSNO) for the use of earth observation (including remote sensing). They argue that all of the current metadata models are not sufficient for sensor data discovery. This conclusion is based on an evaluation of six criteria. Three steps have been identified in the process of obtaining relevant sensor data for earth observation, which have been used to derive criteria for their evaluation framework. These steps are sensor filtration, sensor optimisation and sensor dispatch. The filtration of sensors should result in a set of sensors that meets the requirements of the application: it should measure the right phenomenon, be active, be inside the spatial and temporal range, and have a certain sample interval. In sensor optimisation the selected sensors should be combined to complement or enhance each other. To do this, the observation quality, coverage and application is relevant. In the last step - sensor dispatch - the data should be retrieved, stored transmitted. In every evaluated model sensors can describe in different ways or only partially, which affects the outcome of the sensor dispatch.

Therefore, a metadata model is proposed that "reuses and extends the existing sensor observation-related metadata standards" (Hu et al., 2014, p. 10546). It is composed of five modules: observation breadth, observation depth, observation frequency, observation quality and observation data. They should be derived from metadata elements described using the Dublin Core metadata element set. These five modules can then be formalized following the SensorML schema which can be queried by users via the 'Unified Sensor Capability Description Model-based Engine' (figure 2.3).

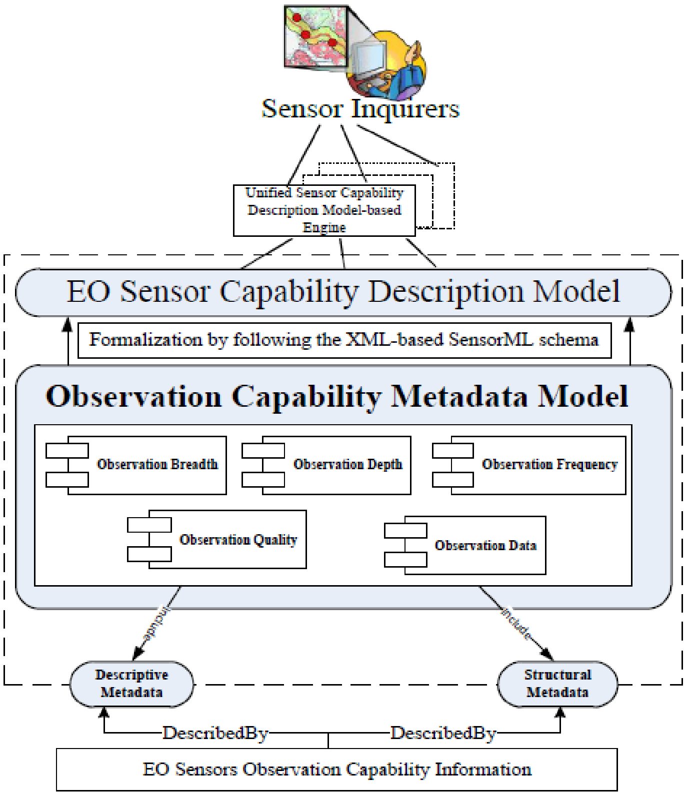

Figure 2.2: Architecture of the sensor discovery system (Hu et al., 2014, p. 10553)

om-lite & sam-lite ontologies

Cox (2015a) has been working on a new semantic ontology based on O&M. Previous efforts, such as the SSNO have been using pre-existing ontologies and frameworks. However, there are already many linked data ontologies that could be useful for describing observation metadata, such as space and time concepts. Also, the SSNO does not take sampling features into account. The proposed om-lite ontology defines the concepts from O&M regarding observations, while the sam-lite defines the sampling feature concepts.

It is also described how the PROV vocabulary can be directly inside inside om-lite. The PROV ontology Lebo et al. (2013) is "concerned with the production and transformation of Entities through time-bounded Activities, under the influence or control of Agents" (Cox, 2015a, p. 12). The author also provides a mapping of the SSNO to om-lite and PROV.

linked thesaurus framework for the environment

The linked thesaurus framework for the environment (LusTRE) aims to "help users to easier and better express and use thesauri and controlled vocabularies for metadata work within Spatial Data Infrastructures" (Abecker et al., 2015, p. 137). This ontology does not focus on sensor data, but does describe many phenomenon that are being observed. This fits with the idea of Cox (2015a) to use ontologies that are already available online for defining metadata elements of sensor data.

2.4 SENSOR DATA AGGREGATION

Stasch et al. (2011b) propose to aggregate sensor data based on the geometry of sampling features. Stasch et al. (2011a) proposes a web processing service (WPS) that takes sensor data right from a SOS service in order to aggregate it. The approach by Stasch et al. (2011b) takes sensor data as input that is already published on the semantic web.

Stasch et al. (2014) argue that in order for automatic aggregation to work there needs to be semantics on which kind of aggregation methods are appropriate for a specific kind of sensor data. This requires a formalisation of expert knowledge which they call semantic reference systems.

2.5 CONCLUSION

Sem-SOS (Henson et al., 2009; Pschorr, 2013) as well as SEL (Janowicz et al., 2013) focus on combining the sensor web with the semantic web, but do not address the integration and aggregation of sensor data. Similarly, Atkinson et al. (2015) proposes to expose sensor data to the semantic web in order to find other kinds of related data about the same feature-of-interest. Data that is collected from another area of research for example. Also Atkinson et al. (2015) does not mention the integration of sensor data from heterogeneous sources. Stasch et al. (2011b) and Stasch et al. (2011a) suggest interesting methods for aggregating sensor data based on features-of-interest. However, also these studies use sensor data from a only single source into account. Moreover, Corcho and Garcia-Castro (2010) and Ji et al. (2014) argue that methods for integration and fusion of sensor data on the semantic web is still an area for future research. Data fusion is "a data processing technique that associates, combines, aggregates, and integrates data from different sources" (Wang et al., 2015a, p. 2). This thesis therefore focuses on the discovery, integration and aggregation of sensor data, building on some of the principles proposed by related research discussed in this chapter.

The idea by Jones et al. (2014) of delivering data to users through a service with which they are already familiar is very appealing, because it would enable sensor data to be immediately used in any existing geographical information system (GIS). This is also suggested by Atkinson et al. (2015) to ease the transition to the linked data world. However, current research has mainly been concerned with static geographic data, not with (aggregated) sensor data. Therefore, this thesis aims to provide the service for integrating and aggregating sensor data as a WPS.

3 RESEARCH OBJECTIVES

the research objectives and/or research questions are clearly defined, along with the scope (ie what you will not be doing);

3.1 RESEARCH QUESTION

The main question this thesis will try to answer is:
How can the semantic sensor web improve the discovery, integration and aggregation of distributed sensor data?

To answer the main question a number of sub-questions need to be answered:

- How can sensor metadata be retrieved from a SOS and automatically published on the semantic web?
- How can metadata on the semantic web be linked to relevant features-of-interest and existing vocabularies?
- How can aggregation methods be represented on the semantic web to formalise expert knowledge and prevent meaningless aggregation?
- To what extent can already existing standards for retrieving geographic data be used for a service that supplies integrated and aggregated sensor data?

3.2 OBJECTIVES

This thesis explores a method to store metadata of sensors on the semantic web, and to link it to real world features-of-interest and appropriate methods for aggregation. This should improve the discovery of sensor data through links to other related data on the internet.

To improve the integration of sensor data a middleware architecture will be developed that can return sensor data for features-of-interest from different sources. The returned sensor data will be aggregated. Only appropriate methods of aggregation are offered for each kind of observations, based on a formalisation of expert knowledge on the semantic web.

3.3 SCOPE

4 METHODS

overview of the methodology to be used;

4.1 SENSOR OBSERVATION SERVICE

Retrieve sensor metadata from the sensor observation service. There are a number of different requests that can be made: GetCapabilities, DescribeSensor and GetObservation. These requests can be made as a hypertext transfer protocol (HTTP) GET request or a HTTP POST request. The response is an XML document using the O&M (for GetObservation) or SensorML (for DescribeSensor).

4.2 RESOURCE DESCRIPTION FRAMEWORK

Publishing static geographic data on the semantic web requires a conversion of Shapefile to RDF. First the Shapefile is loaded into a Postgres database with the Postgis extension. After that a Python script retrieves the records from the database. Attributes of the records will be mapped to classes from predefined ontologies. Then the script creates an RDF graph and serialises it to a certain RDF language. This is written it to a file. The final step is to publish the RDF on the web and create a SPARQL endpoint to query the data (Missier, 2015).

In RDF data is stored in so-called 'triples'. These triples are structured as: subject, predicate and object Berners-Lee et al. (2001). The subject and the object are things and the predicate is the relation between these two things. Three types of data can make up these triples. The first type is an international resource identifier (IRI). This is a reference to a resource and can be used for all positions of the triple. A uniform resource locator (URL) is an example of an IRI, but IRIs can also refer to resources without stating where a location or how it can be accessed. It is a generalisation of an URI, also allowing non-ASCII characters. The second type of data is a literal. A literal is a value which is not an IRI, such as strings, numbers or dates. These values can only be used as object in a triple. Sometimes it's useful to refer to things without assigning them with a global identifier. The third type is the blank node and can be used as an subject or object without using an IRI or literal (Manola et al., 2014).

There are a number of different languages for writing down these triples (serialisation), such as XML (Gandon and Schreiber, 2014), N3 (Berners-Lee and Connolly, 2011) and Turtle (Beckett et al., 2014).

The sensor metadata is also being published on the semantic web. To do this an XML document is automatically retrieved from a SOS by a Python script. This script then extracts the relevant data from the XML and maps it to an ontology. It outputs an RDF file that will be published online. When new sources of sensor data are added the RDF documents will be updated.

4.3 ONTOLOGY MAPPING

The unified modeling language (UML) diagram (figure 4.1) describes different components of a SOS. The SOS has a number of metadata attributes such as the service provider's details (including contact information), its spatial and temporal extent (spatialFiler & temporalFilter) and the capabilities to query a subset of this extent. It receives data from a sensor which makes observations. An observation can be defined as "an action whose result is an estimate of the value of some property of the feature-of-interest, obtained using a specified procedure" (Cox, 2015a).The sensor is placed at a sampling point. The sampling point is part of a sampling features which intents to resemble the feature-of-interest. In the case of air quality the feature-of-interest is the bubble of air surrounding the sensor, therefore the sampling point equals the feature-of-interest (INSPIRE, 2014). The design is that an observation of the sampling feature describes the feature-of-interest through measuring one of its properties. The measurement procedure is described by a short string of text, input and output parameters and the units of measurement of the ouput. The relation between feature-of-interest and administrative units is added to improve the discovery of sensor data on the semantic web.

To publish data on the semantic web ontologies are required to specify the different classes and their relations. An ontology for static geographic data has to be connected to an ontology for sensor metadata. From the UML diagram in figure 4.1 the classes Observation, Process, ObservedProperty and FeatureOfInterest can be mapped to classes belonging to web ontology language (OWL) for observations (Cox, 2015b). SamplingFeature and Sampling point can be mapped to classes from OWL for sampling features Cox (2015c). GeoSPARQL can be used for the administrativeUnite class (Perry and Herring, 2011) and the SSNO for the sensor and sensor observation service classes (W3C Semantic Sensor Network Incubator Group, 2011).

4.4 SENSOR DATA AGGREGATION

There are many different ways to aggregate sensor data, for example by taking the minimum value, the maximum value, the average value, the sum, etc. In order to determine which method of aggregation is applicable for a specific kind of sensor data the sensor metadata will contain links to appropriate aggregation methods. However, which methods are appropriate should be based on expert knowledge. Therefore, this requires a literature analysis.

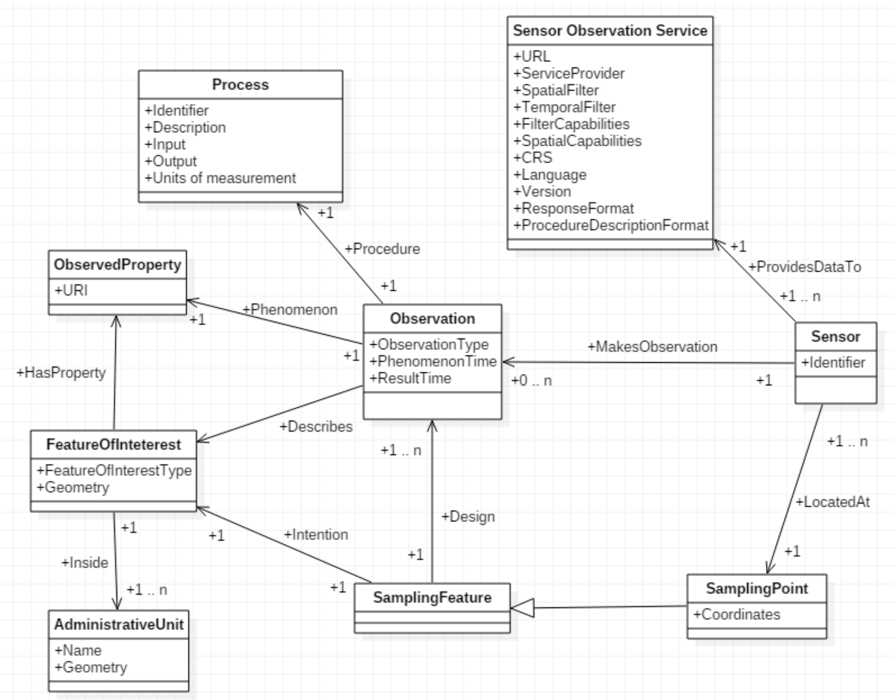

Figure 4.1: UML diagram of sensor observations service

5 PLANNING

time planning—having a Gantt chart is probably a better idea then just a list;

5.1 GANTT CHART

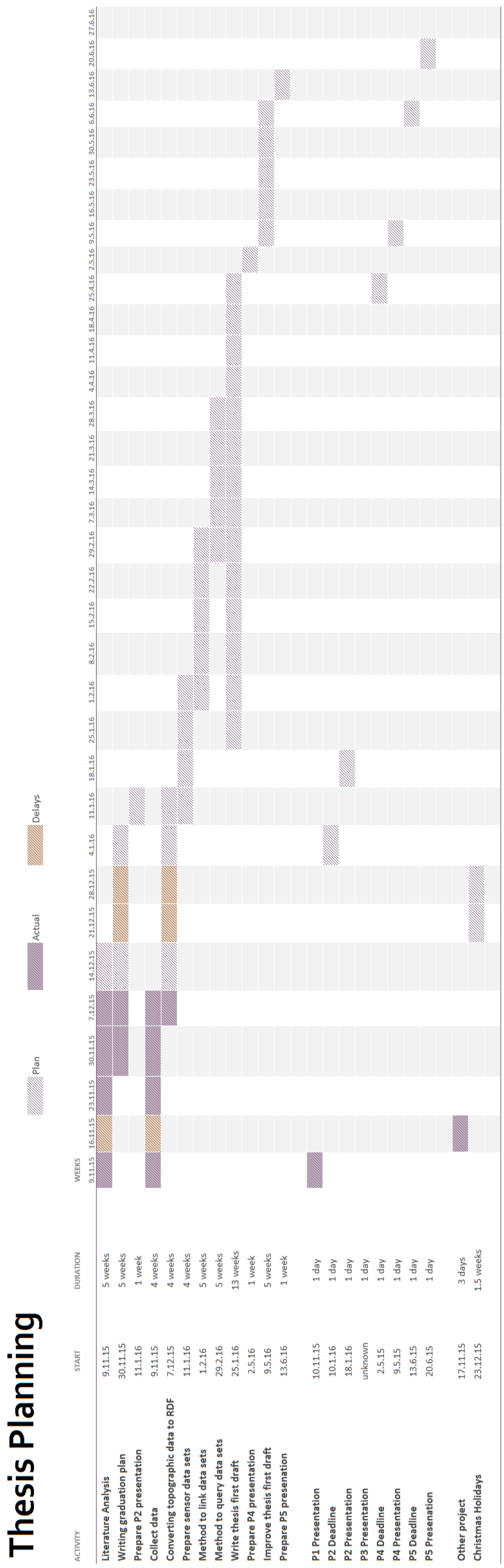

Figure 5.1: GANTT chart showing the planning of the thesis

6 TOOLS AND DATA

since specific data and tools have to be used, it's good to present these concretely, so that the mentors know that you have a grasp of all aspects of the project;

6.1 DATA

Topographic data of neighbourhoods, city districts, municipalities and provinces Air quality sensor data from the RIVM (`http://inspire.rivm.nl/sos/`) and from the Belgian interregional environment agency (IRCEL-CELINE) (`http://sos.irceline.be/`).

6.2 DATABASE

A Postgres database will be used with the Postgis extension.

6.3 SERVER

Prototyping will be done using a localhost at first, but in the end it could be hosted on the university server.

6.4 PROTOTYPE

- The Python programming language will be used for scripting a prototype.
- Psycopg2 will be used to connect a Python script to a Postgres database.
- Python's Request library will be used for making HTTP POST and GET requests.
- For working with XML Python's xml package will be used.
- To create RDF documents the Python library RDFLib will be used.

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