A Hypercat-enabled Semantic Internet of Things Data Hub: Technical Report

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Abstract. An increasing amount of information is generated from the rapidly increasing number of sensor networks and smart devices. A wide variety of sources generate and publish information in different formats, thus highlighting interoperability as one of the key prerequisites for the success of Internet of Things (IoT). The BT Hypercat Data Hub provides a focal point for the sharing and consumption of available datasets from a wide range of sources. In this work, we propose a semantic enrichment of the BT Hypercat Data Hub, using well-accepted Semantic Web standards and tools. We propose an ontology that captures the semantics of the imported data and present the BT SPARQL Endpoint by means of a mapping between SPARQL and SQL queries. Furthermore, federated SPARQL queries allow queries over multiple hub-based and external data sources. Finally, we provide two use cases in order to illustrate the advantages afforded by our semantic approach.

1 Introduction

The emerging notion of a smart city is based on the use of technology in order to improve the efficiency, effectiveness and capability of various city services, thus improving the quality of the inhabitants’ lives [14]. A fundamental difference between smart cities and similar uses of technology in other areas, such as business, government or education, is the vast variety of the technologies used, the types and volumes of data, and the services and applications targeted [5]. Thus, developing successful smart city solutions requires the collection and maintenance of relevant data in the form of IoT data.

Over the past few years, eight industry-led projects were funded by Innovate UK (the UK’s innovation agency) to deliver IoT ‘clusters’, each centred around a data hub to aggregate and expose data feeds from multiple sensor types. The system that has come to be known as the BT

¹ https://www.gov.uk/government/organisations/innovate-uk
Hypercat Data Hub was part of the Internet of Things Ecosystem Demonstrator programme.

Addressing interoperability by focusing on how interoperability could be achieved between data hubs in different domains was a major objective of the programme. Hence, Hypercat [1] was developed, which is a standard for representing and exposing Internet of Things data hub catalogues [6] over web technologies, to improve data discoverability and interoperability. Recent work [13], proposed a semantic enrichment for the core of the Hypercat specification, namely an RDF-based [8] equivalent for a JSON-based catalogue. Other IoT / smart city projects include Barcelona [5] MK:Smart [6] which uses the BT Hypercat Data Hub that is Hypercat-enabled but not semantically enriched, and the D-CAT [7] catalogue approach from W3C.

The main objective of this work is to achieve the semantic enrichment [2] of the data in the BT Hypercat Data Hub and to provide access to the enriched data through a SPARQL endpoint [11]. Furthermore, adding reasoning capabilities and the ability to combine external data sources using federated queries are important aspects of the implemented system.

The BT Hypercat Data Hub provides a focal point for the sharing and consumption of available datasets from a wide range of sources. In order to enable rapid responses, data in the BT Hypercat Data Hub is stored in relational databases. In this work, sensor, event, and location databases, i.e., databases containing information about sensor readings, events and locations are used. In order to provide a semantically richer mechanism of accessing the available datasets, the BT Hypercat Ontology was developed in order to lift semantically data stored within the relational databases. In addition, data translation through output adapters and SPARQL endpoints was defined. Thus, the semantically enriched data can be queried by accessing the developed BT SPARQL Endpoint.

Triplestores contain the information in RDF format combined with a built-in SPARQL endpoint. Thus, triplestores are commonly used for providing SPARQL endpoints. However, as data in the BT Hypercat Data Hub is stored in relational databases and this data is frequently updated, a more dynamic solution has been adopted. Thus, instead of copying

[1] https://connect.innovateuk.org/web/internet-of-things-ecosystem-demonstrator/overview
[2] http://ibarccelona.bcn.cat/en/smart-cities
[3] http://www.mksmart.org
[4] https://www.w3.org/TR/vocab-dcat/
the existing data into a triplestore, submitted SPARQL queries are dynamically translated into a set of SQL queries on top of the existing relational databases. In this way, a fully functioning SPARQL endpoint is provided, while during query execution, not only the SPARQL query itself is taken into consideration, but also the implicit information that is derived through reasoning over the developed ontology.

This work is organized as follows: Section 2 contains background information about the BT Hypercat Data Hub prior to its semantic enrichment. Section 3 contains a description of the BT Hypercat Ontology which was developed in this work in order to define the semantic representation of existing data. The corresponding mapping of data from a relational database to the semantic representation is described in Section 4. The BT SPARQL Endpoint is presented in Section 5 and the capability to combine information from external data sources by means of federated queries is presented in Section 6. Example use cases for the BT Hypercat Data Hub are illustrated in Section 7, while conclusions and future work are discussed in Section 8.

2 Background

The role of the BT Hypercat Data Hub is to enable information from a wide range of sources to be brought onto a common platform and presented to users and developers in a consistent way. Its portal provides a direct interface through which data consumers, such as app developers, can browse a data catalogue and select and subscribe to data feeds that they want to use. In addition, a JSON-based Hypercat [1] machine-readable catalogue, described further below, is also provided (as well as a recently proposed RDF-based Hypercat [13] catalogue). An API enables access to data feeds, secured by API keys, from browsers or within computer programs, while a relational, GIS capable, database enables complex queries that data can be filtered according to a wide range of criteria.

A set of edge adapters enables information coming onto the hub to be converted to a standard format for use inside the platform’s core. It also provides a consistent API to end users and developers. The hub provides a consistent approach to integration between data exposed by sensors, systems and individuals via communication networks and the applications that can use derived information to improve decision making, e.g., in control systems. It includes a set of adapters for ingress (input) and egress (output). These are potentially specific to each data source or
application feed and may be implemented on a case by case basis. There is therefore a need to translate data between arbitrary external formats and the data formats used internally.

In addition, as mentioned above, a Hypercat catalogue is implemented which is included via the Hypercat API. Hypercat is in essence a standard for representing and exposing Internet of Things data hub catalogues over web technologies, to improve data discoverability and interoperability. The idea is to enable distributed data repositories (data hubs) to be used jointly by applications through making it possible to query their catalogues in a uniform machine readable format. This enables the creation of knowledge graphs of available datasets across multiple hubs that applications can exploit and query to identify and access the data they need, whatever the data hub in which they are held.

From this perspective, Hypercat represents a pragmatic starting point to solving the issues of managing multiple data sources, aggregated into multiple data hubs, through linked data and semantic web approaches. It incorporates a lightweight, JSON-based approach based on a technology stack used by a large population of web developers and as such offers a low barrier to entry. Hypercat allows a server (IoT hub) to provide a set of resources to a client, each with a set of metadata annotations. There are a small set of core mandatory metadata relations which a valid Hypercat catalogue must include; beyond this, implementers are free to use any set of annotations to suit their needs.

3 BT Hypercat Ontology

In our previous work [13], we proposed a semantic enrichment for the core of the Hypercat specification, namely an RDF-based equivalent for a JSON-based catalogue. While Hypercat offers a syntactic first step, providing semantically enriched data goes further by allowing the unique identification of existing resources, interoperability across various domains and further enrichment by combining internally stored data with the Linked Open Data (LOD) cloud[^1]. Data enrichment in the BT Hypercat Data Hub is achieved by representing data in RDF using concepts and properties defined in an OWL ontology [9]. Figure 1 shows the top level concepts of the BT Hypercat Ontology and how the BT Hypercat Ontology extends the core of the Hypercat specification, following the proposed guidelines in [13].

[^1]: http://lod-cloud.net/
Feed is the top level class for any data feed that is asserted in the knowledge base. It contains the semantic properties of feeds. These include the feed id, creator, update date, title, url, status, description, location name, domain and disposition. There are also subclasses of class Feed, namely: SensorFeed, EventFeed and LocationFeed representing feeds for sensors, events and locations respectively.

The modelled data has been incorporated in the BT Hypercat Data Hub as one of the following feed types: (a) SensorFeed, (b) EventFeed, and (c) LocationFeed. Practically, each data source can advertise available information through the BT Hypercat Data Hub by providing a feed. A feed should be understood as a source of sensor readings, events or locations. Within each feed, data is available through datastreams (a class Datastream is defined, which has two subclasses namely: SensorStream and EventStream representing datastreams for sensors and events respectively). Thus, a given feed may provide a range of datastreams that are closely related e.g., for a weather data feed, different datastreams may provide sensor readings for temperature, humidity and visibility. Considering information about locations, a feed (of type LocationFeed) provides
information directly by returning locations, namely locations are attached to and provided by a given feed.

A Hypercat online catalogue contains details of feeds and information sources along with additional metadata such as tags, which allow improved search and discovery. The developed semantic model enables a semantic annotation and linkage of available feeds and datastreams. Thus, both classes Feed and Datastream are modelled as subclasses of class Item (which belongs to the core specification of Hypercat), namely feeds and datastreams are advertised as items of a given catalogue. The BT Hypercat Ontology has been developed and made available with the uri:

http://portal.bt-hypercat.com/ontologies/bt-hypercat

4 Data Translation

In this section we describe how data that is stored in a relational database within the BT Hypercat Data Hub, is made available in RDF.

4.1 RDF Adapter

By defining an ontology, semantically enriched data can be provided in RDF format. Note that prior to the semantic enrichment only XML and JSON formats were available. RDF data is represented in N-Triples format since such a format facilitates both storage and processing of data. Thus, each RDF triple is provided within a single line, in the following format: “<subject> <predicate> <object>.”, while a collection of RDF triples is stored as a collection of lines. Note that N-Triples format can easily be transformed into other valid RDF formats, such as RDF/XML. In addition, the generated knowledge base can also be loaded in any given triplestore, namely any given RDF knowledge base, in order to facilitate operations such as query answering. Thus, by following W3C standards interoperability is ensured and the utilization of existing tools and applications is enabled.

The BT Hypercat Data Hub includes additional adapters for egress (output) in order to provide data in RDF format. In the following, examples of how subject, predicate and object are generated for feeds and datastreams, are presented. Initially, the URI of each SensorFeed is generated, namely:

9 http://portal.bt-hypercat.com/cat
10 http://portal.bt-hypercat.com/cat-rdf
Note that `http://api.bt-hypercat.com/` is the prefix URI for any data provided by the BT Hypercat Data Hub. In addition, “/sensors” provides information about the type of the feed (here SensorFeed), followed by “/feeds”, which indicates that this URI belongs to a resource describing a feed, and finally “/feedID” is an id that uniquely identifies the given feed. For each SensorFeed, the BT Hypercat Data Hub provides its type, namely:

| Subject | http://api.bt-hypercat.com/sensors/feeds/feedID |
|---------|-----------------------------------------------|
| Predicate | http://www.w3.org/1999/02/22-rdf-syntax-ns#type |
| Object | http://portal.bt-hypercat.com/ontologies/bt-hypercat#SensorFeed |

Each data property of SensorFeed provides information in the following form (here is an example for property feed_id, other data properties are modelled in a similar fashion):

| Subject | http://api.bt-hypercat.com/sensors/feeds/feedID |
|---------|-----------------------------------------------|
| Predicate | http://portal.bt-hypercat.com/ontologies/bt-hypercat#feed_id |
| Object | “feedID”^^http://www.w3.org/2001/XMLSchema#string |

The URI of a given SensorStream is generated as an extension of the URI of the SensorFeed it belongs to, namely:

`http://api.bt-hypercat.com/sensors/feeds/feedID/datastreams/datastreamID`

Here, “/datastreams” indicates that this URI belongs to a resource describing a datastream, and “/datastreamID” is the identifier of the given datastream. Thus, for each SensorStream, the BT Hypercat Data Hub provides its type, namely:

| Subject | http://api.bt-hypercat.com/sensors/feeds/feedID/datastreams/datastreamID |
|---------|---------------------------------------------------------------------|
| Predicate | http://www.w3.org/1999/02/22-rdf-syntax-ns#type |
| Object | http://portal.bt-hypercat.com/ontologies/bt-hypercat#SensorStream |

In addition, the fact that a given feed has a given datastream needs to be semantically annotated, namely the relation between SensorFeed and SensorStream is defined as follows:
In a similar way as for SensorFeed, SensorStream provides additional information through data properties (here is an example for property `datastream_id`, other data properties are modelled in a similar fashion):

| Subject | <http://api.bt-hypercat.com/sensors/feeds/feedID/datastreams/datastreamID> |
|---------|-------------------------------------------------------------------------|
| Predicate | <http://portal.bt-hypercat.com/ontologies/bt-hypercat#hasSensorStream> |
| Object | “datastreamID”^^^<http://www.w3.org/2001/XMLSchema#string> |

A URI for EventFeed is generated in a similar way as a URI for SensorFeed, namely:

<http://api.bt-hypercat.com/events/feeds/feedID>

Note that the main difference is that “/sensors” is substituted by “/events”.

Thus, for each EventFeed, the BT Hypercat Data Hub provides its type, namely:

| Subject | <http://api.bt-hypercat.com/events/feeds/feedID> |
|---------|--------------------------------------------------|
| Predicate | <http://www.w3.org/1999/02/22-rdf-syntax-ns#type> |
| Object | <http://portal.bt-hypercat.com/ontologies/bt-hypercat#EventFeed> |

Each data property of EventFeed provides information in the following form (here is an example for property `feed_id`, other data properties are modelled in a similar fashion):

| Subject | <http://api.bt-hypercat.com/events/feeds/feedID> |
|---------|--------------------------------------------------|
| Predicate | <http://portal.bt-hypercat.com/ontologies/bt-hypercat#feed_id> |
| Object | “feedID”^^^<http://www.w3.org/2001/XMLSchema#string> |

A URI for EventStream is generated in a similar way as a URI for SensorStream. The URI of a given EventStream is generated as an extension of the URI of the EventFeed it belongs to, namely:
Thus, for each EventStream, the BT Hypercat Data Hub provides its type, namely:

| Subject | <http://api.bt-hypercat.com/events/feeds/feedID/datastreams/datastreamID> |
|---------|------------------------------------------------------------------------|
| Predicate | <http://www.w3.org/1999/02/22-rdf-syntax-ns#type> |
| Object | <http://portal.bt-hypercat.com/ontologies/bt-hypercat#EventStream> |

In addition, the fact that a given feed has a given datastream needs to be semantically annotated, namely the relation between EventFeed and EventStream is defined as follows:

| Subject | <http://api.bt-hypercat.com/events/feeds/feedID> |
|---------|-------------------------------------------------|
| Predicate | <http://portal.bt-hypercat.com/ontologies/bt-hypercat#hasEventStream> |
| Object | <http://api.bt-hypercat.com/events/feeds/feedID/datastreams/datastreamID> |

In a similar way as for EventFeed, EventStream provides additional information through data properties (here is an example for property datastream_id, other data properties are modeled in a similar fashion):

| Subject | <http://api.bt-hypercat.com/events/feeds/feedID/datastreams/datastreamID> |
|---------|------------------------------------------------------------------------|
| Predicate | <http://portal.bt-hypercat.com/ontologies/bt-hypercat#datastream_id> |
| Object | "datastreamID"^^<http://www.w3.org/2001/XMLSchema#string> |

### 4.2 SPARQL to SQL

In order to develop a SPARQL to SQL endpoint, Ontop\[^1\][^3] was used as an external library. Ontop comes with a Protege\[^2\] plug-in that allows the creation of mappings of SPARQL patterns to SQL queries (described below), see Figure 2. In addition, it provides a reasoner that parses the mappings and the ontology, and handles the translation of SPARQL queries into a set of SQL queries in order to return the corresponding results (for

[^1]: http://ontop.inf.unibz.it/
[^2]: http://protege.stanford.edu/
A key advantage of using Ontop is that implicit information that is extracted from the ontology through reasoning is taken into consideration. In this way, semantically richer information compared to the knowledge that is stored in the relational database is provided. A description of how mappings can be created is presented below.

In the following, an example of how a SPARQL triple pattern is mapped into a corresponding SQL query is described, and how the retrieved SQL results are used in order to construct RDF triples. **Mapping ID** corresponds to a unique id for a given mapping, **Target** (Triple Template) is the RDF triple pattern to be generated (note that SQL variables are given in braces, such as `{feed.id}`), and **Source** (SQL Query) is the SQL query to be submitted to the database.

First, the prefixes that are used are defined in order to shorten URIs, for example:

```
bt-sensors: http://api.bt-hypercat.com/sensors/
bt-hypercat: http://portal.bt-hypercat.com/ontologies/bt-hypercat#
```
Then mappings are defined. For example, the following mapping maps the class `SensorFeed`. Note that class `SensorFeed` is subclass of `Feed`, and thus is a valid assertion, while providing semantically richer information:

| Mapping ID          | mapping:SensorFeed |
|---------------------|--------------------|
| Target (Triple Template) | bt-sensors:feeds/{feed.id} a bt-hypercat:SensorFeed . |
| Source (SQL Query)  | SELECT feed.id FROM feed |

The following query can be submitted to a `SPARQL to SQL` endpoint in order to retrieve `Feed`

```sparql
PREFIX hypercat: <http://portal.bt-hypercat.com/ontologies/bt-hypercat#>
SELECT DISTINCT ?s
WHERE{ ?s a hypercat:Feed . }
```

Thus, Ontop will match the triple pattern “?s a hypercat:Feed” with the mapping “mapping:SensorFeed” since class `SensorFeed` is subclass of `Feed`. An SQL query (see Source) will be submitted to the relational database, while the retrieved `ids (feed.id)` will be used in order to generate RDF triples following the triple template (see Target).

The reader is referred to [3] for more details on the internal functionality of Ontop. Note that the generation of other triples follows a similar rational, while a detailed description of triple generation for a given concept or property can be found in Appendix A.

5 BT SPARQL Endpoint

In the following, a description of the high level architecture for the developed `BT SPARQL Endpoint` is presented. As shown in Figure 3 two levels of abstraction are applied. At the lower level, there is a `SPARQL to SQL` endpoint for each relational database in the system, namely each `SPARQL to SQL` endpoint provides a SPARQL endpoint on top of the given relational database. In this way, the system administrator can add or remove a `SPARQL to SQL` endpoint at any time.

At the moment, a `SPARQL to SQL` component is supporting the translation of SPARQL queries to PostgreSQL[13] relational databases that contain information about sensors or events. At the higher level, there is

[13] [https://www.postgresql.org/](https://www.postgresql.org/)
only one SPARQL to SPARQL component (based on the query engine of Apache Jena\textsuperscript{[14]} \textsuperscript{[3]}), which is made available to end users. The underlying functionality indicates that end users submit SPARQL queries to the SPARQL to SPARQL endpoint, while the system queries internally all available SPARQL to SQL endpoints in order to extract the relevant information from existing relational databases. At any given point, the system administrator can add or remove a SPARQL to SQL endpoint depending on the available PostgreSQL databases.

Both SPARQL to SPARQL and SPARQL to SQL endpoints can be accessed using the BT SPARQL Query Editor, which is available for each endpoint. Users can provide the query text, namely the SPARQL query, as shown in Figure 4. In addition, the BT SPARQL Query Editor supports five results formats: HTML, XML, JSON, CSV and TSV.

One of the key advantages of SPARQL queries over SQL queries is that SPARQL queries incorporate semantic reasoning within the returned results. For example, classes EventStream and SensorStream are subclasses of class Datastream. Thus, the reasoner classifies all objects that belong to either EventStream or SensorStream as Datastream. The following query can be submitted to a SPARQL to SPARQL endpoint in order to retrieve Datastreams:

\begin{verbatim}
PREFIX hypercat: <\protect\vrule width0pt\protect\href{http://portal.bt-hypercat.com/ontologies/bt-hypercat#}{http://portal.bt-hypercat.com/ontologies/bt-hypercat#}>
SELECT DISTINCT ?s WHERE{ ?s a hypercat:Datastream . }
\end{verbatim}

\textsuperscript{14} \texttt{https://jena.apache.org/index.html}
BT SPARQL Query Editor

Query Text
```
SELECT * WHERE { ?s ?p ?o . } LIMIT 50
```

Results Format: [HTML](#), [XML](#), [JSON](#), [CSV](#), [TSV](#)

Fig. 4. BT SPARQL Query Editor.

Note that Ontop supports reasoning over RDFS\(^{15}\) and OWL 2 QL\(^{16}\).

6 Federated Querying

As described above, a Federated SPARQL endpoint has been added in order to enable federated queries over both the BT SPARQL Endpoint and other external SPARQL endpoints that are available through the LOD cloud. Such external SPARQL endpoints that are part of the LOD cloud are for example: DBPedia\(^{17}\), FactForge\(^{18}\), OpenUpLabs\(^{19}\) and the European Environment Agency\(^{20}\).

The LOD cloud is expanding and new SPARQL endpoints are added (and removed) allowing for access to new data. Since the Federated SPARQL endpoint does not contain any information itself, it serves as a middle-

\(^{15}\) http://www.w3.org/TR/rdf-schema/
\(^{16}\) https://www.w3.org/TR/owl-profiles/#OWL_2_QL
\(^{17}\) http://dbpedia.org/sparql
\(^{18}\) http://factforge.net/sparql
\(^{19}\) http://gov.tso.co.uk/transport/sparql
\(^{20}\) http://semantic.eea.europa.eu/sparql
ware that combines information coming from other SPARQL endpoints, as depicted in Figure 5.

The *Federated SPARQL* endpoint extends further the functionality of the *BT SPARQL Endpoint* since external SPARQL endpoints can be used in order to retrieve information about events or social and economic information that can be combined with data from the *BT SPARQL Endpoint* for complex data analytics. Examples can be the extraction of data about natural disasters from external datasets combined with related sensor and event data from the *BT SPARQL Endpoint*. Other types of data extracted from external datasets can be, for example, social data related to housing projects and their correlation with sensor and event data from the *BT SPARQL Endpoint*.

Reasoning capabilities and spatiotemporal queries can be combined with external datasets (LOD) in order to retrieve information which is not directly represented in the *BT Hypercat Data Hub*. This can be achieved by means of federated queries spanning over different internal and external SPARQL endpoints.

For example, the following federated query retrieves sensor measurements from the *BT Hypercat Data Hub* related to a specific active bus stop, extracted from an external SPARQL endpoint (OpenUpLabs):

```sparql
PREFIX geo: <http://www.w3.org/2003/01/geo/wgs84_pos#>
PREFIX hypercat: <http://portal.bt-hypercat.com/ontologies/bt-hypercat#>
PREFIX naptan: <http://transport.data.gov.uk/def/naptan/> skos: <http://www.w3.org/2004/02/skos/core#>

SELECT distinct ?d ?at_time ?western_longitude ?southern_latitude ?eastern_longitude ?northern_latitude ?stop ?lat ?long
WHERE {
  SERVICE <http://gov.tso.co.uk/transport/sparql>
  {
    ?stop a naptan:CustomBusStop;
    naptan:naptanCode ?naptanCode;
    naptan:stopValidity ?stopValidity;
  
```
naptan:street "Kingswood Road";
geo:lat ?lat;
geo:long ?long.
?stopValidity naptan:stopStatus ?stopStatus.
?stopStatus skos:prefLabel "Active"@en.
}

SERVICE <http://portal.bt-hypercat.com/BT-SPARQL-Endpoint/sparql>
{
    ?d a hypercat:Datapoint.
    ?d hypercat:datapoint_at_time ?at_time.
    ?d hypercat:datapoint_western_longitude ?western_longitude.
    ?d hypercat:datapoint_southern_latitude ?southern_latitude.
    ?d hypercat:datapoint_eastern_longitude ?eastern_longitude.
    ?d hypercat:datapoint_northern_latitude ?northern_latitude.
    FILTER (?western_longitude > ?long - 0.1)
    FILTER (?southern_latitude > ?lat - 0.1)
    FILTER (?eastern_longitude < ?long + 0.1)
    FILTER (?northern_latitude < ?lat + 0.1)
}
FILTER(BOUND(?d))
}

The following federated query retrieves events from the BT Hypercat Data Hub that took place close to an airport near London, extracted from an external SPARQL endpoint (FactForge):

PREFIX geo: <http://www.w3.org/2003/01/geo/wgs84_pos#>
PREFIX prop: <http://dbpedia.org/property/>
PREFIX hypercat: <http://portal.bt-hypercat.com/ontologies/bt-hypercat#>
PREFIX omgeo: <http://www.ontotext.com/owlim/geo#>
PREFIX dbpediar: <http://dbpedia.org/resource/>
PREFIX dbp-ont: <http://dbpedia.org/ontology/>
PREFIX ff: <http://factforge.net/>
PREFIX om: <http://www.ontotext.com/owlim/>

SELECT distinct ?e ?event_date ?western_longitude ?southern_latitude
    ?eastern_longitude ?northern_latitude ?label ?lat ?long
WHERE {
    SERVICE <http://factforge.net/sparql>
    {
        dbpediar:London geo:lat ?latBase;
geo:long ?longBase.
?airport omgeo:nearby(?latBase ?longBase "50mi");
a dbp-ont:Airport;
ff:preferredLabel ?label;
om:hasRDFRank ?RR;
geo:lat ?lat;
geo:long ?long.
}

SERVICE <\protect\vrule width0pt\protect\href{http://portal.bt-hypercat.com/BT-SPARQL-Endpoint/sparql}{http://portal.bt-hypercat.com/BT-SPARQL-Endpoint/sparql}>
{
?e a hypercat:Event.
?e hypercat:event_sent ?event_date.
?e hypercat:event_western_longitude ?western_longitude.
?e hypercat:event_southern_latitude ?southern_latitude.
?e hypercat:event_eastern_longitude ?eastern_longitude.
?e hypercat:event_northern_latitude ?northern_latitude.
FILTER (?western_longitude > ?long - 0.5)
FILTER (?southern_latitude > ?lat - 0.5)
FILTER (?eastern_longitude < ?long + 0.5)
FILTER (?northern_latitude < ?lat + 0.5)
}
FILTER(BOUND(?e))
}

The following federated query retrieves events from the BT Hypercat Data Hub that took place before a pollutant release, extracted from an external SPARQL endpoint (European Environment Agency):

```sparql
PREFIX hypercat: <\protect\vrule width0pt\protect\href{http://portal.bt-hypercat.com/ontologies/bt-hypercat#}{http://portal.bt-hypercat.com/ontologies/bt-hypercat#}>
PREFIX xsd: <\protect\vrule width0pt\protect\href{http://www.w3.org/2001/XMLSchema#}{http://www.w3.org/2001/XMLSchema#}>
PREFIX purl: <\protect\vrule width0pt\protect\href{http://purl.org/dc/terms/}{http://purl.org/dc/terms/}>

SELECT distinct ?e ?event_date ?western_longitude ?southern_latitude
?eastern_longitude ?northern_latitude ?t ?date
WHERE {
 SERVICE <\protect\vrule width0pt\protect\href{http://semantic.eea.europa.eu/sparql}{http://semantic.eea.europa.eu/sparql}>
{
?s purl:title ?t.
?s purl:issued ?date
FILTER(regex(str(?t)," Pollutant "))
}
```
7 Use Cases

This section is devoted to the description of two example use cases of the BT Hypercat Data Hub.

7.1 The SimplifAI Project

Urban traffic management and control is a primary concern of any city, and urban traffic transport operators often have at their disposal a disparate variety of real time and historical data, traffic controls (the most common of which are traffic signals) and controlling software. Software systems used for traffic management have a vertical design: they are not integrated at a horizontal level and cannot therefore easily share their data, or exploit data provided from other software/sources.

For achieving a higher level of data integration, and to better capture and exploit real-time and historical urban data sources, the SimplifAI project was carried out by a consortium consisting of the University of Huddersfield, British Telecommunications, Transport for Greater Manchester, and two other SMEs. In particular, the project focussed on exploiting the real-time and historical data sources to pursue better congestion control. As study area, a region of greater Manchester, UK was selected.

The overall concept in the improvement of traffic management was to utilise the semantically enriched data to enable the use of an intelligent function which requires both the integration of traffic data from disparate sources, and the transformation of the data into a predicate logic level, in order to operate. The intelligent function was to create traffic signal
strategies in real time to solve challenges caused by exceptional or unexpected conditions.

The initial steps of the SimplifAI project concentrated on the semantic enrichment of traffic data. The raw data was taken from a large number of transport and environment sources and integrated into the BT Hypercat Data Hub, using the mapping of Section 4. After that, the focus was put on the utilisation of semantic data for generating traffic control strategies.

By enriching semantically the imported data, the unique identification of imported data is enabled. This is orthogonal to the problem solved by planning, as planning can also deal with ad hoc data. However, once the study area expands, using semantically enriched data will allow a systematic way of identifying resources that are mentioned in the generated plans. In addition, federated queries allow the developed system to extract data from the LOD cloud and combine it with data stored in the BT Hypercat Data Hub (e.g., the federated query of Section 6 combines bus stop information from an external source with internally stored data).

The intelligent function was based on an Automated Planning approach [7], that is able to generate traffic control strategies (actions which change signals at a specified time) to alleviate traffic congestion caused by exceptional circumstances. The initial state of the modelled urban area, and information about available traffic lights and the struc-
Fig. 7. Interaction between end users and city wayfinding assets.

Fig. 8. Locations of wayfinding infrastructure.

ture of the network, were provided to the planning approach by the BT Hypercat Data Hub. Figure 6 shows the map of the modelled area, in terms of junctions controlled by the planner (red points), links between junctions, and the boundaries of the area (blue dots). Boundaries are sources (destination) of incoming (outcoming) traffic flows. The planner was then executed in order to generate control strategies for a number of test scenarios, which were focused on handling unexpected events.

The quality of the strategies output from the planner was evaluated firstly by hand, inspecting the strategies to check that they were sensible, and by simulating their execution using traffic simulation software. Experts verified that strategies are sensible, and follow what would be expected when using “common sense”. Simulations confirmed that generated strategies can effectively deal with unexpected conditions better than standard urban traffic control approaches: on average, the area is de-congested 20% faster, and tail-pipe emissions are reduced by 2.5%.

7.2 City Concierge

CityVerve is a Manchester, UK based IoT Demonstrator project, established in July 2016 with a two-year focus on demonstrating the capability of IoT applications for smart cities. One of the use cases of the CityVerve project, City Concierge, is aiming to increase uptake of walking and cycling as a preferred travel mode in Greater Manchester. Currently, Greater Manchester lacks integrated, consistent wayfinding services that can be accessed through a variety of media, including digital and print.

The City Concierge aims to develop a city user interface for the city region, integrating transportation and visitor services, allowing users to make informed choices regarding the way they travel. The scope of the use case includes improvements in the way people navigate around the
city with a digital solution in conjunction with physical wayfinding assets, see Figures 7 and 8.

Currently, it has been established that the BT Hypercat Data Hub provides the required infrastructure and functionality in order to enable the City Concierge. Translating data into RDF enables additional query capabilities such as SPARQL queries on top of the developed system and its combination with the LOD cloud through federated queries. Such queries are vital in order to achieve project’s objectives, which include the deployment of IoT and digital software solutions that seek to address current challenges, while having the flexibility for future solutions to be developed on the network deployed as part of the CityVerve project.

The City Concierge use case could be enhanced by the use of SPARQL queries that allow data to be integrated into the application in a much more flexible way. One aim of the City Concierge is to inform travellers about cultural events that are happening in the city. This can be supported by a SPARQL query that queries for events and relies on an ontological reasoning to discover concerts, performances, art shows, exhibitions, etc. which can all be modelled as a subclass of Event in a domain ontology. New types of event would be discovered without knowing in advance what type of event they are. Furthermore a federated SPARQL query could be used to discover local events that are described in a number of different SPARQL endpoints.

8 Conclusion

In this work, the semantic enrichment of the BT Hypercat Data Hub has been presented. More specifically, the BT Hypercat Ontology has been introduced, which is the basis for the translation of existing data into an RDF representation. In addition, the BT SPARQL Endpoint has been implemented as a set of SPARQL endpoints and an additional endpoint, called Federated SPARQL endpoint, has been provided in order to allow the execution of federated queries. Moreover, several example federated queries illustrate how the BT Hypercat Data Hub can be connected to the LOD cloud. Finally, two use cases are illustrating the extended functionality of the system, thus highlighting the benefits of the semantic enrichment.

Future work includes further semantic enrichment of the implemented system. Specifically, current support for SPARQL queries can be extended in order to enable GeoSPARQL queries [10] so as to provide direct access to spatial information that is currently available in the BT Hypercat Data
Hub. In addition, spatiotemporal reasoning [12] is a prominent direction that could provide richer knowledge by reasoning over data that is coming from both the BT Hypercat Data Hub and the LOD cloud.

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Appendix

Here we provide a detailed description of mappings for *Feeds* and *Datastreams*. Note that in the developed system, mappings for sensors and events are implemented separately. The following prefixes are used in order to shorten URIs:

- bt-sensors: `http://api.bt-hypercat.com/sensors/`
- bt-events: `http://api.bt-hypercat.com/events/`
- bt-hypercat: `http://portal.bt-hypercat.com/ontologies/bt-hypercat#`
- wgs84_pos: `http://www.w3.org/2003/01/geo/wgs84_pos#`

The following mapping maps the class *SensorFeed*. Note that class *SensorFeed* is subclass of *Feed*, and thus is a valid assertion, while providing semantically richer information:

| Mapping ID | mapping:SensorFeed |
|------------|--------------------|
| Target (Triple Template) | `bt-sensors:feeds/{feed.id}` a bt-hypercat:SensorFeed . |
| Source (SQL Query) | SELECT feed.id FROM feed |

The following mapping maps the class *EventFeed*. Note that class *EventFeed* is subclass of *Feed*, and thus is a valid assertion, while providing semantically richer information:

| Mapping ID | mapping:EventFeed |
|------------|-------------------|
| Target (Triple Template) | `bt-events:feeds/{feed.id}` a bt-hypercat:EventFeed . |
| Source (SQL Query) | SELECT feed.id FROM feed |

All data properties of both classes *SensorFeed* and *EventFeed* belong to their superclass, namely class *Feed*. Thus, the mappings for class *SensorFeed* are provided, while the corresponding mappings for class *EventFeed* can be defined by substituting the prefix “bt-sensors:” with the prefix “bt-events:”.

The following mapping maps the data property *feed_id* of class *Feed*:

| Mapping ID | mapping:feed_id |
|------------|----------------|
| Target (Triple Template) | `bt-sensors:feeds/{feed.id}` bt-hypercat:feed_id {feed.id} . |
| Source (SQL Query) | SELECT feed.id FROM feed |
The following mapping maps the data property `feed_creator` of class `Feed`:

| Mapping ID | mapping:feed_creator |
|------------|-----------------------|
| Target (Triple Template) | bt-sensors:feeds/{feed.id} |
| | bt-hypercat:feed_creator |
| | {feed.creator} |

| Source (SQL Query) | SELECT feed.id, feed.creator |
| FROM feed |

The following mapping maps the data property `feed_updated` of class `Feed`:

| Mapping ID | mapping:feed_updated |
|------------|-----------------------|
| Target (Triple Template) | bt-sensors:feeds/{feed.id} |
| | bt-hypercat:feed_updated |
| | {updated} |

| Source (SQL Query) | SELECT feed.id, |
| TO_TIMESTAMP(feed.updated) AS updated | |
| FROM feed |

The following mapping maps the data property `feed_title` of class `Feed`:

| Mapping ID | mapping:feed_title |
|------------|-------------------|
| Target (Triple Template) | bt-sensors:feeds/{feed.id} |
| | bt-hypercat:feed_title |
| | {feed.title} |

| Source (SQL Query) | SELECT feed.id, feed.title |
| FROM feed |

The following mapping maps the data property `feed_url` of class `Feed`:

| Mapping ID | mapping:feed_url |
|------------|-----------------|
| Target (Triple Template) | bt-sensors:feeds/{feed.id} |
| | bt-hypercat:feed_url |
| | {feed.url} |

| Source (SQL Query) | SELECT feed.id, feed.url |
| FROM feed |

The following mapping maps the data property `feed_status` of class `Feed`:
| Mapping ID          | mapping:feed_status            |
|-------------------|--------------------------------|
| Target (Triple Template) | bt-sensors:feeds/{feed.id}   |
|                    | bt-hypercat:feed_status       |
|                    | {feed.status} .               |
| Source (SQL Query) | SELECT feed.id, feed.status   |
|                    | FROM feed                    |

The following mapping maps the data property `feed_private` of class `Feed`:

| Mapping ID          | mapping:feed_private            |
|-------------------|--------------------------------|
| Target (Triple Template) | bt-sensors:feeds/{feed.id}   |
|                    | bt-hypercat:feed_private       |
|                    | {feed.private} .               |
| Source (SQL Query) | SELECT feed.id, feed.private   |
|                    | FROM feed                    |

The following mapping maps the data property `feed_description` of class `Feed`:

| Mapping ID          | mapping:feed_description       |
|-------------------|--------------------------------|
| Target (Triple Template) | bt-sensors:feeds/{feed.id}   |
|                    | bt-hypercat:feed_description   |
|                    | {feed.description} .           |
| Source (SQL Query) | SELECT feed.id, feed.description |
|                    | FROM feed                    |

The following mapping maps the data property `feed_icon` of class `Feed`:

| Mapping ID          | mapping:feed_icon              |
|-------------------|--------------------------------|
| Target (Triple Template) | bt-sensors:feeds/{feed.id}   |
|                    | bt-hypercat:feed_icon          |
|                    | {feed.icon} .                 |
| Source (SQL Query) | SELECT feed.id, feed.icon     |
|                    | FROM feed                    |

The following mapping maps the data property `feed_website` of class `Feed`:

| Mapping ID          | mapping:feed_website           |
|-------------------|--------------------------------|
| Target (Triple Template) | bt-sensors:feeds/{feed.id}   |
|                    | bt-hypercat:feed_website       |
|                    | {feed.website} .               |
| Source (SQL Query) | SELECT feed.id, feed.website   |
|                    | FROM feed                    |
The following mapping maps the data property *feed_email* of class *Feed*:

| Mapping ID | mapping:feed_email |
|------------|--------------------|
| Target (Triple Template) | bt-sensors:feeds/{feed.id} bt-hypercat:feed_email {feed.email} . |
| Source (SQL Query) | SELECT feed.id, feed.email FROM feed |

The following mapping maps the data property *feed_tag* of class *Feed*:

| Mapping ID | mapping:feed_tag |
|------------|-----------------|
| Target (Triple Template) | bt-sensors:feeds/{feed.id} bt-hypercat:feed_tag {tag} . |
| Source (SQL Query) | SELECT feed.id, unnest(feed.tag) AS tag FROM feed |

The following mapping maps the data property *feed_location_name* of class *Feed*:

| Mapping ID | mapping:feed_location_name |
|------------|----------------------------|
| Target (Triple Template) | bt-sensors:feeds/{feed.id} bt-hypercat:feed_location_name {feed.location_name} . |
| Source (SQL Query) | SELECT feed.id, feed.location_name FROM feed |

The following mapping maps the data property *feed_exposure* of class *Feed*:

| Mapping ID | mapping:feed_exposure |
|------------|-----------------------|
| Target (Triple Template) | bt-sensors:feeds/{feed.id} bt-hypercat:feed_exposure {feed.exposure} . |
| Source (SQL Query) | SELECT feed.id, feed.exposure FROM feed |

The following mapping maps the data property *feed_domain* of class *Feed*:
The following mapping maps the data property `feed.disposition` of class `Feed`:

| Mapping ID | mapping:feed_disposition |
|------------|--------------------------|
| Target (Triple Template) | bt-sensors:feeds/{feed.id}  
                              bt-hypercat:feed_disposition  
                              {feed.disposition} . |
| Source (SQL Query) | SELECT feed.id, feed.disposition  
                              FROM feed |

The following mapping maps the data property `feed.lat` of class `Feed` as `wgs84_pos:lat`:

| Mapping ID | mapping:feed_lat |
|------------|-----------------|
| Target (Triple Template) | bt-sensors:feeds/{feed.id}  
                              wgs84_pos:lat  
                              {feed.lat} . |
| Source (SQL Query) | SELECT feed.id, feed.lat  
                              FROM feed |

The following mapping maps the data property `feed.lon` of class `Feed` as `wgs84_pos:long`:

| Mapping ID | mapping:feed_lon |
|------------|-----------------|
| Target (Triple Template) | bt-sensors:feeds/{feed.id}  
                              wgs84_pos:long  
                              {feed.lon} . |
| Source (SQL Query) | SELECT feed.id, feed.lon  
                              FROM feed |

The following mapping maps the data property `feed.ele` of class `Feed` as `wgs84_pos:alt`:
The following mapping maps the data property `feed.ele` of class `Feed`:

| Mapping ID       | mapping:feed.ele |
|------------------|------------------|
| Target (Triple Template) | bt-sensors:feeds/{feed.id} wgs84_pos:alt {feed.ele} . |
| Source (SQL Query)       | SELECT feed.id, feed.ele FROM feed |

The following mapping maps the object property `hasSensorStream` of class `SensorFeed`:

| Mapping ID       | mapping:hasSensorStream |
|------------------|-------------------------|
| Target (Triple Template) | bt-sensors:feeds/{datastream.feed} bt-hypercat:hasSensorStream bt-sensors:feeds/{datastream.feed}/datastreams/{datastream.id} . |
| Source (SQL Query)       | SELECT datastream.feed, datastream.id FROM datastream |

The following mapping maps the data property `hasEventStream` of class `EventFeed`:

| Mapping ID       | mapping:hasEventStream |
|------------------|-------------------------|
| Target (Triple Template) | bt-events:feeds/{datastream.feed} bt-hypercat:hasEventStream bt-events:feeds/{datastream.feed}/datastreams/{datastream.id} . |
| Source (SQL Query)       | SELECT datastream.feed, datastream.id FROM datastream |

The following mapping maps the class `SensorStream`. Note that class `SensorStream` is subclass of `DataStream`, and thus is a valid assertion, while providing semantically richer information:
The following mapping maps the class EventStream. Note that class EventStream is subclass of Datastream, and thus is a valid assertion, while providing semantically richer information:

| Mapping ID                  | mapping:EventStream         |
|-----------------------------|-----------------------------|
| Target (Triple Template)    | bt-events:feeds/{datastream.feed}/datastreams/{datastream.id} a bt-hypercat:EventStream . |
| Source (SQL Query)          | SELECT datastream.feed, datastream.id FROM datastream |

All data properties of class EventStream are contained in class SensorStream as well. Thus, these data properties belong to their superclass, namely class Datastream. However, class SensorStream contains additional data properties that do not belong to class EventStream.

For data properties datastream_id, datastream_tag, datastream_current_time and datastream_current_value, the mappings for class SensorFeed are provided, while the corresponding mappings for class EventFeed can be defined by substituting the prefix “bt-sensors:" with the prefix “bt-events:". On the other hand, for data properties datastream_max_value, datastream_min_value, datastream_unit_symbol, datastream_unit_type and datastream_unit_text the mappings are provided only for class SensorFeed (these data properties do not belong to class EventStream).

The following mapping maps the data property datastream_id of class Datastream:

| Mapping ID                  | mapping:datastream_id       |
|-----------------------------|-----------------------------|
| Target (Triple Template)    | bt-sensors:feeds/{datastream.feed}/datastreams/{datastream.id} a bt-hypercat:datastream_id {datastream.id} . |
| Source (SQL Query)          | SELECT datastream.feed, datastream.id FROM datastream |
The following mapping maps the data property `datastream_tag` of class `DataStream`:

| Mapping ID | mapping:datastream_tag |
|------------|------------------------|
| Target (Triple Template) | bt-sensors:feeds/{datastream.feed}/datastreams/{datastream.id} |
| Source (SQL Query) | SELECT datastream.feed, datastream.id, unnest(datastream.tag) AS tag |
|             | bt-hypercat:datastream_tag {tag} |

The following mapping maps the data property `datastream_current_time` of class `DataStream`:

| Mapping ID | mapping:datastream_current_time |
|------------|---------------------------------|
| Target (Triple Template) | bt-sensors:feeds/{datastream.feed}/datastreams/{datastream.id} |
| Source (SQL Query) | SELECT datastream.feed, datastream.id, TO_TIMESTAMP(datastream.c_time) AS current_time |
|             | bt-hypercat:datastream_current_time {current_time} |

The following mapping maps the data property `datastream_current_value` of class `DataStream`:

| Mapping ID | mapping:datastream_current_value |
|------------|----------------------------------|
| Target (Triple Template) | bt-sensors:feeds/{datastream.feed}/datastreams/{datastream.id} |
| Source (SQL Query) | SELECT datastream.feed, datastream.id, datastream.c_value |
|             | bt-hypercat:datastream_current_value {datastream.c_value} |

The following mapping maps the data property `datastream_max_value` of class `SensorStream`:

| Mapping ID | mapping:datastream_max_value |
|------------|------------------------------|
| Target (Triple Template) | bt-sensors:feeds/{datastream.feed}/datastreams/{datastream.id} |
| Source (SQL Query) | SELECT datastream.feed, datastream.id, datastream.max_value |
|             | bt-hypercat:datastream_max_value {datastream.max_value} |
The following mapping maps the data property `datastream_min_value` of class `SensorStream`:

| Mapping ID          | mapping:datastream_min_value |
|---------------------|------------------------------|
| Target (Triple Template) | bt-sensors:feeds/{datastream.feed}/datastreams/{datastream.id} \ bt-hypercat:datastream_min_value \ {datastream.min_value} . |
| Source (SQL Query)  | SELECT datastream.feed, datastream.id, datastream.min_value FROM datastream |

The following mapping maps the data property `datastream_unit_symbol` of class `SensorStream`:

| Mapping ID          | mapping:datastream_unit_symbol |
|---------------------|-------------------------------|
| Target (Triple Template) | bt-sensors:feeds/{datastream.feed}/datastreams/{datastream.id} \ bt-hypercat:datastream_unit_symbol \ {datastream.unit_symbol} . |
| Source (SQL Query)  | SELECT datastream.feed, datastream.id, datastream.unit_symbol FROM datastream |

The following mapping maps the data property `datastream_unit_type` of class `SensorStream`:

| Mapping ID          | mapping:datastream_unit_type |
|---------------------|-------------------------------|
| Target (Triple Template) | bt-sensors:feeds/{datastream.feed}/datastreams/{datastream.id} \ bt-hypercat:datastream_unit_type \ {datastream.unit_type} . |
| Source (SQL Query)  | SELECT datastream.feed, datastream.id, datastream.unit_type FROM datastream |

The following mapping maps the data property `datastream_unit_text` of class `SensorStream`:

| Mapping ID          | mapping:datastream_unit_text |
|---------------------|-------------------------------|
| Target (Triple Template) | bt-sensors:feeds/{datastream.feed}/datastreams/{datastream.id} \ bt-hypercat:datastream_unit_text \ {datastream.unit_text} . |
| Source (SQL Query)  | SELECT datastream.feed, datastream.id, datastream.unit_text FROM datastream |