Discovering Relevant Contents in Social Media and Information Enrichment from External Resources – Utilization of Conceptual Linking

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ABSTRACT

The second generation of the World Wide Web (Web 2.0) comes with a set of technologies that allow users to be a contributor besides being a consumer of the web contents. This ability contributes in the rapid increase of the amount of web contents. These contents are generally linked on the documents level, i.e. they are linked via keywords or simple tags that describe the documents and not the data. Thus, lots of valuable data remains undiscoverable. Linked data is a possible solution to create links on the data level and thus makes it possible to reveal relevant data by crawling these links. A set of technologies are required to link data, including Resource Description Framework (RDF), Web Ontology language (OWL) and SPARQL Protocol and RDF Query Language (SPARQL).
One explicit manifestation of the Web 2.0 is the social media platforms (e.g. Twitter, Facebook, and Wikipedia) and the geospatial crowdsourcing platforms (e.g. OpenStreetMap). Lots of relevant information can be deduced by linking data of these resources.
In this research we investigate linking data in discovering relevant tweets and information enrichment in the context of the selected use case.
To achieve that, we firstly build an ontology for our use case in order to 1. Utilize it in creating conceptual links among the tweets of our dataset and then 2. Creating conceptual links to other linked datasets including Geonames, LinkedGeoData (the linked version of OpenStreetMap dataset), DBpedia (the linked version of Wikipedia dataset), Freebase, Vehicle Sale ontology, the Event ontology and WGS84 Positioning ontology.

Keywords
Linked data, RDF, Crowdsourcing, Social media, Ontology, LinkedGeoData, Geonames,

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1. INTRODUCTION

1.1. Motivation and problem statement

The way individuals surf the internet has dramatically changed and with the second generation of the World Wide Web (Web 2.0) the user who has always been an information consumer can now be an active producer of valued and useful content (Goodchild, 2007; Johnson & Sieber, 2011 ; Rouse, Bergeron, & Harris, 2007). This capability of Web 2.0 has unquestionable impact in shaping our current life in the electronic space.

The term Crowdsourcing data has come to be used to refer to the data contributed or generated by the user community. Social media are platforms that built to disseminate and share crowdsourcing data such as Facebook[1] and Twitter2. Crowdsourcing data can include geographic information and it is referred to by crowdsourcing geospatial data or by the term Volunteered Geographic Information (VGI) to point out that the geospatial contents are produced by the crowds. In this paper, the term crowdsourcing geospatial data will be used to describe this type of data. Crowdsourcing geospatial data have become a valuable resource for geospatial information especially when real-time data is needed; for example in case of natural disasters. Some of the most prominent examples of crowdsourcing geospatial data applications are OpenStreetMap[3] and Google Map Maker[4].

Although lots of the crowdsourcing geospatial data can be accessed and collected easily, there is still hidden crowdsourcing geospatial data which is, for some reason, invisible and ignored by the search engines(Pellicer, 2011; Sherman & Price, 2001). For example, Google search[5]. Current search engines work basically on keywords-based matching among non-structured or semi-structured data on the web to generate search results. Full effective access to crowdsourcing geospatial data is very essential to decision-making and to increase the geospatial knowledge(Pellicer, 2011). In order to achieve this full access to crowdsourcing geospatial data, it is essential to construct a structure for data on the web and define formal relationships among them(Campbell & MacNeill, 2010) and this is the main principle of third generation of the World Wide Web (Web 3.0) or as some prefer to use the term Semantic Web to refer to the same thing. Semantic web technology is based on defining explicit meanings for data on the web and thus creating unambiguous meaningful relationships that link data with each other to eventually make data on the web readable by machine as well as human. In this paper we interchangeably refer to this meaningful linking by semantic linking or conceptual linking.

Building formal structured data on the web with explicit relationships among them is leading forward to what is known as Linked Data (LD). Linked Data; as the term implies, refers to the technology of linking data on the web from different resources and datasets based on linking entities and defining explicit relationships between them (Bizer, Heath, & Berners-Lee, 2009b). Two essential issues need to be dealt with when we talk about linking data on the web. One of them is the Resource Description Framework (RDF)[6] and the other is Ontology. In the progress of linking data on the web; data on the web should be converted into RDF form (Bizer et al., 2009b). RDF is a data model which has been adopted and approved by World Wide Web Consortium (W3C)[7] to describe entities and describe relations between

[1] http://www.facebook.com/
[2] http://twitter.com/
[3] http://openstreetmap.org
[4] http://www.google.com/mapmaker
[5] https://www.google.com/
[6] http://www.w3.org/RDF/
[7] http://www.w3.org/

them (Oren, 2009). There are different entities in the world and each entity is related to one or more concepts and Ontology[8] is essential to remove ambiguity in determination of these entities and the interactions between them(D. Fensel). For instance, there is a difference between entity "book" as a conceptualization of literature and entity "book" as a conceptualization for materialization of literature. Therefore, Web Ontology Language (OWL)[9] has been developed to deal with ontologies processing more efficiently than RDF.

Crowdsourcing geospatial data is a specific and very important type of data on the web. Linking crowdsourcing geospatial data in the social media and linking them to other sources can deduct very valuable and relevant information. A number of applications have already been developed to link geospatial information among different type of social media and platforms of crowdsourcing data. However, links are created through searching for simple keywords or tags without considering other links that might have related information but do not have the same mentioned keywords or tags. Linking geospatial data in crowdsourcing platforms based on keywords or tags; as mentioned previously, generates shallow connections among them which make it not easy mission to reveal other invisible relevant information.

Developing solution to the scenario mentioned above necessarily requires researching the current structure of data on the web and studying ontologies that have been used and how they are represented and if the vocabularies used are sufficient to convey the meaning of the concepts and entities which they represent and studying the interactions among these concepts and entities.

1.2. Research identification

The main goal of this research is to investigate semantic linking towards developing intelligent search for geospatial content in platforms of crowdsourcing data and social media.

1.2.1. Research objectives

There are three main objectives for this research:

1. Defining explicitly the concepts that are utilized by the social media in the context of the use case.
2. Defining explicitly the corresponding concepts in some geospatial and non-geospatial semantic webs including Geonames, LinkedGeoData and Dbpedia.
3. Building formalized structure of the social media concepts, in the context of the selected use case, including:
   A. Creating conceptual links among social media concepts
   B. Creating conceptual links between social media concepts and the corresponding concepts in the mentioned semantic webs.

1.2.2. Research questions

1. How to relate tweets contents to concepts in the context of the selected use case?
2. How to derive relevant concepts, instances and relationships for the selected use case?
3. How to define the abovementioned concepts, instances and relationships via formalized structure using the *Resource Description Framework RDF*?
4. How to conceptually link these concepts and instances to their corresponding in geospatial and non-geospatial RDF datasets?
5. How can the conceptual links be utilized to discover relevant contents in the social media?

[8] Ontology is "The science or study of being; that branch of metaphysics concerned with the nature or essence of being or existence" resource: Oxford English Dictionary http://www.oed.com/view/Entry/131551?redirectedFrom=ontology#eid

[9] http://www.w3.org/TR/owl-features/

6. How can the conceptual links be utilized in information enrichment from geospatial and non-geospatial RDF datasets?

1.2.3. Innovation aimed at

This research is aimed at developing method to discover relevant contents hidden within different type of platforms of crowdsourcing data and social media. For example, twitter. In this research we attempt to show that social media contents can be linked not only via simple keywords or tags but can also be linked conceptually and thus develop more intelligent search for relevant geospatial and non-geospatial contents, among platforms of crowdsourcing data and social media to integrate them and make the full use of geospatial knowledge provided by the user community.

1.2.4. Related work

World Wide Web Consortium W3C has endorsed in its recommendation for semantic web standards the RDF data model to describe metadata of data resources on the web. RDF is a framework with which data from different sources on the web can be linked and integrated (World Wide Web Consortium W3C, 2004).
The Linking Open Data Project LOD[10] is adopted and supported by World Wide Web Consortium (W3C). LOD project has started a movement toward web of data instead of web of HTML documents which implies two basic things: 1- transfer the existing open-licensed data sets into RDF and 2- Publishing those data on the web (Bizer et al., 2009b). LOD has currently terabytes of structured data: "Over 31 billion RDF triples, which are interlinked by around 504 million RDF links (September 2011)" (W3C SWEO LOD, 2012). LOD follows the same principle of LD which makes use of two well-known web technologies: Uniform Resource Identifier URI which is used as a data identifier, HyperText Transfer Protocol HTTP which makes it possible for the data source to be searchable on the web (Bizer, Heath, Ayers, & Raimond, 2007; Bizer et al., 2009b) and RDF technology which creates semantic links between data in different nature datasets on the web. Some prominent instances of the many open dataset that have been linked and embedded in LOD project are DBpedia[11], Friend of a Friend (FOAF)[12] and also GeoNames[13].

LinkedGeoData[14] (LGD) organization was also established upon the same concept of mapping data sets into RDF. However, LGD deals with specific and important type of data which is crowdsourcing geospatial data as LGD is primarily based on converting OpenStreetMap data sets into RDF and thus it can be the core for a web of linked spatial open data (Auer, Lehmann, & Hellmann, 2009; Stadler, Lehmann, Höffner, & Auer, 2012)

Step closer into crowdsourcing and social media, Ushahidi SwiftRiver[15] Platform is a good example of analyzing data in the social media (e.g. Twitter, SMS, email) based on keywords and semantic analysis for the content of tweets, email and SMS (Ushahidi, 2008).

EuroGEOSS Web 2.0 search engine has been built to allow user to discover relevant information from different types of social media (e.g. Twitter, Flicker[16], Wikipedia[17], YouTube[18]) through creating links based on searching for keywords and/or tags.

[10] http://www.w3.org/wiki/SweoIG/TaskForces/CommunityProjects/LinkingOpenData
[11] http://dbpedia.org
[12] http://www.foaf-project.org/
[13] http://www.geonames.org/
[14] http://linkedgeodata.org/About
[15] http://ushahidi.com/products/swiftriver-platform
[16] http://www.flickr.com/
[17] http://www.wikipedia.org/
[18] http://www.youtube.com/

In this research we attempt to conceptually link geospatial data in the crowdsourcing platforms and social media; specifically chosen to be twitter in this thesis, not only via simple keywords or tags but via semantics or meanings of different concepts and build the relationships among them. The relationships between different sources of social media such as Flicker and news item will be part of this research as well. LinkedGeoData will be utilized to achieve the aim of this research as they can be the tools to identify some ambiguous connections between some concepts in social media. For example, how to explicitly represent concepts of sport field, match and rugby that used in social media comparing with corresponding concepts that used in LinkedGeoData and how to create semantic links between them. Human has the capability to perceive these concepts and to understand the relations that link them together in their minds; however, this is not the case with machine. We attempt in this research to investigate relationships that can link tweets in the context of the selected use case to build a formal structure for the connections in social media including extracting ontologies and relations between concepts based on LinkedGeoData.

1.3. Method Adopte

1. Review the literature related to and around discovering and linking open data to study the principles, the recent development, and the tools used to conduct this technology regarding software and technical issues.
2. Design the selected use-case. Basically, the selected use case is that of the news content in Twitter. In this stage of the research we will identify common classifications and ontology that currently utilized by crowdsourcing platforms and social media.
3. Research the relationships between different classes in the context of the selected use case in order to develop a method to conceptually interlink those classes with each other. As mentioned previously, LinkedGeoData will be utilized to facilitate representing ontologies and recognizing ambiguous connections among different concepts of different classes.
4. Test the results of developed method through building some queries to be implemented against the collected dataset.

1.4. Thesis Structure

This thesis was structured as follows:
Chapter 1: introduces the motivation of conducting this research and addresses the questions that need to be answered to achieve the research objectives which mentioned also in the same Chapter. This Chapter describes the Methodology that is adopted to conduct this research.

Chapter 2: reviews the literature concerning the usefulness of using linked data technologies in order to create conceptual links among data. This Chapter discusses the main principles to link data that include Resource description Framework *RDF* and Ontology Web Language *OWL*.

Chapter 3: focuses on the selected use case and begins by a brief introduction about the social media and its applications and it discusses the current development of the linked data in the social media. Designing the ontology for the use case is discussed in this Chapter as well as linking our ontology to other namespaces on both concepts level and instances level. Geocoding the geographic instances in our ontology has been briefly described in this Chapter.

Chapter 4: describes the implementation of the designed ontology, mapping our tweets dataset into RDF triples, storing the RDF triples in the RDF triple store and finally implementing some queries that shows how the conceptual links have enhanced discovering relevant contents in the context of the use case. Ranking issue has been discussed briefly in this Chapter .

Chapter 5: discusses findings and limitations of our proposed solution, conclusions that have been drawn based on these findings and recommendations.

2. CONCEPTUAL FRAMEWORK

2.1. The 3rd generation of the World Wide Web (Web3.0) - The Semantic Web

As Sean parker's[19] character says in The Social Network movie: "We lived on farms, then we lived in cities, and now we're going to live on the internet!"

Searching for information is increasingly becoming part of our regular; if not daily, activity over the internet nowadays and Web search engine is the most popular and utilized tool to query information against the web network (Antoniou & Harmelen, 2008).

Most of the web content is represented to be human-comprehensible (Antoniou & Harmelen, 2008) and that implies human effort during web searching session to supervise and crawl via retrieved documents to fetch the requested piece of data.

Let us consider the following statements: *The vice president is in an official visit to Sana'a. The vice president is in an official visit to Yemen.*

It is obvious for a human reader that both sentences refer to the same facts and in the same context because in the media it is common to refer to the country by the name of its capital; however it is not a trivial mission for the machine[20] to end up with the same conclusion.

One robust reflection of the inability of the search engines to understand the web content can be realized through high recall and low precision of retrieved result during web search session(Antoniou & Harmelen, 2008). In simple words it means that the machine retrieves large number of web documents while there is relatively small number among these retrieved web documents can be considered to be relevant.

Two solutions proposed to make web content more understandable by the machine. One of them is working on developing technologies that utilized in querying and retrieving data over the web. The other alternative is to work on the data itself to construct a well-structured data that is more interpretable by the machine. A web of a well-structured data is one of the important features that characterize what is called a web 3.0 or the semantic web.
The semantic web is an initiative led by the World Wide Web Consortium W3 towards web of linked data (W3C, 2012). The fundamental goal of the semantic web is to establish a knowledge management system out of the current web content within the worldwide network (Antoniou & Harmelen, 2008). This knowledge management system can be thought of as a global database system where the web content acquire the conceptual dimension and the links can be created among different concepts within the same or across various web resources according to their meaning and their context to form a web of a linked data.

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[19] Sean Parker was the first president of the Social network website *Facebook*: www.facebook.com (Wikipedia, 2012a)

[20] Machine refers here to the hardware and software set on both web server and browser that is involved to complete search and retrieve process for the web content

2.2. Linked Data

2.2.1. Linked Data Principles

Most of the web content is represented as web documents and not as web data and that is because of the language in which they are written, Hyper Text Markup Language HTML (Heath & Bizer, 2011).
HTML describes the structure of the web page content as a document block including the title, the head and the body of the web document as the following HTML example illustrates:

```
<!DOCTYPE html>
<html>
 <head>
  <title>Hello HTML</title>
 </head>
 <body>
  <p>Hello World!</p>
 </body>
</html>
```

Listing 1 : source (Web, 1999)

This technology has a strong influence in producing isolated islands of documents on the web or at best case raising the barrier to link data. The starting point to resolve this issue is to reconsider the technology that is used to disseminate data over the web. The vision of linked data is to gradually evolve concepts to be the very single elements of the web data rather than documents. With existence of unambiguous concepts the connections can be built to link concepts with each other and thus query will be executed against web data and not web documents. Creating conceptual linking among data in the same or over various resources might not be the magic wand to make the machine explore data of something that the user does not know anything about but rather tell more related to what he already has some knowledge about. This knowledge; even if it is very limited, is highly critical and crucial in the beginning of the web crawling and discovering session.
The corner stone of the linked data technology is the metadata. Metadata is data that describes other data. Metadata of the document on the web is needed to describe the document to the machine. If we look to the previous example that is written in HTML web language we can see that there is not any explicit metadata except for the title of the document. Metadata of this web document can for instance be: the creator of the document, the subject of the document, the published date of the document.
Explicit metadata will not just clearly describe the web document to the machine but will enable to build links to other web resources to gain more knowledge, for instance, the contact information of the creator that could be stored in other web knowledge base.

Linked data makes use of the current web architecture in the four basic specifications of linked data that have been introduced by Tim Berners-Lee(Berners-Lee, 2006):

1- Uniform Resource Identifier (URI) is used to identify concepts, the instances of the concepts as well as the relations among concepts and among instances and between them (Heath & Bizer, 2011).
2- Hyper Text Transfer Protocol (HTTP) is utilized to make these URIs of concepts and relationships accessible and thus discoverable (Heath & Bizer, 2011).

3- Resource Description Framework (RDF) (Heath & Bizer, 2011) which is a data model to describe anything on the web like objects or relations and it was built upon two main web standards: Extensible Markup Language XML and URI(Web, 2004). RDF is a model to describe data as triple statement consisting of three elements: subject, predicate and object as shown in Figure 1.

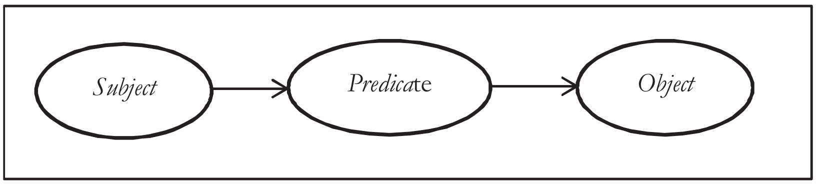


Figure 1 RDF data model

RDF discusses in details in the coming section. However and before going any further with discussing linked data principles, it is of great importance to mention briefly the different formats of RDF serialization. It is essential to understand that RDF is a data model and not a language by itself (Heath & Bizer, 2011) and that is why it is must to convert the simple RDF triple statement to a data format that can be stored and processed in a computer environment and that is what is meant by serialization(Cline, 2012). There are four main serialization formats for RDF and they are: RDF/XML, RDFa, Turtle, N-Triples and RDF/JSON(Heath & Bizer, 2011). RDF/XML is a the basic data format to express the RDF triple statement in XML syntax (W3C, 2004c). RDF/XML includes abbreviations of the namespaces for the used ontologies as we see in the following simple example of RDF/XML serialization:

```
<rdf:RDF
xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
        xmlns:feature="http://www.linkeddatatools.com/clothing-features#">

        <rdf:Description rdf:about="http://www.linkeddatatools.com/clothes#t-shirt">
            <feature:size>12</feature:size>
        </rdf:Description>
</rdf:RDF>
```

Listing 2 : source (LinkedDataTools, 2009)

In the previous RDF/XML serialization, rdf and feature are defined as abbreviations of the RDF and clothing-features ontologies respectively. Both predesigned ontologies are utilized to state that the size of some t-shirt is 12. The two ontologies abbreviations are declared in the beginning of the serialization to avoid the redundancy when using some property from this ontology or that, for example tag <feature:size> in the above serialization is used instead of writing the full version of size's URI http://www.linkeddatatools.com/clothing-features# size and so on.

N-Triples is rather the most clear format for expressing RDF data model because it replaces the elements of the RDF statement by their full URIs (Heath & Bizer, 2011).Above RDF/XML serialization can be mapped into N-triple format as below:

<http://www.linkeddatatools.com/clothes#t-shirt> <http://www.linkeddatatools.com/clothing-features#size> "12".

Here we discussed two serialization format of RDF which we interchangeably use throughout this research. Discussing other serialization formats of RDF is out of the scope of this research and one can refer to the work of (Heath & Bizer, 2011) for more explanation.

4- The last specification of linked data is Hyperlinks. Hyperlink is a link to follow in order to explore other web content or rather other web documents. However hyperlinks are used in RDF to link between entities on the web as well as web documents (Heath & Bizer, 2011).

Let us consider the following RDF example to illustrate the mentioned four bases of linked data:

```
<rdf:RDF xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
        xmlns:geo="http://www.w3.org/2003/01/geo/wgs84_pos#">
  <geo:Point>
    <geo:lat>55.701</geo:lat>
    <geo:long>12.552</geo:long>
  </geo:Point>
</rdf:RDF>
```

Listing 3 : source (mappinghacks, 2005)

In the above RDF example the URI has been used to name a spatial thing: *"Point"* and also to name two properties: latitude *"lat"* & longitude *"long"*. The URI of the concept *"Point"* is: <geo:Point> and the full version of Point's URI can be accumulated by replacing *"geo"* with its URI as follows: <http://www.w3.org/2003/01/geo/wgs84_pos#Point>. The URI of the property *"lat"* is: <http://www.w3.org/2003/01/geo/wgs84_pos#lat> and the URI for the property *"long"* is: <http://www.w3.org/2003/01/geo/wgs84_pos#long>. HTTP is clearly adopted here within each URI. The first line states clearly that this code is RDF document and that is through RDF node and RDF namespace which both called RDF root element for the RDF document (LinkedDataTools, 2009) as illustrated in Figure 2 .

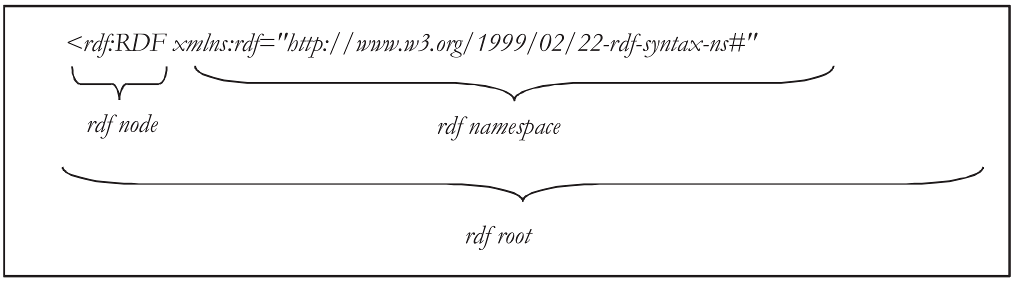


Figure 2 RDF root elements

The previous snapshot of RDF/XML code in Listing 3 tells the machine that a point has a position of (latitude=55.701, longitude=12.552) in WGS84 system utilizing the first three principles of linked data that mentioned previously in this section. The fourth and the last principle of linked data is manifested in the following example:

```
<rdf:RDF xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
  xmlns:foaf="http://xmlns.com/foaf/0.1/">
        <rdf:Description rdf:about="http://richard.cyganiak.de/foaf.rdf#cygri">
        <foaf:topic_interest rdf:resource ="http://DBpedia.org/resource/Tetris" />
        </rdf:Description>
</rdf:RDF>
```

Listing 4 : Source in N-triple format (Jentzsch, 2012)

The above RDf serialization uses hyperlink in Dbpedia[21] to enrich data about a person called Richard Cyganiak in Friend of a Friend FOAF[22] linked dataset. It tells the machine that topic of interest of Richard Cyganiak can be crawled via hyperlink to other data resource which is http://DBpedia.org/resource/Tetris in this case. Hyperlinks in RDF called RDF links to differentiate them from classic hyperlinks which link web document to other web document (Heath & Bizer, 2011).

2.2.2. Resource Description Framework RDF

RDF is a data model to describe anything on the web including a web document, a person, a place or a concept and it is based on Extensible Markup Language XML, i.e. it follows the basic syntax of XML language and it is one of World Wide Web Consortium W3C recommendation[23] (Antoniou & Harmelen, 2008).

So one may ask what is the need to adopt RDF as we already have XML? Well, saying that RDF is following the basic specification of XML does not mean they are the same. The essence of the difference between RDF and XML can be summarized in two points:

- XML is a data model to describe the structure of data and not the data itself. Let us explore the snippet of XML code in Listing 5 to address this observation:

```
<?xml version="1.0" encoding="ISO-8859-15"?>
<!-- Students grades are updated bi-monthly -->
<class_list>
        <student>
                <name>Robert</name>
                <grade>A+</grade>
        </student>
        <student>
                <name>Lenard</name>
                <grade>A-</grade>
        </student>
</class_list>
```

Listing 5 : Source (tizag)

[21] http://dbpedia.org/
[22] http://www.foaf-project.org/
[23] http://www.w3.org/

The different elements of this code have been defined clearly but there is no specific meaning of *"student"* defined to the machine. Is student part of University staff or not? Is student is the same as freshman or not? What is the relation between the student and its grade? These questions can be answered easily by a human but it will not be a trivial task for the machine (Oren, 2009). RDF has been developed to overcome these problems and it has the ability and the tools needed to address explicit meaning of such concept to the machine as we will see further in the section.

- The second basic difference is the way RDF expresses the data. The RDF model describes data as triple statements (Antoniou & Harmelen, 2008).

RDF triple, as the name refers, is composed of three basic elements: the subject, the predicate and the object. The subject or as other refer to it by using the term "the resource" is anything we like to represent by its description (Antoniou & Harmelen, 2008). Resources should be identified via Uniform Description Identifier URI as we mentioned previously in Section 2.2.1. URI can be thought of as the address of this resource on the web. This URI can be an actual web address and is referred to by Uniform Resource Locator URL which is specific type of URI (Antoniou & Harmelen, 2008) as we can see in Figure 3.

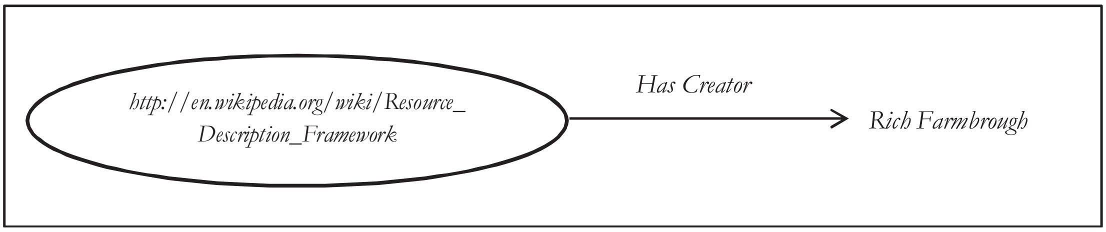


Figure 3 An example of RDF triple

The subject of this triple statement is a web page in Wikipedia[24] and can be looked up by its URL. This RDF triple states that Rich Farmbrough is the creator of this Wikipedia article. Not all resources are URL type and their URI can refer to a real world entity like for example a person(Bizer, Heath, & Berners-Lee, 2009a). Obviously it is impossible to retrieve the person himself by a URI but a description about the person can be retrieved by his URI(Bizer et al., 2009a). Let us observe the RDF triple in Figure 4 :

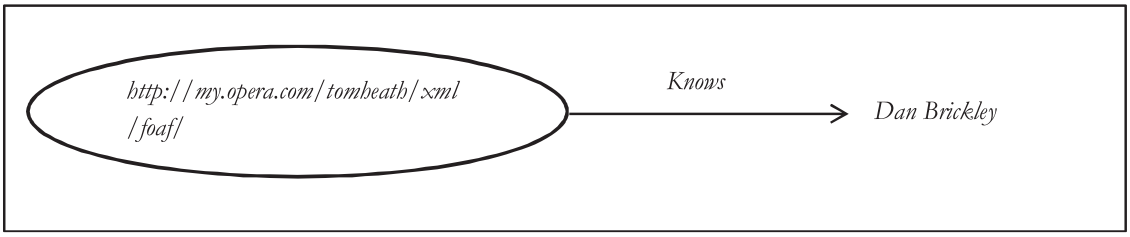


Figure 4

The subject here identified by its URI as shown above and when it is looked up in the web browser it will not retrieved a web page about Tom Heath but it will retrieve a description about Tom Heath saved in RDF file format and a snip of this file can be seen in Listing 6:

[24] www.wikipedia.com

```
<foaf:Person rdf:ID="me">
        <foaf:name >Tom Heath</foaf:name>
        .
        .
         <foaf:knows rdf:resource="http://my.opera.com/danbri/xml/foaf#me"/>
        .
        .
</foaf:Person>
```

Listing 6

URI of the subject can also refer to abstract concept(Heath & Bizer, 2011) like crime or robbery as we will see in Chapter 2 where we discuss designing the use case.

The second element of the RDF triple is the predicate. A predicate is what makes the RDF triple statement meaningful. A predicate describes some properties that subject may have like for example: has_father, located_in, knows and that is why it is common to use the term *"property"* to also refer to the predicate. From linked data point of view the predicate specifies the relationships between subjects in the very same web space or among different web spaces. URI, as for the subject, is utilized to identify property as well. For more clarification, let us observe the following examples of properties identified by their URIs: *http://purl.org/NET/c4dm/event.owl#place* .The previous URI refers to a property called *"place"* which is described in some part of a web document as the property that links an event with its location. The document that includes this property and other properties can be looked up by the mentioned place property URI or through this link: http://motools.sourceforge.net/event/event.html. The document actually is the event ontology document which was designed to describe events in RDF frameworks. Ontology is going to be discussed in detail in Section 2.2.3.

The third and last component of the RDF triple statement is the object. Object is the value of property that assigned to the subject(Antoniou & Harmelen, 2008).Object and value are interchangeably used to refer to the same thing. Unlike subject and predicate, the object can be identified by URI or it can simply be literals like a plain text for instance(Oren, 2009). The object of the triple statement[25] shown in Figure 5 has literal datatype which is the creation date of the Geonames[26] ontology documentation on the web.

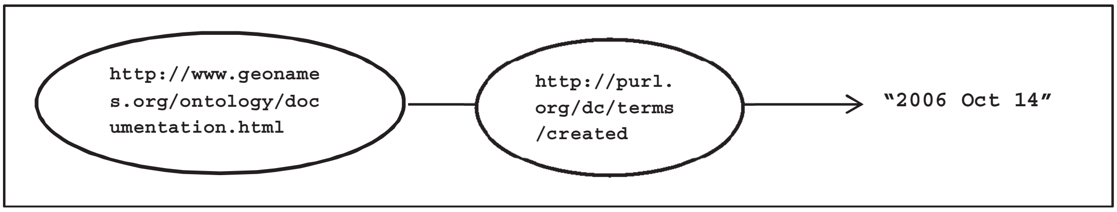


Figure 5

As previously mentioned, the object can be identified by using URI as well and it is very important to understand that object identified by URI in one RDF triple can be the subject of other triple statement. In

[25] This example has been inspired from similar example in (infowebml)

[26] http://www.geonames.org/

fact this capability is one of the most essential issues when we talk about linked data. It is what makes it possible to link heterogeneous dataset over the web. Each RDF triple statement has extendable branches in its two ends. Subject in a triple A is the object of other triple B and the object in triple A is the object in other triple C and so on to form what is called RDF Graph. Figure 6 shows a sample of how RDF graph may look like. Figure 6 illustrates how two datasets in different web spaces are linked utilizing the extendable ends that we mentioned.

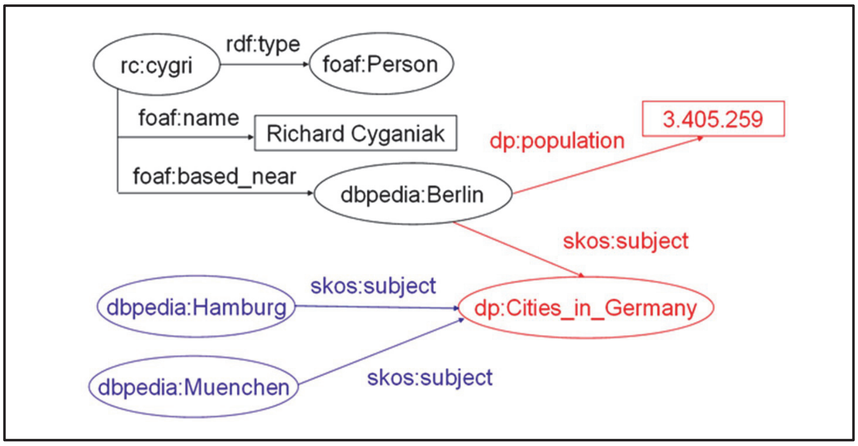


Figure 6 An example of RDF graph : Source (Bizer, Cyganiak, & Heath, 2007)

A person in FOAF dataset called Richard Cyganiak and his location is somewhere near Berlin and Berlin is one of the German cities in Dbpedia dataset and German cities dataset includes also Hamburg and Muenchen cities(Bizer, Cyganiak, et al., 2007). Note that the predicates that glue the different elements in the RDF graph are the properties of the subjects to which they attach(Heath & Bizer, 2011). Note also that above RDF graph has a literal object expresses the number of population in Berlin city. Predefined term *"skos:subject"* in existing ontology of Simple Knowledge Organization System[27] (SKOS) has been reused In Figure 6. It is very important to mention that literal object is the end of the road in RDF graph and that means no further linking is possible from literal object(Oren, 2009).

2.2.3. Ontology in linked data

In a broad generic point of view, ontology is a branch of philosophy concerning the nature of existence(Lawson, 2004). However, from linked data perspective, ontology is the study of organizing concepts in some field of interest and defining their properties and relationships between them(Cai, Eske, & Wang). Concepts represent the human comprehension of some beings in a context of some area of interest. Ontologies are attempts to convey what might be obvious in human minds to the machine. Ontology is domain-dependent and thus different ontologies have been designed for different domains. Dbpedia, FOAF and Geonames are some prominent examples of various ontologies designed for different areas of interests. Each of them has its own set of vocabularies with which the concepts, the relations and the properties are described. RDF as it has been discussed in the last section is a domain-independent model to describe data as triple statements with subject, predicate and object, however, for each domain of interest that is desired to follow linked data principles, RDF by itself is found insufficient to do so. A set of common accepted terminologies has to be specified along with their relationships and properties in order to explicitly describe concepts in a specific domain and that what is called the ontology

[27] http://www.w3.org/2004/02/skos/

of that domain. This can be illustrated briefly through the following example (Delteil, Faron-Zucker, & Dieng, 2004).

Catherine has cat and cat lives in the house.

If we would like to map this statement according to RDF model, it can be something like what is shown in Figure 7.

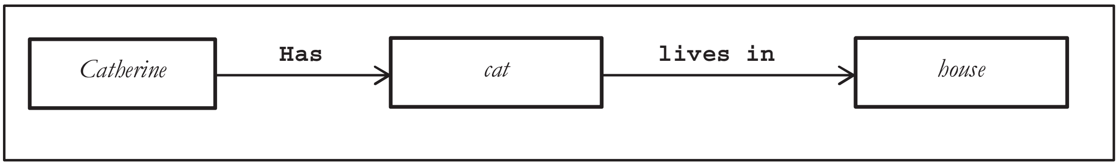


Figure 7

As shown above, the statement has been mapped into two RDF triples. One of them addresses that Catherine has cat and the other states that cat lives in House. Is that what is needed to be part of linked data? The answer is no. There are several questions related to the being of these elements in triples that RDF by its own is not able to answer. Questions like: what is Catherine? Is Catherine a person, animal or something else? Can Catherine, cat and house be grouped in one category? Answers for such questions can be obtained through ontology(Oren, 2009). Such ontology has been developed for RDF and is called RDF Schema RDFS. It defines set of vocabularies that are needed to develop domain-specific ontologies(W3Schools). RDFS will be briefly overviewed in the coming sub-section.

2.2.3.1. RDF Schema

RDFS can be generally understood to mean: "a language for describing lightweight ontologies in RDF; these are often referred to as vocabularies"(Heath & Bizer, 2011). RDFS defines a set of vocabularies grouped in two basic categories: Classes and Properties. For some reason, this set of vocabularies distributed in two RDF documents and thus two different namespaces http://www.w3.org/1999/02/22-rdf-syntax-ns# and http://www.w3.org/2000/01/rdf-schema# (Heath & Bizer, 2011). RDFS defines rdfs:Class which is the class of all classes and that means all RDF resources and all classes are instances of class rdfs:Class (W3, 2004). RDFS also defines rdfs:Resource which is the superclass of everything that are described by RDF and thus all classes are subclasses of rdfs:Resource(W3, 2004). Separated class is also defined for RDF properties as rdf:Property of which properties like rdfs:subClassOf, rdf:type and rdfs:subPropertyOf are instances. Instances, or as some prefer to use term *"individuals"*, of a class can be declared by utilizing RDF property rdf:type. For example, we would like to state that Netherlands is a Country. By following RDF data model and RDFS vocabulary model, this can be mapped into RDF triple represented in Figure 8.

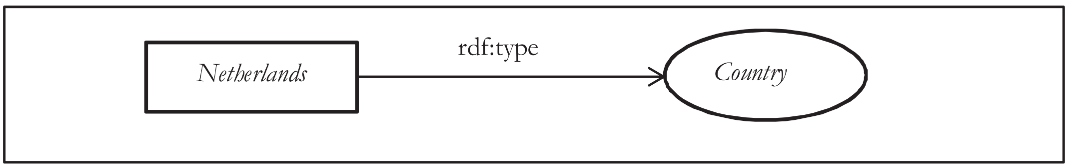


Figure 8

Or in expanded version where we replace rdf by its full namespace http://www.w3.org/1999/02/22-rdf-syntax-ns# as shown in Figure 9.

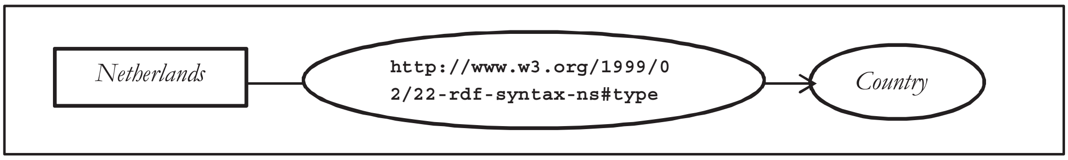


Figure 9

One other important RDF property is rdfs:subClassOf. This property is very powerful since it saves the cost of declaring that instances of class A are also instances of other class B by only declaring that class A is subclass of class B. For example, any instance of class *"#Feature"* in Geonames ontology[28] is also instance of class *"#SpatialThing"* in WGS84 Geo Positioning ontology[29] and that is done in one step through assigning explicitly that class *"#Feature"* is subclass of class *"#SpatialThing"* in some part of Geonames ontology document and as shown below:

```
<owl:Class rdf:about="#Feature">
.
.
        <rdfs:subClassOf
rdf:resource="http://www.w3.org/2003/01/geo/wgs84_pos#SpatialThing"/>
.
.
</owl:Class>
```

Listing 7

Any property can be a sub-property of other property and that is can be described by the RDF property rdfs:subPropertyOf and that means if a resource A is related by a property A` and property A` is a sub-property of property B`, implies that resource A is also related by property B`. This can be illustrated by the example in Figure 10, which shows a triple statement reports that Cinema Roxy is located in Cairo. According to WGS84 Geo Positioning ontology specification which specifies the property *"#location"* to be a sub-property of the property *"/based_near"*, we could also state that Cinema Roxy is based_near Cairo.

[28] http://www.geonames.org/ontology#
[29] http://www.w3.org/2003/01/geo/wgs84_pos#

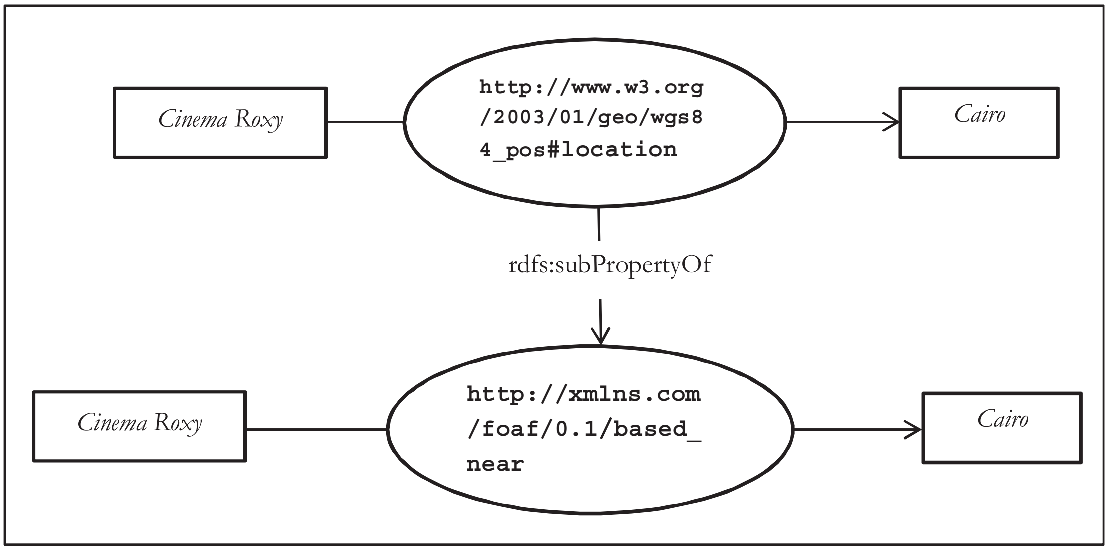


Figure 10 An example of RDF property "rdfs:subPropertyOf" and its application

Domain and range are other important properties in RDF ontology. The property *"rdfs:domain"* specifies to which class the described resource or the subject of the RDF triple belongs while property *"rdfs:range"* specifies to which class the object or the value of the property belongs. The domain can be assigned to more than one class as well as the range, i.e. the described resource can be instance of more than one class and the value of the property in the RDF triple can also be instance of more than one class(W3, 2004). This can be clarified in the following example. Let us consider a property rdf:ID=*"flowingtowards"* that is described in some ontology. This property is restricted by utilizing two RDF properties *"rdfs:domain"* and *"rdfs:range"* as in Listing 8[30]:

```
<rdf:Property rdf:ID="flowingtowards ">
        <rdfs:domain rdf:resource="#River"/>
        <rdfs:domain rdf:resource="#WaterBody"/>
        <rdfs:range rdf:resource="#Sea"/>
        <rdfs:range rdf:resource="#Ocean "/>
</rdf:Property>
```

Listing 8

As shown in the above example, a property *"flowingtowards"* has two domains: *"#River"* and *"#WaterBody"*. That means any described resource by property *"flowingtowards"* can be instance of class *"#River"* or can be instance of class *"# WaterBody"*. The same thing can be said regarding the range of property *"flowingtowards"*, i.e. the possible values of property *"flowingtowards"* can be instance of class *"#Sea"* or can be instance of class *"#Ocean"*. This is better illustrated in Figure 11.

[30] This example has been inspired from similar example in (Costello & Jacobs, 2003)

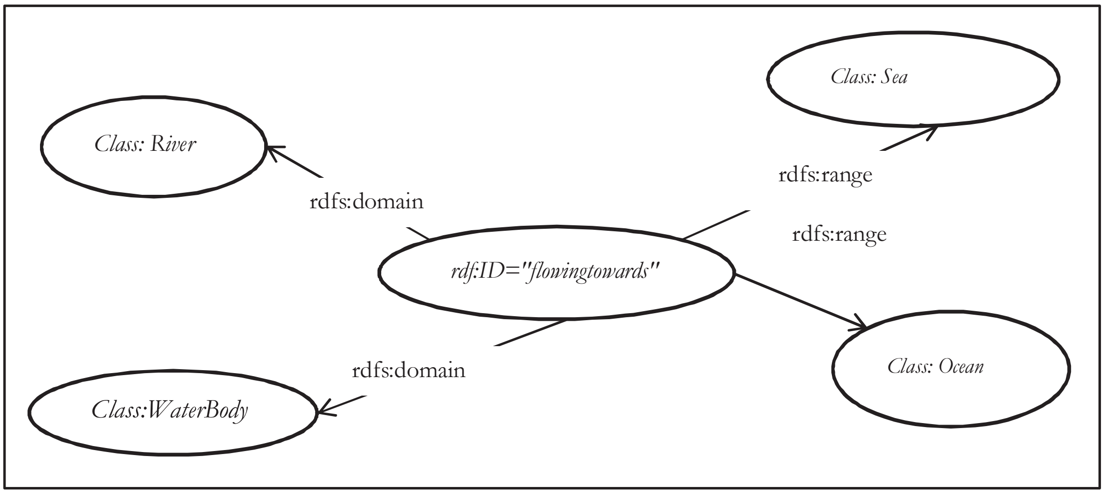


Figure 11 An example of multiple domains and multiple ranges

2.2.3.2. Web Ontology Language OWL

OWL is a web ontology language that recommended by W3C and is also based on XML syntax (Heflin, 2008). OWL is an extension of RDFS ontology and was specifically designed due to some limitation of RDFS (Heflin, 2008). OWL defines some additional ontologies that are based on Description Logic DL as mentioned in The Description Logic Handbook (Heflin, 2008). With OWL, we can specify that two classes are equivalent to each other by using pre-defined OWL property owl:equivalentClass. This property is used to define synonyms for a class, for example we could assign that Nation and Country are equivalent classes as following:

```
<owl:Class rdf:about="#Nation">
  <equivalentClass rdf:resource="#Country"/>
</owl:Class>
```

Listing 9

Same thing can be applied to properties and by using owl:equivalentProperty it is possible to define a property occurred_in as the synonym for a property happened_in. Other powerful OWL property is owl:sameAs which explicitly declares that two resources are referring to the same individuals like for example[31] Netherlands in Dbpedia namespace and Netherlands in Geonames namespace as in Listing 10.

```
<rdf:Description rdf:about="http://dbpedia.org/resource/Netherlands">

  <owl:sameAs rdf:resource="http://sws.geonames.org/2750405/" />
</rdf:Description>
```

Listing 10

[31] This example has been inspired from similar example written in Turtle format in(Heath & Bizer, 2011)

In Listing 10, we state that individuals referenced in Dbpedia by *"Netherlands"* and in Geonames by *"2750405"* are representation for the same individual which is Kingdom of Netherlands in this case. There are more properties defined in OWL that can be looked up in (W3C, 2004a) and we are going to describe some of them if needed in the coming chapter when we discuss the design of the use case.

OWL Lite, OWL DL and OWL Full are the three types of OWL and they are different from each other in terms of the restrictions they state and the expressivity they offer (Heflin, 2008). One basic difference between them is that resources in both OWL Lite and OWL DL must be assigned to a type, meaning that anything must be defined as a a type of class, instance, object property or datatype property while this restriction is absent in OWL Full where it is not necessary to state the type of things (Heflin, 2008). Hence, a resource can be treated as an instance and as a class in the same OWL Full document while this is not allowed with OWL Lite and OWL DL (Heflin, 2008). Other basic difference is that OWL Lite offer less expressivity than the other two types, for example the property *"owl:hasValue"* is only available by OWL DL and OWL Full but not in OWL Lite. Technically, both OWL DL and OWL Full offer the same set of constructs as shown in (W3C, 2004a), however we chose OWL Full to build the ontology of the use case of this research because some classes in our ontology need to be treated as instaces even though they have been assigned to a type, to be able to align them to other classes in diferrent datasets as conceptually equal classes as explained in Section 3.3.4.

3. THE USE CASE - LINKING CROWDSOURCING NEWS IN CONTEXT OF ILLEGAL ACTS IN SOME NEIGHBOURHOODS - MIAMI CITY

3.1. Social Media & Social Media Applications

Social media is web-based applications that have been evolving along with the emergence of the second generation of the World Wide Web: the Web 2.0 (Crymble, 2010; Reips & Garaizar, 2011). There are two essential and basic features of the social media which are also considered to be two among other reasons behind Social media evolution and they are (Crymble, 2010):

1. large variety of users from different backgrounds and interests are feeding and sharing different types of web contents
2. Ability of documentation the shared contents, based on the date as a rule of thumb or any other criteria.

Many social media applications have been built to publish and share different forms of media content starting from plain text to photographs, motion pictures or even maps. Semanticfocus[32] blog, Flickr[33], Facebook[34] and Twitter[35] are some robust examples of social media applications. As discussed in Chapter1, crowdsourcing is the term that used to refer to the social contents due to being produced by the user community. In Chapter 1, we have also seen that social media applications are the platforms of broadcast crowdsourcing contents. Twitter is going to be our resource for collecting some crowdsourcing data in the context of the selected use case which focuses on some aspects of illegal acts in some neighbourhoods in Miami City. Twitter is categorized under the social networking service and it is among the top 10 most visited websites in the world and it comes the second after Facebook among the most significant social network services today (Teufl & Kraxberger, 2011; Wikipedia, 2012b) . Twitter is a service that allows exchanging compressed messages driven by real-time events ranging from self-concerning issues to worldwide events. These messages are called tweets and they are documented in ascending order where the most recent message appears first and so on.

We will not deepen more in the details of Twitter, for now, but some insight details of Twitter and tweets can be mentioned throughout this thesis where necessary.

There are several reasons why we chose Twitter as the resource to collect crowdsourcing news in the mentioned context to be our dataset in this study. . first of all Twitter have hundreds of millions of registered user accounts around the world and it has millions of new posts and tweets every day. Other reason is that Twitter is considerably open and most of the tweets are searchable and readable by non-registered users and thus larger audience can be reached (Crymble, 2010). The last and most important reason is that a tweet is restricted to 140 characters; advantage of this is that these short messages are telling what really matters or rather what is the most important point the user wants to convey.

[32] http://www.semanticfocus.com/blog/
[33] http://www.flickr.com/
[34] www.facebook.com
[35] https://twitter.com/

3.2. Social Media and Linked data

Social media services offer the ability for user community to publish share and access a wide range variety of data on the web almost for free. This ability is what makes social media application is one of the richest data sources on the web(Kalampokis, Tambouris, Hausenblas, & Tarabanis, 2011). In Chapter 2, we have discussed semantic web as initiative to bootstrap the current web with linked data principles in order to evolve semantic web (web 3.0) out of the current web (web2.0). Social media contents represent considerable part of the existing data on the current web and different categories of users or even organizations, contribute into social media streams with different types of content starting from plain text into multimedia content or hybrid combination of two or more type of contents. The enormous amount of contributed contents of the social media can be exploited to deduct valuable information in different domains and interests. Undoubtedly, the vast amount of social media contents can be overwhelming especially that social media contents are semi, if not fully, unstructured contents on the web. The lack of explicit structure for the social media contents makes it tedious job, not only to consume these data efficiently but it also leaves some of the valuable social media contents undiscoverable. Constructing a formal structure for the social media content can be achieved through applying linked data principles that we previously discussed in Chapter 2. Linked data principles has been adopted and applied by some of the existing crowdsourcing and social media services like for instance, Dbpedia, FlickrWrappr[36] (Heath & Bizer, 2011; Kaplan & Haenlein, 2010).

Dbpedia is the *"linked-data"* version of Wikipedia as it is an attempt to extract structured information from Wikipedia through applying the four principles of linked data. Let us observe one example of linked data from Dbpedia that is extracted from Wikipedia to illustrate how linked data principles have been embraced in the Dbpedia framework. The example in Listing 11[37] is part of the structured data that has been extracted from Wikipedia entry of *"Enschede"* city and serialized in RDF/XML form.

The first linked data principle applied in the Listing 11 is using URI to identify every concept which mostly represents a geographic entity in this case like *"Enschede"* or *"Overijssel"* or nongeographic entity like datatype represented by URI *"..#float"*. HTTP is clearly adopted to make these URIs defererenceable, meaning that it can be looked up over the web. Third and core principle of linked data is shown in the modelling data as triples in each statement about resource *"Enschede"* as shown in Listing 12.

[36] http://www4.wiwiss.fu-berlin.de/flickrwrappr/

[37] The full RDF/XML serialization for Enschede in Dbpedia can be found in: http://dbpedia.org/data/Enschede.rdf

```
<rdf:RDF xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
        xmlns:foaf="http://xmlns.com/foaf/0.1/" xmlns:dbpedia-owl="http://dbpedia.org/ontology/"     xmlns:dbpprop="http://dbpedia.org/property/"
        xmlns:geo="http://www.w3.org/2003/01/geo/wgs84_pos#"
        xmlns:owl="http://www.w3.org/2002/07/owl#"
  …
        <rdf:Description rdf:about="http://dbpedia.org/resource/Enschede">
                <foaf:name xml:lang="en">Enschede</foaf:name>
                <dbpedia-owl:abstract xml:lang="en">Enschede, also known as Eanske in the local dialect of Twents, is…</dbpedia-owl:abstract>
                <dbpprop:populationTotal rdf:datatype="http://www.w3.org/2001/XMLSchema#int">157587</dbpprop:populationTotal>
                <geo:lat rdf:datatype="http://www.w3.org/2001/XMLSchema#float">52.22</geo:lat>
                <geo:long rdf:datatype="http://www.w3.org/2001/XMLSchema#float">6.89639</geo:long>
                <dbpprop:subdivisionName rdf:resource="http://dbpedia.org/resource/Overijssel" />
                <owl:sameAs rdf:resource="http://rdf.freebase.com/ns/m.0ps4p" />
        </rdf:Description>
  …
  </rdf:RDF>
```

Listing 11 part of the structured data that has been extracted from Wikipedia entry of "Enschede" city and serialized in RDF/XML form

- *Enschede* → *populationTotal* → *157587*
- *Enschede* → *long* → *6.89639*
- *Enschede* → *sameAs* → *m.0ps4p*

Listing 12 modelling data as triples about resource "Enschede"

It is important to notice that all vocabularies that are used to describe these RDF statements and their description are defined within different ontologies in different namespaces as they are referred to in the RDF root element in the beginning of the RDF/XML serialized code, for instance: to look up the description of term *"long"* we can check out the WGS84 Geo Positioning ontology[38] to which term *"long"* belongs, to easily see that is a term used to describe the longitude property of any spatial thing in WGS84 coordinate system. *"Enschede"* source that is described in Dbpedia is linked internally to other Dbpedia source which is *"Overijssel"* by dbpprop property *"subdivisionName"* and also linked to an external resource which is *"http://rdf.freebase.com/ns/m.0ps4p"* through owl property *"sameAs"* to declare that the same entity *"Enschdede"* has been described in two different datasets and thus there is a possibility to integrate them to enrich our knowledge about this entity.

[38] http://www.w3.org/2003/01/geo/wgs84_pos#

This external link is what makes Dbpedia fits its place in the global linked open data cloud graph as shown in Figure 12 and with RDF internal and external links Dbpedia has applied the fourth and the last principle of linked data as previously mentioned in Section 2.2.1.

Linking data on Social media has been depending on describing metadata of the social contents explicitly like for example the topic, the label or the location. Various ontologies have been built to define set of vocabularies that utilized to describe metadata of some social media contents and some significant examples of them can be Open Graph Protocol[39] and SIOC Core Ontology Specification[40].

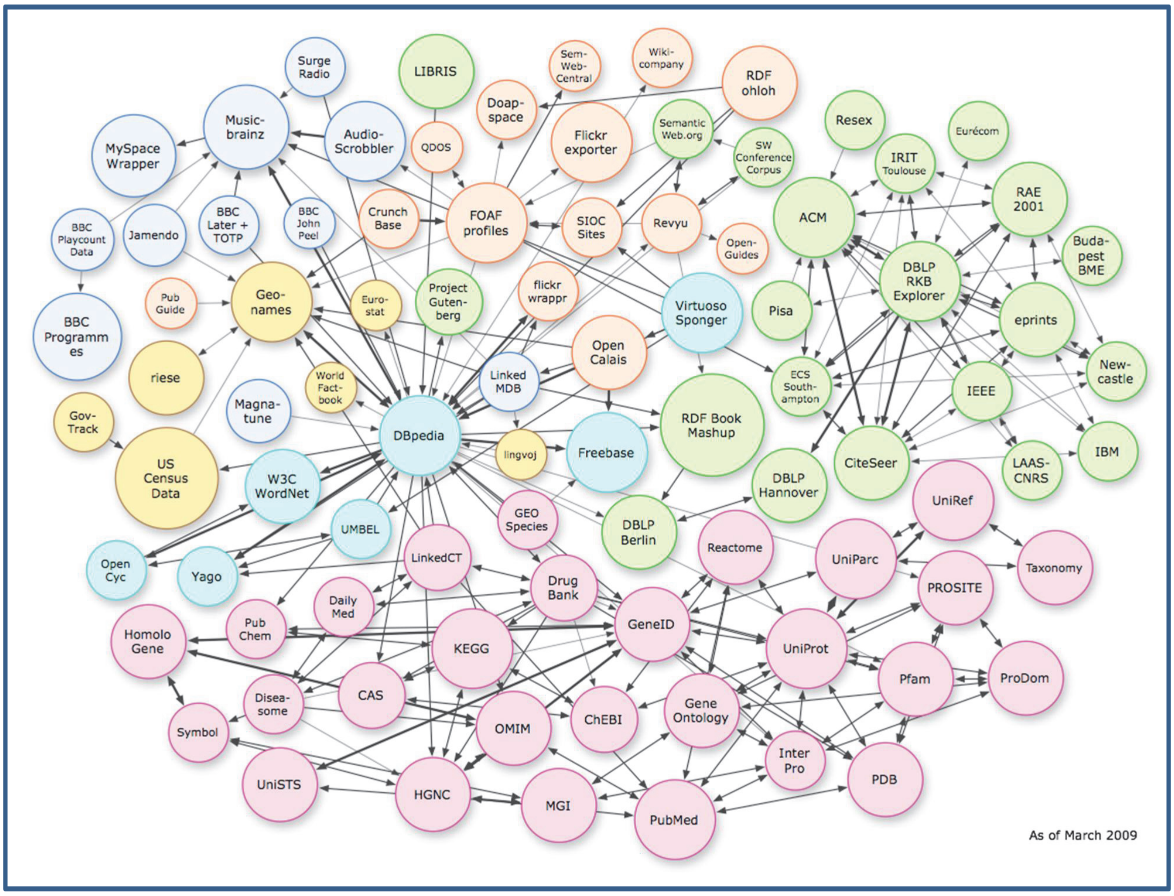


Figure 12 Linked Open Data cloud graph: Source (Cyganiak & Jentzsch, 2011)

Open Graph Protocol and SIOC Core Ontology Specification are examples of existing ontologies that have been designed to link data among Social media graph and to extend the knowledge in this graph with data from outside Social media communities. However, the mentioned predesigned ontologies link Social media in more generic way, meaning that the mentioned ontologies can generally be applied for any Social media contents but cannot be applied for a specific-domain of interest.

The ontology of the use case of this research is designed in a context of a specific domain of interest which is selected to be *"Crimes"* or *"Illegal acts"* in more specific way and in a particular geographic extent

[39] http://opengraphprotocol.org/
[40] http://rdfs.org/sioc/spec/

which is selected to be in four neighbourhoods in *"Miami"* city in in the United States as we will see in the coming section.

3.3. The Use Case: Linking crowdsourcing news in context of illegal acts in some neighbourhoods - MIAMI CITY

We are going to investigate the conceptual linking in discovering relevant news in the social media in the context of three main categories of illegal acts that occur in a specific geographic extent which is assigned by city Miami and four of its neighbourhoods. Figure 13 shows the flow diagram of how the proposed IAINM ontology that we are going to design for the selected use case in Section 3.3.3, is going to utilized in searching for relevant tweets in the context of the use case. The Discussion of the different stages of the flow diagram seen in Figure 13 is distributed over this Chapter and Chapter 4.

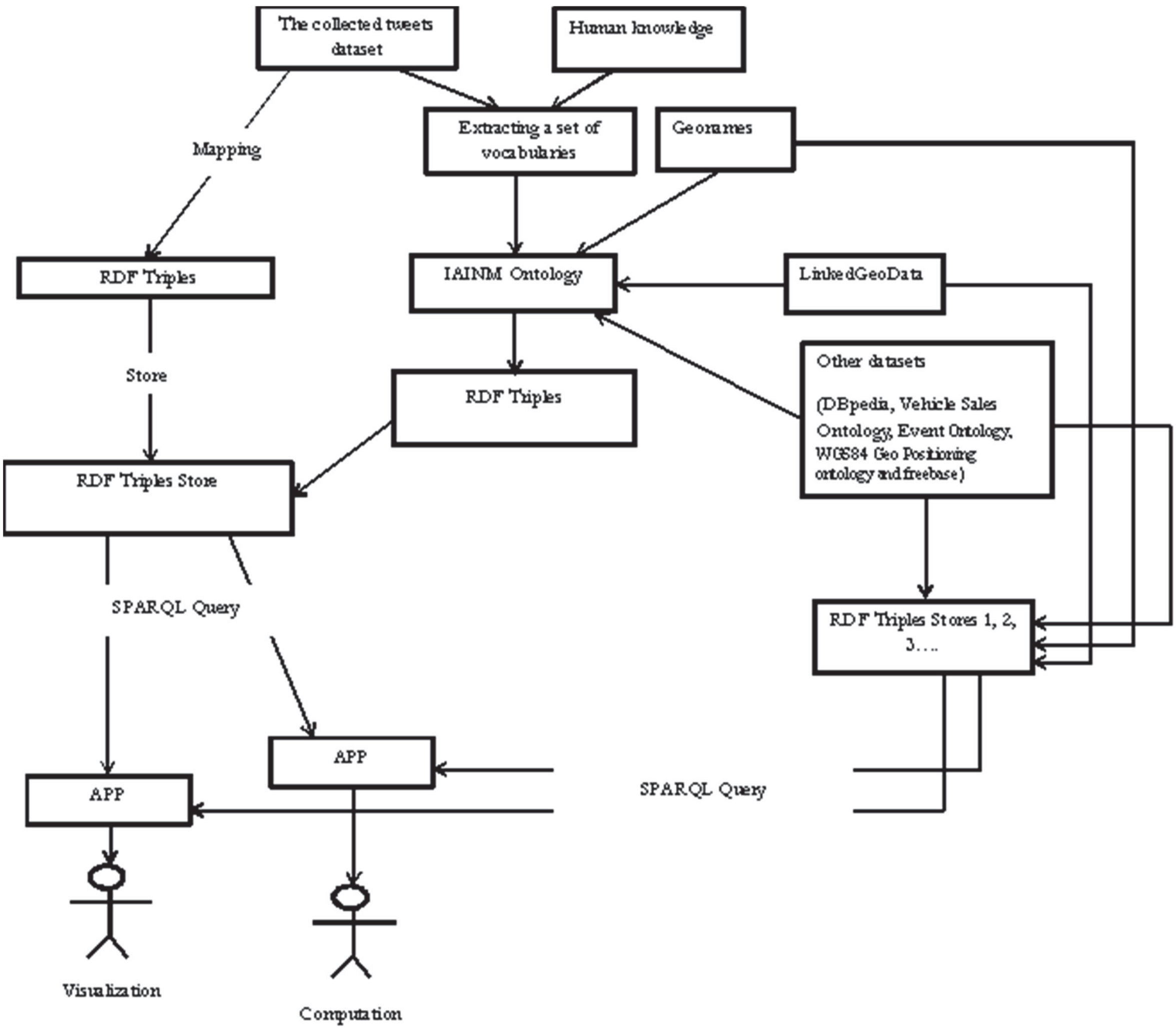


Figure 13 the flow diagram that illustrates how IAINM ontology will be utilized in searching for relevant contents in the context of the use case

3.3.1. Extracting a set of vocabularies and designing the domain data model

A set of vocabularies is needed before designing any ontology as discussed in Section 2.2.3 in Chapter 2. Our set of vocabularies has been extracted manually according to our common understanding of the illegal acts, the pre-assigned geographic extent including Miami city and four of its neighbourhoods and the nature of social news contents on Twitter. Two issues have been taken into account when extracting the vocabulary set: one of them is that social news contents can be affected by the official news agencies and thus it can show more formality than the social news that is lacking for this influence. The second issue is that the news which correspond with a considerable geographic extent, like for example the news that occur in an international level, continental level, countrywide level or even in some administrative levels like a city, a state or a town, has a high possibility to be circulated with the official news agencies. However; the news that involve low geographic and/or administrative level, such as the neighbourhoods; has a lower possibility to be reported by the official news agencies. The latter type of news can be disseminated via the social media user community as social media news contents showing less formality. Whether the social news show more or less formality; both cases has to be considered when extracting the vocabulary set.

The mentioned set of vocabularies is needed to build a domain knowledgebase, i.e. the domain ontology, for our use case that concerns with the three categories of illegal acts in specified four neighbourhoods in Miami city. The extracted vocabularies should be corresponding with one of three different groups of concepts as shown in Figure 14.

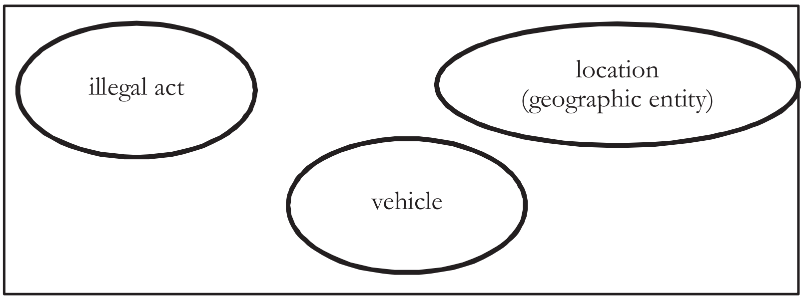


Figure 14 three groups of concepts to one of which the extracted vocabularies should belong

The three groups of concepts have been selected due to the domain data model we designed for this knowledge base as illustrated in Figure 15.

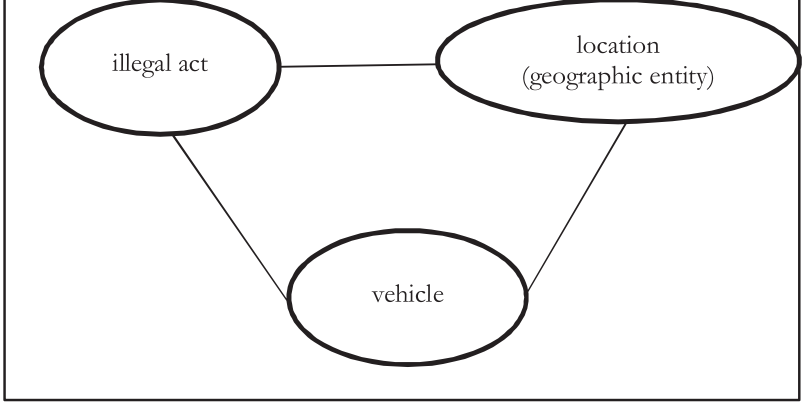


Figure 15 the domain data model

We designed our data model to be at least one of the two following conceptual features combinations: the illegal act and the geographic location that held this act or the other combination which is the illegal acts and the geographic location that held this act and the stolen vehicle in case the illegal act belongs to a *Robbery* category and it is a vehicle robbery.

Theft, Shooting, Carjacking, Stolen are examples of some vocabularies that belong to *illegal act* group. *Car, Truck, Bicycle* are examples of some vocabularies that belong to *vehicle* group. *Location* is populated with the pre-determined geographic extent represented by city *Miami* and four of its neighbourhoods: *Downtown Miami, Liberty City, Little Haiti* and *Overtown*.

Another list of vocabularies have been extracted to be used in a ranking phase to increase the possibility of retrieving the most relevant social news when querying against the RDF triples that will be mapped from the collected dataset of tweets as it will be discussed in the Chapter 4 and we call this set of vocabularies *"ranking set"* to distinguish it from the earlier vocabularies set that is utilized to build the IAINM ontology. Ranking set includes strong and unambiguous domain vocabularies that when they are occurred simultaneously in the possible conceptual features combinations, that were mentioned previously, it indicates high degree of relevance of the corresponding RDF triple in which they have occurred. *Police, Armed, Thief, Stray bullet, Burglar* are examples of some vocabularies that belong to ranking set. Ranking and ranking set utilization is discussed in details in the Section 4.5.

3.3.2. The collected dataset

Before proceeding with the design of IAINM Ontology and assigning the main classes and properties we should firstly collect the proper dataset of tweets in the context of the *"illegal acts"* in the mentioned geographic extent. Our dataset consists of 114 tweets collected via keyword searching with the TOPSY[41] search engine. The keywords used to collect our dataset are combination of two components: the illegal act + the location. We have tried searching with the different combinations of illegal acts and the four chosen neighbourhoods. Three categories of illegal acts have been considered: *Gunfire, Robbery* and *Vandalize* in the four neighbourhoods in Miami which are: *Downtown Miami, Liberty City, Little Haiti* and *Overtown*. Different synonyms for each illegal act category have been used; due to the informality of the social media contents, combined with each one of the four neighbourhoods to reveal more undiscovered social news (tweets) in the mentioned context. Searching based on different Keyword combinations has been tedious job to do. Eventually, what we are attempting to achieve in this research is to link social news conceptually, i.e. relating the social news content through semantic linking as well as the keyword linking and thus reduce the effort that is needed to discover relevant social news in a particular context.

3.3.3. Designing IAINM Ontology

There are two main components in our IAINM ontology: Classes, Properties that link classes with each other and individuals that belong to some classes.

- **Classes**: There is a default super class called *Thing* of which all classes are subclasses. We have created three main classes in IAINM ontology: *Crime, Location and Vehicle*.
    - *Crime*: is the superclass of all three illegal acts categories:
        - *Gunfire*
        - *Robbery*: is a superclass of class *Carjacking*
        - *Vandalize*
    - *Location*: is the class of the venue in which crime has happened and it is the superclass of:
        - *City*
        - *Neighbourhoods*

[41] http://topsy.com/tweets

- *Vehicle*: this class has been created separately for class Robbery to allow as many combinations as it possible between both classes through a property called Object. Vehicle is the superclass of:
    - *Bike*
    - *Bus*
    - *Car*
    - *Motorcycle*
    - *Tractor*
    - *Truck*
    - *Van*

- **Properties**: are the links that connect different components of the ontology. They can be thought of as attributes in relational database. All the following properties are subclasses of a class rdf:Property.
  - *Has_Neighbourhoods*: is the property that links *City* with *Neighbourhoods* and thus the domain of this property is class *City* and its range is class *Neighbourhoods*.
  - *Neighbourhoods_of*: is the inverse property of the property *Has_Neighbourhoods* and thus its domain is class *Neighbourhoods* and its range is class *City*.
  - *locatedIn*: the domain of this property is class *Crime* and its rang is class *Location*.
  - *locationOf: is the inverse property of the property Located_in and thus its domain is* class *Location* and its range is class *Crime*.
  - *Object*: is the property that links class *Robbery* with class *Vehicle* to address what is the object that has been robbed and/or used. The object can be anything but we focus in this ontology on vehicles.

- **Individuals**: are the instances that belong to our classes. Individual is a unique entity that has unique properties that make it distinguished from anything else. This relation is represented by RDF property rdf:type to assign that subject of the RDF statement is an instance of a class.
    - *Miami*: is an instance of class *City*.
    - *Downtown_Miami, Liberty_City, Little_Haiti, Overtown* are instances of class *Neighbourhoods*.

- **Synonyms**: the possible informality of the social news contents should be taking care of and thus we have assigned synonyms for some classes to empower the knowledge base of this ontology and that has been achieved through OWL property *owl:equivalentClass* as following:
  - A class called *Theft* has been created.
  - Social media contents can be expressed in different verbal tenses like for example the tweets that are shown in Figure 16. Hence, we have created classes: *Rob* and *Steal* and their corresponding verbal tenses as separated classes as well.

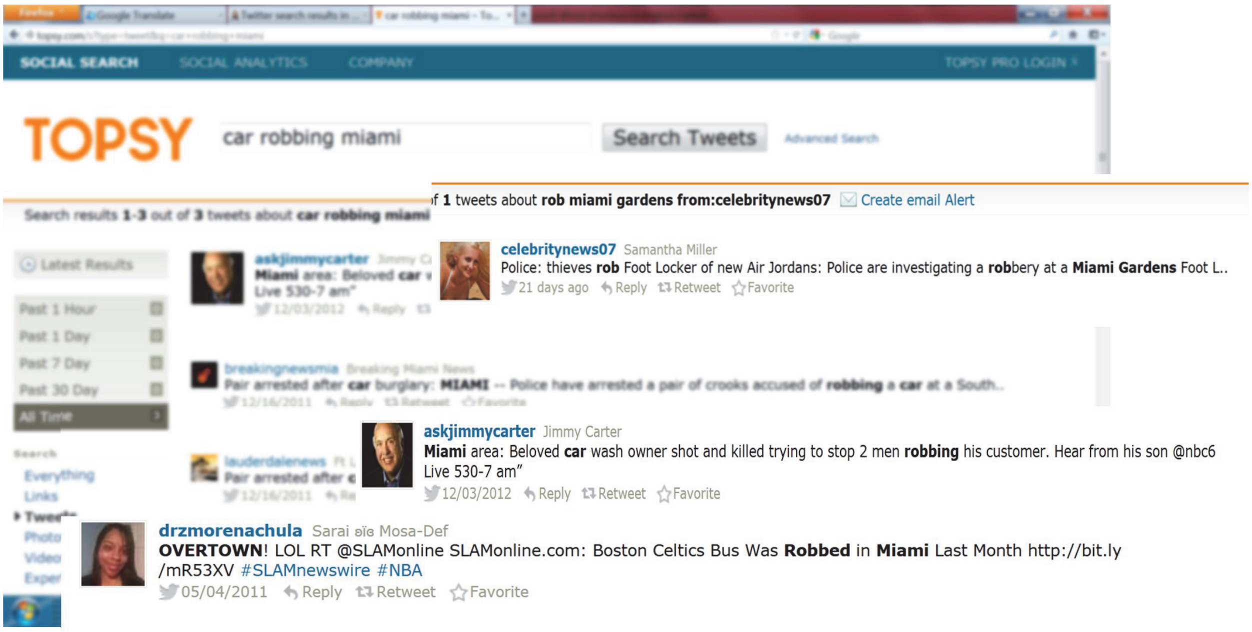


Figure 16 Social media news can be expressed in different verbal tenses

- Assigning classes *Theft*, *Robbery, Rob*, *Steal* and the classes of the verbal tenses of class *Rob* and *Steal* synonyms for each other.

3.3.4. Translation IAINM ontology to other existing ontologies

The main goal of translation concepts in IAINM ontology to the corresponding concepts in other ontologies is to create the possibility of integration same type of data among various datasets (Heath & Bizer, 2011). Two approaches have been considered to translate our IAINM ontology to some other existing ontologies including Geographic ontologies like Geonames, LinkedGeoData and WGS84 Geo Positioning and non-geographic ontologies like Dbpedia, Vehicle Sales Ontology[42] and The Event Ontology[43]. One of them is to reuse pre-defined terms in some existing ontologies (Heath & Bizer, 2011) if they have the exact intended meaning with which we like to describe some data on our ontology. There are several considerations when reusing predefined terms from existing ontologies and they are:

- No further description for reused terms is allowed since they already have been described in their original ontology. Otherwise, we would not have reused them in the first place.
- In case additional description is needed for the reused terms; then we could either:
  - Define other suitable terms in the namespace of the ontology that is intended to be built
  - Or we could replace the both ontologies with one ontology by merging them. RDF and OWL does not support merging process and such support is offered by other ontology mapping languages such as SPARQL++(Heath & Bizer, 2011).

The other approach, and this one is the one we utilized in our research, is ontology alignment approach. Alignment is the process of assigning relationships between corresponding terms of two or more ontologies and these terms can be classes, properties or even individuals (Parundekar, Knoblock, & Ambite, 2010a). In linked data scope, it is common to use term *"mapping"* and *"aligning"* to refer to the

[42] http://purl.org/vso/ns
[43] http://purl.org/NET/c4dm/event.owl

same thing; however our understanding for term *"mapping"* is that it is tended to be more used to refer to the set of triples that has been resulted from the alignment process. RDF and OWL define set of properties that are used to support ontology alignment. OWL has defined property *owl:equivalentClass* that can be used to address that two terms from different ontologies namespaces are equivalent and thus they have the exact same set of individuals. Let us consider the classes *A* and *B* and given that both classes are defined in different ontologies and we would like to align these two classes by using OWL property *owl:equivalentClass* because they describe the same exact set of individuals; in this case *owl:equivalentClass* can be expressed by sets intersection as following: $A \cap B = A = B$ (Parundekar et al., 2010a) In case *A* and *B* are classes that existed in the same ontology; then *owl:equivalentClass* is most probably used to address that *A* and *B* are synonyms for each other. In IAINM ontology, we have not exploited property *owl:equivalentClass* for more than assigning synonyms for classes and less tightly alignment has been adopted through utilizing properties *rdfs:subClassOf* and *owl:sameAs*.

3.3.4.1. Alignment IAINM ontology with Geonames

Geonames is a geographic gazetteer for more than 8.3 million names of geographical places where there are semantic links between these geographic names. The Geonames has a geonames ontology[44] that defines these semantic links. The geonames ontology has been designed to have a class called "*Feature*" where all geonames are individuals of this class (Parundekar, Knoblock, & Ambite, 2010b). A classic geographic feature would be linked to class "*Class*" by property "*featureClass*" and also linked to class "*Code*" via property "*featureCode*". "*Class*" is the class who has 9 different classes that represent nine different groups of geographic features as illustrated in Table 1.

Class	***Description***
A	*country, state, region*
H	*stream, lake, ...*
L	*parks, area, ...*
P	*city, village,...*
R	*road, railroad, ...*
S	*spot, building, farm, ...*
T	*mountain, hill, rock, ...*
U	*undersea*
V	*forest, heath, ...*

Table 1 Description of Geonames class "*Class*"

Class "*Code*" can be thought of as an extension of class "*Class*" because it divides up the 9 classes of *"Class"* into smaller groups. "*Code*" has 690 codes represent smaller groups for each of the nine classes. For example, class *"S"* in "*Class*" can be divided up into smaller groups including for example government buildings, commercial buildings, banks, hospitals, casinos and many more as depicted in Table 2. No SPARQL Endpoint[45] has been detected for Geonames, thus Geonames classes, object properties and datatype properties have been retrieved through executing SPARQL queries[46] against Geonames ontology file that was locally stored in Virtuoso[47]quad store. SPARQL queries for retrieve Geonames main classes, "*Feature*" subclasses, "*Code*" subclasses, object properties and datatype properties are depicted in Listing

[44] http://www.geonames.org/ontology#
[45] SPARQL Endpoint is a web service that executes SPARQL queries (DuCharme, 2011).
[46] SPARQL is the language that is utilized to formalize and execute queries on data that is in RDF format (W3C, 2009) and SPARQL is acronym name that stands for *SPARQL Protocol and RDF Query Language* (W3C, 2008).
[47] http://virtuoso.openlinksw.com/

13, Listing 14, Listing 15, Listing 16 and Listing 17 respectively and the results of these queries can be found in ANNEX B.

Code	*Description*
S.ADMF	*a government building*
S.BLDO	*commercial building where business and/or services are conducted*
S.BANK	*A business establishment in which money is kept for saving or commercial purposes or is invested, supplied for loans, or exchanged*
S.HSP	*a building in which sick or injured, especially those confined to bed, are medically treated*
S.CSNO	*a building used for entertainment, especially gambling*
P.PPL	*a city, town, village, or other agglomeration of buildings where people live and work*
L.AREA	*a tract of land without homogeneous character or boundaries*

Table 2 some examples of codes in class *"Code"*

```
select *
where
{
?Geonames_main_classes rdf:type owl:Class.
}
```

Listing 13 SPARQL query to retrieve all Geonames main classes

```
select *
where
{
?Geonames_Feature_subclasses rdf:type gn:Class.
}
```

Listing 14 SPARQL query to retrieve Geonames "*Feature*" subclasses

```
select *
where
{
?Geonames_Code_subclasses rdf:type gn:Code.
}
```

Listing 15 SPARQL query to retrieve Geonames *"Code"* subclasses

```
select *
where
{
?Geonames_ObjectProperties rdf:type owl:ObjectProperty.
}
```

Listing 16 SPARQL query to retrieve Geonames object properties

```
select *
where
{
?Geonames_DatatypeProperties rdf:type owl:DatatypeProperty.}
```

Listing 17 SPARQL query to retrieve Geonames datatype properties

Geonames has also classes: *"Map"*, *"RDFData"* and *"WikipediaArticle"*. Class *"Map"* includes URLs of the webpages that display the maps of the corresponding features. Geonames property *"locationMap"* links class "*Feature"* with class *"Map"*. *"RDFData"* is a class of RDF documents that describe features that are linked to other features with one of the following Geonames properties: *"childrenFeatures"*, *"nearbyFeatures"* and *"neighbouringFeatures"* and thus *"RDFData"* class is the range of these 3 properties.
For example city *"Enschede"* in Geonames has several nearby features that are described in RDF document: *http://sws.geonames.org/2756071/nearby.rdf*. Feature *"Enschede"* is linked to this separated RDF document by Geonames property "*nearbyFeatures"* in the basic RDF document that has all the Geonames description about Enschede as shown in Listing 18[48].
"WikipediaArticle" is the class of the Wikipedia articles about the corresponding features. Features in class "*Feature"* are linked to the corresponding Wikipedia articles in class *"WikipediaArticle"* via property *"wikipediaArticle"* and thus class "*"WikipediaArticle"* is the range of the property *"wikipediaArticle"*. In Listing 18, feature "Enschede" is linked to its English Wikipedia article represented by the URL "*http://en.wikipedia.org/wiki/Enschede"* by Geonames property "*gn:wikipediaArticle"*. Note that class is distinguished from the property by having a capital "W" where the property has the small "w". It is also important to notice that URI "*http://sws.geonames.org/2756071"* is different from URI "*http://sws.geonames.org/2756071/about.rdf"* because the first one represents the feature *"Enschede"* and the second one represents the RDF document that includes all information that Geonames has about feature *"Enschede"*.

[48] The full RDF/XML serialization for Enschede in Geonames can be found in: http://sws.geonames.org/2756071/about.rdf

```
…
<rdf:RDF>
  <gn:Feature rdf:about="http://sws.geonames.org/2756071/">
    <rdfs:isDefinedBy rdf:resource="http://sws.geonames.org/2756071/about.rdf"/>
    <gn:name>Enschede</gn:name>
    <gn:countryCode>NL</gn:countryCode>
    <gn:population>153655</gn:population>
    <wgs84_pos:lat>52.21833</wgs84_pos:lat>
    <wgs84_pos:long>6.89583</wgs84_pos:long>
    <gn:wikipediaArticle rdf:resource="http://en.wikipedia.org/wiki/Enschede"/>
…
    <gn:nearbyFeatures rdf:resource="http://sws.geonames.org/2756071/nearby.rdf"/>
…
</rdf:RDF>
```

Listing 18 Snippet of Geonames RDF document of feature "Enschede"

IAINM ontology has been mapped to Geonames ontology as following:

- Class *"Location"* in IAINM ontology is defined as a subset of Geonames class "*Feature"* as depicted in Figure 17.

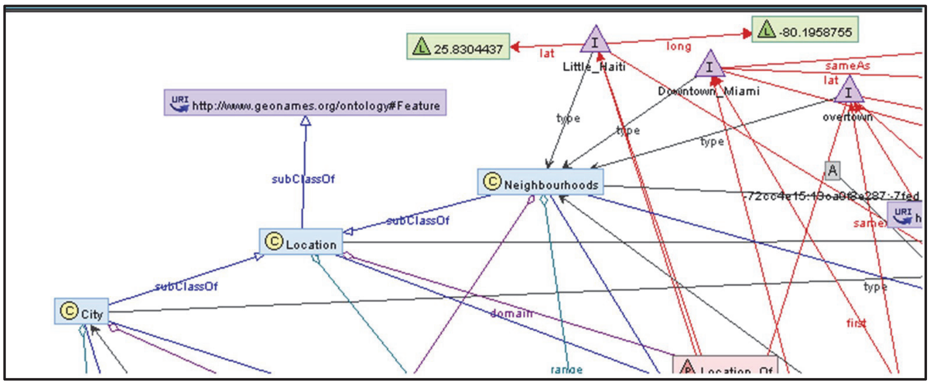


Figure 17 mapping class *"Location"* in IAINM ontology to Geonames ontology

A general analysis has been carried out to the Geonames ontology including:

- A brief review for classes, codes and properties
- And examination for a sample consists of 25 neighbourhoods[49] including the 4 neighbourhoods in IAINM ontology to check their corresponding codes in Geonames as shown in Table 3. 32% from this sample have a code value *"P.PPL"*, to refer to the concept

[49] The original source of this sample is http://projects.nytimes.com/census/2010/map and it is collected as a table in http://en.wikipedia.org/wiki/Neighborhoods_in_Miami

"populated place", and 4% from this sample has a code *"L.AREA"*, to refer to *"area"*, as corresponding classes to "*Neighbourhoods"* class in IAINM ontology.

According to this brief analysis; we have come to the following observations: 1) the structure of the Geonames ontology supports the land-use classification and that is manifested in the 690 different codes that are designed to be assigned to different Geonames features and this may explain the second observation 2) there is no a clear distinction has been detected in Geonames ontology between concept "*City"* and "*Neighbourhoods"* in terms of they both are considered as populated places in Geonames.

Neighbourhood in Miami	**Corresponding code in Geonames**
Allapattah	P.PPL
Brickell	P.PPL
Buena Vista	P.PPL
Civic Center	-
Coconut Grove	P.PPL
Coral Way	P.PPL
Design District	-
Downtown	L.AREA
Edgewater	-
Flagami	P.PPL
Grapeland Heights	-
Liberty City	-
Little Haiti	-
Little Havana	P.PPL
Lummus Park	-
Midtown	-
Omni	-
Overtown	-
Park West	-
The Roads	P.PPL
Upper East Side	-
Venetian Islands	-
Virginia Key	-
West Flagler	-
Wynwood	-

Table 3 examination for a sample consists of 25 neighbourhoods including the 4 neighbourhoods in IAINM ontology to check their corresponding codes in Geonames

- Based on the above, both classes *"City"* and "*Neighbourhoods"* in IAINM ontology have been mapped as a restricted subset of Geonames features that are related with the property *"featureCode"* and has the value: *"P.PPL"* and another value *"L.AREA"* has been added when mapping class *"Neighbourhoods",* as unified group with "*"P.PPL"* value, to cover the case of neighbourhood "*Downtown_Miami"* that has been found as a Geonames feature with *"L.AREA"* as *"featureCode"* value. The above mapping is shown in Figure 19 and Figure 18 respectively.

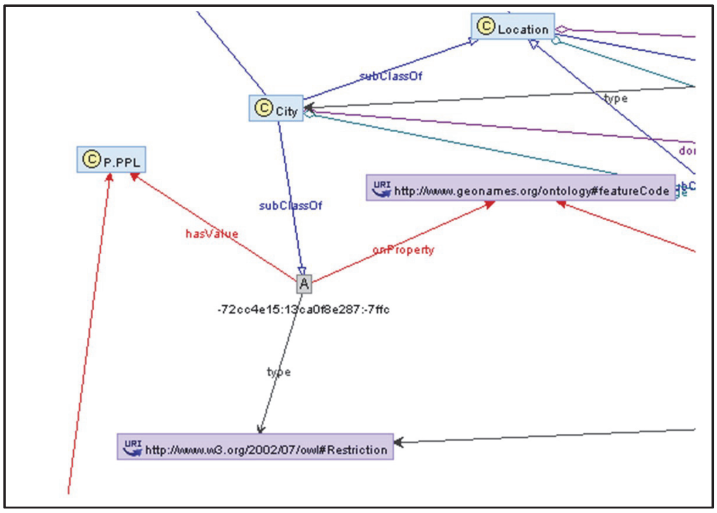


Figure 19 mapping class *"City"* in IAINM ontology to Geonames ontology

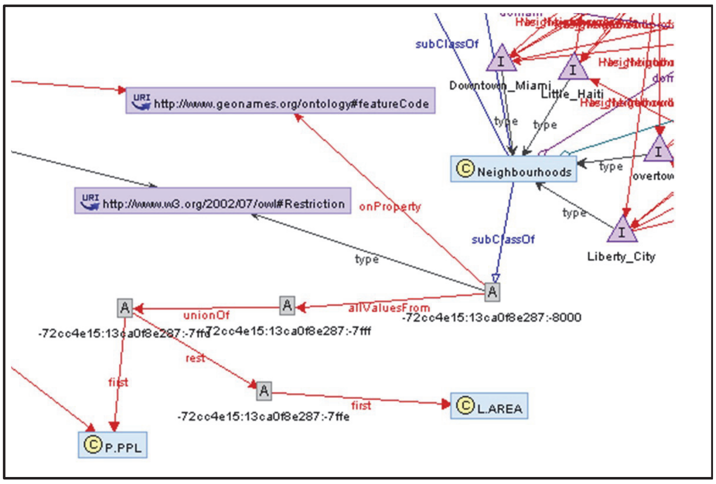


Figure 18 mapping class *"Neighbourhoods"* in IAINM ontology to Geonames ontology

3.3.4.2. Alignment IAINM ontology with LinkedGeoData (LGD)

LinkedGeoData[50] is the RDF version of OpenStreetMap[51] project and LinkedGeoData ontology[52] is mainly derived from tags in OpenStreetMap (Stadler et al., 2012). Classes and subclasses in LinkedGeodata ontology have been derived from classification tags in OpenStreetMap (Auer et al., 2009), for example tags <Leisure, SportsCentre> in OpenStreetMap would be mapped into two classes *"Leisure"* and *"SportsCentre"* where second one is subclass of the first one.
Object properties in LinkedGeoData ontology have been mapped from description tags in OpenStreetMap and the description tag values have been mapped into resources that represent the values of the respective mapped object properties (Auer et al., 2009), for example tags <religion, Christian> in OpenStreetMap would be in LinkedGeoData ontology an object property *"religion"* and a resource *"Christian"*. Finally, datatype properties in LinkedGeoData ontology are driven from data tags in OpenStreetMap and the data tag values have been mapped into RDF literals (Auer et al., 2009). LGD Live Sparql Endpoint[53] has been used to query all LGD classes, object properties and datatype properties as depicted in Listing 19, Listing 20 and Listing 21 respectively and the results of these queries can be found in ANNEX C. A general analysis has also been carried out for the different components of LGD ontology including:

- a brief review for classes, codes and properties
- and examination for the previously mentioned sample of 25 neighbourhoods to check their corresponding type in LGD as depicted in Table 4. 32% from this sample have a class *"Hamlet"* as their type and as corresponding class to "*Neighbourhoods"* class in IAINM ontology.

According to the mentioned analysis, the data model we adopt in IAINM ontology and also the matching result between LGD ontology and Geonames ontology that has been published in (Stadler et al., 2012); we have mapped our ontology to LGD ontology as follows:

- Class *"City"* in IAINM ontology is defined as a subclass of class *"City"* in LGD ontology as shown in Figure 20.

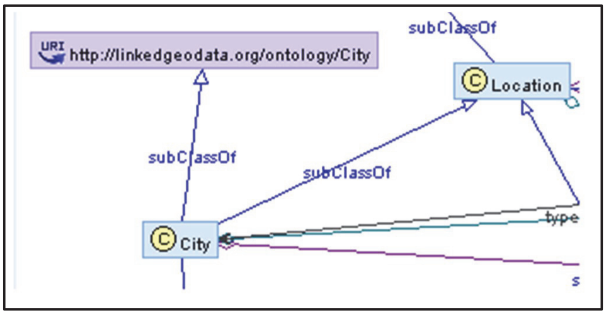


Figure 20 mapping class *"City"* in IAINM ontology to LGD ontology

- Class *"Neighbourhoods"* in IAINM ontology has been mapped as a subset of a class *"Hamlet"* in LGD ontology as shown in Figure 21.

50 http://linkedgeodata.org/About
51 http://openstreetmap.org
52 downloads.linkedgeodata.org/releases/110406/LGD-Dump-110406-Ontology.nt.bz2
53 http://live.linkedgeodata.org/sparql

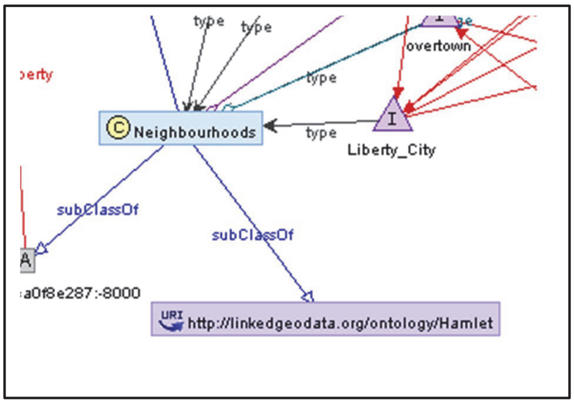


Figure 21 mapping class *"Neighbourhoods"* in IAINM ontology to LGD ontology

```
Prefix lgd:<http://linkedgeodata.org/> Prefix lgdo:<http://linkedgeodata.org/ontology/>
Select *
From <http://linkedgeodata.org> {
?LGD_Classes rdf:type owl:Class .
}
```

Listing 19 SPARQL query to retrieve all LGD classes

```
Prefix lgd:<http://linkedgeodata.org/> Prefix lgdo:<http://linkedgeodata.org/ontology/>
Select *
From <http://linkedgeodata.org> {
?LGD_ObjectProperties rdf:type owl:ObjectProperty .
}
```

Listing 20 SPARQL query to retrieve all LGD object properties

```
Prefix lgd:<http://linkedgeodata.org/> Prefix lgdo:<http://linkedgeodata.org/ontology/>
Select *
From <http://linkedgeodata.org> {
?LGD_DatatypeProperties rdf:type owl:DatatypeProperty .
}
```

Listing 21 SPARQL query to retrieve all LGD datatype properties

Neighbourhood in Miami	Corresponding code in LGD
Allapattah	Hamlet
Brickell	Hamlet
Buena Vista	Hamlet
Civic Center	-
Coconut Grove	Hamlet
Coral Way	Hamlet
Design District	-
Downtown	-
Edgewater	-
Flagami	Hamlet
Grapeland Heights	-
Liberty City	-
Little Haiti	-
Little Havana	Hamlet
Lummus Park	-
Midtown	-
Omni	-
Overtown	-
Park West	-
The Roads	Hamlet
Upper East Side	-
Venetian Islands	-
Virginia Key	-
West Flagler	-
Wynwood	-

Table 4 examination for a sample consists of 25 neighbourhoods including the 4 neighbourhoods in IAINM ontology to check their corresponding codes in LGD

3.3.4.3. Alignment IAINM ontology with DBpedia

In the above alignment, rdf property "*rdfs:subClassOf*" has been utilized to map IAINM ontology to some geospatial ontologies including: Geonames and LinkedGeoData. It is important to understand that property "*rdfs:subClassOf*" does not imply the conceptual equality but rather implies that some concept is a subset of other concept, meaning that any instance (individual) of the subclass is also an individual of the superclass. However, conceptual equality can be the type of relationships between mapped classes and this can be achieved by dealing with intended classes as individuals and representing the conceptual equality by owl property "*owl:sameAs*" (W3C, 2004b) which is utilized to align IAINM ontology to DBpedia as follows:

- Class *"Crime"* is defined as equal class to class *"Crime"* in DBpedia as shown in Figure 22.

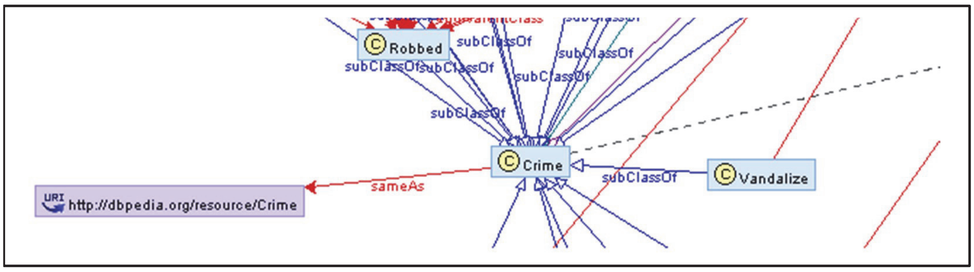


Figure 22 mapping class *"Crime"* in IAINM ontology to DBpedia

- Class *"Carjacking"* is defined as equal class to class *"Carjacking"* and as subclass of class *"Motor_vehicle_theft"* in DBpedia as shown in Figure 23

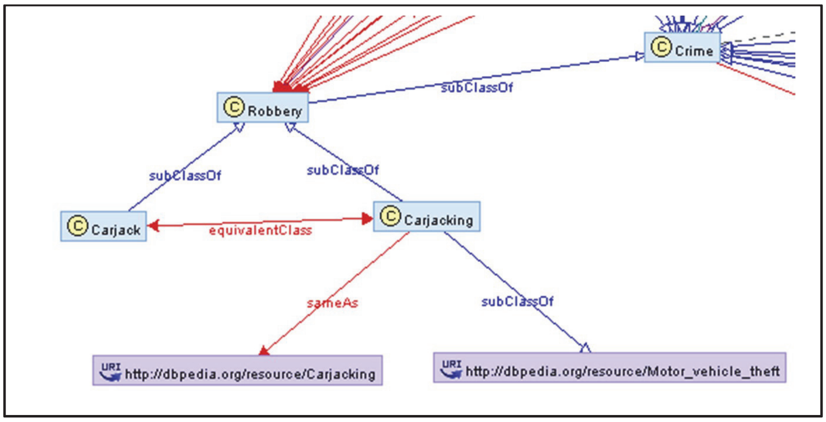


Figure 23 mapping class "*Carjacking*" in IAINM ontology to DBpedia

- Class *"Robbery"* is defined as equal class to class "*Robbery*" in DBpedia as shown in Figure 24 .

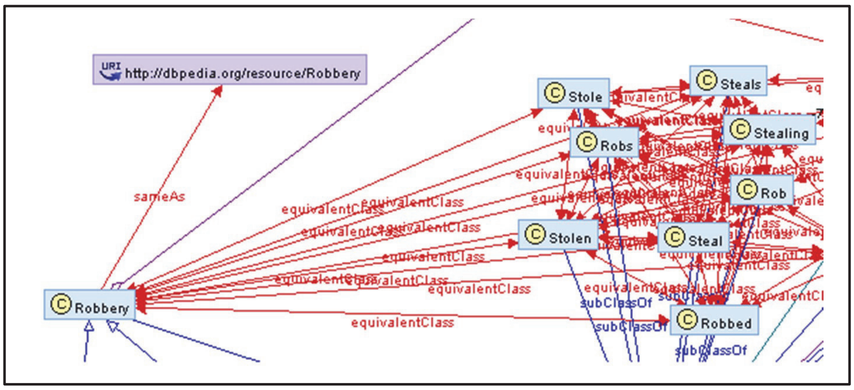


Figure 24 mapping class "*Robbery"* in IAINM ontology to DBpedia

- Class *"Theft"* is defined as equal class to class "*Theft*" in DBpedia as shown in Figure 25.

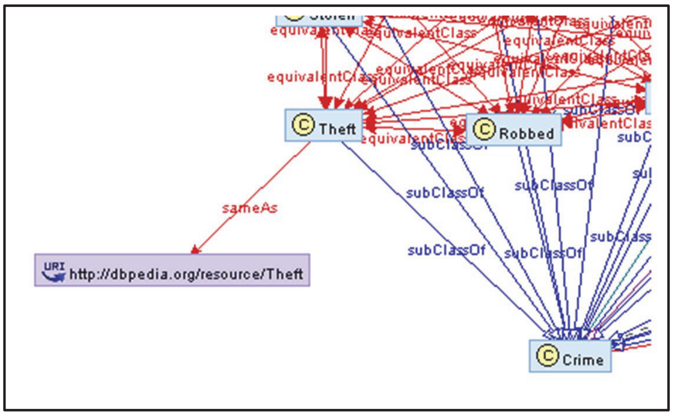


Figure 25 mapping class "*Theft"* in IAINM ontology to DBpedia

- Class *"Shooting"* is defined as equal class to class "*Shooting*" in DBpedia as shown in Figure 26.

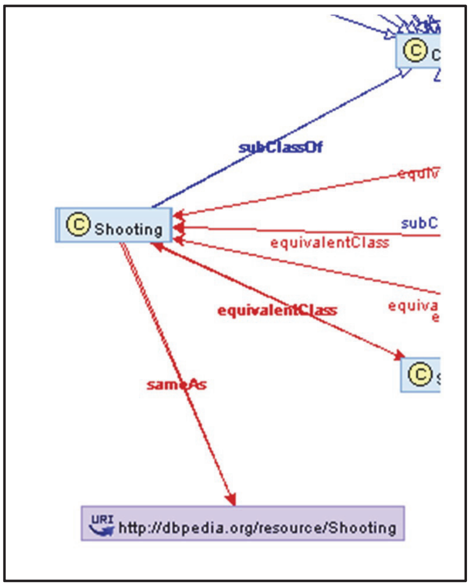


Figure 26 mapping class "*Shooting"* in
IAINM ontology to DBpedia

- Class *"Vandalize"* is defined as equal class to class "*Vandalism*" in DBpedia as shown in Figure 27.

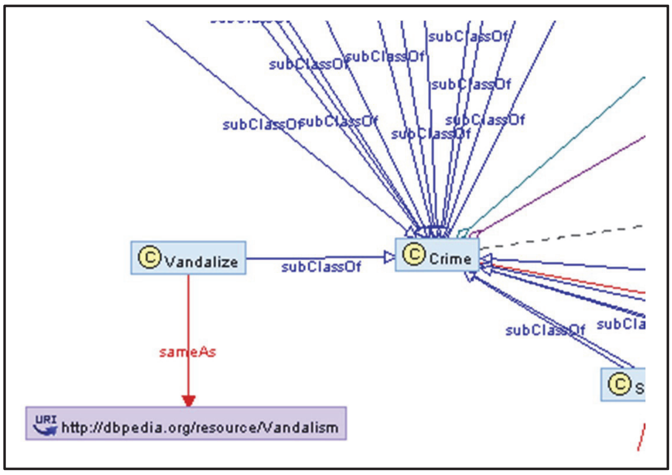


Figure 27 mapping class "*Vandalize*" in IAINM ontology to DBpedia

3.3.4.4. Alignment IAINM ontology with Vehicle Sales Ontology

Different classes of vehicle in IAINM ontology have been mapped into Vehicle Sales Ontology through properties *"rdfs:subClassOf"* and *"owl:sameAs"* as summarized in Figure 28.

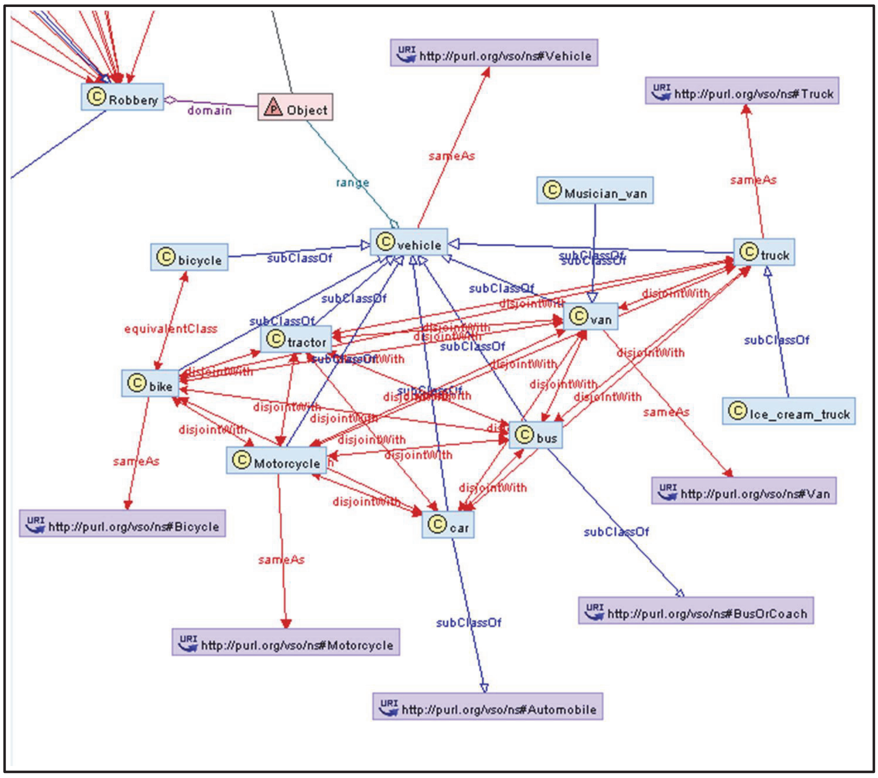


Figure 28 mapping different subclasses of class"*vehicle*" in IAINM ontology to Vehicle Sales Ontology

3.3.4.5. Alignment IAINM ontology with The Event Ontology & WGS84 Geo Positioning ontology

Event ontology as the name implies is ontology that has been designed to deal with event as the main concept which has different properties like: time, position, product and other things as illustrated in the Event ontology model that shown in Figure 29. IAINM ontology is approaching the Event ontology in terms of the Crime as type of event and the location of the crime and thus, an alignment has been done between IAINM ontology with The Event ontology as following:

- Class *"Crime"* is defined as a subclass of class *"Event"* in Event ontology as depicted in Figure 30.

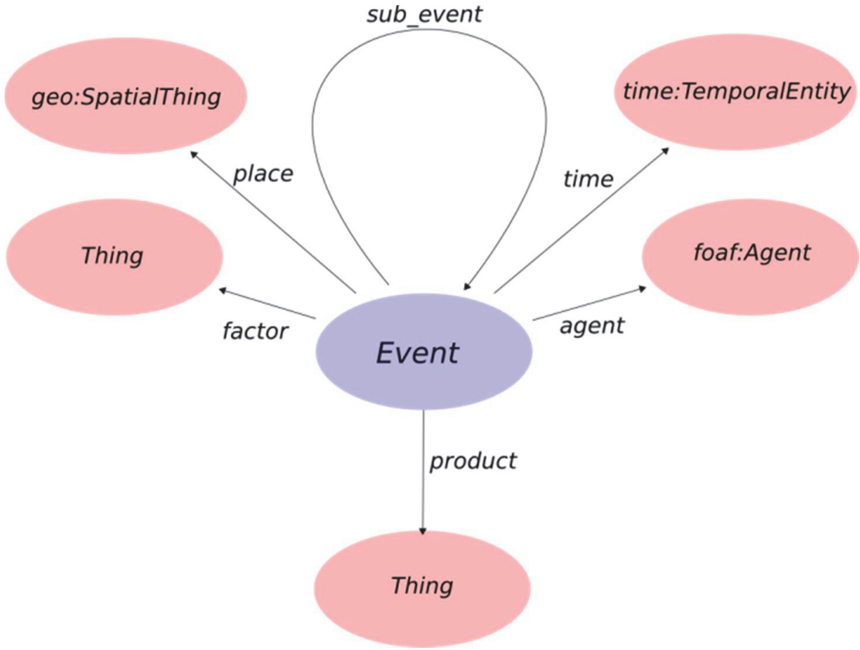


Figure 29 Event ontology model: Source (Raimond & Abdallah, 2007)

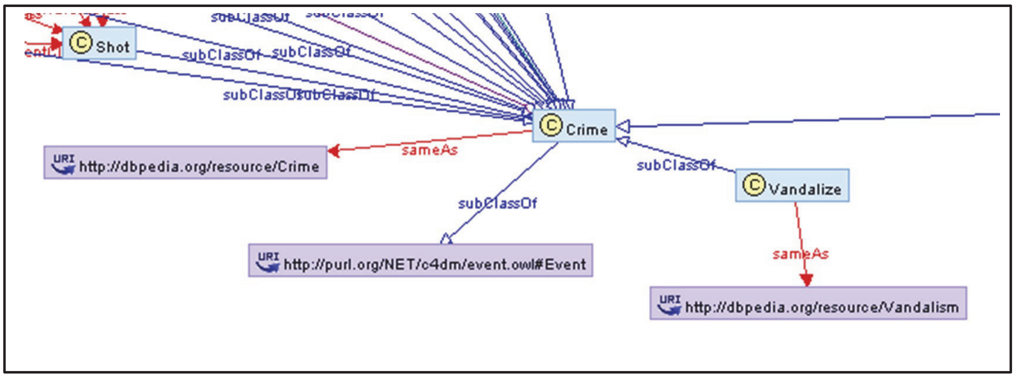


Figure 30 mapping class "*Crime*" in IAINM ontology to Event Ontology

- Class *"Location"* is defined as subclass of class *"SpatialThing"* as shown in Figure 31, with taking into account that class *"SpatialThing"* is defined in other ontology which is WGS84 Geo Positioning ontology[54].

[54] http://www.w3.org/2003/01/geo/wgs84_pos#

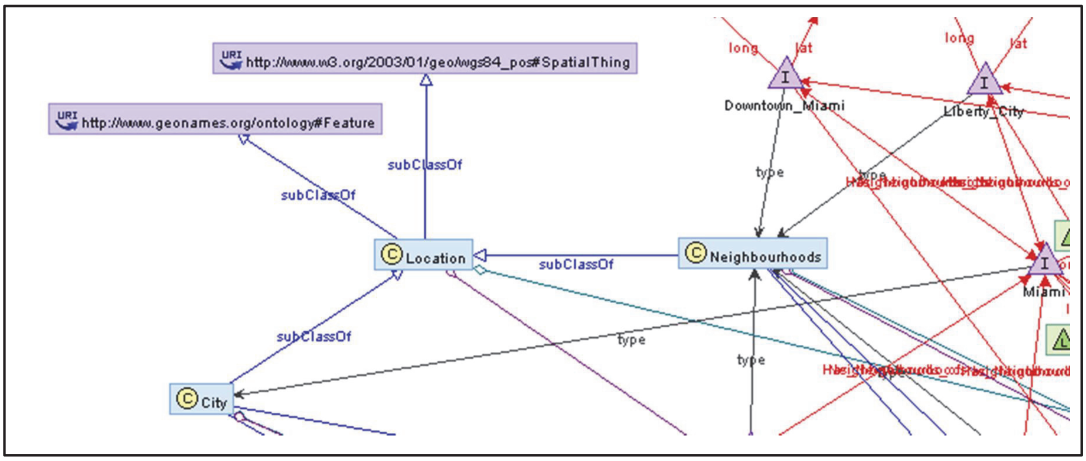


Figure 31 mapping class "*Location*" in IAINM ontology to WGS84 Geo Positioning ontology

3.3.5. Geocoding "Miami" city and the four neighbourhoods

City *"Miami"* and the four neighbourhoods have been geocoded through generating requests of the location string against the Google Geocoding API (Keßler, Janowicz, & Kauppinen, 2012)which returned files in XML format that include the longitude and latitude of the requested places. For example, the following requests: http://maps.googleapis.com/maps/api/geocode/xml?address=+miami&sensor=false and http://maps.googleapis.com/maps/api/geocode/xml?address=+libertycity,+miami&sensor=false are used to retrieve the geographic information of city *"Miami"* and neighbourhood *"Liberty_city"* respectively. Pre-defined terms from WGS84 Geo Positioning ontology have been reused to describe the longitude and latitude information for city *"Miami"* and the neighbourhoods as shown in Figure 32. By this way we have successfully geocoded city *"Miami"* and the neighbourhoods, except for the neighbourhood *"Downtown_Miami"*.

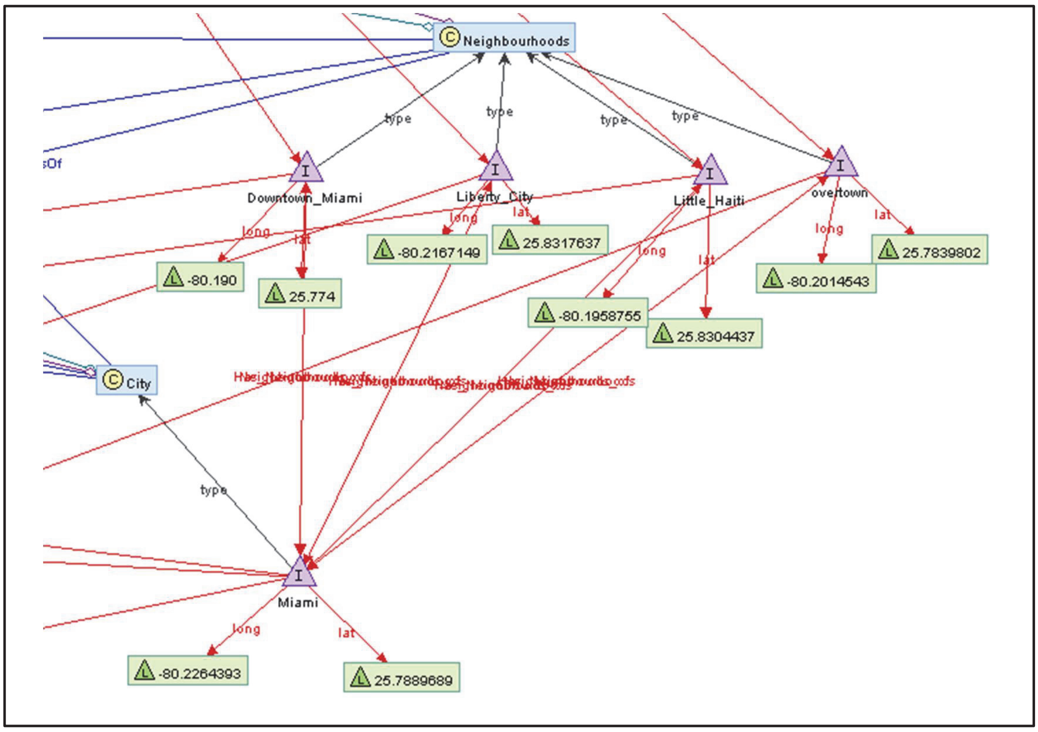


Figure 32 Geocoding city *"Miami"* and the neighbourhoods

3.3.6. Linking IAINM graph to the Linked Open Data cloud graph

It is essential to connect our IAINM graph to the global graph of linked data, through RDF links, to expand the knowledge base of the web of data as well as to enrich the knowledge base of our IAINM graph. Basically, there are two categories of RDF links: vocabulary links and resources links. Vocabulary links are the links that connect IAINM graph to the global graph of Linked Data at the ontology level, meaning that the RDF links are utilized to link corresponding terms that are defined in different ontologies in different namespacesand this type of links and its implementation have been discussed in Section 3.3.4. The second category of RDF links is the resources links which are the links that connect IAINM graph to the global graph of Linked Data at the actual data level. Resources links can be represented in two types of links: relationship links and identity links(Heath & Bizer, 2011). Relationship links is when a resource that is described in other namespace is set in the rdf triple in time of mapping actual data to rdf triples like the example we mentioned in Listing 4. In Listing 4, subject of the rdf triple statement is related to other resource in DBpedia as its topic of interest. It is important to realize that no further description for the DBpedia resource have been or should be presented in the rdf triple statement in Listing 4. In case the data provider would like to provide further description of the same resource; then he/she should identify the resource with a URI in his/her own namespace in order to provide further description for this resource and then a link can be set between the resource that is described in his/her own namespace and the corresponding resource that is described in other namespace. The corresponding resources are called *"aliases"* since both resources refer to the same entity and the links that are set between them are the identity links (Heath & Bizer, 2011) which is the second type of the resource links. Identity links has been utilized in Listing 11 to link geographic entity *"Enschede"* that is described in DBpedia namespace to its alias in freebase[55] namespace via OWL property "*owl:sameAs*" . We have also applied Identity links via property "*owl:sameAs*" as shown in Figure 33 to connect some entities in IAINM graph to the corresponding entities in the Linked Open Data cloud graph as following:

- City *"Miami"* has been linked to its alias in Geonames and LinkedGeoData.
- The four neighbourhoods have been linked to the corresponding alias in Geonames in case of neighbourhood *"Downtown_miami"* and to freebase namespace for the remaining three neighbourhoods.

[55] http://rdf.freebase.com

-

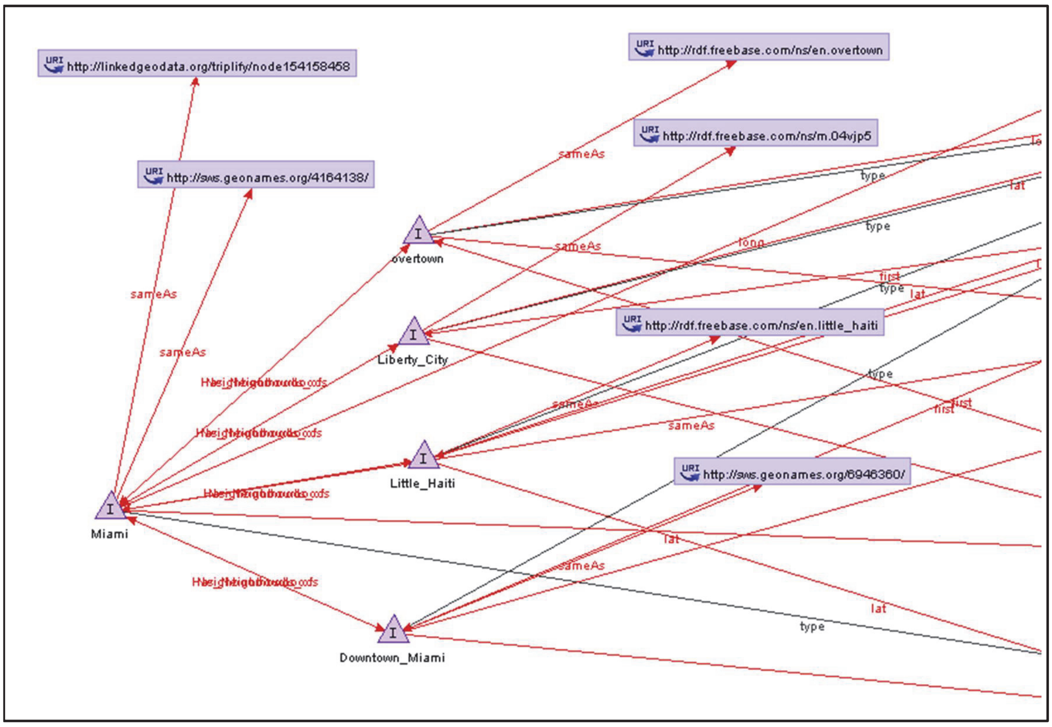


Figure 33 linking entities in IAINM namespace to the corresponding alias in other namespaces

4. IMPLEMENTATION

4.1. Implmenting IAINM ontology

Designing ontology is: “a complex and largely domain-oriented process that can be benefited from tool support” (Khondoker & Mueller, 2010) and this process can be created fully manually as the ontology would be eventually serialized to one of RDF serialization forms that can be written and edited in one of the text editors like for example Notepad++[56] .
In this research we used the well-known ontology editor Protégé[57] to create our model in the domain of social news about three main categories of illegal acts in four neighbourhoods in Miami city. Protégé has a graphic user interface which facilitates the ontology designing process and Protégé was found to be the most utilized, domain-independent and user-friendly tool among other ontology tools including for instance: Top Braid[58] and Internet Business Logic[59] and that is Depending on an online survey that has been carried out for ontology development community and its results that was published in a five pages journal article (Khondoker & Mueller, 2010). The namespace for our IAINM Ontology is selected to be *“http://www.TSMER.com/Ontology.owl#”* and has *“TS”* as its abbreviation.

4.1.1. Issue in implementing synonyms with Protégé

Assigning synonyms was carried out fully manually due to some limitation of Protégé in assigning synonyms. For more explanation, let us consider two classes *A* and *B* and we assigned *B* as a synonym for *A*. Protégé would automatically assign *A* as a synonym for *B* according to the Protégé description logic as shown in Figure 34 through OWL property *owl:equivalentClass* as illustrated in the RDF/XML serialization for implementing these two synonyms in Listing 22.

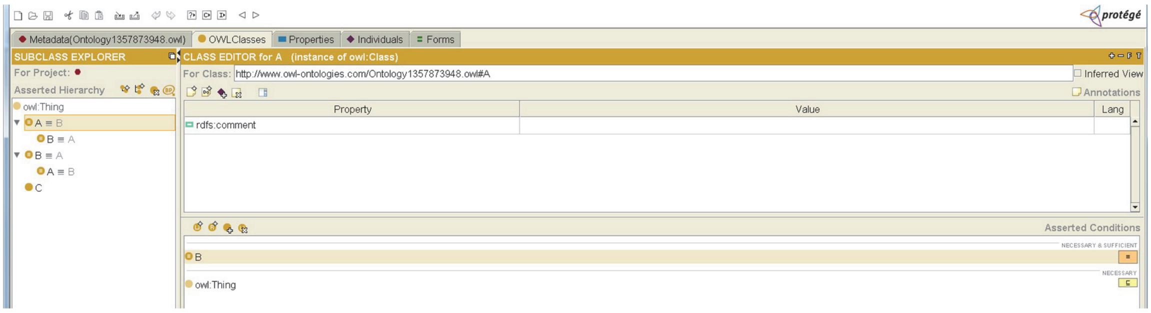


Figure 34 Implementing synonyms for two classes A and B in Protégé

[56] www.notepad-plus-plus.org
[57] http://protege.stanford.edu/
[58] http://www.topbraidcomposer.com
[59] http://www.semanticweb.org/wiki/Internet_Business_Logic

```
<owl:Class rdf:ID="A">
    <owl:equivalentClass rdf:resource="#B"/>
    <rdfs:subClassOf rdf:resource="&owl;Thing"/>
</owl:Class>
<owl:Class rdf:ID="B">
    <owl:equivalentClass rdf:resource="#A"/>
    <rdfs:subClassOf rdf:resource="&owl;Thing"/>
</owl:Class>
```

Listing 22 RDF/XML serialization of implementing two classes A and B in Protégé

Let us now attempt to assign synonyms for more than two classes; let them *A*, *B* and *C*. In this case we first assign *B* as a synonym for *A* and then we assign *C* as a synonym for *B* and we would then expect Protégé according to its description logic to infer that *A* and *C* are synonyms for each other but this is not quiet what happened as we see in the resulted serialization of implementing synonyms for three classes in Protégé in Listing 23.

```
…
<owl:Class rdf:ID="B">
    <owl:equivalentClass>
      <owl:Class>
        <owl:intersectionOf rdf:parseType="Collection">
          <owl:Class rdf:about="#A"/>
          <owl:Class rdf:about="#C"/>
        </owl:intersectionOf>
      </owl:Class>
    </owl:equivalentClass>
…
```

Listing 23 RDF/XML serialization of implementing synonyms for three classes *A*, *B* and *C* in Protégé

Listing 23 shows that Protégé has utilized the property *owl:equivalentClass* to indicate that classes *A*, *B* and *C* are equivalent in terms of having the same class extension, i.e. they all have the same set of individuals and not to assign the three classes as synonyms for each other as in the previous case when implementing synonyms for only two classes. Listing 23 can be expressed with sets intersection as following: $B = A \cap C$. Protégé in this case has dealt with classes' equality as mentioned in W3C Web Ontology Language Reference under definition of OWL property *owl:equivalentClass*[60]. For all what mentioned previously; we assigned synonyms manually as combinatorics, for example to assign classes: Theft, Robbery, Stealing and Robbing as synonyms for each other; we would explicitly link each one of them with each possible combination via *owl:equivalentClass* property as illustrated in Figure 35.

By implementing synonyms this way; we would retrieve all the other three classes (synonyms) when querying the equivalent classes of any one of them. Synonyms for class *"Gunfire"* have been implemented in the same way and the RDF/XML serialization of implementing synonyms manually for IAINM ontology is quiet long and one can refer to the full serialization of IAINM ontology in the ANNEX A.

[60] For detailed explanation : http://www.w3.org/TR/owl-ref/#equivalentClass-def

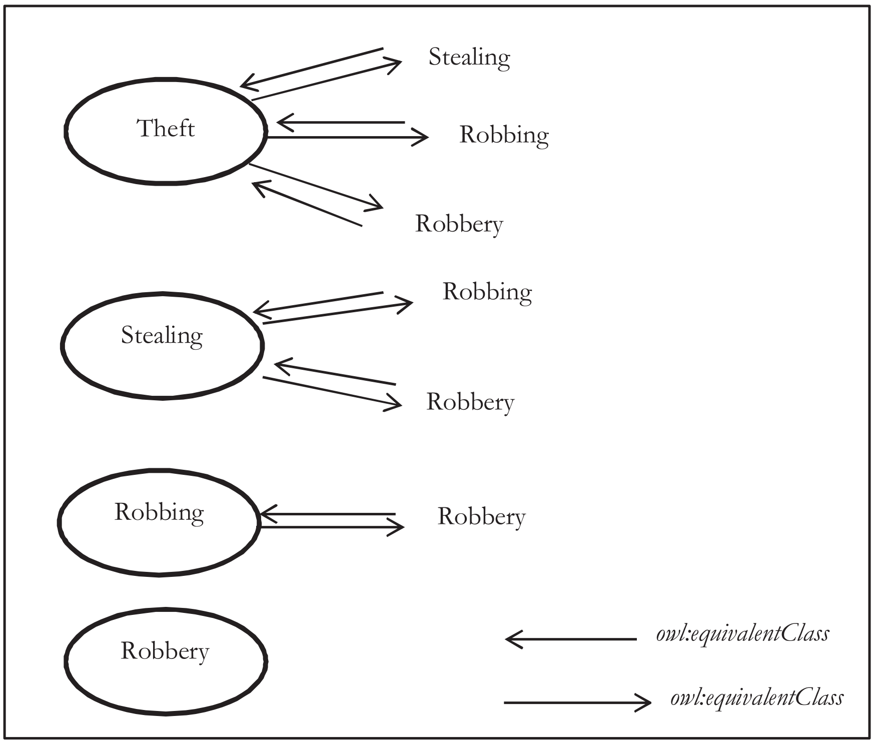


Figure 35 the possible combinatorics of four classes

4.2. Mapping tweets dataset into RDF triple statements

In order to execute some SPARQL queries against the collected tweet dataset; we have to map our tweets dataset into RDF triple statements and that is has been carried out according to the domain data model shown in Figure 15 and through utilization the pre-designed IAINM ontology . Illegal act, location and vehicle have been extracted from each tweet and relations have been created among them according to the pre-designed IAINM ontology. Each illegal act, that is to be mapped from the tweet, has been given a unique identifier that is called *"illegal_act id"* where id is incremental number starts from number 1 and increase by 1 for every new illegal act that is to be mapped from a tweet. The identified illegal act relates to the corresponding illegal act concept by RDF property *"rdf:type"*, i.e. each mapped illegal act is defined as instance of the corresponding illegal act class. Hence, the defined instance inherits the properties of the class it belongs to and thus each identified illegal act relates to class *"Location"* by the property *"Located_in"* and relates to class *"Vehicle"* via property *"Object"*. RDF property *"rdfs:comment"* has been utilized to define the full content of the tweet message when mapping each tweet to RDF triple statement.
For more illustration, let us consider the following example of mapping one tweet from our tweet dataset. In Figure 36, we see an ordinary tweet message that is mapped, according to the pre-designed IAINM ontology and domain data model, to the RDF triple statements that is depicted in Listing 24.

Figure 36 a tweet from our collected tweet dataset

```
<owl:Class rdf:about="http://www.TSMER.com/Ontology.owl#illegal_act1">
        <rdf:type rdf:resource="http://www.TSMER.com/Ontology.owl#Robbery"/>
        <TS:locatedIn rdf:resource="http://www.TSMER.com/overtown"/>
        <TS:Object rdf:resource="http://www.TSMER.com/Ontology.owl#car"/>
        <rdfs:comment>Alleged car involved in jewelry store robbery found: HIALEAH, Fla. -- A car
found in Miami's overtown neighborhood... http://dlvr.it/1xLTZy</rdfs:comment>
</owl:Class>
```

Listing 24 mapping the tweet in Figure 36 to RDF triple statements

The illegal act that is to be mapped from the above tweet, has given identifier *"illegal_act1"* and has been described with four triple statements that state the identified illegal act as a type of the class *"Robbery"* which is located in neighbourhood *"overtown"* and has an object *"car"* and the full text of the tweet has been mapped as a comment. Other tweets in our dataset have been mapped in the same way, with taking into consideration that triple *"object"* is not necessarily mapped for every tweet (as we have previously discussed in designing the domain data model in Section 3.3.1) either because it is simply not mentioned within the corresponding tweet or because the corresponding illegal act is from classes other than class *"Robbery"*.

4.2.1. Issues in mapping tweets dataset into RDF triple statements

There are several issues that have been detected, during the process of mapping the tweets to RDF triples, which have to be taken into consideration. Specifically if the process of mapping tweets to RDF triple statements is planned to be automated. The following handcrafted rules have been formed to deal with these issues:

1. If the city and neighbourhood occur in the same tweet, then the neighbourhood has the priority to be mapped to raise the level of detail.
2. If two types of illegal act occur in the same tweet, then the two illegal acts identified and mapped separately. For example, *"robbery"* and *"shooting"* are two types of illegal acts that have been detected within the tweet that is shown in Figure 37. The two types of illegal acts are going to be identified and described separately as depicted in Listing 25.
3. If a type of illegal act and one or more of its synonyms occur in the same tweet, then any one of them can be selected to represent the type of the illegal act since they all are equivalent to each other as we have discussed when implementing synonyms (see Section 3.3.3).

Figure 37 a tweet from our tweet dataset that includes two types of illegal acts

```
<owl:Class rdf:about="http://www.TSMER.com/Ontology.owl#illegal_act7">
        <rdf:type rdf:resource="http://www.TSMER.com/Ontology.owl#Robbery"/>
        <TS:locatedIn rdf:resource="http://www.TSMER.com/Ontology.owl#Little Haiti"/>
        <rdfs:comment>Woman shot in Little Haiti robbery; suspect in custody: A man accused of
shooting a woman in a Little Haiti robb... http://hrld.us/UsPQXS</rdfs:comment>
</owl:Class>

<owl:Class rdf:about="http://www.TSMER.com/Ontology.owl#illegal_act8">
        <rdf:type rdf:resource="http://www.TSMER.com/Ontology.owl#Shooting"/>
        <TS:locatedIn rdf:resource="http://www.TSMER.com/Ontology.owl#Little Haiti"/>
        <rdfs:comment>Woman shot in Little Haiti robbery; suspect in custody: A man accused of
shooting a woman in a Little Haiti robb... http://hrld.us/UsPQXS</rdfs:comment>
</owl:Class>
```

Listing 25 mapping the tweet in (Figure 37) to RDF triple statements

4.3. Storing IAINM ontology and the mapped tweet dataset in RDF triple stores

So far, we have IAINM ontology and the mapped tweets dataset serialized in two separated RDF/XML files. In order to execute SPARQL queries against the mapped tweets dataset with exploiting the conceptual structure of IAINM ontology, we have to store both files in RDF triple stores. We use "Virtuoso Open-Source Edition on Windows"[61] as our database server. Both RDF/XML files have been stored through "Quad Store Upload"[62] service that supports importing RDF files in almost any formats of RDF serialization. Both RDF/XML files have been stored locally in virtuoso named graph "http://localhost:8890/DAV".

[61] http://virtuoso.openlinksw.com/dataspace/dav/wiki/Main/VOSUsageWindows
[62] http://docs.openlinksw.com/virtuoso/htmlconductorbar.html#rdfadm

4.4. Formalizing and executing SPARQL queries against the mapped tweet dataset

As the IAINM ontology and the mapped dataset have been stored in RDF triple store, we are able to execute some SPARQL queries against mapped dataset.

4.4.1. Query 1: Retrieve all tweets relevant to (Robbery in Miami)

One natural question for a user can be: retrieve all tweets that are relevant to the topic **"Robberies that happen in Miami"**. SPARQL query can be formalized and executed against the mapped tweets dataset to answer this question with making use of formal structure of the concerning concepts in IAINM ontology as shown in Listing 26. In Listing 26, we have formalized a unified query that consists of eight queries: first one would retrieve the tweets, which are described as comments, that include illegal acts of type *"Robbery"* and located in *"Miami"*. Second query would retrieve tweets that include illegal acts of types of the equivalent classes (synonyms) of *"Robbery"* and located in *"Miami"*. Third and fourth queries are related to spatial analysis of the requested location, meaning that if the user requests to retrieve all the tweets about illegal acts happen in *"Miami"* city, it implies that he also requests the illegal acts that happen in places that are geographically contained by *"Miami"* city. These contained places are represented by *"neighbourhoods"* in our designed use case domain. Hence, third and fourth queries would retrieve all tweets that include illegal acts of type *"Robbery"* and located in one of the four neighbourhoods, and tweets that include illegal acts of types of the equivalent classes (synonyms) of *"Robbery"* and located in one of the four neighbourhoods respectively. The conceptual link that relates Robbery with its subclasses has been utilized in this query to also retrieve the tweets that are relevant to illegal acts of types that are subclasses of *"Robbery"*. Tweets that refer to subclasses of *"Robbery"* that occur in *"Miami"* or its neighbourhoods have been retrieved with the fifth and sixth queries respectively. Seventh and eighth queries would retrieve the tweets that refer to equivalent classes of the subclasses (i.e. the synonyms of the subclasses) that occur in *"Miami"* or its neighbourhoods respectively. By exploiting the conceptual links in the IAINM ontology and through using the only two keywords *"Robbery"* and *"Miami"*, we could retrieve all tweets about *"Robbery in Miami"* and revealing the relevant tweets to the same topic that do not necessarily include the same keywords as shown in Figure 38.

```
select ?illegal_act ?Tweet where {{?illegal_act rdf:type TS:Robbery. ?illegal_act TS:locatedIn
TS:Miami.?illegal_act rdfs:comment ?Tweet.} UNION {?synonyms owl:equivalentClass
TS:Robbery.?illegal_act rdf:type ?synonyms. ?illegal_act TS:locatedIn TS:Miami.?illegal_act
rdfs:comment ?Tweet.} UNION {TS:Miami TS:Has_Neighbourhoods
?Neighbourhoods.?illegal_act rdf:type TS:Robbery.?illegal_act TS:locatedIn
?Neighbourhoods. ?illegal_act rdfs:comment ?Tweet.} UNION {?synonyms
owl:equivalentClass TS:Robbery. ?illegal_act rdf:type ?synonyms.TS:Miami
TS:Has_Neighbourhoods ?Neighbourhoods. ?illegal_act TS:locatedIn ?Neighbourhoods.
   ?illegal_act rdfs:comment ?Tweet.} UNION {?subclasses rdfs:subClassOf TS:Robbery.
   ?illegal_act rdf:type ?subclasses.?illegal_act TS:locatedIn TS:Miami.
   ?illegal_act rdfs:comment ?Tweet.}UNION {?subclasses rdfs:subClassOf  TS:Robbery.
   ?illegal_act rdf:type ?subclasses.TS:Miami TS:Has_Neighbourhoods ?Neighbourhoods.
   ?illegal_act TS:locatedIn ?Neighbourhoods. ?illegal_act rdfs:comment ?Tweet.}UNION
{?subclasses rdfs:subClassOf  TS:Robbery.?synonyms owl:equivalentClass
?subclasses.?illegal_act rdf:type ?synonyms. ?illegal_act TS:locatedIn TS:Miami.?illegal_act
rdfs:comment ?Tweet.} UNION {?subclasses rdfs:subClassOf  TS:Robbery.?synonyms
owl:equivalentClass ?subclasses.?illegal_act rdf:type ?synonyms. TS:Miami
TS:Has_Neighbourhoods ?Neighbourhoods.?illegal_act TS:locatedIn
?Neighbourhoods.?illegal_act rdfs:comment ?Tweet.}}
```

Listing 26 Query 1: Retrieve all tweets relevant to (Robbery in Miami)

Google Translate | Quad Store Upload | http://loca...0&debug=on

localhost:8890/sparql?default-graph-uri=http%3A%2F%2Flocalhost%3A8890%2FDAV&query=select+%3Fillegal_act+%3FTweet+where+{{%3Fillegal_act+rdf%3Atyp

illegal_act	Tweet
http://www.TSMER.com/Ontology.owl#illegal_act5	Robbery In Reverse: Burglars back stolen car through front window of North Miami cell phone store (VIDEO) http://t.co/5EjFlfOY
http://www.TSMER.com/Ontology.owl#illegal_act6	Thieves steal copper from street lights http://t.co/7SlzuHLq #miami
http://www.TSMER.com/Ontology.owl#illegal_act9	Truck driver held after trailer found to be stolen: A Miami man is being held in Coffee County on a $506,000 bon... http://bit.ly/Rim6qK
http://www.TSMER.com/Ontology.owl#illegal_act10	Police looking for van stolen from Miami Beach pharmacy: http://t.co/kvkD9ON9
http://www.TSMER.com/Ontology.owl#illegal_act11	STOLEN BIKE ALERT - Two very nice bikes stolen outside @TheVagabondMIA after Miami Critical Mass!
http://www.TSMER.com/Ontology.owl#illegal_act12	Industrial equipment stolen from van in Miami Lakes: A thief stole a Nikon camera with accessories and a laptop ..
http://www.TSMER.com/Ontology.owl#illegal_act14	Miami Herald- Bicycle stolen from Junior Seau's garage recovered http://t.co/BS2oWxov
http://www.TSMER.com/Ontology.owl#illegal_act15	MElderly woman robbed, bruised in Miami Shores: A motorcycle was stolen from the 3500 block of Main Highway Oct. ..
http://www.TSMER.com/Ontology.owl#illegal_act17	Related to alleged Celtics bus theft in Miami on 4/10, as reported by Yahoo, police and security sources tell AP that no reports were filed.
http://www.TSMER.com/Ontology.owl#illegal_act22	Police: Tampa teller, man conspire to rob bank http://dlvr.it/2pS717 #miami
http://www.TSMER.com/Ontology.owl#illegal_act25	Crooks ram van into boutique, steal merchandise: MIAMI -- Police are searching for the thieves who used a stolen van..
http://www.TSMER.com/Ontology.owl#illegal_act26	STOLEN BIKE ALERT silver Giant Rincon MTB taken from inside a van in driveway of residence in North Miami http://t.co/JNRW7Eo
http://www.TSMER.com/Ontology.owl#illegal_act27	STOLEN BIKE ALERT silver Giant Rincon MTB taken from inside a van in driveway of residence in North Miami http://t.co/JNRW7Eo
http://www.TSMER.com/Ontology.owl#illegal_act28	Musician's Van Stolen From Coral Gables Gas Station - NBC 6 Miami http://t.co/Eqhv15SA #florida
http://www.TSMER.com/Ontology.owl#illegal_act29	Cold theft: Jaxsons ice cream truck stolen http://t.co/301hgocL #miami
http://www.TSMER.com/Ontology.owl#illegal_act7	Woman shot in Little Haiti robbery; suspect in custody: A man accused of shooting a woman in a Little Haiti robb... http://hrld.us/UsPQXS
http://www.TSMER.com/Ontology.owl#illegal_act3	7Skyforce is over the scene of a bank robbery in Downtown Miami. Watch live coverage: http://www.wsvn.com/skyforce/
http://www.TSMER.com/Ontology.owl#illegal_act1	Alleged car involved in jewelry store robbery found: HIALEAH, Fla. -- A car found in Miami's overtown neighborhood... http://dlvr.it/1xLTZy
http://www.TSMER.com/Ontology.owl#illegal_act2	Jason, a career criminal with four convictions for armed robbery, in the back of a police car in Liberty City http://tmblr.co/Zi4fgxZNoKwZ
http://www.TSMER.com/Ontology.owl#illegal_act13	Bicycle stolen from female cyclist at gunpoint tonight in Little Haiti (Miami) 53cm Bianchi Via Brera http://t.co/KzogupyU
http://www.TSMER.com/Ontology.owl#illegal_act4	Stolen Bike Alert - black Cervelo P2 red Jamis Ventura Comp (Downtown Miami) http://t.co/jAxdBzZX#bikemia #triathlon
http://www.TSMER.com/Ontology.owl#illegal_act16	Two bicycles stolen from an apartment at Vizcayne (244 Biscayne Blvd) in downtown Miami earlier this week. A..
http://www.TSMER.com/Ontology.owl#illegal_act19	#OverTown Churches got bars over the window cuz the bums stole the benches had the pple sittin Indian style Sunday mornin
http://www.TSMER.com/Ontology.owl#illegal_act30	OVERTOWN! LOL RT @SLAMonline SLAMonline.com: Boston Celtics Bus Was Robbed in Miami Last Month http://bit.ly/mR53XV #SLAMnewswire #NBA
http://www.TSMER.com/Ontology.owl#illegal_act20	Man robs members at Liberty City church: Miami Police are searching for a man who robbed ch.. http://bit.ly/6zLjT http://bit.ly/105Fmv
http://www.TSMER.com/Ontology.owl#illegal_act23	A firefighter was robbed and shot at while checking a fire hydrant in Liberty City, Miami. Thankfully, he was not... http://fb.me/Q0sapAxd
http://www.TSMER.com/Ontology.owl#illegal_act18	Police search for attempted carjacking thieves http://t.co/UTW65rJ4 #miami
http://www.TSMER.com/Ontology.owl#illegal_act21	Miami Girl Safe After Taking Ride With Carjacker: A little girl is back in the arms of her parents after a carjack... http://bit.ly/9pzCrA
http://www.TSMER.com/Ontology.owl#illegal_act21	Miami Girl Safe After Taking Ride With Carjacker: A little girl is back in the arms of her parents after a carjack... http://bit.ly/9pzCrA
http://www.TSMER.com/Ontology.owl#illegal_act18	Police search for attempted carjacking thieves http://t.co/UTW65rJ4 #miami

Figure 38 the result of Query 1

4.4.2. Query 2: Retrieve all tweets relevant to (Carjacking in Downtown Miami)

Executing this query with only making use of the equivalent classes to class *"Carjacking"*, as shown in Listing 27, would retrieve an empty set as seen in Figure 39. However we can provide the user with useful suggestion that is built upon his original request. This suggestion can be a query to retrieve all tweets that is relevant to *"Carjacking"* but in a higher administrative level that contains neighbourhood *"Downtown Miami"* as well as the other neighbourhoods that are contained by the same administrative level. The suggested query is depicted in Listing 28 which retrieves two tweets that are relevant to the topic as shown in Figure 40.

```
select ?illegal_act ?Tweet where {{?illegal_act rdf:type TS:Carjacking.
?illegal_act TS:locatedIn <http://www.TSMER.com/Downtown_Miami>.
?illegal_act rdfs:comment ?Tweet.} UNION
{?synonyms owl:equivalentClass TS:Carjacking.
?illegal_act rdf:type ?synonyms.
?illegal_act TS:locatedIn <http://www.TSMER.com/Downtown_Miami>.
?illegal_act rdfs:comment ?Tweet.}}
```

Listing 27 Query 2: Retrieve all tweets relevant to (Carjacking in Downtown Miami) with making use of equivalent classes to class *"Carjacking"*

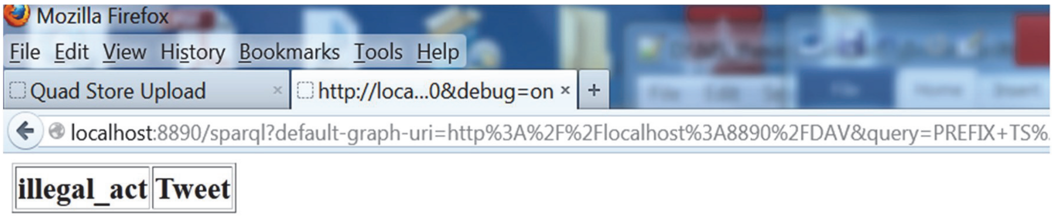
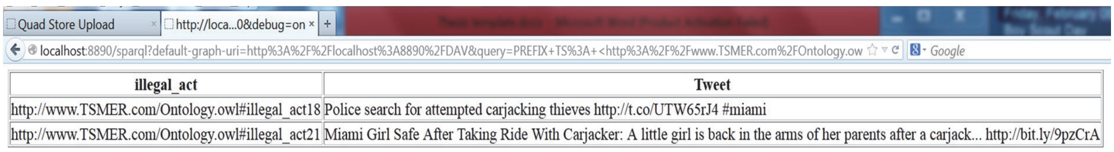


Figure 39 the result of Query 2

```
select ?illegal_act ?Tweet where {{?illegal_act rdf:type TS:Carjacking.
<http://www.TSMER.com/Downtown_Miami> TS:Neighbourhoods_of ?City.
?illegal_act TS:locatedIn ?City.
?illegal_act rdfs:comment ?Tweet.} UNION
{?synonyms owl:equivalentClass TS:Carjacking.
?illegal_act rdf:type ?synonyms.
<http://www.TSMER.com/Downtown_Miami> TS:Neighbourhoods_of ?City.
?illegal_act TS:locatedIn ?City.
?illegal_act rdfs:comment ?Tweet.} UNION
{ <http://www.TSMER.com/Downtown_Miami> TS:Neighbourhoods_of ?City.
?City TS:Has_Neighbourhoods ?Neighbourhoods.
?illegal_act rdf:type TS:Carjacking.
?illegal_act TS:locatedIn ?Neighbourhoods.
?illegal_act rdfs:comment ?Tweet.} UNION
{ <http://www.TSMER.com/Downtown_Miami> TS:Neighbourhoods_of ?City.
?City TS:Has_Neighbourhoods ?Neighbourhoods.
?synonyms owl:equivalentClass TS:Carjacking.
?illegal_act rdf:type ?synonyms.
?illegal_act TS:locatedIn ?Neighbourhoods.
?illegal_act rdfs:comment ?Tweet.}}
```

Listing 28 suggested query that is built upon Query 2



illegal_act	Tweet
http://www.TSMER.com/Ontology.owl#illegal_act18	Police search for attempted carjacking thieves http://t.co/UTW65rJ4 #miami
http://www.TSMER.com/Ontology.owl#illegal_act21	Miami Girl Safe After Taking Ride With Carjacker: A little girl is back in the arms of her parents after a carjack... http://bit.ly/9pzCrA

Figure 40 the result of suggested query in Listing 28

It is important to note that suggested query in Listing 28 does not refer directly to instance *"Miami"* or the neighbourhoods, however it utilizes the conceptual linking (class and properties) in IAINM ontology to retrieve tweets that are relevant to **"Carjacking in Miami"**.

4.4.3. Query 3: Retrieve all tweets relevant to (Stolen Car in Overtown)

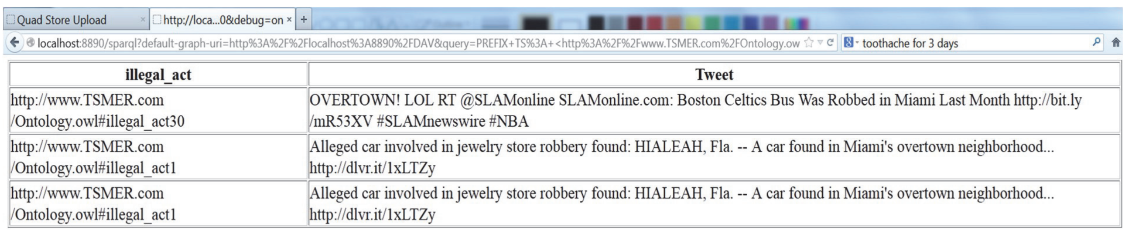
If we execute this query straightforward without making use of the conceptual linking in IAINM ontology as shown in Listing 29; we would retrieve empty set, as shown in Figure 39; since not a single mapped tweet includes the combination of these keywords. However, with utilizing the conceptual linking of classes *"Stolen"* and *"Car"* we would suggest a query to retrieve all tweets that are relevant to **"Stolen Vehicle in Overtown"** as seen in Listing 30. Suggested Query in Listing 30 makes use of property *"rdfs:subClassOf"* to expand the query to include vehicles other than car, and property *"owl:equivalentClass"* to include the classes that are equivalent to class *"Stolen"*, i.e. the synonyms of *"Stolen"*. The result of the suggested query that is built upon original query 3 is depicted in Figure 41. Clearly, illegal act1 has been retrieved twice and that is because class *"Car"* in IAINM ontology is subclass of two classes: class *"Vehicle"* and class *"Automobile"* in Vehicle Sales Ontology as we have discusses in Section 3.3 and thus illegal act1, which has object *"Car"*; will be retrieved twice. This can be solved with SPARQL filtering keyword *Distinct* as shown in Listing 31 to prevent duplicate answers in the result as seen in Figure 42.

```
select ?illegal_act ?Tweet where {
?illegal_act rdf:type TS:Stolen.
?illegal_act TS:locatedIn <http://www.TSMER.com/overtown>.
?illegal_act TS:Object TS:car.
?illegal_act rdfs:comment ?Tweet.}
```

Listing 29 Query 3: Retrieve all tweets relevant to (Stolen Car in Overtown) without making use of the conceptual linking in IAINM ontology

```
select ?illegal_act ?Tweet where
{ {?illegal_act rdf:type TS:Stolen.
?illegal_act TS:locatedIn <http://www.TSMER.com/overtown>.
TS:car rdfs:subClassOf ?Vehicle.
?vehicle rdfs:subClassOf ?Vehicle.
?illegal_act TS:Object ?vehicle.
?illegal_act rdfs:comment ?Tweet.}
UNION {TS:Stolen owl:equivalentClass ?synonyms.
TS:car rdfs:subClassOf ?Vehicle.
?vehicle rdfs:subClassOf ?Vehicle.
?illegal_act rdf:type ?synonyms.
?illegal_act TS:locatedIn <http://www.TSMER.com/overtown>.
?illegal_act TS:Object ?vehicle.
?illegal_act rdfs:comment ?Tweet.} }
```

Listing 30 suggested query to retrieve tweets that are relevant to (Stolen Vehicle in Overtown) with making use of the conceptual linking in IAINM ontology

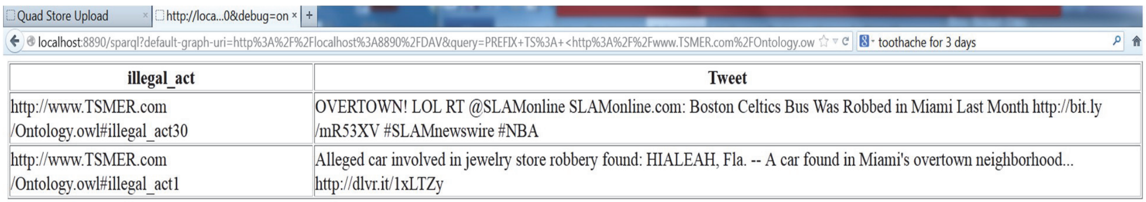


illegal_act	Tweet
http://www.TSMER.com /Ontology.owl#illegal_act30	OVERTOWN! LOL RT @SLAMonline SLAMonline.com: Boston Celtics Bus Was Robbed in Miami Last Month http://bit.ly /mR53XV #SLAMnewswire #NBA
http://www.TSMER.com /Ontology.owl#illegal_act1	Alleged car involved in jewelry store robbery found: HIALEAH, Fla. -- A car found in Miami's overtown neighborhood... http://dlvr.it/1xLTZy
http://www.TSMER.com /Ontology.owl#illegal_act1	Alleged car involved in jewelry store robbery found: HIALEAH, Fla. -- A car found in Miami's overtown neighborhood... http://dlvr.it/1xLTZy

Figure 41 the result of suggested query in Listing 30

```
select Distinct ?illegal_act ?Tweet where { {?illegal_act rdf:type TS:Stolen.
?illegal_act TS:locatedIn <http://www.TSMER.com/overtown>.
TS:car rdfs:subClassOf ?Vehicle.
?vehicle rdfs:subClassOf ?Vehicle.
?illegal_act TS:Object ?vehicle.
?illegal_act rdfs:comment ?Tweet.} UNION
{TS:Stolen owl:equivalentClass ?synonyms.
TS:car rdfs:subClassOf ?Vehicle.
?vehicle rdfs:subClassOf ?Vehicle.
?illegal_act rdf:type ?synonyms.
?illegal_act TS:locatedIn <http://www.TSMER.com/overtown>.
?illegal_act TS:Object ?vehicle.
?illegal_act rdfs:comment ?Tweet.}}
```

Listing 31 using SPARQL filtering keyword *Distinct* with suggested query in Listing 30



illegal_act	Tweet
http://www.TSMER.com /Ontology.owl#illegal_act30	OVERTOWN! LOL RT @SLAMonline SLAMonline.com: Boston Celtics Bus Was Robbed in Miami Last Month http://bit.ly /mR53XV #SLAMnewswire #NBA
http://www.TSMER.com /Ontology.owl#illegal_act1	Alleged car involved in jewelry store robbery found: HIALEAH, Fla. -- A car found in Miami's overtown neighborhood... http://dlvr.it/1xLTZy

Figure 42 the result of the query in Listing 31

4.4.4. Query 4: Retrieve all tweets relevant to (Gunfire in Miami)

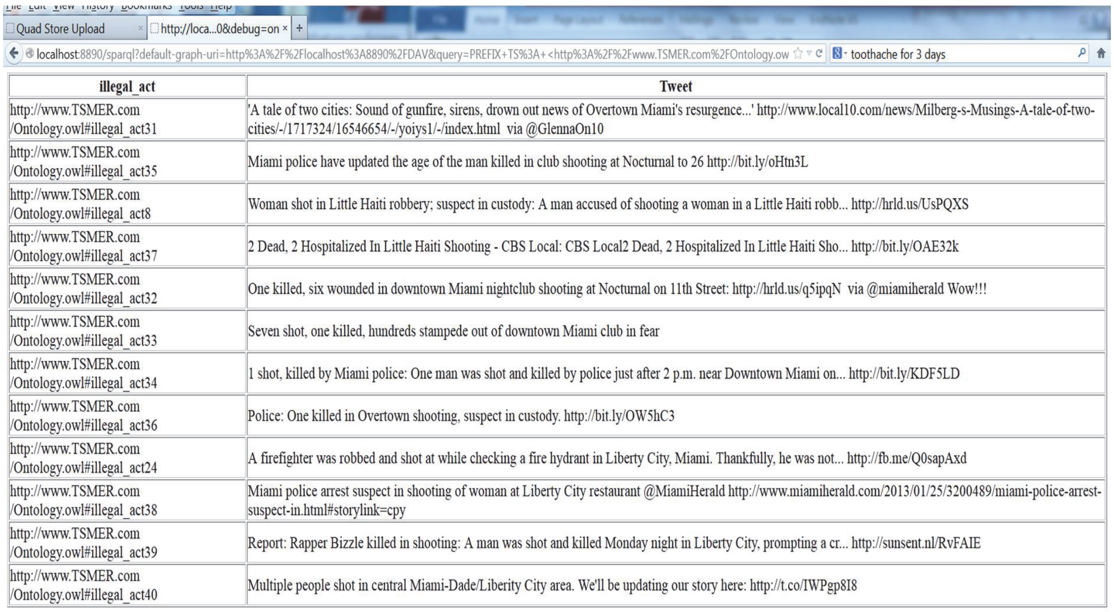
For more clarification for the importance of the conceptual linking in revealing relevant tweets; we would firstly formalize a query depending on the mentioned keywords in the original request which are basically refer to class *"Gunfire"* and instance *"Miami"* as shown in Listing 32. This query results an empty set as seen in Figure 39. Let us make use of the conceptual linking of *"Gunfire"* and *"Miami"* in IAINM ontology to raise the resolution of the query to include classes that are equivalent to *"Gunfire"* in locations of lower administrative level in Miami. With exploiting what mentioned conceptual links we could formalized a modified query that is built upon the original request as seen in Listing 33 of which the result reveals tweets that are relevant to the same topic as shown in Figure 43.

```
select ?illegal_act ?Tweet where
{?illegal_act rdf:type TS:Gunfire.
?illegal_act TS:locatedIn TS:Miami.
?illegal_act rdfs:comment ?Tweet.}
```

Listing 32 Query 4: Retrieve all tweets relevant to (Gunfire in Miami), depending only on the mentioned keywords in the original request

```
select ?illegal_act ?Tweet where { {?illegal_act rdf:type TS:Gunfire.
?illegal_act TS:locatedIn TS:Miami.
?illegal_act rdfs:comment ?Tweet.} UNION
{?illegal_act rdf:type TS:Gunfire.
TS:Miami TS:Has_Neighbourhoods ?Neighbourhoods.
?illegal_act TS:locatedIn ?Neighbourhoods.
?illegal_act rdfs:comment ?Tweet.} UNION
{TS:Gunfire owl:equivalentClass ?synonyms.
?illegal_act rdf:type ?synonyms.
?illegal_act TS:locatedIn TS:Miami.
?illegal_act rdfs:comment ?Tweet.} UNION
{TS:Gunfire owl:equivalentClass ?synonyms.
TS:Miami TS:Has_Neighbourhoods ?Neighbourhoods.
?illegal_act rdf:type ?synonyms.
?illegal_act TS:locatedIn ?Neighbourhoods.
?illegal_act rdfs:comment ?Tweet.}}
```

Listing 33 Query 4: Retrieve all tweets relevant to (Gunfire in Miami), depending on the mentioned keywords in the original request as well as the conceptual linking in IAINM ontology



illegal_act	Tweet
http://www.TSMER.com /Ontology.owl#illegal_act31	'A tale of two cities: Sound of gunfire, sirens, drown out news of Overtown Miami's resurgence...' http://www.local10.com/news/Milberg-s-Musings-A-tale-of-two-cities/-/1717324/16546654/-/yoiys1/-/index.html via @GlennaOn10
http://www.TSMER.com /Ontology.owl#illegal_act35	Miami police have updated the age of the man killed in club shooting at Nocturnal to 26 http://bit.ly/oHtn3L
http://www.TSMER.com /Ontology.owl#illegal_act8	Woman shot in Little Haiti robbery; suspect in custody: A man accused of shooting a woman in a Little Haiti robb... http://hrld.us/UsPQXS
http://www.TSMER.com /Ontology.owl#illegal_act37	2 Dead, 2 Hospitalized In Little Haiti Shooting - CBS Local: CBS Local2 Dead, 2 Hospitalized In Little Haiti Sho... http://bit.ly/OAE32k
http://www.TSMER.com /Ontology.owl#illegal_act32	One killed, six wounded in downtown Miami nightclub shooting at Nocturnal on 11th Street: http://hrld.us/q5ipqN via @miamiherald Wow!!!
http://www.TSMER.com /Ontology.owl#illegal_act33	Seven shot, one killed, hundreds stampede out of downtown Miami club in fear
http://www.TSMER.com /Ontology.owl#illegal_act34	1 shot, killed by Miami police: One man was shot and killed by police just after 2 p.m. near Downtown Miami on... http://bit.ly/KDF5LD
http://www.TSMER.com /Ontology.owl#illegal_act36	Police: One killed in Overtown shooting, suspect in custody. http://bit.ly/OW5hC3
http://www.TSMER.com /Ontology.owl#illegal_act24	A firefighter was robbed and shot at while checking a fire hydrant in Liberty City, Miami. Thankfully, he was not... http://fb.me/Q0sapAxd
http://www.TSMER.com /Ontology.owl#illegal_act38	Miami police arrest suspect in shooting of woman at Liberty City restaurant @MiamiHerald http://www.miamiherald.com/2013/01/25/3200489/miami-police-arrest-suspect-in.html#storylink=cpy
http://www.TSMER.com /Ontology.owl#illegal_act39	Report: Rapper Bizzle killed in shooting: A man was shot and killed Monday night in Liberty City, prompting a cr... http://sunsent.nl/RvFAIE
http://www.TSMER.com /Ontology.owl#illegal_act40	Multiple people shot in central Miami-Dade/Liberty City area. We'll be updating our story here: http://t.co/IWPgp8I8

Figure 43 the result of the query in Listing 33

4.4.5. Query 5: Retrieve all tweets relevant to (Shooting in Downtown Miami) and provide me with information regarding a hospital near by the mentioned neighbourhood

The answer for the first part of this query is coming from our mapped tweet dataset. However this is not the case for the second part of the query. The answer for the second part of query would come from an external geospatial dataset which is Geonames in this case. One query can be formalized to answer the two part of the query and fetch the required information from the two datasets, through utilizing property "*owl:sameAs*" that we have used to assign alias for city *"Miami"* and the neighbourhoods in other datasets. In the first part of the query that is shown in Listing 34, we retrieve the tweets that are relevant to the illegal act *"Shooting"* and its equivalent classes that occur in neighbourhood *"Downtown Miami"* and in the last part of the query we used Geonames properties *"gn:nearby"* and *"gn:featureCode"* to request the feature that is near *"Downtown Miami"* and has a code *"S.HSP"*, i.e. it is a hospital.
The result for this query is shown in Figure 44 where the relevant tweets to the topic of interest are retrieved from the mapped tweet dataset and also the Geonames feature that fulfils the mentioned conditions which is represented by URI *"http://sws.geonames.org/4164172/"*. As seen in Listing 34; neighbourhood *"Downtown Miami"* is the connection that links the first part of the query with the last part to answer both requests in one go.

```
select ?illegal_act ?Tweet ?nearbyFeatures where{
{?illegal_act rdf:type TS:Shooting.
?illegal_act TS:locatedIn <http://www.TSMER.com/Downtown_Miami>.
?illegal_act rdfs:comment ?Tweet.}
UNION
{TS:Shooting owl:equivalentClass ?synonyms.
?illegal_act rdf:type ?synonyms.
?illegal_act TS:locatedIn <http://www.TSMER.com/Downtown_Miami>.
?illegal_act rdfs:comment ?Tweet.}
UNION
{<http://www.TSMER.com/Downtown_Miami> owl:sameAs ?alias.
?nearbyFeatures gn:nearby ?alias.
?nearbyFeatures gn:featureCode gn:S.HSP.}}
```

Listing 34 Query 5

illegal_act	Tweet	nearbyFeatures
http://www.TSMER.com/Ontology.owl#illegal_act32	One killed, six wounded in downtown Miami nightclub shooting at Nocturnal on 11th Street: http://hrld.us/q5ipqN via @miamiherald Wow!!!	
http://www.TSMER.com/Ontology.owl#illegal_act33	Seven shot, one killed, hundreds stampede out of downtown Miami club in fear	
http://www.TSMER.com/Ontology.owl#illegal_act34	1 shot, killed by Miami police: One man was shot and killed by police just after 2 p.m. near Downtown Miami on... http://bit.ly/KDF5LD	
		http://sws.geonames.org/4164172/

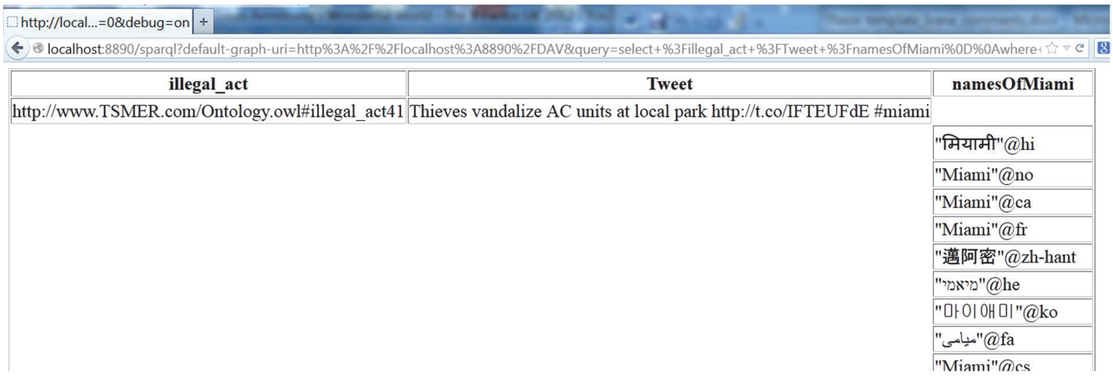
Figure 44 the result of Query 5

4.4.6. Query 6: Retrieve all tweets relevant to (Vandalize in Miami) and provide me with names of the mentioned location in different languages.

Like query 5, query 6 is fetching the requested data from two different dataset: one of them is the mapped tweets dataset and the other is Freebase dataset. Listing 35 shows the query 6 and the result is depicted in Figure 45.

```
select ?illegal_act ?Tweet ?namesOfMiami where {
{?illegal_act rdf:type TS:Vandalize.
?illegal_act TS:locatedIn TS:Miami.
?illegal_act rdfs:comment ?Tweet.}
UNION
 {TS:Miami owl:sameAs ?alias.
?alias fb:type.object.name ?namesOfMiami.}}
```

Listing 35 Query 6



http://local...=0&debug=on
localhost:8890/sparql?default-graph-uri=http%3A%2F%2Flocalhost%3A8890%2FDAV&query=select+%3Fillegal_act+%3FTweet+%3FnamesOfMiami%0D%0Awhere

illegal_act	Tweet	namesOfMiami
http://www.TSMER.com/Ontology.owl#illegal_act41	Thieves vandalize AC units at local park http://t.co/IFTEUFdE #miami	
		"मियामी"@hi
		"Miami"@no
		"Miami"@ca
		"Miami"@fr
		"邁阿密"@zh-hant
		"מיאמי"@he
		"마이애미"@ko
		"میامی"@fa
		"Miami"@cs

Figure 45 the result of Query 6

4.4.7. Query 7: Retrieve all tweets relevant to (any type of illegal acts in Little Haiti)

In this query, all tweets of any type of illegal act would be retrieved provided that they are linked through the location *"Little Haiti"*. In Listing 36; we assign location *"Little Haiti"* as the only condition to filter the retrieved tweets. The result of this query, as seen in Figure 46 contains the tweets of different illegal acts that occur in neighbourhoods *"Little Haiti"*.

```
select ?illegal_act ?Tweet
where
{?illegal_act TS:locatedIn <http://www.TSMER.com/Little_Haiti>.
?illegal_act rdfs:comment ?Tweet.}
```

Listing 36 Query 7

illegal_act	Tweet
http://www.TSMER.com/Ontology.owl#illegal_act7	Woman shot in Little Haiti robbery; suspect in custody: A man accused of shooting a woman in a Little Haiti robb... http://hrld.us/UsPQXS
http://www.TSMER.com/Ontology.owl#illegal_act8	Woman shot in Little Haiti robbery; suspect in custody: A man accused of shooting a woman in a Little Haiti robb... http://hrld.us/UsPQXS
http://www.TSMER.com/Ontology.owl#illegal_act13	Bicycle stolen from female cyclist at gunpoint tonight in Little Haiti (Miami) 53cm Bianchi Via Brera http://t.co/KzogupyU
http://www.TSMER.com/Ontology.owl#illegal_act37	2 Dead, 2 Hospitalized In Little Haiti Shooting - CBS Local: CBS Local2 Dead, 2 Hospitalized In Little Haiti Sho... http://bit.ly/OAE32k

Figure 46 the result of Query 7

As shown in the result in Figure 46, illegal_act7 and illegal_act8 refer to the same tweet and both of them have been retrieved because they are identified as two different illegal acts. One of them is type of illegal act *"Robbery"* and the other is type of illegal act *"Shooting"*.

4.4.8. Query 8: Retrieve all tweets relevant to (Bike Robbery acts in Miami)

This query can be thought of as the reverse of the Query 7, meaning that all tweets that are relevant to one type of illegal act which is *"Robbery"* and has one type of object which is *"Bike"* would be retrieved regardless the location in which they occur, meaning that there is no need to specify the location in the query since Miami and its four neighbourhoods is the assigned geographic extent in this research. In Listing 37, we utilize conceptual links in the query to include equivalent classes of illegal act *"Robbery"* and object *"Bike"* and the possible combination between them. The result of this query can be seen in Figure 47.

```
select ?illegal_act ?Tweet  where {{?illegal_act rdf:type TS:Robbery.
?illegal_act TS:Object TS:bike.
?illegal_act rdfs:comment ?Tweet.} UNION
{TS:bike owl:equivalentClass ?bike_Syno.
?illegal_act rdf:type TS:Robbery.
?illegal_act TS:Object ?bike_Syno.
?illegal_act rdfs:comment ?Tweet.} UNION
{TS:Robbery owl:equivalentClass ?synonyms.
?illegal_act rdf:type ?synonyms.
?illegal_act TS:Object TS:bike.
?illegal_act rdfs:comment ?Tweet.} UNION
{TS:Robbery owl:equivalentClass ?synonyms.
TS:bike owl:equivalentClass ?bike_Syno.
?illegal_act rdf:type ?synonyms.
?illegal_act TS:Object ?bike_Syno.
?illegal_act rdfs:comment ?Tweet.}}
```

Listing 37 Query 8

illegal_act	Tweet
http://www.TSMER.com/Ontology.owl#illegal_act4	Stolen Bike Alert - black Cervelo P2 red Jamis Ventura Comp (Downtown Miami) http://t.co/jAxdBzZX#bikemia #triathlon
http://www.TSMER.com/Ontology.owl#illegal_act11	STOLEN BIKE ALERT - Two very nice bikes stolen outside @TheVagabondMIA after Miami Critical Mass!
http://www.TSMER.com/Ontology.owl#illegal_act26	STOLEN BIKE ALERT silver Giant Rincon MTB taken from inside a van in driveway of residence in North Miami http://t.co/JNRW7Eo
http://www.TSMER.com/Ontology.owl#illegal_act13	Bicycle stolen from female cyclist at gunpoint tonight in Little Haiti (Miami) 53cm Bianchi Via Brera http://t.co/KzogupyU
http://www.TSMER.com/Ontology.owl#illegal_act14	Miami Herald- Bicycle stolen from Junior Seau's garage recovered http://t.co/BS2oWxov
http://www.TSMER.com/Ontology.owl#illegal_act16	Two bicycles stolen from an apartment at Vizcayne (244 Biscayne Blvd) in downtown Miami earlier this week. A..

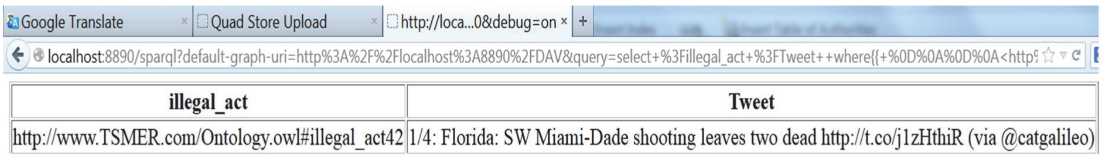
Figure 47 result o Query 8

4.4.9. Query 9: Utilizing conceptual links to Geonames in suggested query that is built upon a query of retrieving all tweets relevant to (Gunfire acts in Downtown Miami)

This query is one example of how conceptual links to Geonames can be utilized in discovering tweets that are relevant to (Gunfire acts in Downtown Miami). In this query we focus only on using the conceptual links to Geonames since the conceptual links within the IAINM namespace have been have been utilized in the most of the previous queries. Query 9 as shown in Listing 38 has exploited the identity link of neighbourhood *"Downtown_Miami"* to Geonames in order to discover relevant tweets that occur in a higher administrative level that contains neighbourhood *"Downtown Miami"* in Geonames. Figure 48 shows the result of this query where a tweet about illegal act of type *"Gunfire"* has been retrieved, even though it refer to a geographic instance that is not defined in our IAINM ontology which is *"Miami-Dade"*.

```
select ?illegal_act ?Tweet  where{{
<http://www.TSMER.com/Downtown_Miami> owl:sameAs ?alias.
?alias gn:parentFeature ?parent.
?illegal_act rdf:type TS:Gunfire.
?illegal_act TS:locatedIn ?parent.
?illegal_act rdfs:comment ?Tweet.} UNION
{ <http://www.TSMER.com/Downtown_Miami> owl:sameAs ?alias.
?alias gn:parentFeature ?parent.
TS:Gunfire owl:equivalentClass ?synonyms.
?illegal_act rdf:type ?synonyms.
?illegal_act TS:locatedIn ?parent.
?illegal_act rdfs:comment ?Tweet.}}
```

Listing 38 Query 9



illegal_act	Tweet
http://www.TSMER.com/Ontology.owl#illegal_act42	1/4: Florida: SW Miami-Dade shooting leaves two dead http://t.co/j1zHthiR (via @catgalileo)

Figure 48 the result of Query 9

4.5. Mock-up visualization

Figure 49 shows a mock-up visualization of our information system. As seen in Figure 49, the interactive map is supposed to show the locations of city "Miami" and the four selected neighbourhoods (the blue marks has placed manually) and there are three sections in this mock-up. Two of them represent the main concepts in our domain data model. The first section represents the concept "Location" and its instances "Miami" and the four neighbourhoods in a hierarchal style that represents their relationships in IAINM ontology. The second section represents the concept "Illegal act" with its three subclasses and the subclasses of the subclasses that are shown also in a hierarchal style that represent their relationships in the IAINM ontology. The third section is reserved for displaying the tweets. the user can choose the location and the type of the illegal act that he/she wants to retrieve the relevant tweets about. In case user just click on the city "Miami" or one on the four neighbourhoods in the interactive map, the system would retrieve all tweets that refer to the chosen location regardless of the type of the illegal act. in case user choose the upper class of any type of illegal act, the system would automatically include the subclasses of the chosen type of illegal act but not the vice versa, meaning that if the user choose a subclass of any type of the illegal act, the system will not include the upper class in retrieving process. However, suggested queries can be formed based on the original choice of the user like for example the higher administrative level of the chosen location. In case user select a type of illegal act without selecting the location, the system would retrieve the tweets that refer to the selected type of illegal act regardless the location.

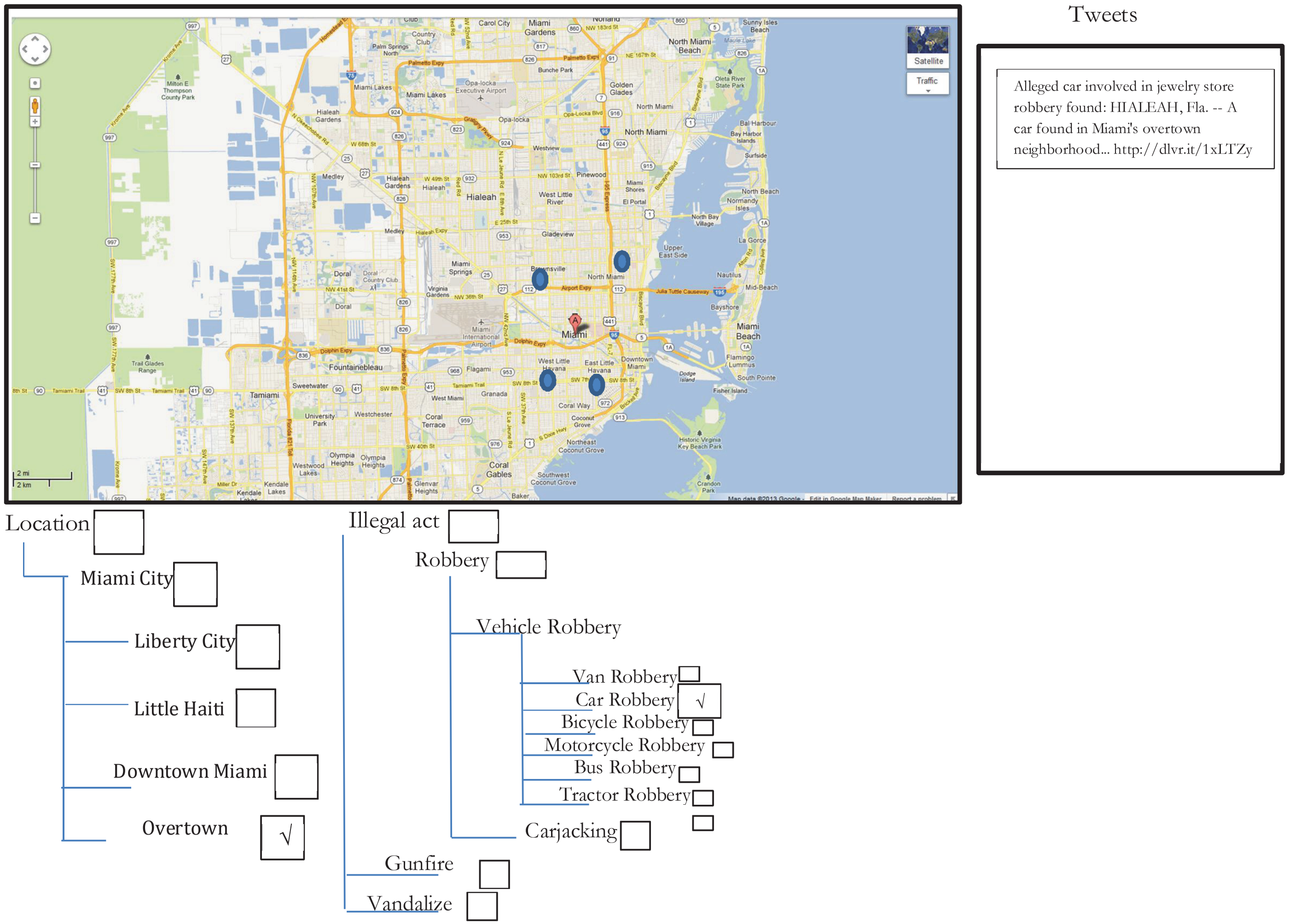


Figure 49 the mock-up visualization

4.6. Ranking issue

The goal of this process is to give a high ranking for those tweets that are more relevant to the topic of interest. In last paragraph of section 0 we have pointed out to extracted set of vocabularies that is called *"ranking set"* which is a set of vocabularies that are extracted from the tweets dataset to increase the ranking for the relevant tweets. For more clarification for this point, let us consider the following tweet: *"Justin Bieber. While* ***shooting*** *in* ***Miami****, Florida on new 3D movie documentary http://t.co/GleE32Hn"*. Although two components of our IAINM ontology has been detected within the mentioned tweet which are: class *"Shooting"* and instance *"Miami"*, but the tweet itself is considered to be not relevant according to the domain of interest in our designed ontology which is *" illegal acts"*. The *"ranking set"* is utilized to higher the rank of the tweets that considered to be relevant in our domain of interest. Vocabularies in the *"ranking set"* are not the same for the three main categories of illegal act. *"Robbery"*, *"Gunfire"* and *"Vandalize"* have different filtering set as shown in Table 5. Vocabularies in the three ranking sets would be the entries of a keyword based filtering process to arrange the ranking of the retrieved tweets to put the tweets that are considered to be more relevant in a higher ranking than the other tweets. The keyword based filtering process is working according to the following equation[63]:

RT = ∑count FV (n), where RT stands for ranking a tweet and FV (n) stands for the vocabularies in the corresponding ranking set. The equation above specify a rank value for the intended tweet depending on the summation of the occurrence of the vocabularies of the corresponding ranking list within this tweet. For more explanation, let us consider the previous example of the tweet that says: *"Justin Bieber. While shooting in Miami, Florida on new 3D movie documentary http://t.co/GleE32Hn"* and the following tweet: *"2 dead, 2 injured in Miami shooting. Read more: http://t.co/Fxx6pFX8 or mobile friendly: http://t.co/1ZzXfvWL"*. Both previous tweets include the illegal act *"Shooting"*, which is an equivalent to illegal act *"Robbery"*, and the instance *"Miami"*; however not both tweets are in the context of the domain of interest of the pre-designed IAINM ontology.

Through utilizing the mentioned equation we would rank the first and second tweets respectively as following:

RT1= count Police + count Gunpoint + count Killing + count Gunman + count Gunmen+ count Killed + count Stray_bullet + count Armed + count Killed + count Victim + count Wounded + count Injured = 0

RT2= count Police + count Gunpoint + count Killing + count Gunman + count Gunmen+ count Killed + count Stray_bullet + count Armed + count Killed + count Victim + count Wounded + count Injured = 1

As seen above, the rank for the second tweet is higher than the first tweet since a ranking vocabulary *"Injured"* has occurred one time in the second tweet. Hence, second tweet will have a higher rank than the first tweet in the retrieved result. It is essential to mention that ranking process will take place after and not before implementing the proper SPARQL query against the tweet dataset.

Filtering set for "Robbery"	Filtering set for "Gunfire"	Filtering set for "Vandalize"
Police	Police	Police
Thief	Gunpoint	Vandals
Thieves	Killing	Vandal
Burglars	Gunman	-

[63] This equation has been inspired by similar equation in (Abel, Hauff, Houben, & Tao, 2012)

Cops	Gunmen	-
-	Killed	-
-	Stray_bullet	-
-	Armed	-
-	Killed	-
-	Victim	-
-	Wounded	-
-	Injured	-

Table 5 *"ranking set"* for the three classes of illegal act

5. DISCUSSION, CONCLUSION AND RECOMMENDATIONS

5.1. Discussion

The findings that resulted from conducting this research will be discussing with guidance of the objectives and questions proposed for this research.

1. How to relate tweets contents to concepts in the context of the selected use case?
   In Chapter 3, we have designed IAINM ontology, which represents a formal conceptual structure for the selected use case, and thus it becomes possible to relate tweets to concepts that are explicitly defined in the designed IAINM ontology. In the IAINM ontology, we have defined concepts that are utilized in crowdsourcing news in the context of specific types of illegal act based on our knowledge of the illegal act concepts and the terms that are extracted from the collected tweets dataset to refer to the mentioned types of illegal act. Some domain concepts that were defined based on the human knowledge, for example, concept *"Crime"*, are not necessarily used in the crowdsourcing news. On the other hand, not all concepts that were extracted from the tweets dataset are taken into account according to the knowledge of the domain of interest, for example the different verbal tenses that are driven from some illegal act concepts and utilized in the crowdsourcing news in the mentioned context. Ranking set that we defined in Chapter 4 is a collection of other domain concepts that can be an additional indication to decide the degree of relatedness of the tweet to the corresponding concept in the assigned domain of interest.
   It is important to mention that concepts in IAINM ontology have been presented based on our knowledge in the domain of interest and the vocabulary set which have been extracted from a considerably small tweets dataset. Hence, unknown concepts might be utilized in tweets in the context of our use case.
2. How to derive relevant concepts, instances and relationships for the selected use case?
   Geographic location is the second key concept, besides the *illegal act* concept in our domain data model that is discussed in Section 0. *"Vehicle"* is an additional concept besides concepts *"Illegal act"* and *"Location"* that represents the third component in the mentioned data model, which is involved with some types of illegal act. Having *"Illegal act"*, *"Location"* and *"Vehicle"* concepts as the three main concepts in our domain data model; we were able to derive more concepts and instances that correspond with these three main concepts. For example, Miami and the four selected neighbourhoods are extracted instances, from the tweets dataset, that represent the geographic location concept for the selected use case of this research. Hence, concepts like *"City"* and *"Neighbourhood"* had to be driven to disambiguate between Miami and any of its neighbourhoods in terms of the different concepts they represent. Finally, different concepts that are corresponding to *"Vehicle"* concept were extracted from the tweets dataset. All the relevant concepts and instances have been classified into three main classes that represent the three main concepts in our domain data model. The first type of relationships was defined in the overall level of the three main classes within the designed domain data model as the *"Illegal act"* must have a *"Location"* and might relate to *"Vehicle"* class in case of specific type of *"Illegal act"*. Other types of relationships were defined on other levels when building IAINM ontology.
3. How to define the abovementioned concepts, instances and relationships via formalized structure using the *Resource Description Framework RDF*?
   OWL language has been utilized to build a formal structure (i.e. ontology) for our domain data model according to the standard data model provided by RDF.

First level of relationships were defined on the level of the three main classes to assign some concepts that belong to one of the three main classes as subclasses of the main class they belong to, using the property "*rdfs:subClassOf*" like for example, *"Robbery"* as subclass of *"Crime"*. Using the same property, we have defined a second level of relationships on the level of subclasses to assign some concepts as subclasses of other subclasses like for example, *"Carjacking"* as subclass of *"Robbery"*. It is important to mention that according to the description logic of OWL, assigning a class as a subclass of other class would define the instances of the subclass to be instances also of all higher classes in the same hierarchy and thus instances in class *"Carjacking"* are also instances in class *"Robbery"* and class *"Crime"* . Other Type of relationships has been driven on the instances level to assign which instance represents which class and it is expected from the reader to comprehend by now the difference between the concept which is represented by a class and the instances of the class that represent the concept. For example, *"Overtown"* is an instance (individual) that represents concept *"Neighbourhood"* and thus it is an instance in class *"Neighbourhoods"*. Property *owl:equivalentClass* has been utilized to assign classes synonyms. Last type of relationships were derived on the level of different classes of our ontology through defining our own properties including properties like *"locatedIn"* and *"Object"* to relate the three main classes according to our domain data model, and properties like *"Has_Neighbourhoods"* and *"Neighbourhoods_of"* to relate subclasses *"City"* and *"Neighbourhoods"*. All own properties are type of object properties since they relate instance with instance and not instance with literal.

4. How to conceptually link these concepts and instances to their corresponding in geospatial and non-geospatial RDF datasets?
   Two forms of relationships between a concept in our IAINM ontology and its corresponding concept in other ontologies in different namespaces are possible:
   1. Both concepts are conceptually equal, meaning that they both convey the same exact meaning regardless of their instances and property "*owl:sameAs*" has been used to assign this type of relationships.
   2. An IAINM concept is a subset of the corresponding concept, meaning that instances in the IAINM concept are also instances of the corresponding concept and property *"rdfs:subClassOf"* is used to define this type of relationships. We have utlized this type of relationships to align class *"City"* in our ontology to class *"City"* in LinkedGeoData (LGD) ontology. That is simply because we cannot claim that class *"City"* in LGD have the same intended meaning of class *"City"* in our ontology, especially that there is no description found for class *"City"* in LGD ontology, unlike the case when aligning with Dbpedia dataset or Vehicle Sales Ontology where a class description is presented through property *"rdfs:comment"*.

   There is also a third type of relationships that can link corresponding concepts and that is when both concepts have the same exact set of instances regardless of their conceptual equality and property *"owl:equivalentClass"* is used to define this type of relationships. This type of relationships have not been utilized in any of the alignment for our ontology since creating this type of relationships between corresponding concepts would necessarily mean that we have to have the control over the namespaces of the corresponding concepts which is not the case. We only have the control over the namespace that we have created for our IAINM ontology but we do not have the control over any of the namespaces of the other datasets and ontologies, with which we aligned our IAINM ontology.

   On the instances level, we have utilized identity links to relate instances in IAINM ontology to corresponding instances (aliases) in other namespace via property "*owl:sameAs*". One may ask why not to reuse predefined alias instead of defining new ones in our namespace and then linking them to those alias? The answer is that we need to provide our description for these instances, like for example defining *"Miami"* as instance of *"City"* or relating *"Little Haiti"* with *"Miami"* via IAINM property *"Neighbourhoods_of"*, and that is only can be done in a namespace which we control. This is the reason we have identified city *"Miami"* and their four neighbourhoods in our own ontology and then linking them to corresponding aliases in other namespaces.

5. How can the conceptual links be utilized to discover relevant contents in the social media?
   In our IAINM ontology, we have utilized the conceptual links that relate equivalent concepts (synonyms) to discover the tweets that are in the same context but they do not necessarily include the same term that represents the queried concept (as we have seen with most implemented SPARQL queries in Chapter 4) . The conceptual links that relate concepts with their sub-concepts have been utilized to discover the tweets that refer to a sub-concept of the queried concept, like the case of concept *"Robbery"* and its sub-concept *"Carjacking"* in query 1 in Chapter 4. The conceptual links that relates concepts through IAINM properties, has been also utilized to discover the tweets that refer to a geographic entity which is contained by the queried geographic entity and that is specifically through IAINM property "*Has_Neighbourhoods"*, like the case of *"Miami"* and its neighbourhoods in query 1 in Chapter 4. Suggested queries can be also built based on the original queries to discover the tweets that refer to the upper concept of the requested concept like the case of *"Downtown_Miami"* and *"Miami"* in suggested query that is built upon query 2 in Chapter 4 via utilizing IAINM property "*Neighbourhoods_of"*.
   It is of great importance to consider the limitation of using the conceptual links in our IAINM to discover relevant contents in the different types of social media other than microblogging[64] (e.g. Twitter) because of the possible reasons:
   1. The larger amount of content can raise the possibility of finding heterogeneous context within the same entry.
   2. Other types of social media might use other concepts in the context of our use case, which we have not considered when we built the concepts in IAINM ontology.

6. How can the conceptual links be utilized in information enrichment from geospatial and non-geospatial RDF datasets?
   Both concepts and instances links that are mentioned in discussing question 4 is what connect data in the IAINM RDF graph that is depicted in ANNEX D to the global linked data RDF graph that is shown in Figure 12. Both types of links make it possible to enrich the description of the concepts and instances in our graph with information from external resources. Integration same type of data is specifically carried out through linking concepts to their corresponding concepts in other namespaces (aligning). For example, data described by term *"City"* in LGD namespace and data described by term *"City"* in our ontology (basically we have only one instance in this class which is *"Miami"*) can be integrated in one view and consumed in various linked data applications as stated in (Berlin et al., 2012) since we have aligned term *"City"* in our ontology to term *"City"* in LGD ontology. Information enrichment on instances level simply means crawling via identity links to fetch further description that is presented in other namespace about the same instance (alias) like what we have seen in Query 5 in Chapter 4. In Chapter4, in case of implementing queries that involves querying data from other datasets (like Geonames or Freebase), we had to store some parts of these datasets in our Virtuoso quad store because Virtuoso version that we have used in this research does not support querying from multiple SPARQ endpoints or what is called *"SPARQL Federated Query"*[65]. Subsequently, any updating in

[64] Microblogging is "Internet-based applications, which allow users to exchange small elements of content such as short sentences, individual images, or video links" as defined in (Kaplan & Haenlein, 2011)

[65] http://www.w3.org/TR/sparql11-federated-query/

these datasets will not be detected by our system. As seen in Chapter 4, writing SPARQL queries requires the person to have a sufficient knowledge of forming queries on linked data as well as the structure of the ontologies and datasets that are to be queried. Mockup visualization is an idea of designing the information system of the use case in a user-friendly way.

5.2. Conclusion

Based on the objectives that have led to conduct this research the following conclusions can be drawn:

- Concepts that are used by the social media in the context of the use case have been linked conceptually via a formal conceptual structure which is represented by IAINM ontology
- Subsequently, social media contents that include these concepts are linked conceptually and not only via keywords.
- Exploiting the abovementioned conceptual links in searching for relevant contents are resulted in discovering relevant contents that were hidden when utilizing only the keyword-based searching.
- The defined concepts and instances in our namespace have been conceptually linked to corresponding concepts and instances in other namespaces, including linking the instances that represent concept *"Location"* in the IAINM ontology with their corresponding in some geospatial sematic webs like LinkedGeoData and Geonames and non-geospatial semantic webs like freebase.
- As a result for creating conceptual links to data in other namespaces, we were able to answer questions that require querying data form different datasets (i.e. information enrichment).
- Through IAINM ontology, we were able to describe concepts and instances that are utilized by the social media (in the context of the use case) to the machine and thus narrower the gap between our understanding and the machine understanding of these concepts and instances. This has been resulted in enhancing the searching functionality for relevant contents in the context of the use case.

5.3. Recommendations

Based on the results of this research, we recommend the following as subjects for further researches in Linked Data:

1. Develop specifications that allow implementing SPARQL queries (in case of discovering relevant contents in Social media platforms) against social media stream.
2. Develop specifications that allow using data type "literals" as linking parameter in implementing SPARQL queries against linked datasets that utilize unified literals in their data description like for example LinkedGeoData.
3. Investigate the data modeling in building domain-dependent linked-data applications that support naïve users who do not have sufficient knowledge of linked data and linked data technologies.

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ANNEX A

FULL RDF/XML SERIALIZATION OF IAINM ONTOLOGY


```
<?xml version="1.0"?>
<rdf:RDF
  xmlns:xsp="http://www.owl-ontologies.com/2005/08/07/xsp.owl#"
  xmlns:TS="http://www.TSMER.com/Ontology.owl#"
  xmlns:swrlb="http://www.w3.org/2003/11/swrlb#"
  xmlns:swrl="http://www.w3.org/2003/11/swrl#"
  xmlns:protege="http://protege.stanford.edu/plugins/owl/protege#"
  xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
  xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
  xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
  xmlns:owl="http://www.w3.org/2002/07/owl#"
  xmlns:gn="http://www.geonames.org/ontology#"
 xml:base="http://www.TSMER.com/Ontology.owl"
 xmlns:wgs84_pos="http://www.w3.org/2003/01/geo/wgs84_pos#">
 <owl:Ontology rdf:about="">
  <rdfs:comment xml:lang="en">&lt;p style="margin-top: 0"&gt;&#xD;
    This is the ontology of Safety in Neighbourhoods in Miami&#xD;
  &lt;/p&gt;</rdfs:comment>
 </owl:Ontology>
 <owl:Class rdf:ID="Shot">
  <rdfs:subClassOf>
    <owl:Class rdf:about="#Crime"/>
  </rdfs:subClassOf>
 </owl:Class>
 <owl:Class rdf:about="#Crime">
  <rdfs:comment xml:lang="en">&lt;p style="margin-top: 0"&gt;&#xD;
    This is the class of Crime &#xD;
  &lt;/p&gt;</rdfs:comment>
  <owl:sameAs rdf:resource="http://dbpedia.org/resource/Crime"/>
  <rdfs:subClassOf rdf:resource="http://purl.org/NET/c4dm/event.owl#Event"/>
 </owl:Class>
 <owl:Class rdf:about="#Location">
  <rdfs:subClassOf
rdf:resource="http://www.w3.org/2003/01/geo/wgs84_pos#SpatialThing"/>
  <rdfs:subClassOf rdf:resource="http://www.geonames.org/ontology#Feature"/>
 </owl:Class>
 <owl:Class rdf:about="#vehicle">
```

```
  <owl:sameAs rdf:resource="http://purl.org/vso/ns#Vehicle"/>
</owl:Class>
<owl:Class rdf:ID="Stole">
  <rdfs:subClassOf rdf:resource="#Crime"/>
</owl:Class>
<owl:Class rdf:ID="Carjacking">
  <owl:equivalentClass>
    <owl:Class rdf:ID="Carjack"/>
  </owl:equivalentClass>
  <rdfs:subClassOf>
    <owl:Class rdf:ID="Robbery"/>
  </rdfs:subClassOf>
  <owl:sameAs rdf:resource="http://dbpedia.org/resource/Carjacking"/>
  <rdfs:subClassOf rdf:resource="http://dbpedia.org/resource/Motor_vehicle_theft"/>
</owl:Class>
<owl:Class rdf:ID="Robbery">
  <owl:equivalentClass>
    <owl:Class rdf:ID="Rob"/>
  </owl:equivalentClass>
  <rdfs:subClassOf rdf:resource="#Crime"/>
  <owl:sameAs rdf:resource="http://dbpedia.org/resource/Robbery"/>
</owl:Class>
<owl:Class rdf:about="#Rob">
  <owl:equivalentClass rdf:resource="#Robbery"/>
  <rdfs:subClassOf rdf:resource="#Crime"/>
</owl:Class>
<owl:Class rdf:ID="Robbery">
  <owl:equivalentClass>
    <owl:Class rdf:ID="Stole"/>
  </owl:equivalentClass>
  <rdfs:subClassOf rdf:resource="#Crime"/>
</owl:Class>
 <owl:Class rdf:ID="Robbery">
  <owl:equivalentClass>
    <owl:Class rdf:ID="Steals"/>
  </owl:equivalentClass>
  <rdfs:subClassOf rdf:resource="#Crime"/>
</owl:Class>
<owl:Class rdf:ID="Steals">
  <owl:equivalentClass>
    <owl:Class rdf:ID="Robbery"/>
  </owl:equivalentClass>
  <rdfs:subClassOf rdf:resource="#Crime"/>
</owl:Class>
```

```
<owl:Class rdf:ID="Rob">
  <owl:equivalentClass>
    <owl:Class rdf:ID="Steals"/>
  </owl:equivalentClass>
  <rdfs:subClassOf rdf:resource="#Crime"/>
</owl:Class>
<owl:Class rdf:ID="Steals">
  <owl:equivalentClass>
    <owl:Class rdf:ID="Rob"/>
  </owl:equivalentClass>
  <rdfs:subClassOf rdf:resource="#Crime"/>
</owl:Class>
<owl:Class rdf:ID="Steal">
  <owl:equivalentClass>
    <owl:Class rdf:ID="Steals"/>
  </owl:equivalentClass>
  <rdfs:subClassOf rdf:resource="#Crime"/>
</owl:Class>
<owl:Class rdf:ID="Steals">
  <owl:equivalentClass>
    <owl:Class rdf:ID="Steal"/>
  </owl:equivalentClass>
  <rdfs:subClassOf rdf:resource="#Crime"/>
</owl:Class>
<owl:Class rdf:ID="Stolen">
  <owl:equivalentClass>
    <owl:Class rdf:ID="Steals"/>
  </owl:equivalentClass>
  <rdfs:subClassOf rdf:resource="#Crime"/>
</owl:Class>
<owl:Class rdf:ID="Steals">
  <owl:equivalentClass>
    <owl:Class rdf:ID="Stolen"/>
  </owl:equivalentClass>
  <rdfs:subClassOf rdf:resource="#Crime"/>
</owl:Class>
<owl:Class rdf:ID="Stealing">
  <owl:equivalentClass>
    <owl:Class rdf:ID="Steals"/>
  </owl:equivalentClass>
  <rdfs:subClassOf rdf:resource="#Crime"/>
</owl:Class>
<owl:Class rdf:ID="Steals">
  <owl:equivalentClass>
```

```
    <owl:Class rdf:ID="Stealing"/>
  </owl:equivalentClass>
  <rdfs:subClassOf rdf:resource="#Crime"/>
</owl:Class>
<owl:Class rdf:ID="Stole">
  <owl:equivalentClass>
    <owl:Class rdf:ID="Steals"/>
  </owl:equivalentClass>
  <rdfs:subClassOf rdf:resource="#Crime"/>
</owl:Class>
<owl:Class rdf:ID="Steals">
  <owl:equivalentClass>
    <owl:Class rdf:ID="Stole"/>
  </owl:equivalentClass>
  <rdfs:subClassOf rdf:resource="#Crime"/>
</owl:Class>
<owl:Class rdf:ID="Theft">
  <owl:equivalentClass>
    <owl:Class rdf:ID="Steals"/>
  </owl:equivalentClass>
  <rdfs:subClassOf rdf:resource="#Crime"/>
</owl:Class>
<owl:Class rdf:ID="Steals">
  <owl:equivalentClass>
    <owl:Class rdf:ID="Theft"/>
  </owl:equivalentClass>
  <rdfs:subClassOf rdf:resource="#Crime"/>
</owl:Class>
<owl:Class rdf:ID="Stealing">
  <owl:equivalentClass>
    <owl:Class rdf:ID="Robbery"/>
  </owl:equivalentClass>
  <rdfs:subClassOf rdf:resource="#Crime"/>
</owl:Class>
<owl:Class rdf:ID="Robbery">
  <owl:equivalentClass>
    <owl:Class rdf:ID="Stealing"/>
  </owl:equivalentClass>
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  </owl:equivalentClass>
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  </owl:equivalentClass>
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```

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  </owl:equivalentClass>
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  </owl:equivalentClass>
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<owl:Class rdf:about="#Stole">
  <owl:equivalentClass rdf:resource="#Robbery"/>
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  </owl:equivalentClass>
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  </owl:equivalentClass>
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  </owl:equivalentClass>
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</owl:Class>
<owl:Class rdf:about="#Stole">
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  <rdfs:subClassOf rdf:resource="#Crime"/>
</owl:Class>
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    <owl:Class rdf:ID="Stole"/>
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```

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    <owl:Class rdf:ID="Robbed"/>
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      <owl:disjointWith>
        <owl:Class rdf:ID="truck"/>
      </owl:disjointWith>
      <rdfs:subClassOf>
        <owl:Class rdf:ID="vehicle"/>
      </rdfs:subClassOf>
      <rdfs:subClassOf rdf:resource="http://purl.org/vso/ns#BusOrCoach"/>
    </owl:Class>
    <owl:Class rdf:ID="Steal">
      <rdfs:subClassOf rdf:resource="#Crime"/>
    </owl:Class>
    <owl:Class rdf:ID="Neighbourhoods">
      <rdfs:subClassOf>
         <owl:Class rdf:ID="Location"/>
      </rdfs:subClassOf>
      <rdfs:subClassOf rdf:resource="http://linkedgeodata.org/ontology/Hamlet"/>
      <rdfs:subClassOf>
         <owl:Restriction>
            <owl:onProperty
rdf:resource="http://www.geonames.org/ontology#featureCode"/>
            <owl:allValuesFrom>
```

```
                <owl:Class>
                  <owl:unionOf rdf:parseType="Collection">
                    <owl:Class rdf:about="http://www.geonames.org/ontology#P.PPL"/>
                    <owl:Class rdf:about="http://www.geonames.org/ontology#L.AREA"/>
                  </owl:unionOf>
                </owl:Class>
            </owl:allValuesFrom>
          </owl:Restriction>
        </rdfs:subClassOf>

</owl:Class>
<owl:Class rdf:about="#Motorcycle">
  <rdfs:subClassOf rdf:resource="#vehicle"/>
  <owl:disjointWith>
    <owl:Class rdf:about="#van"/>
  </owl:disjointWith>
  <owl:disjointWith>
    <owl:Class rdf:about="#tractor"/>
  </owl:disjointWith>
  <owl:disjointWith>
    <owl:Class rdf:about="#car"/>
  </owl:disjointWith>
  <owl:disjointWith>
    <owl:Class rdf:about="#bike"/>
  </owl:disjointWith>
  <owl:disjointWith rdf:resource="#bus"/>
  <owl:disjointWith>
    <owl:Class rdf:about="#truck"/>
  </owl:disjointWith>
 <owl:sameAs rdf:resource="http://purl.org/vso/ns#Motorcycle"/>
</owl:Class>
<owl:Class rdf:ID="Theft">
  <rdfs:subClassOf rdf:resource="#Crime"/>
 <owl:sameAs rdf:resource="http://dbpedia.org/resource/Theft"/>
</owl:Class>
<owl:Class rdf:ID="Shoot">
  <rdfs:subClassOf rdf:resource="#Crime"/>
</owl:Class>
<owl:Class rdf:ID="Stolen">
  <rdfs:subClassOf rdf:resource="#Crime"/>
</owl:Class>
<owl:Class rdf:ID="Rob">
  <rdfs:subClassOf rdf:resource="#Crime"/>
</owl:Class>
```

```xml
<owl:Class rdf:about="#van">
  <owl:disjointWith>
    <owl:Class rdf:about="#tractor"/>
  </owl:disjointWith>
  <owl:disjointWith>
    <owl:Class rdf:about="#car"/>
  </owl:disjointWith>
  <owl:disjointWith>
    <owl:Class rdf:about="#bike"/>
  </owl:disjointWith>
  <owl:disjointWith rdf:resource="#bus"/>
  <owl:disjointWith rdf:resource="#Motorcycle"/>
  <owl:disjointWith>
    <owl:Class rdf:about="#truck"/>
  </owl:disjointWith>
  <rdfs:subClassOf rdf:resource="#vehicle"/>
  <owl:sameAs rdf:resource="http://purl.org/vso/ns#Van"/>
</owl:Class>
<owl:Class rdf:ID="Gunfire">
  <rdfs:subClassOf rdf:resource="#Crime"/>
</owl:Class>
<owl:Class rdf:ID="Shoots">
  <rdfs:subClassOf rdf:resource="#Crime"/>
</owl:Class>
<owl:Class rdf:ID="bicycle">
  <owl:equivalentClass>
    <owl:Class rdf:about="#bike"/>
  </owl:equivalentClass>
  <rdfs:subClassOf rdf:resource="#vehicle"/>
</owl:Class>
<owl:Class rdf:about="#bike">
  <owl:disjointWith rdf:resource="#van"/>
  <owl:disjointWith>
    <owl:Class rdf:about="#tractor"/>
  </owl:disjointWith>
  <owl:disjointWith>
    <owl:Class rdf:about="#car"/>
  </owl:disjointWith>
  <owl:disjointWith rdf:resource="#bus"/>
  <owl:disjointWith rdf:resource="#Motorcycle"/>
  <owl:disjointWith>
    <owl:Class rdf:about="#truck"/>
  </owl:disjointWith>
  <owl:equivalentClass rdf:resource="#bicycle"/>
```

```
  <rdfs:subClassOf rdf:resource="#vehicle"/>
  <owl:sameAs rdf:resource="http://purl.org/vso/ns#Bicycle"/>
</owl:Class>
<owl:Class rdf:about="#City">
  <rdfs:subClassOf rdf:resource="#Location"/>
  <rdfs:subClassOf rdf:resource="http://linkedgeodata.org/ontology/City"/>
    <rdfs:subClassOf>
      <owl:Restriction>
              <owl:onProperty
rdf:resource="http://www.geonames.org/ontology#featureCode"/>
              <owl:hasValue rdf:resource="http://www.geonames.org/ontology#P.PPL" />
       </owl:Restriction>
    </rdfs:subClassOf>
</owl:Class>
<owl:Class rdf:ID="Shooting">
  <rdfs:subClassOf rdf:resource="#Crime"/>
  <owl:sameAs rdf:resource="http://dbpedia.org/resource/Shooting"/>
</owl:Class>
<owl:Class rdf:about="#tractor">
  <rdfs:subClassOf rdf:resource="#vehicle"/>
  <owl:disjointWith rdf:resource="#van"/>
  <owl:disjointWith>
    <owl:Class rdf:about="#car"/>
  </owl:disjointWith>
  <owl:disjointWith rdf:resource="#bike"/>
  <owl:disjointWith rdf:resource="#bus"/>
  <owl:disjointWith rdf:resource="#Motorcycle"/>
  <owl:disjointWith>
    <owl:Class rdf:about="#truck"/>
  </owl:disjointWith>
</owl:Class>
<owl:Class rdf:about="#Carjack">
  <owl:equivalentClass rdf:resource="#Carjacking"/>
  <rdfs:subClassOf>
    <owl:Class rdf:about="#Robbery"/>
  </rdfs:subClassOf>
</owl:Class>
<owl:Class rdf:about="#car">
  <owl:disjointWith rdf:resource="#van"/>
  <owl:disjointWith rdf:resource="#tractor"/>
  <owl:disjointWith rdf:resource="#bike"/>
  <owl:disjointWith rdf:resource="#bus"/>
  <owl:disjointWith rdf:resource="#Motorcycle"/>
  <owl:disjointWith>
```

```
    <owl:Class rdf:about="#truck"/>
  </owl:disjointWith>
  <rdfs:subClassOf rdf:resource="#vehicle"/>
  <rdfs:subClassOf rdf:resource="http://purl.org/vso/ns#Automobile"/>
</owl:Class>
<owl:Class rdf:about="#Robbery">
  <rdfs:subClassOf rdf:resource="#Crime"/>
</owl:Class>
<owl:Class rdf:about="#truck">
  <owl:disjointWith rdf:resource="#van"/>
  <owl:disjointWith rdf:resource="#tractor"/>
  <owl:disjointWith rdf:resource="#car"/>
  <owl:disjointWith rdf:resource="#bike"/>
  <owl:disjointWith rdf:resource="#bus"/>
  <owl:disjointWith rdf:resource="#Motorcycle"/>
  <rdfs:subClassOf rdf:resource="#vehicle"/>
  <owl:sameAs rdf:resource="http://purl.org/vso/ns#Truck"/>
</owl:Class>
<owl:Class rdf:ID="Vandalize">
  <rdfs:subClassOf rdf:resource="#Crime"/>
  <owl:sameAs rdf:resource="http://dbpedia.org/resource/Vandalism"/>
</owl:Class>
<owl:ObjectProperty rdf:ID="Neighbourhoods_of">
  <rdfs:range rdf:resource="#City"/>
  <owl:inverseOf>
    <owl:ObjectProperty rdf:ID="Has_Neighbourhoods"/>
  </owl:inverseOf>
  <rdfs:domain rdf:resource="#Neighbourhoods"/>
</owl:ObjectProperty>
<owl:ObjectProperty rdf:about="#Has_Neighbourhoods">
  <owl:inverseOf rdf:resource="#Neighbourhoods_of"/>
  <rdfs:domain rdf:resource="#City"/>
  <rdfs:range rdf:resource="#Neighbourhoods"/>
</owl:ObjectProperty>
<owl:ObjectProperty rdf:ID="Object">
  <rdfs:domain rdf:resource="#Robbery"/>
  <rdfs:range rdf:resource="#vehicle"/>
</owl:ObjectProperty>
<owl:ObjectProperty rdf:ID="locationOf">
  <rdfs:domain rdf:resource="#Location"/>
  <owl:inverseOf>
    <owl:ObjectProperty rdf:ID="#locatedIn"/>
  </owl:inverseOf>
  <rdfs:range rdf:resource="#Crime"/>
```

```
</owl:ObjectProperty>
<owl:ObjectProperty rdf:about="#locatedIn">
  <rdfs:domain rdf:resource="#Crime"/>
  <rdfs:range rdf:resource="#Location"/>
  <owl:inverseOf rdf:resource="#locationOf"/>
</owl:ObjectProperty>
<owl:Class rdf:ID="Ice_cream_truck">
      <rdfs:subClassOf rdf:resource="#truck"/>
  </owl:Class>
<owl:Class rdf:ID="Musician_van">
      <rdfs:subClassOf rdf:resource="#van"/>
</owl:Class>
<owl:AllDifferent/>
<owl:AllDifferent>
  <owl:distinctMembers rdf:parseType="Collection">
    <TS:Neighbourhoods rdf:about="http://www.TSMER.com/Little_Haiti">
     <owl:sameAs rdf:resource="http://rdf.freebase.com/ns/en.little_haiti"/>
     <wgs84_pos:lat>25.8304437</wgs84_pos:lat>
     <wgs84_pos:long>-80.1958755</wgs84_pos:long>
      <TS:Neighbourhoods_of>
        <TS:City rdf:ID="Miami">
          <TS:Has_Neighbourhoods rdf:resource="http://www.TSMER.com/Little_Haiti"/>
          <TS:Has_Neighbourhoods>
            <TS:Neighbourhoods rdf:about="http://www.TSMER.com/Downtown_Miami">
              <TS:Neighbourhoods_of rdf:resource="#Miami"/>
                     <owl:sameAs rdf:resource="http://sws.geonames.org/6946360/"/>
                     <wgs84_pos:lat>25.774</wgs84_pos:lat>
                     <wgs84_pos:long>-80.190</wgs84_pos:long>
            </TS:Neighbourhoods>
          </TS:Has_Neighbourhoods>
          <TS:Has_Neighbourhoods>
            <TS:Neighbourhoods rdf:about="http://www.TSMER.com/Liberty_City">
              <TS:Neighbourhoods_of rdf:resource="#Miami"/>
                     <owl:sameAs rdf:resource="http://rdf.freebase.com/ns/m.04vjp5"/>
                     <wgs84_pos:lat>25.8317637</wgs84_pos:lat>
                     <wgs84_pos:long>-80.2167149</wgs84_pos:long>
            </TS:Neighbourhoods>
          </TS:Has_Neighbourhoods>
          <TS:Has_Neighbourhoods>
            <TS:Neighbourhoods rdf:about="http://www.TSMER.com/overtown">
              <TS:Neighbourhoods_of rdf:resource="#Miami"/>
                     <owl:sameAs rdf:resource="http://rdf.freebase.com/ns/en.overtown"/>
                     <wgs84_pos:lat>25.7839802</wgs84_pos:lat>
                     <wgs84_pos:long>-80.2014543</wgs84_pos:long>
```

```xml
        </TS:Neighbourhoods>
       </TS:Has_Neighbourhoods>
      <owl:sameAs rdf:resource="http://sws.geonames.org/4164138/"/>
      <owl:sameAs rdf:resource="http://linkedgeodata.org/triplify/node154158458"/>
      <owl:sameAs rdf:resource="http://rdf.freebase.com/ns/en.miami"/>
      <wgs84_pos:lat>25.7889689</wgs84_pos:lat>
      <wgs84_pos:long>-80.2264393</wgs84_pos:long>
      </TS:City>
     </TS:Neighbourhoods_of>
    </TS:Neighbourhoods>
    <TS:Neighbourhoods rdf:about="http://www.TSMER.com/Downtown_Miami"/>
    <TS:Neighbourhoods rdf:about="http://www.TSMER.com/overtown"/>
    <TS:Neighbourhoods rdf:about="http://www.TSMER.com/Liberty_City"/>
   </owl:distinctMembers>
  </owl:AllDifferent>
  <owl:AllDifferent/>
  <owl:AllDifferent/>
  <owl:AllDifferent>
   <owl:distinctMembers rdf:parseType="Collection">
   </owl:distinctMembers>
  </owl:AllDifferent>
  <owl:DataRange>
   <owl:oneOf rdf:parseType="Resource">
    <rdf:rest rdf:parseType="Resource">
     <rdf:first rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
     >Steal</rdf:first>
     <rdf:rest rdf:parseType="Resource">
      <rdf:first rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
      >Stole</rdf:first>
      <rdf:rest rdf:parseType="Resource">
       <rdf:rest rdf:resource="http://www.w3.org/1999/02/22-rdf-syntax-ns#nil"/>
       <rdf:first rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
       >Theft</rdf:first>
      </rdf:rest>
     </rdf:rest>
    </rdf:rest>
    <rdf:first rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
    >Robbery</rdf:first>
   </owl:oneOf>
  </owl:DataRange>
  <owl:AllDifferent/>
</rdf:RDF>

<!-- Created with Protege (with OWL Plugin 3.5, Build 649)  http://protege.stanford.edu -->
```

ANNEX B

GEONAMES MAIN CLASSES, "FEATURE" SUBCLASSES, "CODE" SUBCLASSES, OBJECT PROPERTIES AND DATATYPE PROPERTIES

Geonames_main_classes
http://www.geonames.org/ontology#Feature
http://www.geonames.org/ontology#Class
http://www.geonames.org/ontology#Code
http://www.geonames.org/ontology#GeonamesFeature
http://www.geonames.org/ontology#Map
http://www.geonames.org/ontology#RDFData
http://www.geonames.org/ontology#WikipediaArticle

Geonames_Feature_subclasses
http://www.geonames.org/ontology#S
http://www.geonames.org/ontology#A
http://www.geonames.org/ontology#H
http://www.geonames.org/ontology#L
http://www.geonames.org/ontology#P
http://www.geonames.org/ontology#R
http://www.geonames.org/ontology#T
http://www.geonames.org/ontology#U
http://www.geonames.org/ontology#V

Geonames_Code_subclasses
http://www.geonames.org/ontology#S.SCH
http://www.geonames.org/ontology#A.ADM1
http://www.geonames.org/ontology#A.ADM2
http://www.geonames.org/ontology#A.ADM3
http://www.geonames.org/ontology#A.ADM4
http://www.geonames.org/ontology#A.PCLI
http://www.geonames.org/ontology#A.ADM5
http://www.geonames.org/ontology#A.ADMD

http://www.geonames.org/ontology#A.LTER
http://www.geonames.org/ontology#A.PCL
http://www.geonames.org/ontology#A.PCLD
http://www.geonames.org/ontology#A.PCLF
http://www.geonames.org/ontology#A.PCLIX
http://www.geonames.org/ontology#A.PCLS
http://www.geonames.org/ontology#A.PRSH
http://www.geonames.org/ontology#A.TERR
http://www.geonames.org/ontology#A.ZN
http://www.geonames.org/ontology#A.ZNB
http://www.geonames.org/ontology#H.AIRS
http://www.geonames.org/ontology#H.ANCH
http://www.geonames.org/ontology#H.BAY
http://www.geonames.org/ontology#H.BAYS
http://www.geonames.org/ontology#H.BGHT
http://www.geonames.org/ontology#H.BNK
http://www.geonames.org/ontology#H.BNKR
http://www.geonames.org/ontology#H.BNKX
http://www.geonames.org/ontology#H.BOG
http://www.geonames.org/ontology#H.CAPG
http://www.geonames.org/ontology#H.CHN
http://www.geonames.org/ontology#H.CHNL
http://www.geonames.org/ontology#H.CHNM
http://www.geonames.org/ontology#H.CHNN
http://www.geonames.org/ontology#H.CNFL
http://www.geonames.org/ontology#H.CNL
http://www.geonames.org/ontology#H.CNLA
http://www.geonames.org/ontology#H.CNLB
http://www.geonames.org/ontology#H.CNLD
http://www.geonames.org/ontology#H.CNLI
http://www.geonames.org/ontology#H.CNLN
http://www.geonames.org/ontology#H.CNLQ
http://www.geonames.org/ontology#H.CNLSB
http://www.geonames.org/ontology#H.CNLX
http://www.geonames.org/ontology#H.COVE
http://www.geonames.org/ontology#H.CRKT
http://www.geonames.org/ontology#H.CRNT

http://www.geonames.org/ontology#H.CUTF
http://www.geonames.org/ontology#H.DCK
http://www.geonames.org/ontology#H.DCKB
http://www.geonames.org/ontology#H.DOMG
http://www.geonames.org/ontology#H.DPRG
http://www.geonames.org/ontology#H.DTCH
http://www.geonames.org/ontology#H.DTCHD
http://www.geonames.org/ontology#H.DTCHI
http://www.geonames.org/ontology#H.DTCHM
http://www.geonames.org/ontology#H.ESTY
http://www.geonames.org/ontology#H.FISH
http://www.geonames.org/ontology#H.FJD
http://www.geonames.org/ontology#H.FJDS
http://www.geonames.org/ontology#H.FLLS
http://www.geonames.org/ontology#H.FLLSX
http://www.geonames.org/ontology#H.FLTM
http://www.geonames.org/ontology#H.FLTT
http://www.geonames.org/ontology#H.GLCR
http://www.geonames.org/ontology#H.GULF
http://www.geonames.org/ontology#H.GYSR
http://www.geonames.org/ontology#H.HBR
http://www.geonames.org/ontology#H.HBRX
http://www.geonames.org/ontology#H.INLT
http://www.geonames.org/ontology#H.INLTQ
http://www.geonames.org/ontology#H.LBED
http://www.geonames.org/ontology#H.LGN
http://www.geonames.org/ontology#H.LGNS
http://www.geonames.org/ontology#H.LGNX
http://www.geonames.org/ontology#H.LK
http://www.geonames.org/ontology#H.LKC
http://www.geonames.org/ontology#H.LKI
http://www.geonames.org/ontology#H.LKN
http://www.geonames.org/ontology#H.LKNI
http://www.geonames.org/ontology#H.LKO
http://www.geonames.org/ontology#H.LKOI
http://www.geonames.org/ontology#H.LKS
http://www.geonames.org/ontology#H.LKSB

http://www.geonames.org/ontology#H.LKSC
http://www.geonames.org/ontology#H.LKSI
http://www.geonames.org/ontology#H.LKSN
http://www.geonames.org/ontology#H.LKSNI
http://www.geonames.org/ontology#H.LKX
http://www.geonames.org/ontology#H.MFGN
http://www.geonames.org/ontology#H.MGV
http://www.geonames.org/ontology#H.MOOR
http://www.geonames.org/ontology#H.MRSH
http://www.geonames.org/ontology#H.MRSHN
http://www.geonames.org/ontology#H.NRWS
http://www.geonames.org/ontology#H.OCN
http://www.geonames.org/ontology#H.OVF
http://www.geonames.org/ontology#H.PND
http://www.geonames.org/ontology#H.PNDI
http://www.geonames.org/ontology#H.PNDN
http://www.geonames.org/ontology#H.PNDNI
http://www.geonames.org/ontology#H.PNDS
http://www.geonames.org/ontology#H.PNDSF
http://www.geonames.org/ontology#H.PNDSI
http://www.geonames.org/ontology#H.PNDSN
http://www.geonames.org/ontology#H.POOL
http://www.geonames.org/ontology#H.POOLI
http://www.geonames.org/ontology#H.RCH
http://www.geonames.org/ontology#H.RDGG
http://www.geonames.org/ontology#H.RDST
http://www.geonames.org/ontology#H.RF
http://www.geonames.org/ontology#H.RFC
http://www.geonames.org/ontology#H.RFX
http://www.geonames.org/ontology#H.RPDS
http://www.geonames.org/ontology#H.RSV
http://www.geonames.org/ontology#H.RSVI
http://www.geonames.org/ontology#H.RSVT
http://www.geonames.org/ontology#H.RVN
http://www.geonames.org/ontology#H.SBKH
http://www.geonames.org/ontology#H.SD
http://www.geonames.org/ontology#H.SEA

http://www.geonames.org/ontology#H.SHOL
http://www.geonames.org/ontology#H.SILL
http://www.geonames.org/ontology#H.SPNG
http://www.geonames.org/ontology#H.SPNS
http://www.geonames.org/ontology#H.SPNT
http://www.geonames.org/ontology#H.STM
http://www.geonames.org/ontology#H.STMA
http://www.geonames.org/ontology#H.STMB
http://www.geonames.org/ontology#H.STMC
http://www.geonames.org/ontology#H.STMD
http://www.geonames.org/ontology#H.STMH
http://www.geonames.org/ontology#H.STMI
http://www.geonames.org/ontology#H.STMIX
http://www.geonames.org/ontology#H.STMM
http://www.geonames.org/ontology#H.STMQ
http://www.geonames.org/ontology#H.STMS
http://www.geonames.org/ontology#H.STMSB
http://www.geonames.org/ontology#H.STMX
http://www.geonames.org/ontology#H.STRT
http://www.geonames.org/ontology#H.SWMP
http://www.geonames.org/ontology#H.SYSI
http://www.geonames.org/ontology#H.TNLC
http://www.geonames.org/ontology#H.WAD
http://www.geonames.org/ontology#H.WADB
http://www.geonames.org/ontology#H.WADJ
http://www.geonames.org/ontology#H.WADM
http://www.geonames.org/ontology#H.WADS
http://www.geonames.org/ontology#H.WADX
http://www.geonames.org/ontology#H.WHRL
http://www.geonames.org/ontology#H.WLL
http://www.geonames.org/ontology#H.WLLQ
http://www.geonames.org/ontology#H.WLLS
http://www.geonames.org/ontology#H.WTLD
http://www.geonames.org/ontology#H.WTLDI
http://www.geonames.org/ontology#H.WTRC
http://www.geonames.org/ontology#H.WTRH
http://www.geonames.org/ontology#L.AGRC

http://www.geonames.org/ontology#L.AMUS
http://www.geonames.org/ontology#L.AREA
http://www.geonames.org/ontology#L.BSND
http://www.geonames.org/ontology#L.BSNP
http://www.geonames.org/ontology#L.BTL
http://www.geonames.org/ontology#L.CLG
http://www.geonames.org/ontology#L.CMN
http://www.geonames.org/ontology#L.CNS
http://www.geonames.org/ontology#L.COLF
http://www.geonames.org/ontology#L.CONT
http://www.geonames.org/ontology#L.CST
http://www.geonames.org/ontology#L.CTRB
http://www.geonames.org/ontology#L.DEVH
http://www.geonames.org/ontology#L.FLD
http://www.geonames.org/ontology#L.FLDI
http://www.geonames.org/ontology#L.GASF
http://www.geonames.org/ontology#L.GRAZ
http://www.geonames.org/ontology#L.GVL
http://www.geonames.org/ontology#L.INDS
http://www.geonames.org/ontology#L.LAND
http://www.geonames.org/ontology#L.LCTY
http://www.geonames.org/ontology#L.MILB
http://www.geonames.org/ontology#L.MNA
http://www.geonames.org/ontology#L.MVA
http://www.geonames.org/ontology#L.NVB
http://www.geonames.org/ontology#L.OAS
http://www.geonames.org/ontology#L.OILF
http://www.geonames.org/ontology#L.PEAT
http://www.geonames.org/ontology#L.PRK
http://www.geonames.org/ontology#L.PRT
http://www.geonames.org/ontology#L.QCKS
http://www.geonames.org/ontology#L.REP
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http://www.geonames.org/ontology#U.RDSU
http://www.geonames.org/ontology#U.RFSU
http://www.geonames.org/ontology#U.RFU
http://www.geonames.org/ontology#U.RISU
http://www.geonames.org/ontology#U.RMPU
http://www.geonames.org/ontology#U.RNGU
http://www.geonames.org/ontology#U.SCNU
http://www.geonames.org/ontology#U.SCSU
http://www.geonames.org/ontology#U.SDLU
http://www.geonames.org/ontology#U.SHFU
http://www.geonames.org/ontology#U.SHLU
http://www.geonames.org/ontology#U.SHSU
http://www.geonames.org/ontology#U.SHVU
http://www.geonames.org/ontology#U.SILU
http://www.geonames.org/ontology#U.SLPU
http://www.geonames.org/ontology#U.SMSU
http://www.geonames.org/ontology#U.SMU
http://www.geonames.org/ontology#U.SPRU
http://www.geonames.org/ontology#U.TERU
http://www.geonames.org/ontology#U.TMSU
http://www.geonames.org/ontology#U.TMTU
http://www.geonames.org/ontology#U.TNGU
http://www.geonames.org/ontology#U.TRGU
http://www.geonames.org/ontology#U.TRNU
http://www.geonames.org/ontology#U.VALU
http://www.geonames.org/ontology#U.VLSU
http://www.geonames.org/ontology#V.BUSH
http://www.geonames.org/ontology#V.CULT
http://www.geonames.org/ontology#V.FRST
http://www.geonames.org/ontology#V.FRSTF
http://www.geonames.org/ontology#V.GRSLD
http://www.geonames.org/ontology#V.GRVC
http://www.geonames.org/ontology#V.GRVO
http://www.geonames.org/ontology#V.GRVP
http://www.geonames.org/ontology#V.GRVPN
http://www.geonames.org/ontology#V.HTH
http://www.geonames.org/ontology#V.MDW

http://www.geonames.org/ontology#V.OCH
http://www.geonames.org/ontology#V.SCRB
http://www.geonames.org/ontology#V.TREE
http://www.geonames.org/ontology#V.TUND
http://www.geonames.org/ontology#V.VIN
http://www.geonames.org/ontology#V.VINS
http://www.geonames.org/ontology#A.ADM1H
http://www.geonames.org/ontology#A.ADM2H
http://www.geonames.org/ontology#A.ADM3H
http://www.geonames.org/ontology#A.ADM4H
http://www.geonames.org/ontology#A.ADMH
http://www.geonames.org/ontology#A.PCLH
http://www.geonames.org/ontology#A.PPCLH
http://www.geonames.org/ontology#A.PPLH
http://www.geonames.org/ontology#L.RGNH
http://www.geonames.org/ontology#S.HMSD

Geonames_ObjectProperties
http://www.geonames.org/ontology#featureClass
http://www.geonames.org/ontology#featureCode
http://www.geonames.org/ontology#parentFeature
http://www.geonames.org/ontology#parentCountry
http://www.geonames.org/ontology#parentADM1
http://www.geonames.org/ontology#nearbyFeatures
http://www.geonames.org/ontology#locationMap
http://www.geonames.org/ontology#parentADM2
http://www.geonames.org/ontology#parentADM3
http://www.geonames.org/ontology#parentADM4
http://www.geonames.org/ontology#childrenFeatures
http://www.geonames.org/ontology#locatedIn
http://www.geonames.org/ontology#nearby
http://www.geonames.org/ontology#neighbour
http://www.geonames.org/ontology#neighbouringFeatures
http://www.geonames.org/ontology#wikipediaArticle

Geonames_DatatypeProperties

http://www.geonames.org/ontology#name
http://www.geonames.org/ontology#countryCode
http://xmlns.com/foaf/0.1/name
http://www.geonames.org/ontology#geonamesID
http://www.geonames.org/ontology#population
http://www.geonames.org/ontology#alternateName
http://www.geonames.org/ontology#colloquialName
http://www.geonames.org/ontology#historicalName
http://www.geonames.org/ontology#officialName
http://www.w3.org/2004/02/skos/core#prefLabel
http://www.geonames.org/ontology#postalCode
http://www.geonames.org/ontology#shortName
http://www.w3.org/2004/02/skos/core#notation

ANNEX C

LGD CLASSES, OBJECT PROPERTIES AND DATATYPE PROPERTIES

LGD_Classes
http://linkedgeodata.org/ontology/CycleBarrier
http://linkedgeodata.org/ontology/%3C%D1%80%D0%B0%D0%B7%D0%BB%D0%B8%D1%87%D0%BD%D1%8B%D0%B5%3E
http://linkedgeodata.org/ontology/RailwayMilestone
http://linkedgeodata.org/ontology/BarrierStile
http://linkedgeodata.org/ontology/Union+Station+-+Navy+Yard+Metro
http://linkedgeodata.org/ontology/HighwayPlatform
http://linkedgeodata.org/ontology/SpeedCamera
http://linkedgeodata.org/ontology/Woodley+Park+-+Adams+Morgan+-+McPherson+Square+Metro
http://linkedgeodata.org/ontology/HighwaySign
http://linkedgeodata.org/ontology/TollBridge
http://linkedgeodata.org/ontology/Generator
http://linkedgeodata.org/ontology/Viva+Blue
http://linkedgeodata.org/ontology/HighwayGate
http://linkedgeodata.org/ontology/BicycleLockers
http://linkedgeodata.org/ontology/PowerTower
http://linkedgeodata.org/ontology/HampshireGate
http://linkedgeodata.org/ontology/HighwayFIXME
http://linkedgeodata.org/ontology/ObservationTower
http://linkedgeodata.org/ontology/Highway%3Cdifferent%3E
http://linkedgeodata.org/ontology/Hedge
http://linkedgeodata.org/ontology/HighwayJunction
http://linkedgeodata.org/ontology/BarrierGate
http://linkedgeodata.org/ontology/PrimaryLink
http://linkedgeodata.org/ontology/MiniRoundabout
http://linkedgeodata.org/ontology/ManMadeFireHydrant
http://linkedgeodata.org/ontology/MarkedTrail
http://linkedgeodata.org/ontology/PowerConstruction

http://linkedgeodata.org/ontology/Chicane
http://linkedgeodata.org/ontology/HighwayService
http://linkedgeodata.org/ontology/HighwayCheckpoint
http://linkedgeodata.org/ontology/Squeeze
http://linkedgeodata.org/ontology/BarrierTollBooth
http://linkedgeodata.org/ontology/Wall
http://linkedgeodata.org/ontology/WasteBin
http://linkedgeodata.org/ontology/StepOver
http://linkedgeodata.org/ontology/HighwaySpeedBump
http://linkedgeodata.org/ontology/BarrierEntrance
http://linkedgeodata.org/ontology/BarrierBuoy
http://linkedgeodata.org/ontology/HighwaySignpost
http://linkedgeodata.org/ontology/R76
http://linkedgeodata.org/ontology/Turnstile
http://linkedgeodata.org/ontology/AbandonedStation
http://linkedgeodata.org/ontology/HalfLiftGate
http://linkedgeodata.org/ontology/Survey
http://linkedgeodata.org/ontology/StoppingPoint
http://linkedgeodata.org/ontology/HouseConnectionBox
http://linkedgeodata.org/ontology/Transformer
http://linkedgeodata.org/ontology/Gate%3Alift
http://linkedgeodata.org/ontology/HighwayBusStation
http://linkedgeodata.org/ontology/Primary
http://linkedgeodata.org/ontology/Chain
http://linkedgeodata.org/ontology/HighwayCattleGrid
http://linkedgeodata.org/ontology/Stones
http://linkedgeodata.org/ontology/TrafficCalming
http://linkedgeodata.org/ontology/CycleGate
http://linkedgeodata.org/ontology/Steps
http://linkedgeodata.org/ontology/Secondary
http://linkedgeodata.org/ontology/HighwayTrack
http://linkedgeodata.org/ontology/LevelCrossing
http://linkedgeodata.org/ontology/Signal
http://linkedgeodata.org/ontology/R77
http://linkedgeodata.org/ontology/Bollard
http://linkedgeodata.org/ontology/Traffic+signals
http://linkedgeodata.org/ontology/Path

http://linkedgeodata.org/ontology/LightRail
http://linkedgeodata.org/ontology/Box
http://linkedgeodata.org/ontology/TollGantry
http://linkedgeodata.org/ontology/Convention+Center+-+SW+Waterfront
http://linkedgeodata.org/ontology/RailwayCrossing
http://linkedgeodata.org/ontology/RailwayPlatform
http://linkedgeodata.org/ontology/PrimaryJunction
http://linkedgeodata.org/ontology/Node
http://linkedgeodata.org/ontology/PostBox
http://linkedgeodata.org/ontology/Amenity
http://linkedgeodata.org/ontology/TourismInformation
http://linkedgeodata.org/ontology/Fuel
http://linkedgeodata.org/ontology/City
http://linkedgeodata.org/ontology/Waterway
http://linkedgeodata.org/ontology/BicycleParking
http://linkedgeodata.org/ontology/Village
http://linkedgeodata.org/ontology/Surveillance
http://linkedgeodata.org/ontology/Cinema
http://linkedgeodata.org/ontology/Viewpoint
http://linkedgeodata.org/ontology/Mast
http://linkedgeodata.org/ontology/Attraction
http://linkedgeodata.org/ontology/Leisure
http://linkedgeodata.org/ontology/SurveyPoint
http://linkedgeodata.org/ontology/NaturalWood
http://linkedgeodata.org/ontology/Sport
http://linkedgeodata.org/ontology/Hostel
http://linkedgeodata.org/ontology/Wetland
http://linkedgeodata.org/ontology/Restaurant
http://linkedgeodata.org/ontology/Farm
http://linkedgeodata.org/ontology/Marina
http://linkedgeodata.org/ontology/CaravanSite
http://linkedgeodata.org/ontology/AerialwayStation
http://linkedgeodata.org/ontology/Aerialway
http://linkedgeodata.org/ontology/Telephone
http://linkedgeodata.org/ontology/Weir
http://linkedgeodata.org/ontology/State
http://linkedgeodata.org/ontology/Derestricted+speed+limit

http://linkedgeodata.org/ontology/Layby
http://linkedgeodata.org/ontology/NaturalBeach
http://linkedgeodata.org/ontology/Cairn
http://linkedgeodata.org/ontology/Aqueduct
http://linkedgeodata.org/ontology/Boatyard
http://linkedgeodata.org/ontology/PublicBuilding
http://linkedgeodata.org/ontology/Basketball
http://linkedgeodata.org/ontology/AerowayTower
http://linkedgeodata.org/ontology/Works
http://linkedgeodata.org/ontology/DepartmentStore
http://linkedgeodata.org/ontology/TourismGallery
http://linkedgeodata.org/ontology/Building
http://linkedgeodata.org/ontology/AlpineHut
http://linkedgeodata.org/ontology/WasteDisposal
http://linkedgeodata.org/ontology/TableTennis
http://linkedgeodata.org/ontology/Bank
http://linkedgeodata.org/ontology/Fountain
http://linkedgeodata.org/ontology/IceCream
http://linkedgeodata.org/ontology/PicnicArea
http://linkedgeodata.org/ontology/Fishing
http://linkedgeodata.org/ontology/GuestHouse
http://linkedgeodata.org/ontology/Vacant
http://linkedgeodata.org/ontology/Bay
http://linkedgeodata.org/ontology/Consulate
http://linkedgeodata.org/ontology/BuildingChapel
http://linkedgeodata.org/ontology/Croquet
http://linkedgeodata.org/ontology/Casino
http://linkedgeodata.org/ontology/Sluice
http://linkedgeodata.org/ontology/Stationery
http://linkedgeodata.org/ontology/HistoricWell
http://linkedgeodata.org/ontology/Scree
http://linkedgeodata.org/ontology/Point
http://linkedgeodata.org/ontology/Internet
http://linkedgeodata.org/ontology/Centre
http://linkedgeodata.org/ontology/BorderControl
http://linkedgeodata.org/ontology/LanduseIndustrial
http://linkedgeodata.org/ontology/Windsock

http://linkedgeodata.org/ontology/NotAShop
http://linkedgeodata.org/ontology/NaturalStone
http://linkedgeodata.org/ontology/ReservoirCovered
http://linkedgeodata.org/ontology/Athletics
http://linkedgeodata.org/ontology/Nightclub
http://linkedgeodata.org/ontology/SportFishing
http://linkedgeodata.org/ontology/HorseRiding
http://linkedgeodata.org/ontology/MusicVenue
http://linkedgeodata.org/ontology/Volcano
http://linkedgeodata.org/ontology/Tourism
http://linkedgeodata.org/ontology/Parking
http://linkedgeodata.org/ontology/BicycleRental
http://linkedgeodata.org/ontology/Hamlet
http://linkedgeodata.org/ontology/ManMade
http://linkedgeodata.org/ontology/Suburb
http://linkedgeodata.org/ontology/TourismHotel
http://linkedgeodata.org/ontology/BusStation
http://linkedgeodata.org/ontology/Library
http://linkedgeodata.org/ontology/Football
http://linkedgeodata.org/ontology/SportsCentre
http://linkedgeodata.org/ontology/FireStation
http://linkedgeodata.org/ontology/TourismMuseum
http://linkedgeodata.org/ontology/Soccer
http://linkedgeodata.org/ontology/Cricket
http://linkedgeodata.org/ontology/Bench
http://linkedgeodata.org/ontology/PicnicSite
http://linkedgeodata.org/ontology/Canal
http://linkedgeodata.org/ontology/Convenience
http://linkedgeodata.org/ontology/Newsagent
http://linkedgeodata.org/ontology/Theatre
http://linkedgeodata.org/ontology/TourismArtwork
http://linkedgeodata.org/ontology/Atm
http://linkedgeodata.org/ontology/HistoricTower
http://linkedgeodata.org/ontology/Shops
http://linkedgeodata.org/ontology/Courthouse
http://linkedgeodata.org/ontology/ArtsCentre
http://linkedgeodata.org/ontology/HistoricRuins

http://linkedgeodata.org/ontology/HistoricBuilding
http://linkedgeodata.org/ontology/CarRepairShop
http://linkedgeodata.org/ontology/TourismZoo
http://linkedgeodata.org/ontology/10pin
http://linkedgeodata.org/ontology/ChurchHall
http://linkedgeodata.org/ontology/Waterfall
http://linkedgeodata.org/ontology/HistoricHouse
http://linkedgeodata.org/ontology/Paintball
http://linkedgeodata.org/ontology/Stream
http://linkedgeodata.org/ontology/CommunityCentre
http://linkedgeodata.org/ontology/Shower
http://linkedgeodata.org/ontology/Gasometer
http://linkedgeodata.org/ontology/Motorcycle
http://linkedgeodata.org/ontology/Kindergarten
http://linkedgeodata.org/ontology/HorseRacing
http://linkedgeodata.org/ontology/Electronics
http://linkedgeodata.org/ontology/Bbq
http://linkedgeodata.org/ontology/BuildingChurch
http://linkedgeodata.org/ontology/Retail
http://linkedgeodata.org/ontology/Bar
http://linkedgeodata.org/ontology/Gymnastics
http://linkedgeodata.org/ontology/Kiosk
http://linkedgeodata.org/ontology/Cliff
http://linkedgeodata.org/ontology/FloristShop
http://linkedgeodata.org/ontology/WastewaterPlant
http://linkedgeodata.org/ontology/Battlefield
http://linkedgeodata.org/ontology/VendingMachine
http://linkedgeodata.org/ontology/Prison
http://linkedgeodata.org/ontology/Archery
http://linkedgeodata.org/ontology/DisusedPub
http://linkedgeodata.org/ontology/RecreationGround
http://linkedgeodata.org/ontology/FoodCourt
http://linkedgeodata.org/ontology/Climbing
http://linkedgeodata.org/ontology/CaveEntrance
http://linkedgeodata.org/ontology/NaturalWater
http://linkedgeodata.org/ontology/Skiing
http://linkedgeodata.org/ontology/Gym

http://linkedgeodata.org/ontology/Crematorium
http://linkedgeodata.org/ontology/BuildingEntrance
http://linkedgeodata.org/ontology/Municipality
http://linkedgeodata.org/ontology/Motor
http://linkedgeodata.org/ontology/Alcohol
http://linkedgeodata.org/ontology/EstateAgent
http://linkedgeodata.org/ontology/Optician
http://linkedgeodata.org/ontology/InternetCafe
http://linkedgeodata.org/ontology/Beverages
http://linkedgeodata.org/ontology/Biergarten
http://linkedgeodata.org/ontology/Organic
http://linkedgeodata.org/ontology/Books
http://linkedgeodata.org/ontology/Runway
http://linkedgeodata.org/ontology/Badminton
http://linkedgeodata.org/ontology/LitterBin
http://linkedgeodata.org/ontology/DeadPub
http://linkedgeodata.org/ontology/County
http://linkedgeodata.org/ontology/Skating
http://linkedgeodata.org/ontology/Country
http://linkedgeodata.org/ontology/Stripclub
http://linkedgeodata.org/ontology/Lookout
http://linkedgeodata.org/ontology/ScubaDivingShop
http://linkedgeodata.org/ontology/PlaceOfWorship
http://linkedgeodata.org/ontology/Pub
http://linkedgeodata.org/ontology/Island
http://linkedgeodata.org/ontology/Place
http://linkedgeodata.org/ontology/Natural
http://linkedgeodata.org/ontology/Monument
http://linkedgeodata.org/ontology/Historic
http://linkedgeodata.org/ontology/RailwayStation
http://linkedgeodata.org/ontology/Landuse
http://linkedgeodata.org/ontology/Railway
http://linkedgeodata.org/ontology/Memorial
http://linkedgeodata.org/ontology/Marsh
http://linkedgeodata.org/ontology/GolfCourse
http://linkedgeodata.org/ontology/ManMadeTower
http://linkedgeodata.org/ontology/Park

http://linkedgeodata.org/ontology/ArchaeologicalSite
http://linkedgeodata.org/ontology/Hill
http://linkedgeodata.org/ontology/Aeroway
http://linkedgeodata.org/ontology/CarRental
http://linkedgeodata.org/ontology/CarSharing
http://linkedgeodata.org/ontology/ThemePark
http://linkedgeodata.org/ontology/Hospital
http://linkedgeodata.org/ontology/Stadium
http://linkedgeodata.org/ontology/Castle
http://linkedgeodata.org/ontology/VillageHall
http://linkedgeodata.org/ontology/Hide
http://linkedgeodata.org/ontology/FerryTerminal
http://linkedgeodata.org/ontology/Nursery
http://linkedgeodata.org/ontology/Beacon
http://linkedgeodata.org/ontology/WasteBasket
http://linkedgeodata.org/ontology/Slipway
http://linkedgeodata.org/ontology/Watermill
http://linkedgeodata.org/ontology/Mall
http://linkedgeodata.org/ontology/HealthCentre
http://linkedgeodata.org/ontology/WaterTower
http://linkedgeodata.org/ontology/Garden
http://linkedgeodata.org/ontology/Doctors
http://linkedgeodata.org/ontology/NaturalSpring
http://linkedgeodata.org/ontology/BuildingBarn
http://linkedgeodata.org/ontology/Lighthouse
http://linkedgeodata.org/ontology/Mooring
http://linkedgeodata.org/ontology/WaterPoint
http://linkedgeodata.org/ontology/SportScubaDiving
http://linkedgeodata.org/ontology/Rugby
http://linkedgeodata.org/ontology/MilitaryBunker
http://linkedgeodata.org/ontology/Military
http://linkedgeodata.org/ontology/GardenCentre
http://linkedgeodata.org/ontology/IceCreamShop
http://linkedgeodata.org/ontology/NatureReserve
http://linkedgeodata.org/ontology/GraveYard
http://linkedgeodata.org/ontology/Curling
http://linkedgeodata.org/ontology/Skateboard

http://linkedgeodata.org/ontology/LanduseRetail
http://linkedgeodata.org/ontology/WaterPark
http://linkedgeodata.org/ontology/Track
http://linkedgeodata.org/ontology/ManMadePumpingStation
http://linkedgeodata.org/ontology/Butcher
http://linkedgeodata.org/ontology/Manor
http://linkedgeodata.org/ontology/HistoricChurch
http://linkedgeodata.org/ontology/TricycleStation
http://linkedgeodata.org/ontology/Riverbank
http://linkedgeodata.org/ontology/Palace
http://linkedgeodata.org/ontology/DryCleaning
http://linkedgeodata.org/ontology/LanduseCemetery
http://linkedgeodata.org/ontology/Hardware
http://linkedgeodata.org/ontology/LanduseFarm
http://linkedgeodata.org/ontology/IceRink
http://linkedgeodata.org/ontology/Rapids
http://linkedgeodata.org/ontology/SkatePark
http://linkedgeodata.org/ontology/Well
http://linkedgeodata.org/ontology/CarWash
http://linkedgeodata.org/ontology/FireHydrant
http://linkedgeodata.org/ontology/YouthCentre
http://linkedgeodata.org/ontology/BuildingHouse
http://linkedgeodata.org/ontology/LockGate
http://linkedgeodata.org/ontology/TramStop
http://linkedgeodata.org/ontology/EmergencyPhone
http://linkedgeodata.org/ontology/School
http://linkedgeodata.org/ontology/Town
http://linkedgeodata.org/ontology/Peak
http://linkedgeodata.org/ontology/Common
http://linkedgeodata.org/ontology/Golf
http://linkedgeodata.org/ontology/ManMadeBarn
http://linkedgeodata.org/ontology/CampSite
http://linkedgeodata.org/ontology/Tea
http://linkedgeodata.org/ontology/Shop
http://linkedgeodata.org/ontology/Recycling
http://linkedgeodata.org/ontology/Tennis
http://linkedgeodata.org/ontology/Halt

http://linkedgeodata.org/ontology/Police
http://linkedgeodata.org/ontology/Aerodrome
http://linkedgeodata.org/ontology/FastFood
http://linkedgeodata.org/ontology/Cafe
http://linkedgeodata.org/ontology/Toilets
http://linkedgeodata.org/ontology/University
http://linkedgeodata.org/ontology/NaturalTree
http://linkedgeodata.org/ontology/PostOffice
http://linkedgeodata.org/ontology/Shelter
http://linkedgeodata.org/ontology/Motel
http://linkedgeodata.org/ontology/Multi
http://linkedgeodata.org/ontology/Islet
http://linkedgeodata.org/ontology/Grocery
http://linkedgeodata.org/ontology/College
http://linkedgeodata.org/ontology/Windmill
http://linkedgeodata.org/ontology/Bakery
http://linkedgeodata.org/ontology/Townhall
http://linkedgeodata.org/ontology/Taxi
http://linkedgeodata.org/ontology/Playground
http://linkedgeodata.org/ontology/Car
http://linkedgeodata.org/ontology/SwimmingPool
http://linkedgeodata.org/ontology/Swimming
http://linkedgeodata.org/ontology/BicycleShop
http://linkedgeodata.org/ontology/Pitch
http://linkedgeodata.org/ontology/WaysideCross
http://linkedgeodata.org/ontology/Supermarket
http://linkedgeodata.org/ontology/BedAndBreakfast
http://linkedgeodata.org/ontology/Lock
http://linkedgeodata.org/ontology/NaturalWaterfall
http://linkedgeodata.org/ontology/TurningPoint
http://linkedgeodata.org/ontology/Coastline
http://linkedgeodata.org/ontology/Rowing
http://linkedgeodata.org/ontology/Marketplace
http://linkedgeodata.org/ontology/Canoe
http://linkedgeodata.org/ontology/FarmShop
http://linkedgeodata.org/ontology/Doityourself
http://linkedgeodata.org/ontology/Terminal

http://linkedgeodata.org/ontology/Sports
http://linkedgeodata.org/ontology/DrinkingWater
http://linkedgeodata.org/ontology/Baseball
http://linkedgeodata.org/ontology/Helipad
http://linkedgeodata.org/ontology/Beach
http://linkedgeodata.org/ontology/MilitaryAirfield
http://linkedgeodata.org/ontology/Sailing
http://linkedgeodata.org/ontology/Pharmacy
http://linkedgeodata.org/ontology/Equestrian
http://linkedgeodata.org/ontology/FirstAid
http://linkedgeodata.org/ontology/Bowls
http://linkedgeodata.org/ontology/ShelteredHousing
http://linkedgeodata.org/ontology/Dock
http://linkedgeodata.org/ontology/Pier
http://linkedgeodata.org/ontology/BureauDeChange
http://linkedgeodata.org/ontology/Clock
http://linkedgeodata.org/ontology/Dentist
http://linkedgeodata.org/ontology/Greengrocer
http://linkedgeodata.org/ontology/HairdresserShop
http://linkedgeodata.org/ontology/Laundry
http://linkedgeodata.org/ontology/Heritage
http://linkedgeodata.org/ontology/Cards
http://linkedgeodata.org/ontology/Embassy
http://linkedgeodata.org/ontology/WaysideShrine
http://linkedgeodata.org/ontology/SportFitness
http://linkedgeodata.org/ontology/CoastlineOld
http://linkedgeodata.org/ontology/BuildingSchool
http://linkedgeodata.org/ontology/BirdHide
http://linkedgeodata.org/ontology/Fairtrade
http://linkedgeodata.org/ontology/Barracks
http://linkedgeodata.org/ontology/Drain
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http://linkedgeodata.org/ontology/VillageSign
http://linkedgeodata.org/ontology/Allotments
http://linkedgeodata.org/ontology/Fishmonger
http://linkedgeodata.org/ontology/PicnicTable
http://linkedgeodata.org/ontology/ManMadeLamp
http://linkedgeodata.org/ontology/Health
http://linkedgeodata.org/ontology/ShopFIXME
http://linkedgeodata.org/ontology/Table
http://linkedgeodata.org/ontology/K2195
http://linkedgeodata.org/ontology/Rig
http://linkedgeodata.org/ontology/Stationary
http://linkedgeodata.org/ontology/ManMadeSign
http://linkedgeodata.org/ontology/NaturalShelter
http://linkedgeodata.org/ontology/Orienteering
http://linkedgeodata.org/ontology/TourismParking
http://linkedgeodata.org/ontology/BeachResort
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http://linkedgeodata.org/ontology/Borderstone
http://linkedgeodata.org/ontology/Billard
http://linkedgeodata.org/ontology/Souvenir
http://linkedgeodata.org/ontology/BuildingApartments
http://linkedgeodata.org/ontology/ArchitectOffice
http://linkedgeodata.org/ontology/BuildingBuilding
http://linkedgeodata.org/ontology/CitymapPost
http://linkedgeodata.org/ontology/BuildingKiosk
http://linkedgeodata.org/ontology/Picknick
http://linkedgeodata.org/ontology/StreetLight
http://linkedgeodata.org/ontology/BuildingOffice
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http://linkedgeodata.org/ontology/HealthFood
http://linkedgeodata.org/ontology/GovermentBuilding
http://linkedgeodata.org/ontology/BuildingHall
http://linkedgeodata.org/ontology/DogWaste
http://linkedgeodata.org/ontology/WineryShop
http://linkedgeodata.org/ontology/Shipping

http://linkedgeodata.org/ontology/Pavilion
http://linkedgeodata.org/ontology/PetroleumWell
http://linkedgeodata.org/ontology/StoneCircle
http://linkedgeodata.org/ontology/RealEstate
http://linkedgeodata.org/ontology/BuildingNo
http://linkedgeodata.org/ontology/WaterwayRock
http://linkedgeodata.org/ontology/FitnessShop
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http://linkedgeodata.org/ontology/HomeImprovement
http://linkedgeodata.org/ontology/Adult
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http://linkedgeodata.org/ontology/WasteBasket%3Brecycling
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http://linkedgeodata.org/ontology/Keys

http://linkedgeodata.org/ontology/TourismValley
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http://linkedgeodata.org/ontology/TourismObservatory
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http://linkedgeodata.org/ontology/NationalForest
http://linkedgeodata.org/ontology/CarRepair

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http://linkedgeodata.org/ontology/Meadow
http://linkedgeodata.org/ontology/ManMadeStorage
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http://linkedgeodata.org/ontology/Vdsl-aru
http://linkedgeodata.org/ontology/ReceptionArea

LGD_ObjectProperties
http://linkedgeodata.org/ontology/agricultural
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http://linkedgeodata.org/ontology/wheelchair
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http://linkedgeodata.org/ontology/surfaces

LGD_DatatypeProperties
http://www.w3.org/2000/01/rdf-schema#label
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http://linkedgeodata.org/ontology/animals
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http://linkedgeodata.org/ontology/namacity%3Aclassrooms
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http://linkedgeodata.org/ontology/lanes%3Apsv
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http://linkedgeodata.org/ontology/dcgis%3Ashape_len
http://linkedgeodata.org/ontology/tiger%3Azip_left_151
http://linkedgeodata.org/ontology/name%3Akct_learning
http://linkedgeodata.org/ontology/ourfootprints%3Aroad_type
http://linkedgeodata.org/ontology/psv%3Aoneway
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http://linkedgeodata.org/ontology/inline
http://linkedgeodata.org/ontology/census2001%3AVILLCOLLEG

http://linkedgeodata.org/ontology/Wikipedia
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http://linkedgeodata.org/ontology/finely_mown
http://linkedgeodata.org/ontology/is_name
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http://linkedgeodata.org/ontology/track.segregated
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http://linkedgeodata.org/ontology/SETR_CLSE_
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http://linkedgeodata.org/ontology/structure%3Aname
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http://linkedgeodata.org/ontology/NYSTL%3APARCELS_ID

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http://www.w3.org/2003/01/geo/wgs84_pos#geometry
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ANNEX D

RDF GRAPH OF IAINM ONTOLOGY

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