

Automating Government Spatial Transactions

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Abstract: The land development approval process between local authorities and government land and planning departments is manual, time consuming and resource intensive. For example, when new land subdivisions, new roads and road naming, and administrative boundary changes are requested, approval and changes to spatial datasets are needed. The land developer submits plans, usually on paper, and a number of employees use rules, constraints and policies to determine if such plans are acceptable. This paper presents an approach using Semantic Web and Artificial Intelligence techniques to automate the decision-making process in Australian jurisdictions. Feedback on the proposed plan is communicated to the land developer in real-time, thus reducing process handling time for both developer and the government agency. The Web Ontology Language is used to represent relationships between different entities in the spatial database schema. Rules on geometry, policy, naming conventions, standards and other aspects are obtained from government policy documents and subject-matter experts and described using the Semantic Web Rule Language. Then when the developer submits an application, the software checks the rules against the request for compliance. This paper describes the proposed approach and presents a case study that deals with new road proposals and road name approvals.

1 INTRODUCTION

Land developers and local government authorities are required to submit proposals for new subdivisions to land and planning departments for approval. These new subdivisions include new land parcel boundaries, roads and road names, and changes to local authority boundaries. The approval process often spans many work teams and new information, such as property addresses may need to be generated. This manual process can be time consuming and resource intensive.

New methods are required to reduce data handling and support the automation of transactions with government. Current workflows are characterised by several decision points and a trail of paper documents are often created to formalise the decision-making process and to provide a reference point for legal transactions further along the land administration process (Varadharajulu et al., 2015). As a result, there is often a time delay of several weeks during which a new subdivision is considered by authorities from the various land development

and planning perspectives.

This research seeks to automate the spatial transaction process using artificial intelligence with ontologies to create rules that replace the human decision-making process for land development approvals. A case study examining new road proposals, road names and land administration boundary changes is used to demonstrate the approach. This research is being conducted in conjunction with the Western Australian Land Information Authority (Landgate). Landgate is the approving authority for all new subdivisions in Western Australia, and is responsible for land administration boundary changes resulting from land development activity.

The Semantic Web was first introduced by Tim Berners-Lee who imagined it as “a web of data that can be processed directly and indirectly by machines” (Berners-Lee and Fischetti, 1999). This research is inspired by the increased bandwidth of the Internet and advances in Semantic Web technologies, which now make it possible to automate the human elements of the decision-making process on the Web.

Rule-based systems have been used for decision support in the past but these are typically closed client bases systems. However the advantage of the Semantic Web is that the data, ontologies and rules are described using well defined standards (w3c.org) and can be made available over the Web as published resources, typically in one of a number of machine (and human) readable formats (Gupta and Knoblock, 2010). The vision is that, ontologies, especially those of a general nature, can be shared and re-used in many applications. In our case, it is envisaged that once a working solution for the approvals process has been validated for one jurisdiction (Western Australia), the ontologies and rules can be used in other jurisdictions (Victoria, New South Wales etc.) and domains.

The work is part of a research program into Spatial Data Infrastructures being conducted at the Cooperative Research Centre for Spatial Information (CRCSI), Australia. One of the objectives of the research program is to automate spatial data supply chains from end-to-end to enable access to the right data, at the right time, at the right price (McMeekin and West, 2012).

This research is focusing on the first stage in the spatial data supply chain process, which is the creation of spatial data generated through a land development business process. Instead of paper-based systems, the method enables the capture of spatial information in machine-readable form at its inception point. This is a significant step towards achieving downstream workflow automation. It also supports the recording of data provenance in machine-readable form at the commencement of a spatial transaction to support legal and data quality attribution.

The development consists of two stages. In the first stage, a GUI-based interactive system called Protégé is used to design ontologies and rules from spatial data schema and various documents including policies. The second stage uses a runtime environment (Jena and Java) to process the ontologies and rules along with existing and proposed road data to determine compliance with policies etc.

2 BACKGROUND AND RELATED RESEARCH

Methods for spatial data processing and integration have been researched and developed over the past few years, however little work has considered the

automation of the decision-making process where spatial data is an input to the approval process.

One of the objectives of the Semantic Web is to evolve into a universal medium for information, data and knowledge exchange, rather than just being a source for information. To attain this, it uses the well known http protocol and technologies (Shadbolt et al., 2006) (Millard, 2010), such as URIs (Universal Resource Identifiers), RDF (Resource Description Framework) and ontologies with reasoning and rules.

One of the most important components is the RDF, which is a language for representing information about resources on the Web (<http://www.w3.org/RDF/>). RDF aims to organize information in a machine-readable format by representing information as triples: <subject, predicate, object>, a concept from the artificial intelligence community. RDF was originally considered as metadata but now covers data as well. RDF triples can be used to represent tables, graphs, trees, ontologies and rules because it describes the relationship between subject and object resources where a 'object in the <subject, predicate, object> triple can be another subject enabling subjects to be linked together. Each of the triple components can also be a URI so information can be linked across the Web. RDF formatted data is much easier to process, because its generic format contains information that is clearly understandable as a distributed model.

Reasoning and rules are an important part of this research and in the Semantic Web, the Ontology Web Language (OWL-2), based on RDF, is used for defining Web ontologies that include rules, axioms and constraints allowing inferencing (discovery of new knowledge) to be performed.

The Semantic Web has been used for queries by a user for natural events using observation sensor data (Devaraju et al., 2015) (Yu and Liu, 2013). In particular Devaraju et al (2015) describe a number of ontologies used to model various sensors and rules used to map queries such as flooding in an area to the need to sample a number of point water sensors. Methods have been proposed that have potential to automate land development approval processes. For example, the Sensing Geographical Occurrences Ontology (SEGO) model supports inferences of institutionalized events (Reitsma, 2005) based on time. However they do not resolve any conflicts arising if an event qualifies based on both policy and business rules. This research does not cover the sensor-specific technical details (Reitsma, 2005), but instead concentrates on the business knowledge rules.

A large number of open source and proprietary tools are available for semantic web research and development. This research uses the Protégé framework (<http://protege.stanford.edu/>) to develop ontologies and rules because its GUI environment allows fast design, interactive navigation of the relationships in OWL ontologies and visualization. It allows some rule-based analysis to be performed and can read and write RDF-based files in a number of different formats. Rules are defined in the form of ontological vocabularies using SWRL. Like many other rule languages, a SWRL rule has the form of a link between antecedent and consequent. The antecedent refers to the body of the rule, consisting or one or more conditions, and the consequent refers to its head, typically one condition. Whenever the conditions specified in the antecedent are satisfied, those specified in the consequent must also be satisfied (O'Connor et al., 2005). Once ontologies and rules have been defined, they can be imported into the Apache Jena framework complete with the Pellet reasoner (<http://clarkparsia.com/pellet/>) to support OWL for runtime querying and analysis (Segaran et al., 2009). Combining both Jena and OWL API libraries, Pellet infers logical consequences from a set of asserted facts or axioms.

3 CASE STUDY

Landgate administers all official naming actions for Western Australia under the authority of the Minister for Lands. The relevant local government authority generally submits all naming proposals for ratification by Landgate. All new proposals must satisfy government policies and standards. The current process has an online submission form, but for the most part the process is paper-based and requires significant human involvement. Current methods often require negotiation between the parties involved (i.e. local government and Landgate). While there are specific rules applying to new road name approvals, there are grey areas within policy that are often challenged and can only be resolved by an experienced negotiator. A request for a new road name may be transferred back-and-forth until an outcome is achieved that is satisfactory to both parties. Outcomes may be different depending on the expertise of the negotiator/approver.

Automation is needed to reduce the manual overhead by extracting expert knowledge for road name approvals to create a standard set of rules. The notion is to create a self-service online mechanism

for developers to submit new road names for approval, underpinned by a complex rule-base and querying process. Complexity comes from the flow on effect of such changes. A new land development results in a change to the surrounding road network. This has a flow on impact to property street addressing and an administrative boundary change.

The case study uses the Landgate geographic road names database, called GEONOMA, to process the road name proposal. The current online submission process has the following issues that complicate the approval process:

- The online form is only used to test whether new road names are allowable based on a set of road names that have been reserved for use. If a proposed name is a reserved road name then the request will fail. There is no opportunity to contest the decision.
- A maximum of ten names per application is allowed; meaning separate applications are required for larger subdivisions. It is not possible to conduct cross-reference checks against other submissions and therefore the process is open to error.
- The current system does not consider the spatial extent of roads. Figure 1 shows a schematic submitted for road name approvals that does not represent the actual proposed location of roads. Roads do not actually meet up; they are stylized with solid and dashed lines with arrows etc. Manual editing and digitising is therefore necessary to extract the full topology of the proposed road network complete with coordinates of junctions.
- The current system does not permit checks on phonetics and this is an issue for similar

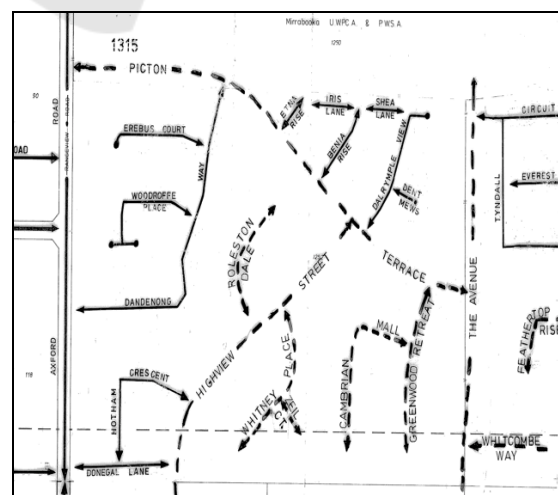


Figure 1: Hardcopy road network plan with road name application.

sounding names (e.g., Bailey, Baylee, Bayley, Baylea). Similar or ‘like’ names (e.g. Whyte and White) are not allowable under policy guidelines as they can cause confusion for applications such as emergency services dispatch. Similarly, the same road name or a similar sounding road name is not permitted within close proximity.

- Where an extension to an existing road occurs or where a road ‘type’ (e.g. cul-de-sac, highway) changes, the current system is unable to return an extension to a road name or change to road suffix, respectively

4 APPROACH

Figure 2 shows the different phases in the land transaction process from knowledge acquisition to

final feedback. Data is extracted from the various databases in formats such as html, json, csv and xml and converted to RDF. Ontologies in OWL are created from database schema and models in the interactive GUI based Protégé environment. Rules are generated in SWRL by an expert. Once the system has been developed, the data, ontologies and rules can be used in the runtime environment Jena with a rule engine by a developer to process road changes.

4.1 Knowledge Acquisition

Knowledge acquisition was used to extract, structure and organise knowledge from policy documents, data dictionaries and by interviewing subject matter experts. This knowledge was then used to create the road naming rules. The knowledge acquisition process used the following sources:

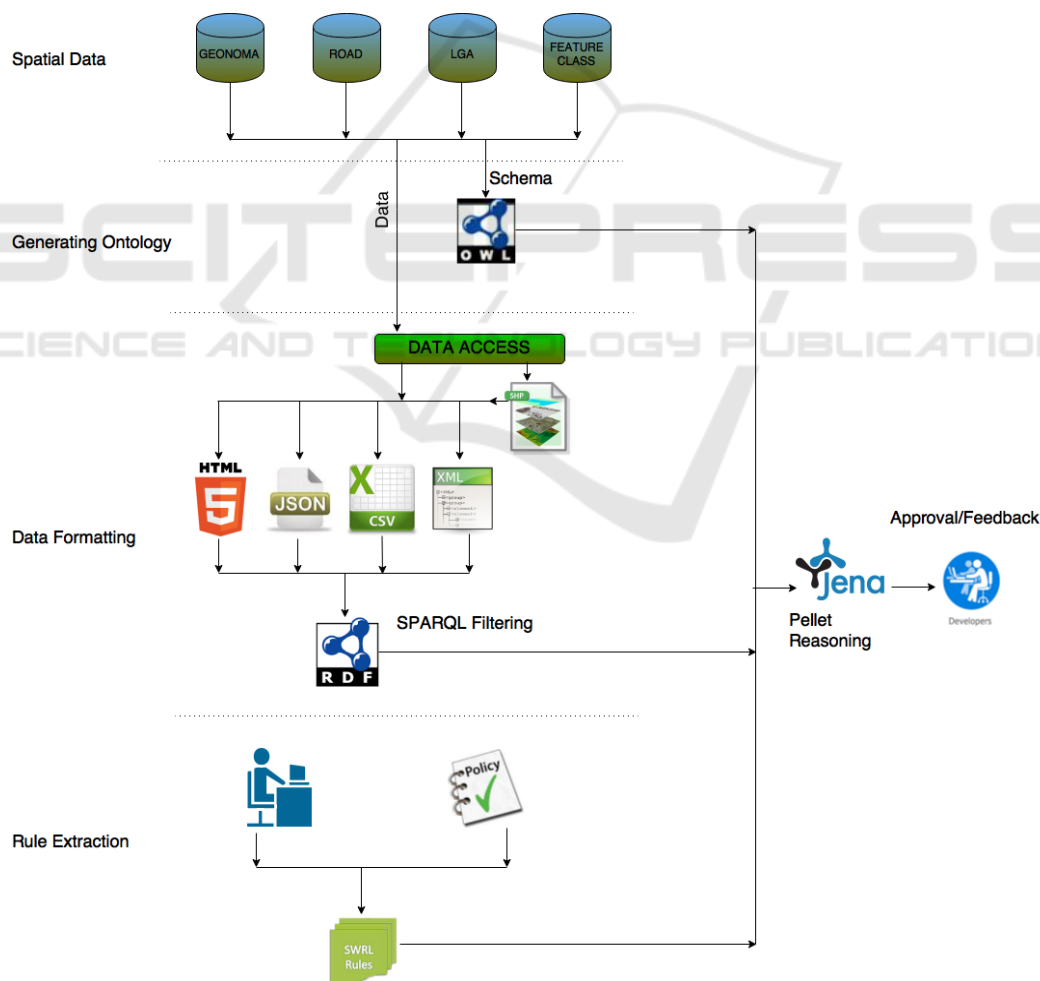


Figure 2: Data integration/reasoning architecture.

- 1 Rules sourced from policy standards:
 - A road name cannot be used if it already exists within a 10km radius of the new road in city areas or 50km in rural areas
 - A road name may not be used more than 15 times in the State of Western Australia
- 2 Rules sourced by interviewing subject matter experts:
 - A name must not relate to a commercial business trading name or non-profit organisation
 - A name must not sound like an existing name
 - A name with the suffix type 'place' or 'close' cannot be assigned to a road greater than a specified length (200m)
 - A historical name, such as ANZAC, cannot be used
 - A name with road type 'rise' can only be used for roads that have elevation or are at an incline
 - Abbreviated names derived from the suburb name are not acceptable for new road names
- 3 Rules sourced by accessing data dictionaries:
 - Discriminatory or derogatory names are not allowed
 - A name in an original Australian Indigenous language will be considered for a new road name with reference to its origin

With the current traditional naming process, satisfying the rules identified above is time consuming because of the back-and-forth process between developer and approver. As an example, from a process perspective, when a land developer or local authority requests a new road name within a development site, a spatial validation process is run to test whether the proposed name:

- is already in use in the local authority and if so, whether it is within 10km of the new site; and
- has already been used 15 times across the State.

In addition to policy rules, subject matter experts use broader contextual knowledge when determining if a new road name is valid. For example, during the approval process experts check the scope for the proposed subdivision within the wider development site to avoid subsequent changes resulting from incorrect initial decisions.

Figure 3 presents a further example of where expert knowledge in the road naming process, from initial application to final approval, is required. During the negotiation phase with the land developer, documents are transferred back and forth between both parties; each making changes to a paper plan by way of communication. The following

notes, written by Landgate to the developer, illustrate typical negotiations (See Figure 3):

- Jindee Avenue: The road type is suitable, however the name Jindee is not. Apart from sounding similar to the suburb name, this is also an abbreviated name derived from the suburb name and is not acceptable. A replacement name is required.
- Limestone Street and Twinfin Way: The street is continuous so one street name can be used for this street.
- Noserider Drive: The name is suitable, however the road type Drive is not (as this road is adjacent below in this case) to a future open space then relevant types are Way, Vista, View, or if it shaped like a crescent, then Crescent can be used).
- Longboard Lane: The name complies with policy, however it is too long a word for that road. Also a portion of the extent is a part of Hilltop Lane (mentioned in green). A short name with its origin is required. Alternatively, the developer can hold the name Longboard for future use when a long road name is needed in the vicinity.
- Lifesaver Lane: the name is suitable, however it appears that there will be a third entry off Twinfin Court. Clarification of this will be necessary and an additional name for a portion (i.e. the northern east/west portion) will be needed.
- Midsummer Avenue and Treat Street: extensions are suitable because there are possibilities for the future development. The roads on the south side of Jindee Avenue (A & B) are currently unnamed as they are part of a later development stage.

4.2 Ontology Development

Once the rules behind both policy standards and business processes are understood, the next step is to generate the ontology model from multiple sources of information. This ontology is developed as a global schema that means that while it works with the Landgate GEONOMA database, it can also be used in conjunction with other databases that link the spatial extent of a road to the road naming process. Figure 4 presents an overview of the generated Geo_feature ontology containing classes, data and object properties, and instances. Links show relationships such as domain, range and subClassOf. The ontological components are summarised below.

4.2.1 Geo_feature Ontology

The GEONOMA dataset is exported to XML and then imported into Protégé to help with the ontology generation process. Protégé was chosen as it is an open source tool with wide community support that supports ontology development and reasoning, and importantly OWL DL, W3C description logic standard. The Geo_feature ontology consists of OWL classes, data and object properties, and individuals and is expressed in the form of OWL-2. Each OWL class is associated with a set of individuals. Object properties link individuals of one class to other class individuals. Data properties link one individual to its data values. Value constraints and cardinality constraints are used to restrict the attributes of the individual. For example each ROAD instance much have only one ROAD_TYPE through an object property link. Figure 5 shows the relationships between class instances. An example for a ROAD_TYPE instance is shown at bottom right. It has property restrictions handled by cardinality constraints. Each instance must have information about its type, description and whether

it is a cul-de-sac or an open ended road type. Typically, further work is required to create the full semantics in the ontology. All semantic relationships (links) between data components are needed because mapping from datasets directly is not adequate to explain the full model (Ghawi and Cullot, 2009). For example, every instance of ROAD, LGA and LOCALITY has a link with an instance of GEONOMA. Similarly every ROAD has a link with LGA and LOCALITY. These are inferred in Protégé by invoking the OWL-DL rule reasoner.

4.2.2 Ontological Classifications and Spatial Relations

The resulting Geo_feature ontology represents the spatial relationship between several datasets including the road network, local government authority boundaries, locality and language. These datasets combined are used in the road name approval process and checked for constraints. The spatial relationship distinction is mainly based on source datasets. However, from a realistic viewpoint, these source datasets can only supply



Figure 3: Road Naming process in Jindalee-City of Wanneroo Western Australia.

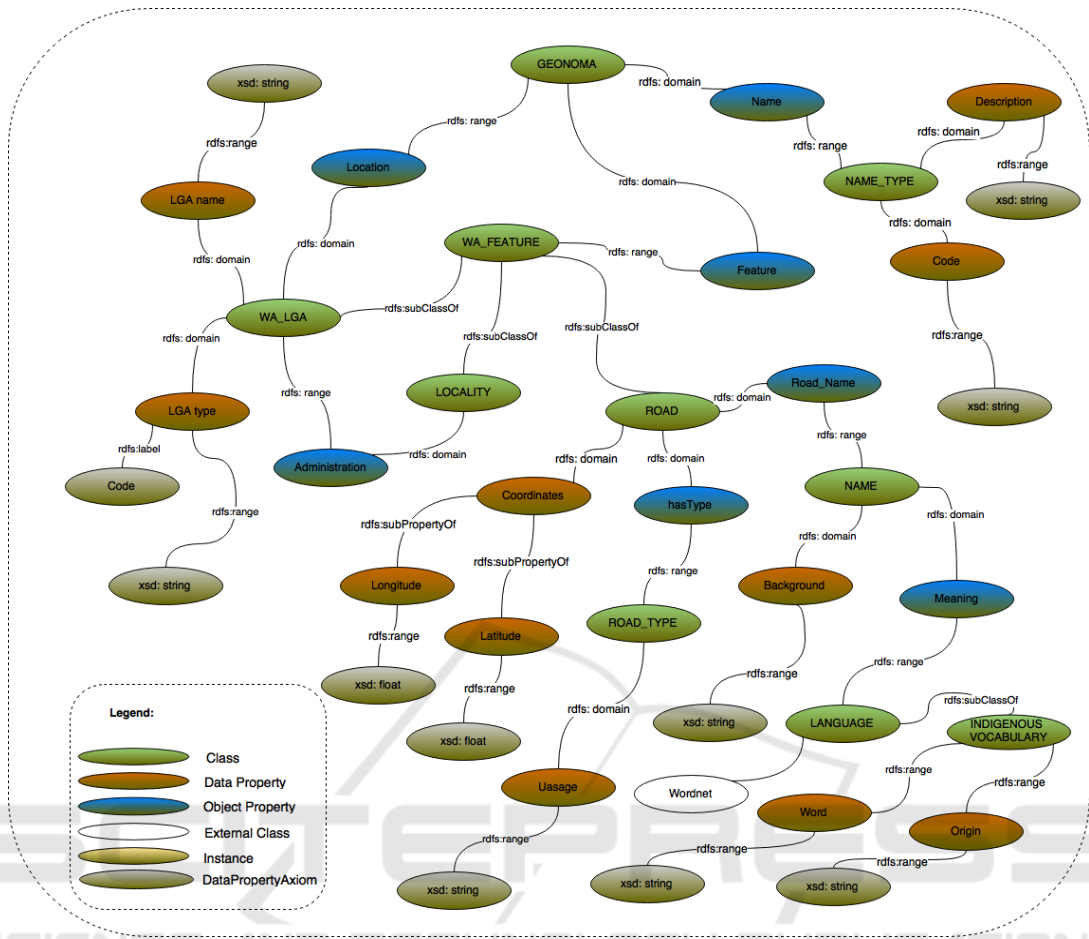


Figure 4: An overview of Geo_feature ontology.

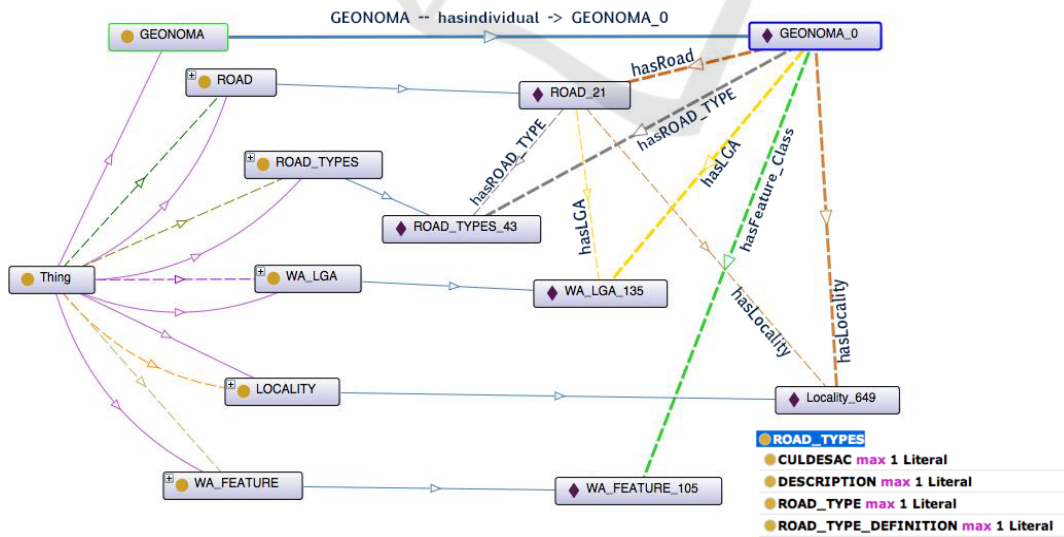


Figure 5: OntoGraf representation for classes and instances.

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<owl:NamedIndividual rdf:about="http://www.semanticweb.org/ontologies/LandInfo#GEONOMA_0">
  <rdf:type rdf:resource="#GEONOMA;GEONOMA"/>
  <GEONOMA:FEATURE_NUMBER rdf:datatype="xsd:integer">100062011</GEONOMA:FEATURE_NUMBER>
  <GEONOMA:NAME_TYPE rdf:datatype="xsd:string">Approved Name</GEONOMA:NAME_TYPE>
  <GEONOMA:FEATURE_STATUS rdf:datatype="xsd:string">CURRENT</GEONOMA:FEATURE_STATUS>
  <GEONOMA:DISPLAY_NAME rdf:datatype="xsd:string">Chancery CT</GEONOMA:DISPLAY_NAME>
  <GEONOMA:FULL_NAME rdf:datatype="xsd:string">Chancery CT</GEONOMA:FULL_NAME>
  <GEONOMA:SECURITY_CLASS rdf:datatype="xsd:string">Complete Access</GEONOMA:SECURITY_CLASS>
  <GEONOMA:LOCALITY_NAME rdf:datatype="xsd:string">Forrestfield</GEONOMA:LOCALITY_NAME>
  <GEONOMA:LGA_NAME rdf:datatype="xsd:string">Kalamunda, Shire of</GEONOMA:LGA_NAME>
  <FEATURE_CLASS rdf:datatype="xsd:string">Public Road</FEATURE_CLASS>
  <CATEGORY rdf:datatype="xsd:string">Road</CATEGORY>
  <hasLGA rdf:resource="#LGA;WA_LGA_135"/>
  <hasFeature_Calss rdf:resource="#Ontology1445038673;WA_FEATURE_105"/>
  <hasRoad rdf:resource="#Ontology1445238488;ROAD_21"/>
  <hasLocality rdf:resource="http://www.semanticweb.org/ontologies/LandInfo#Locality_649"/>
  <hasROAD_TYPE rdf:resource="http://www.semanticweb.org/ontologies/LandInfo#ROAD_TYPES_43"/>
</owl:NamedIndividual>
    
```

Figure 6: Source data in RDF format.

certain details relating to a feature name. To make it more meaningful there is a need to add additional vocabularies such as the Australian indigenous language dictionary and the WordNet ontology. By adding these we can check the meaning of a name and whether or not it complies with the chosen road-naming theme. To process a road request the road structure needs to be examined. By adding road coordinates it is possible to check where the proposed road will be actually developed.

4.3 Rule Development

Figures 4 and 5 shows several relations between spatial datasets, such as the link between road and locality. Many of these relationships are inferred by the rule-based mechanism automatically from constraints, axioms and links defined in the ontology, thereby reducing the need for manual specification for all instances. The Pellet reasoner is used to infer decisions from these rules in Protégé. More complex, nested conditions can be handled by Boolean operators in SWRL rules are executed with the rule engine (Powell, 2014).

4.4 Data Formatting/Conversion

Once the ontology and rules have been developed the next stage is to access the source datasets to reason with the ontologies. To make this happen it is necessary to convert the source dataset into RDF triple format. In this way all data are accessible in one common format and ready for initial reasoning (Broekstra et al., 2002). There are many data conversion and integration tools (Karma, MASTRO, OpenRefine and TripleGeo) that can be used for this conversion. MASTRO has been shown to be a successful Ontology-Based Data Access (OBDA) system through a series of demonstrations

(Calvanese et al., 2011, Poggi et al., 2008, Savo et al., 2010, Rodriguez-Muro et al., 2008, Zhang et al., 2013). It can be accessed by means of a Protégé plugin. The facilities offered by Protégé can be used for ontology editing, and functionalities provided by the MASTRO plugin can be used to access external data sources. Openrefine (<http://openrefine.org/>) is used to convert data to RDF format. Spatial information from a shape file can be converted into RDF triples (Patroumpas et al., 2014) (<https://github.com/GeoKnow/TripleGeo>). Figure 6 shows an RDF instance. Having the data instances in RDF format, Apache Jena, with the help of MAVEN repositories is used to link all the ontologies, instances and rules at runtime.

5 PROCESS/OPERATION

5.1 System Implementation

Figure 7 shows the runtime system architecture,

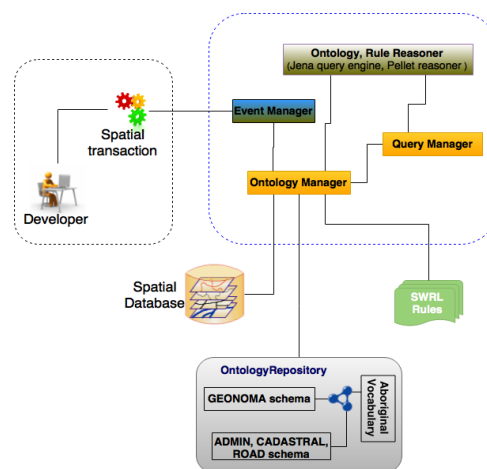


Figure 7: System architecture.

Table 1: SWRL rules with the action of each of the rules.

	Purpose	SWRL rules
R1	Relate a road link with existing road either directly or thru another proposed road	Road(?R1), Road(?Old), hasRoadLink(?R1, ? Old), status(?R1, "New"), status(?Old, "Existing"), notEqual(?R1, ?R2) -> isAllowed(?R1, true)
R2	Check the road length to against road types	Road(?R1), Road(?R2), Road(?Old), hasRoadLink(?R1, ? R2), hasRoadLink(?R2, Old), notEqual(?R1, ?R2), notEqual(?Old, ?R2), status(?Old, "Existing"), status(?R1, "New"), status(?R2, "Aproved"), -> RType(?T1), Road(?R1), Road_Type(?R1, ?T1), hasLength(?R1, ?\$200\$), SameAs (?T1, ?\$Close\$) -> isAllowed(?R1, true)
R3	Check the road access against road type	Road(?R1), hasRoadUse(?R1, "Openended"), Road(?Old1), Road(?Old2), hasRoadLinkS(?R1, ?Old1), hasRoadLinkE(?R1, ?Old2), status(?R1, "New"), status(?Old1, "Existing"), status(?Old2, "Existing"), notEqual(?R1, ?Old1), -> isAllowed(?R1, true)
R4	Check the road usage against road link.	Road(?R1), hasRoadUse(?R1, "cul-de-sac"), Road(?Old1), Road(?Old2), hasRoadLinkS(?R1, ?Old1), hasRoadLinkE(?R1, ?Old2), status(?R1, "New"), status(?Old1, "Existing"), status(?Old2, "Existing"), notEqual(?R1, ?Old1), -> isAllowed(?R1, false)
R5	Check the roadway with view	RType(?T1), Road(?R1), Road_Type(?R1, ?T1), SameAs (?T1, ?\$Vista\$) -> isAllowed(?R1, true)
R6	Check the road name with definite article	Road(?R1), containsIgnoreCase(?R1, "The") -> isAllowed(?R1, false)

which has been implemented using Jena in Java. The ontology repository consists of multiple ontologies derived from the data schema, data individuals, and rules, as well as non-specific ontologies such as Aboriginal vocabularies. The event manager collects the land transaction information and supports the ontology manager to infer the information relevant to that application. For example, if the application relates to a new subdivision, then it will gather the details spatially related to that land area, or if the proposed road name relates to a road name change, then it will gather information related to naming from the policy. The Ontology Manager collates the land information from the spatial database into the knowledge base.

5.2 Reasoning

The initial stage of reasoning is carried out in Jena with the Pellet OWL reasoner that checks the logical consistency of the model, processes the individuals (current, approved and proposed roads), infers new information including links and relationships, and updates the model with the inferred information. Through consistency checking, the system confirms whether or not any contradictory facts appear within the ontology. For example, the domain and range constraints on the feature relation: GEONOMA Features: Feature_Class. Constraints on the relation mean that GEONOMA has features, which come

under only one of the Feature_Class categories. The reasoner will throw relevant errors if any ontological inconsistency appears given the proposed roads, for example if an instance of GEONOMA is linked to an instance of a ROAD and missing any property restriction relations.

Similarly, assigning an individual to two disjointed categories such as LGA and Locality will make the ontology inconsistent. Consider the case where every GEONOMA instance is represented with the ROAD feature type; it must have at least two coordinates and link to other road instances. This is declared as a necessary and mandatory condition for instances of the ROAD category in the OWL class description. When an individual in OWL satisfies such a condition then the reasoner automatically deduces that the individual is an instance of the specified category.

As well as the reasoning described above, to gather more information additional reasoning is required. Rules are expressed in terms of ontological vocabularies using SWRL. Table 1 shows some examples of implemented rules. As mentioned earlier, in each rule, the antecedent refers the body of the rule and the consequent refers to the head. The head and body consist of a conjunction of one or more atoms. Atoms are stated in the form of C(?R) P(?R,?X), where C and P represent an OWL description and property, respectively. Variables representing the individuals are in the form, for

example ?R, where the variable R is prefixed with a question mark. Table 1 shows some examples of rules related to the application.

- Rule R1 automatically infers information with the help of a road link between proposed and existing roads from the source dataset with reference to road coordinates and feature id. This rule is necessary as every road needs to link with at least one other road to allow access.
- Rule R2 checks road length against road type. Checking the road length for shortest road types ('Place', 'Close' and 'Lane') is necessary to avoid confusion with the preference for road usage.
- Rules R3 and R4 check the compatibility between road usage and road links. For example an open-ended road must have a road link at both start and end points of the road.
- Rule R5 checks whether or not the proposed road has a wide panoramic view across surrounding areas.
- Rule R6 prevents the definite article ('The') being used in the road name.

6 CONCLUSIONS

This paper proposes a Semantic Web solution for automating the decision making process for spatially related transactions. Examples of such transactions are approvals for new roads and road names. The method develops a Geo feature ontology, which comprises knowledge of roads and constraints, axioms and rules extracted from sources such as experts, policy, geometry and past decision documents. The method shows how ontologies are manipulated with reasoning techniques to infer new information.

Semantic Web techniques are used as the solution because it allows the ontologies and rules to be published in RDF and made available for other application domains. For example, similar processing is envisaged for points of interest (bridges, parks), and the reconciliation of addresses.

This method has proven successful for the process that involves simple spatial queries, such as a request for road name approval. More rules and relationships with existing ontology elements are being developed as further examinations are carried out into the datasets and business rules. Future work is also examining reasoning over other information that can be used to aid the approval process. For example an approver may use aerial photography to

check for the presence of vegetation, as the removal of trees may need approval, and digital elevation maps used to determine if the proposed roads are viable.

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