

Improving content discovery through combining
linked data and data mining techniques

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Abstract

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A comparative study of multiple approaches for extracting linked data from web content published by the BBC for the purposes of applying machine learning to cluster related content.

This project designs and implements a process by which semantic data about any piece of online media content can be extracted into RDF models in multiple ways and feature sets for machine learning can be generated from that data. The clusters produced by fourteen different permutations of techniques are evaluated and a potential application of suggesting related content is mocked up for qualitative evaluation.

It is concluded organisations can very easily make use of embedded semantics within web pages due to better semantic properties being made available in recent years because of pressure from social media sites such as Facebook and Twitter. These embedded semantics provide a good baseline for simple learning that can group content based on broad categorisation.

However, feedback from the evaluation suggests that real value for users from suggesting related content comes additionally from linking items based on topics and themes, which are better found via entity extraction systems such as DBpedia Spotlight.

A simple application of entity extraction shows promising results in evaluation and is highlighted as an area for organisations to explore tuning to provide a powerful complement to embedded semantics.

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INTRODUCTION

Media companies produce ever larger numbers of articles, videos, podcasts, games, etc. – commonly collectively known as “content” – on the World Wide Web. A successful content-producing website not only has to develop systems to aid producing and publishing that content, but there are also demands to engineer effective mechanisms to aid consumers in finding that content.

Approaches used in industry include providing a text-based search, hierarchical categorisation (and thus navigation thereof) and even more tailored recommended content based on past behaviour or content enjoyed by friends (or sometimes simply other consumers who share your preferences).

1.1 Problems

There are several technical and conceptual problems with building effective content discovery mechanisms, including:

- Large organisations can have content across multiple content management systems, in differing formats and data models. Organisations face large-scale enterprise integration problems simply trying to gain a holistic view of all their content.
- Many content items are in fairly opaque formats, e.g. video content may be stored as audio-visual binary data with minimal metadata to display on a containing web page. Video content producers may not be motivated to provide data attributes that might ultimately be most useful in determining if a user will enjoy the video.
- Content is being published continuously, which means any search or discovery system needs to keep up with content as it is published and process

it into the appropriate data structures. Any machine learning previously performed on the data set may need to be re-run.

Many of these problems are felt within the BBC and are potentially issues in many similar organisations. The BBC website officially launched in 1997 and many articles even from that year are still available in archived form. Over the last 20 years, multiple content management systems were created and retired such that today even the active website is served by a mix of emerging, cutting-edge platforms and systems that have been running for a number of years.

1.2 Hypothesis

The following hypotheses are proposed for gaining new insights about an organisation's diverse corpus of content:

- Research and software tools around the concept of *Linked Data* can aid us in rapidly acquiring a broad view (perhaps initially at the expense of depth) of a organisation's content while also providing a platform for simple enrichment of that content's metadata.
- We can establish at least a naïve mapping of an RDF graph representing a content item to an attribute set suitable for data mining. With such a mapping, we can explore applying machine learning – particularly unsupervised learning – across an organisation's whole content corpus.
- Linked Data and Semantic Web *ontologies* and models available can provide data enrichment beyond attributes and keywords explicitly available within content data or metadata.
- Many content-producers currently enrich their web pages with small amounts of semantic metadata to provide better presentation of that content as it is shared on social media. This enables simple collection of a full breadth of content with significantly less effort than direct integration with individual content management systems.

It is proposed also that all the data acquisition, enrichment and mappings can be implemented in a general way when semantics and linked data are used. The standardisations offered by the Semantic Web and Linked Data research fields provide uniform interfaces and patterns of data manipulation such that any software produced can be applied to all of an organisation's content without consideration to any particular class or type of item. This also does not preclude including custom business rules later either, where domain experts can give more guidance to treat data more intelligently.

The core principle in this research is that a generally-applicable software system provides the best trade-off in terms of processing the full breadth of content with the least amount of engineering effort. This can allow media organisations to benefit from things such as insights from machine learning across their whole corpus with near-immediate results rather than embarking on large scale enterprise integration projects over several months or years.

BACKGROUND

This chapter discusses some of the existing research and technologies around machine learning, RDF and combining them. It also covers some of the advantages of using linked data and RDF in an enterprise setting and what tools and approaches are well-defined enough that a corporation could build on top of them rapidly.

Data mining activities such as machine learning rely on structuring data as *feature sets*[3] – a set or vector of properties or attributes that describe a single entity. The process of *feature extraction* generates such feature sets from raw data and is a necessary early phase for many machine learning activities.

The rest of this chapter will show:

1. that extracting feature sets from RDF¹ graphs can be done elegantly and follows naturally from some previous work in this area;
2. that the RDF graph is a suitable and even desirable data model for content metadata in terms of acquiring, enriching and even transforming that data ahead of feature extraction;
3. the use of semantics and RDF models has many benefits in general for an organisation needing to reason across all of its data.

2.1 Data Mining

2.1.1 Overview

Data Mining is a process for finding knowledge and information in data sets by drawing on research from artificial intelligence, machine learning and statistics.[11]

¹<http://www.w3.org/TR/PR-rdf-syntax/>

In this research, the focus is on the machine learning aspect with the feature extraction phase implemented using semantics and RDF.

2.1.2 Supervised Learning

Machine Learning broadly breaks down into *supervised* and *unsupervised* learning. In supervised learning, we have a task with a clear goal for which we attempt to create a computer model that can perform that task. In this context, a task might be to categorise an entity based on its attributed (e.g. diagnose a particular illness based on symptoms and assessment data from a patient exam) or perhaps a more numerical goal such as predicting the chance of rain on a given day based on multiple numerical readings.

Well-known examples include neural networks, decision trees and or linear regression. In all supervised learning techniques, we can normally assess the model's performance against training data for which we already know the answers. We can see supervised learning thus as a computational attempt to extrapolate human knowledge into a reusable model that can predict or determine things at a speed and scale humans would not normally be able to work through manually (e.g. predicting weather without manual calculations or diagnosing patients more quickly and with greater accuracy).

2.1.3 Unsupervised Learning

In unsupervised learning, there is not necessarily a specific goal against which we can judge the models, but instead we are applying more exploratory methods to tell us patterns in the data that maybe we could not easily see for ourselves. If we would have to graph trends over more than two or three dimensions, it is usually difficult to visualise. When we considered items using a tag-based taxonomy to be multi-dimensional vectors of binary attributes (presence or non-presence of a tag), we easily open up the need to reason across thousands or even millions of dimensions.

A well-known example is association rule mining that can find interesting relations in data sets that were perhaps previously unknown. A classic implementation of this technique is in supermarkets and other commercial enterprises where those organisations seek to find rules and patterns in consumer purchasing habits so that they can try to promote items that customers might want to buy based on other items they are currently trying to purchase.

2.1.4 Clustering

Another major unsupervised learning technique – and the focus of this research – is *clustering*. In clustering algorithm, we seek to group similar items or entities together into groups or *clusters*. Clustering has many applications, but in this work the focus will be around *hierarchical* clustering which is effective for grouping together items that appear to be connected in some way – in our case that the media content is connected by virtue of a common theme, topic or genre.

This is based on the premise that users that like a particular content item might well be interested in other items that mention the same topics, fall into the same genres or are in some other way linked.

Note that association rule mining is arguably useful in a similar way. In the case where we know from user behaviour that users like e.g. content item *A* also like content item *B*, then a new user that likes *A* but has not read or watched *B* is likely to be interested in *B*, so we can suggest it to them.

This is very powerful – perhaps more powerful as it models how people behave, not arbitrary tagging or classification of content – but the focus of this research experiment is to explore the insights we can get *from the content data alone*. This is appealing where content producers are struggling to understand their users’ behaviour as collecting meaningful analytics and records of user behaviour is by no means a trivial endeavour in its own right.

Hierarchical clustering differs from, say, *k-means clustering*[29] in that we start with no assumption about the number of clusters or groups the data will be divided into. This method is generally applied *agglomeratively* or *divisively*.

In divisive, hierarchical clustering, we start with all elements in a single cluster and proceed to find divisions that best split that cluster. This is applied recursively until we generate a dendrogram[29] showing a full hierarchy of similarity between the items or we can halt the division based on some condition, e.g. only split clusters with a low cohesion below some threshold and stop on the first attempt to split a cohesive cluster above that threshold.

Agglomerative, hierarchical clustering goes in the opposite direction by starting with all items in their own, individual clusters. The two “nearest” clusters are then recursively merged until, again, we have a full dendrogram or stop before we are about to create a cluster whose cohesion falls below some threshold.

2.1.5 Distance and Linkage

Clustering relies on grouping items that seem close, which creates a necessity to define what is meant by “close”. The distance between any two items is normally determined by a distance function.[29] Such a function will normally

take two items and return a value between 0 (items are the same) up to an unbounded value as the items are considered further and further apart.

Related to distance and specific to clustering is the concept of linkage, which describes the distance between two clusters. A linkage function will make use of a distance function. Three examples of linkage functions include:

- *Complete linkage* between two clusters is defined as the greatest distance of all possible pairs of items, one from each cluster.
- *Single linkage* is similar to complete, but the smallest distance is used.
- *Mean linkage* uses the mean where minimum or maximum are used above.

2.1.6 Clustering Media Content

For media content, agglomerative clustering is a good match for two practical reasons:

1. Content is continuously published, so there is potential to consider a “real-time” clustering system where new items arrive in their own cluster initially and are merged into an appropriate, established cluster when the next merge is performed. This is out of scope for this work, but is an interesting consideration if an organisation is to apply this to its real content in a way that keeps up to date with new content as it is published.
2. The BBC has of the order of tens of millions of pages and thus the content is likely to be very diverse with little to no overlap between the vast majority of it. The agglomerative model appears to fit better with the idea of merging together items where small islands of similar content are found and simply ignoring the large “dark matter” of pages that don’t easily merge or for which we cannot easily extract good metadata (e.g. if the pages are very old).

In this experiment, Jaccard distance[29] is used based on its suitability for binary, asymmetric data.[5] It is argued that the vast vocabulary offered by all potential semantic web RDF triples will lead to very asymmetric binary values based on the presence or non-presence of that triple.

The chosen linkage function was the complete linkage on the basis that it ensures that any two content items within a cluster to be considered related. This avoids the so-called *chaining phenomenon* where single linkage may create clusters where two unrelated items are members because they are each related to an item of chain of related items therebetween.[8]

2.2 RDF and Feature Extraction

The RDF graph is a powerful model for metadata based on representing knowledge as a set of subject-predicate-object *triples*. The query language, SPARQL, gives us a way to query the RDF graph structure using a declarative pattern and return a set of all variable bindings that satisfy that pattern.

For example, the SPARQL query in Listings 2.1 queries an RDF graph that contains contact information and returns the names and email address of all “Person” entities therein.

Notably, Kiefer, Bernstein and Locher[13] proposed a novel approach called SPARQL-ML – an extension to the SPARQL[25] query language with new keywords to facilitate both generating and applying models. However, this means that the system capable of parsing and running standard queries must also run machine learning algorithms – it may be better to decouple these functions in a distributed system for the ability to tune and scale each independently.

Their work involved developing an extension to the SPARQL query engine for *Apache Jena*² that integrates with systems such as *Weka*³. A more suitable software application for enterprise use might focus solely on converting RDF graphs into a neutral data structure that can plug into arbitrary data mining algorithms.

```
PREFIX foaf: <http://xmlns.com/foaf/0.1/>
SELECT ?name ?email
WHERE {
    ?person a foaf:Person .
    ?person foaf:name ?name .
    ?person foaf:mbox ?email .
}
```

Listing 2.1: Example SPARQL query for people’s names and email addresses

We might be able to think of the set of variable bindings returned from a SPARQL query as a feature set in their own right. In the example in listings 2.1, we can think of the name-email result pair as feature sets or vectors $(n, e) \in (S \times S)$ where S is the set of all possible strings.

If we consider an RDF graph, g , to be expressed as a set of triples:

$$(s, p, o) \in g$$

this query could then be expressed as function $f : G \rightarrow (S \times S)$ where G is the set of all possible RDF graphs. This allows the result of the SPARQL query to

²<https://jena.apache.org/>

³<http://www.cs.waikato.ac.nz/ml/weka/>

be expressed as a set of all SELECT variable bindings that satisfy the WHERE clause:

$$q(g, n, e) = \exists p. (p, \text{type}, \text{Person}) \in g \wedge (p, \text{name}, n) \in g \wedge (p, \text{mbbox}, e) \in g$$

$$g \in G \models f(g) = \{(n, e) \subseteq (S \times S) \mid q(g, n, e)\}$$

This could be generalised to express a given feature set as vector (a_1, a_2, \dots, a_n) :

$$g \in G \models (a_1, a_2, \dots, a_n) \in f(g)$$

and in the case where all $a_k \in f(g)$ are literal (e.g. string or numeric) values, we can thus consider a given SPARQL query to be specific function capable of feature extraction from any RDF graph into sets of categorical or numeric features.

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
SELECT ?topic
WHERE {
    ?article rdf:about ?topic .
}
```

Listing 2.2: SPARQL query to determine what

This might allow a query that extracts a country’s population, GDP, etc. provide feature extraction for learning patterns in economics, for example. However, this is limited to features derived from single-valued predicates with literal-valued ranges. It is not immediately clear how to formulate a query that expresses whether or not a content item is about a given topic.

In the RDF model, it would be more appropriate to use a query like that in Listings 2.2 where for a given *?article* identified by URI, we can get a list of URIs identifying concepts which the article mentions. Such a query might be expressed as function $f' : G \rightarrow \mathcal{P}(U)$ where U is set of all URIs such that:

$$g \in G \models f'(g, uri) = \{t \mid (uri, \text{about}, t) \in g\}$$

An approach of generating attributes for a given resource was proposed by Paulheim and Fürnkranz[18]. They defined specific SPARQL queries and provided case study evidence for the effectiveness of each strategy.

Their work focused on starting with relational-style data (e.g. from a relational database) and using *Linked Open Data* to identify entities within literal

values in those relations and generated attributes from SPARQL queries over those entities.

The use of SPARQL in their work has many similarities to the model proposed above to create feature sets based on query results, so this research uses that work as the main inspiration for feature set generation.

For a large content-producer, there is a more general problem where many content items do not have a relational representation and the content source is a body of text or even a raw HTML page. However, the feature generation from Paulheim and F urnkranz proves to be a promising strategy given we can acquire an RDF graph model for content items in the first place.

2.3 RDF in the enterprise

At the end of chapter 1, there is some discussion of the benefits of using semantics and linked data for any process that we wish to apply across the entire corpus.

In the following sections, the goal is to strengthen that case and review other previous work around using linked data in the enterprise. This is a more general argument for any enterprise with data (e.g. internal information about staff or business processes) and not just media organisations.

2.3.1 Data Fragmentation in Organisations

The first thing to highlight is why enterprises struggle to work with all the data spread across the organisation. Where all interesting data is contained in a single database, it is relatively simple to develop software that extracts all that data in a single query and processes it in some way.

It is rare, however, for any large business to keep all data stored in one location and in one format. For example, even fairly simple businesses will have separate data stores for their employee data and all user names and passwords for the corporate email system. Without much effort, a business that implements or purchases two distinct systems for personnel and email has already fragmented its data.

There may be no difficulty from this initially, but then a problem arises where it is noted that employees, in this example, do not automatically have their email accounts disabled when they leave the organisation. Smaller businesses might simply employ administrative staff to keep databases in sync and implement a standard process to handle the case of an employee leaving the company.

In a large organisation, it may be more desirable to automate this. This then steps into the field of *Enterprise Integration*, discussed in the next section.

In a media organisation, it might be argued that while all employee and internal systems data is in bespoke systems, we can ensure all “content” is stored in a single system such as a *content management system*. This can be strained by at least three different pressures:

1. diversity of content;
2. technology refresh cycles; and
3. fragmentation of teams.

Where an organisation produces multiple *types* of content, it may be the case that one system is optimised for writing and editing textual articles (e.g. news) and another system is purchased or created to handle video content. If these systems are built by different teams or, worse, are procured independently as commercial offerings, there is little incentive for the content to be compatible for generalising techniques such as search or data mining.

This is the compounded where development teams decide to rebuild software systems to keep up to date with changes in the industry, implement new features in ways not made possible by the old system or because the old system is becoming more expensive to maintain than it is to replace. This also applies for buying in new systems because a contract was up for renewal and the fresh procurement process chose a competitor’s commercial offering which is incompatible than that of the previous provider.

When this happens, the teams might choose to migrate all the old content to the system, but they also might choose not to if the older system is still running without issues. If it can continue to serve old content in a “read-only” state without issues, then there may not be a strong business case to migrate that old content as long as it continues to work.

The teams may also choose to archive the old content in a flat state not intended for editing. This allows the old system to be decommissioned, but it does leave older content in a format not easily queries and certainly not compatible with how newer content is actively managed.

The final problem highlighted above – that of fragmentation of teams in the organisation – particularly affects very large enterprises such as the BBC. Any media company might find that content production teams work best when given sufficient autonomy. A consequence of this is that multiple teams might implement very similar solutions to the same problems, but without the incentive to share nor unify their approaches. From this, we can ultimately end up with multiple content management systems even for the same type of content, all actively maintained.

A lot of this falls out of what was observed by Conway[6] (sometimes as known as *Conway's Law*) in that an organisation's architecture ends up reflecting its communication structures. From this, we can assume that if two teams in an organisation are not encouraged to communicate well and often, then they are less likely to share software code and data systems.

2.3.2 Enterprise Integration

The field of *Enterprise Integration* is the study and application of overcoming the fragmentation issues described in the previous section. It is concerned with creating interconnectivity between distinct systems, exchanging data between them and dealing with distributed systems within the enterprise.[28]

2.3.3 Organisational Difficulties with Enterprise Integration

Hohpe and Woolf[12] described a comprehensive set of software design and architecture patterns that apply to this field, but almost every pattern implies creating bespoke data flow software for any given integration.

This means for every new system that is purchased or created, a whole set of integration efforts are potentially initiated to move any data into or out of that system.

A significant barrier to creating holistic views of all data produced by an organisation is that each integration brings in a vertical slice of all data required, but only for once source at a time. If a hypothetical organisation has six content management systems with actively-published content within them and each integration effort takes one month, then it is a minimum of six months before it can create something like a search feature over all of that content.

2.3.4 Linked Enterprise Data

Allemang[1] proposed that a *linked data enterprise* can be truly agile by removing bottlenecks created by enterprise integration efforts. There is an appealing argument in using controlled vocabularies and efforts in linking those vocabularies between systems to join up existing data silos rather than trying to write integration layers to move data between those silos.

A more detailed approach was outlined by Servant[26] in how linking enterprise data might work with the view that it could be adopted within Renault.

Real research in this area still seems sparse in the academic literature, but there is arguably a case to be made for these approaches for an organisations public-facing content given that is already available on the public web.

The concept of linked enterprise data could encourage media organisations to consider using linked data within all internal APIs and data stores where possible such that reasoning across all that information is more readily enabled. In this research, it is demonstrated that we can get some value at least from the semantics available via the content as it surfaces on the public World Wide Web, but this value can be only increased if content producers improve the quality of those semantics or linked data principles are used within internal systems to reduce the need for bespoke enterprise integration effort.

SYSTEM DESIGN

In this chapter, a system is inductively derived and concretely design to make use of multiple strategies for:

1. gathering (meta)data about all of an organisations content items;
2. extracting metadata not explicitly modelled in source content management systems;
3. further enriching that metadata with information not explicitly present in the content item itself; and
4. applying machine learning to that content metadata to gain new insights about that content.

Initially, uses cases and a brief technical architecture for the proposed system are given and then a theoretical data pipeline is inductively defined that is the core proposition that extracts semantics and prepares them for machine learning.

It is assumed that an organisation is already publishing its content on HTML pages available on the public Internet and that engineers can make use of existing machine learning algorithms and libraries. It is out of the scope for the paper to deviate from well-established machine learning techniques such as hierarchical clustering.

3.1 Use Cases

Figure 3.1 describes how a proposed “Content Clustering” software application would be used by established roles in a media organisation.

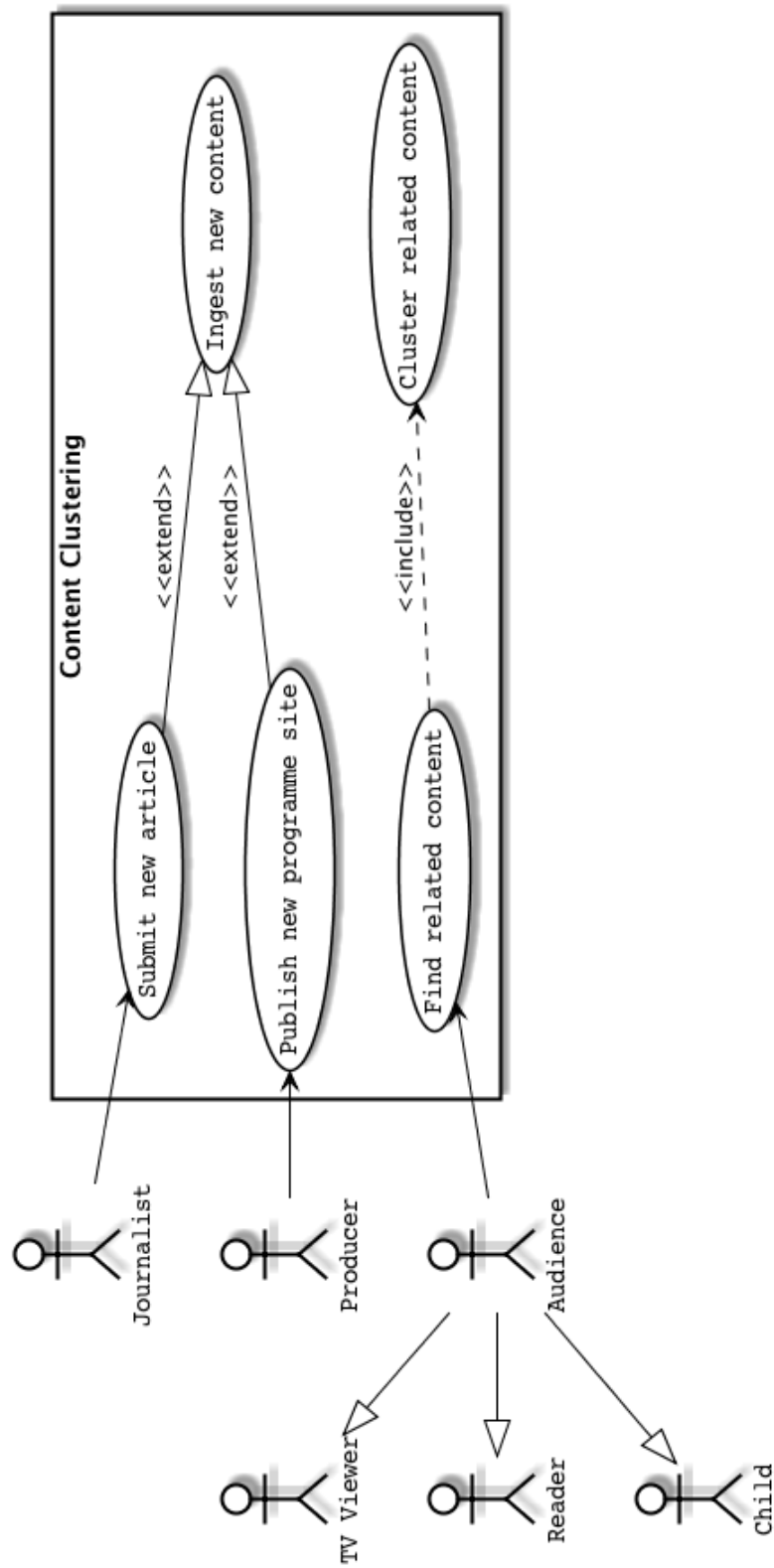


Figure 3.1: Use case diagram for content clustering system

The two main classes of user are those who *produce* content, e.g. journalists and TV programme makers, and those who will then benefit from a potential application of these clusters – in this case, a feature is proposed that allows website users to find content related to content they have just finished. These are the people that *consume* the output of the system.

Note that content production breaks down into several, differing categories. In figure 3.1, we can see two examples of a journalist writing news articles and a TV production team publishing information about a particular episode or series. This is by no means exhaustive as we may well have games developers creating education games for children, editorial staff publishing recipes that have appeared on cooking programmes aired by the BBC or pages delivering the weather forecast for a particular city.

The audience members also break down into multiple categories who could be reading news articles, watching programmes on on-demand catch-up TV (e.g. BBC iPlayer) or a child reading educational materials. These categories are depicted to remind there are multiple ways to consume content as well as produce it, but it is also important to note these roles can be transient if we are to promote content truly on its relevance irrespective of the data store that happens to hold it.

For example, a child or adult reading informative or educational material may be interested in a relevant documentary available on TV catch-up or somebody reading a news article about a topic might wish to be informed that there are more in-depth educational guides describing that topic in greater details (e.g. a press release about a science discovery leading to a full, informative guide on that field of science).

3.2 High-Level Architecture

The use cases depicted and described in Section 3.1 naturally lead to an application with two distinct interfaces: notification of new content to consider for data mining and retrieval of information about content clusters created to date.

Figure 3.2 shows a high-level view of a “Content Miner” software application that provides both interfaces. A set of “notifier” applications can be created to connect different content production and management systems to the data mining system such that it is notified when new content is created. The notification need only be an *IRI* that uniquely identifies that content item.

A *Content Promotion Module* is also depicted as the example application of the use case where website visitors or audience members then use the data mining system to find content related to a page they are currently viewing.

The content miner breaks down into two general components: a pipeline that

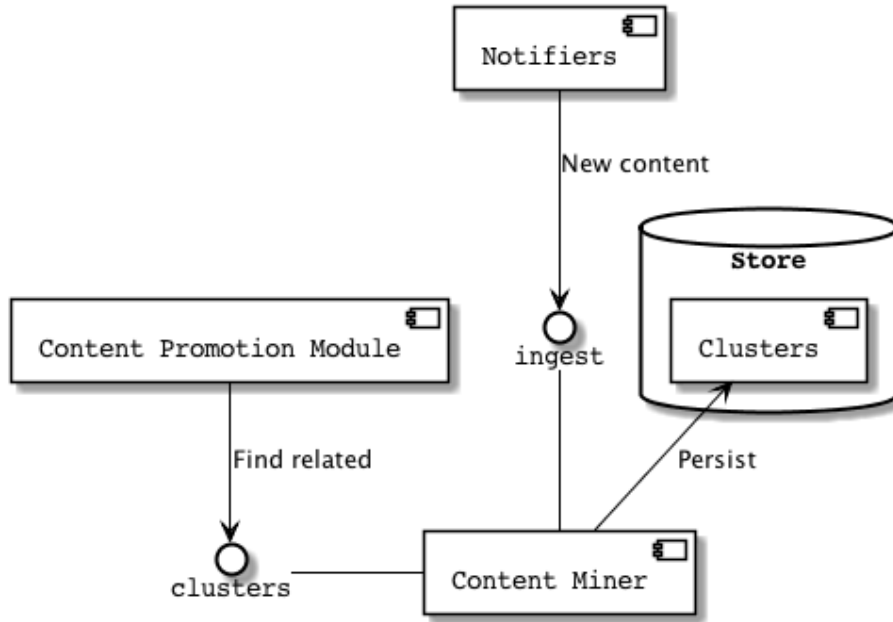


Figure 3.2: High-level component diagram with interfaces for each use case

prepares the data for machine learning and the clustering at the end on that prepared data. The primary focus of this work is to evaluate approaches for the former in the form of a *data pipeline* that uses semantics to take in a content item’s identifier at the source end and produces feature sets for data mining at the output end. This data pipeline is inductively defined and designed in the following section.

3.3 Data Pipeline

As stated in the previous section, a core subsystem in the overall system is a conceptual data pipeline whose input is a URI or IRI identifying a content item published on an organisation’s website and the output is feature sets ready for applying machine learning.

In this section, a theoretical pipeline is inductively defined in steps such that an application of this pipeline would choose to implement some subset of all potential pipeline stages as appropriate for the relevant problem domain.

In Chapter 4, a system is engineered that implements as many of these pipeline stages as possible such that a running instance of the application can configure which components to use and which not to use. Then in Chapter 6, an evaluation of the system is given while it is running each component in isola-

tion to demonstrate which of the theoretically-defined processes in this chapter appears to be most effective in generating feature sets specifically for clustering web content.

3.3.1 Definitions

This system requires some initial definition of some data structures in use:

IRI

The input to the system is a character string conformant to the IRI syntax defined in RFC 3987¹. This allows more generality offered by URIs² but is trivially made compatible with systems that use URIs through the conversion algorithm defined in section 3.2 of RFC 3987. Note that the public URL by which the public can read or otherwise consume the content is a valid identifier, but we are not restricted to that.

Feature Set

The final output of this data pipeline is a data structure analogous to a relation or tuple per IRI fed into the system. Every IRI should have a literal value against all possible columns or fields. For binary fields, (e.g. the presence of absence of a concept tag), a more pragmatic structure might be a list of tags positively associated with the IRI rather than explicitly assigning *false* to all tags to which the content item does not pertain. This is analogous to a sparse matrix when dealing with a large number of dimensions.

Named RDF Graph

The structure used throughout most of the data pipeline is that of an RDF graph. This is used for all the benefits outlined in Section 2.3 such as ease of transformation and combining of data sets. Named graphs are used such that all data acquired are keyed back to the IRI of the content item being processed. This also allows all graphs to be combined in a *triplestore* if needed to allow SPARQL queries across the combined data for all content items. This can be modelled as a data structure in many programming languages, but where a serialisation is used (e.g. examples shown here or to send the data between components), the JSON-LD[27] syntax will be used.

3.3.2 Identity Graph

¹<http://tools.ietf.org/html/rfc3987>

²<http://tools.ietf.org/html/rfc3986>

```
{
  "@id": "http://example.com/entity/1",
  "@graph": []
}
```

Listing 3.1: Identity graph for a content item in JSON-LD syntax

With the knowledge only of a content item’s IRI, we are arguably only able to produce an empty named RDF graph. Such a graph for an example IRI `http://example.com/entity/` is illustrated in JSON-LD syntax in Listings 3.1.

The most naïve feature set we can generate from such an RDF graph is clearly a singleton relation (`"http://example.com/entity/"`) where a single *IRI* field has the value `"http://example.com/entity/"`. It is also clear that a set of one-dimension feature vectors with unique values in each is not suitable for any form of machine learning activity. This does, however, illustrate a baseline for a working software application that is – at least in the syntactic sense – transforming IRI inputs to feature sets outputs. Such a *null* feature generator is depicted in Figure 3.3.

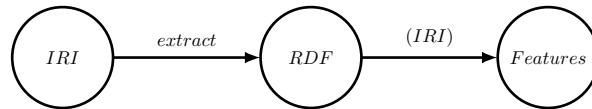


Figure 3.3: Null feature generator

Note that Figure 3.3 shows all three data structures involved despite having no functional use. We can also see top-level definitions of the process where we first *extract* semantic information in RDF from a content item identified by IRI and then *generate* features therefrom. More useful models can now be inductively defined by adding atomic subcomponents that may each add value to the overall transformation.

There are three clear axes along which we can improve this pipeline: *extract* more RDF data knowing only an item’s IRI, expand or *enrich* an existing RDF graph and then improve how we *generate* features for data mining. In the first instance, we can consider the former and add a single pipeline stage for expanding the RDF graph.

3.3.3 RDF Extraction

Tim Berners-Lee outlined four rules[2] for Linked Data, rule number three of which states “When someone looks up a URI, provide useful information, using the standards”. If we assume that many pages have embedded some semantic

web or RDF data, then a simple extraction strategy would be to dereference the content item’s IRI via an HTTP GET and pass the content to a parser capable of extracting RDFa, microformats, etc.

Many tools such as the RDFLib³ provide functionality for taking a URL and returning an RDF graph of all data found when fetching the resource it represents, so this is arguably an ideal first choice in attempting to learn something about a content item from its IRI.

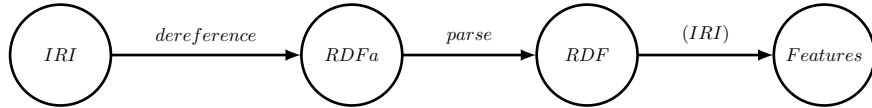


Figure 3.4: Semantic web data extraction

Figure 3.4 depicts the pipeline with a simple dereference step added. Note that the feature set generated is still the singleton relation with only the IRI value. Thus the next step should be to add a step that improves the feature set generation.

3.3.4 Feature Set Generation

Paulheim and Fürnkranz[18] described a number of SPARQL queries for generating feature sets from RDF data, which could inspire a simple query such as that shown in Listings 3.2. This query generates a boolean **true** value for any properties that match and implies **false** for those that do not.

```

SELECT ?p ?v
WHERE { ?iri ?p ?v . }
  
```

Listing 3.2: Generates field `content_?p_?v` with value **true**

As also noted by Paulheim and Fürnkranz, this overlooks the *open world assumption*[22]. However, application of clustering algorithms on binary data can employ asymmetric distance metrics such as Jaccard similarity coefficient[29], which notably avoids deriving similarity from negative values. That is, two content items lacking a particular property will contribute no information about their (dis)similarity. Thus we safely avoid inadvertently grouping together one item that genuinely lacks the property with another that indeed has the property, but we lack the positive assertion thereof in the data extracted.

The basic pipeline in Figure 3.4 can thus be augmented with this basic feature extraction to produce the pipeline depicted in Figure 3.5.

³<https://github.com/RDFLib/rdfliib>

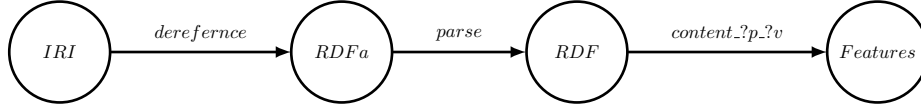


Figure 3.5: Semantic web content extraction with basic SPARQL feature generation

3.3.5 RDF Enrichment

The third and final direction in which this data pipeline can be improved is in terms of data enrichment. A simple strategy here is to repeat the dereferencing used in Section 3.3.3, but for each IRI found as the object of a triple in which the initial IRI is the subject. Formally:

$$g \in G \models \exists p, o. (IRI, p, o) \in g \rightarrow g' = deref(o)$$

That RDF graphs can be modelled as mathematical sets as in Section 2.2 means we can express a graph enriched this way as a *union* of the initial graph with each graph returned from all dereferencing:

$$g \in G \models g' = g \cup \bigcup \{deref(o) \mid (IRI, p, o) \in g\}$$

Figure 3.6 shows the data pipeline with this additional enrichment stage. Note that now we have potential for some stages being executed in parallel.

So far in this section, we have inductively built up a data pipeline from a “null” base working with only identity graphs to a simple pipeline capable of *extracting* an RDF graph, *enriching* it and then *generating* features from it.

What needs to be proven through experimentation is *which* of these provides the information required for effective data mining. As part of this experimentation, we can now look at further techniques and approaches to try.

3.3.6 Improving Extraction

In order to gain a larger set of RDF data at the start of the pipeline, we can derive further ways to get information about a content item given only its IRI as input.

Rizzo and Troncy[21] defined a framework called NERD capable of combining multiple entity extraction systems to provide a unified way of identifying – and disambiguating – named entities within a given body of text. With such a system, we can create a second, parallel RDF extraction strategy that creates a graph of triples in the form:

$$(IRI, rdf:about, Entity)$$

where *Entity* is an IRI representing a concept or entity believed to be found in the content’s textual content. A data pipeline complementing the RDFa-based extraction is depicted in Figure 3.7. Note the ability to apply a simple set union to the result of each extraction as with the enrichment.

Another strategy can be to infer a relationship between two content items where one contents an HTML link to another. It is not always possible to derive precise semantics of such a link (unless the publisher has kindly provided a `rel` attribute), but a weak relationship such as:

$$(IRI_1, ex : related, IRI_2)$$

might prove – through experimentation – to be useful enough for data mining insights.

The fourth and final extraction strategy explored is acquiring metadata from bespoke Content Management Systems and other internal APIs. This is generally the only option used in enterprises settings, as discussed in Section 2.3. This is likely to be the richest source of information where an enterprise has typically preferred bespoke integrations against non-hypermedia interfaces, so experimentation should help quantify or qualify the value such a direct integration adds (perhaps to consider it in combination with the cost of bespoke, repeated integration projects).

The assertion explored here is that such bespoke integrations can *complement* cheaper work such as extracting RDFa with pre-built tools (and thus be developed one-by-one after the initial release of an application such as this data pipeline). Note that repeated custom integration projects means that each data source requires a different application be developed (as opposed to the reuse of a single RDFa parser or HTML link scraper). This also means we are not necessarily comparing like-for-like if we introduce only one at a time. It also makes it difficult to evaluate data mining of a diverse content corpus if an integration against an API provides additional metadata for only, say, 10% of that corpus.

These challenges aside, it is clear that bespoke integrations have a clear place in this data pipeline being applied in a real enterprise setting. Now that we have a complete set of theoretical stages for *extraction*, the remaining improves lie now in the *enrichment* and *feature generation* stages.

3.3.7 Improving Enrichment

In addition to enriching through dereferencing linked entities, it is proposed to explore the following options:

- inferring relationships to hypernyms as defined by Wordnet[17];
- inferring facts based using rules derived from expert domain knowledge;
- using RDFS and OWL to generate new triples with well-established Ontology rules.

In the first approach, we can consider a relationship rule such as:

$$(IRI, ex : related, ex : Dog)$$

and *infer* the fact:

$$(IRI, ex : related, ex : Animal)$$

and produce an enriched graph containing all additional facts inferred in this way.

When dealing with proper nouns and named entities, inferring facts based on domain knowledge may be more appropriate. For instance, the rule in n3 syntax:

```
{
  ?article ex:takesPlaceIn ?city .
  ?city a ex:City .
  ?city ex:capitalOf ?country .
} -> { ?iri ex:takesPlaceIn ?country }
```

might be useful to help cluster articles that take place in the same country – even if the countries are not always explicitly mentioned therein. Such an inference requires knowledge about cities and countries to write and domain experts for different types of content might be able to offer more nuanced rules.

An example for BBC content might be to infer that all articles written under the *Newsround* brand is suitable for children or that programmes that have broadcast times during the day are also suitable for children.

The third and final proposed improvement makes use of standard tools to find *closures* using, e.g. RDFS, ontology rules. With this approach, we can infer that entities that have a given type or class also have their superclasses and supertypes. This gives us similar inference to hypernyms, but with knowledge present in well-established ontologies.

An obvious example might where two content items have been identified as related to the same concept – so they would be candidates for clustering together – but when RDF data are extracted, it is found that two different URIs have been used for each:

$(IRI_1, \langle \text{http://dbpedia.org/property/related} \rangle, ex1 : entity)$

$(IRI_2, \langle \text{http://dbpedia.org/property/related} \rangle, ex2 : anotherEntity)$

In the RDF graph for IRI_2 , say, we might find the source had provided an `owl:sameAs` assertion such as:

$(ex2 : anotherEntity, owl : sameAs, ex1 : entity)$

This is possible in the case where the second item’s data source uses its own set of identifiers for entities, but has chosen to provide equivalences to a more standard set of identifiers (e.g. DBpedia). With this information, our data pipeline can infer:

$(IRI_1, \langle \text{http://dbpedia.org/property/related} \rangle, ex1 : entity)$

$(IRI_2, \langle \text{http://dbpedia.org/property/related} \rangle, ex2 : anotherEntity)$

$(IRI_2, \langle \text{http://dbpedia.org/property/related} \rangle, ex1 : entity)$

and the feature generation stage might provide the common features `dbprop_related_ex1_entity=true` for both content items.

3.3.8 Improving Feature Generation

The feature generation outlined so far relies solely on boolean values indicating whether or not a given content item is related by some property to some entity. This recreates the concept of *tagging* where a given object is either associated or not associated with a series of *tags*.

One of the advantages of the RDF graph model is that we are not constrained necessarily to properties and attributes directly applicable to the entity. We could imagine adding a level of indirection to the query in Listings 3.2 to create the query in Listings 3.3.

```
SELECT ?p1 ?p2 ?v
WHERE {
    ?iri ?p1 ?o .
    ?o ?p2 ?v .
}
```

Listing 3.3: Generates field `content_?p1_?p2_?v` with value `true`

With the this query, features of the form `content_?p1_?p2_?v` can be generated. An example of this might be where a television programme content item has information about the actors that appeared therein, e.g. `ex:hasActor`, and furthermore we have information about those actors such as where they were born, e.g. `ex:bornIn`. With the path created by following both of these predicates, it is possible to create features for a television programme such as `content_ex:hasActor_ex:bornIn_Edinburgh` and we can potentially find similarity between programmes where the actors were born in the same city.

Perhaps a third step in the predicate path followed can give us even more useful features. The example above could be expanded to `content_ex:hasActor_ex:bornIn_ex:cityIn_Scotland` to allow the more general ability to cluster programmes with Scottish actors, for instance.

Appropriate experimentation should show whether more value is gained by adding these additional levels of indirection.

3.3.9 Maximal Data Pipeline

In this section, a data pipeline was inductively built up from a base, identify pipeline with suggestions for potential improvements in different stages. An application of all the ideas discussed so far might look like that depicted in Figure 3.8.

The goal of this work is to evaluate how the quality of unsupervised clustering changes with respect to enabling different combinations of the maximal data pipeline. In the next section, some of the technical architecture of this pipeline is outlined and the next chapter will cover how the overall system is then implemented.

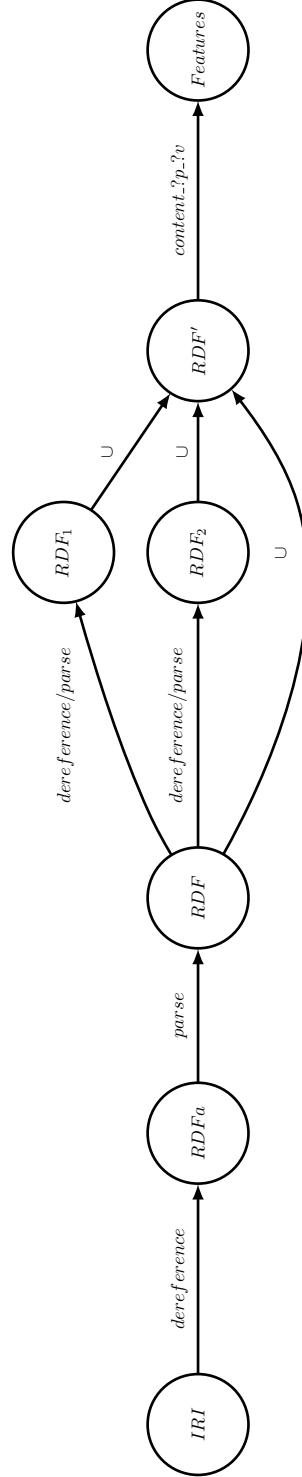


Figure 3.6: Semantic web content miner with additional dereferencing of linked entities

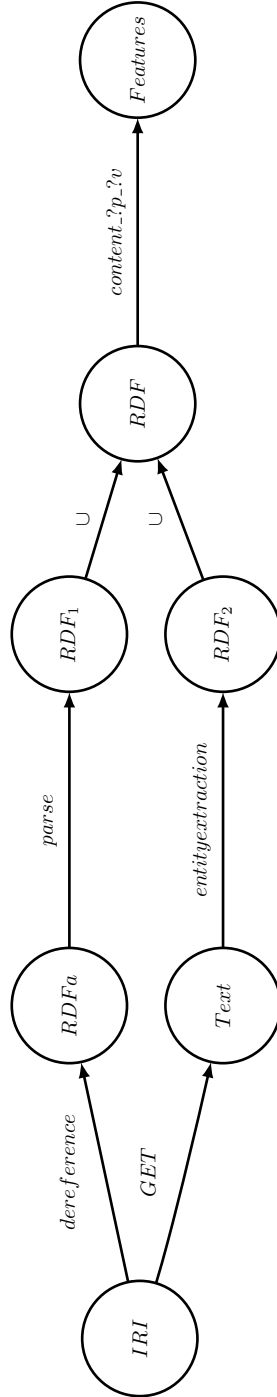


Figure 3.7: Named entity extraction in addition to semantic web extraction

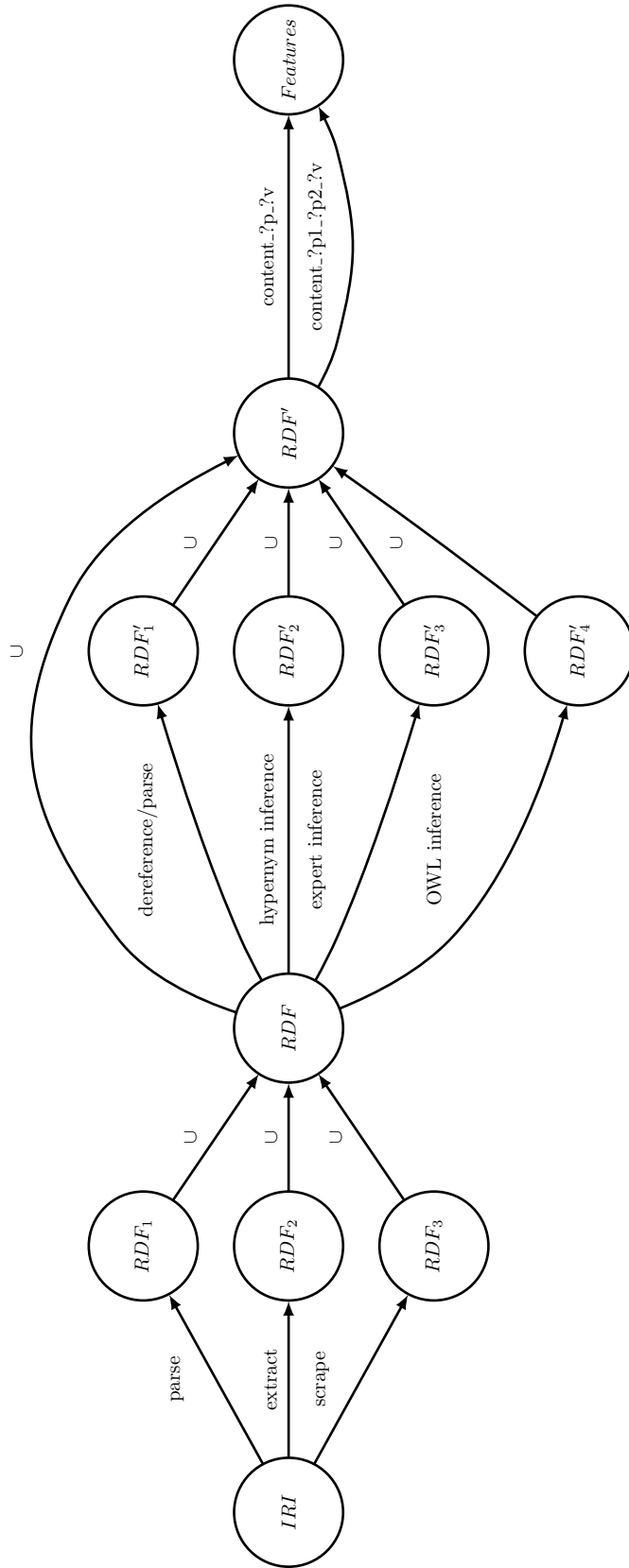


Figure 3.8: Maximal Data Pipeline

IMPLEMENTATION

In this chapter, some of the details of the system implementation are described. Initially, we discuss some of the implementation strategy employed due the experimental nature of the system and the desire to run multiple, competing approaches side-by-side in an efficient way.

The remaining sections walk through the implementation of each part of the data pipeline from upstream to feature sets and the chapter concludes with implementation of the clustering and generation of clusters for evaluation.

4.1 Software Architecture

All functionality was implemented as part of a single Python module named *distillery* that is run via the Unix command line, with different subcommands for each feature. Each command was designed around the Unix Philosophy[20] of doing one job per command and that they were composable via Unix pipes. This allows pipelines to be composed:

```
distillery extract <iris.txt | distillery enrich | distillery generate
```

that resemble the entire theoretical data pipeline described in section 3.3 without the need for middleware such as message queues. More typical enterprise architectures around message oriented middleware or event-driven architecture might need to be employed to scale this system to millions of documents, but the simple approach above is sufficient for tens of thousands of documents.

Even this simple approach would scale very well with suitably low network latency. The largest bottleneck observed was the necessity to do at least one HTTP request per item ingested and then enrich via an HTTP request per object of a triple where the IRI is a subject. For some content items, this

could easily be over 100 HTTP requests at which point parallel CPU cores or asynchronous I/O programming does not overcome the demands on network performance.

Throughput is a particular challenge when data processing systems are first launched. The day-to-day volume of item creations and updates may be low enough for even a low-scale application, but the performance demands increase significantly when we wish to bootstrap a backlog of all content items historically published – of which could easily be tens of millions for organisations such as the BBC.

For this, there is an appeal to designing such a system on a cloud computing platform such that it can be scaled up for the initial import of existing data and then back down for ongoing updates when that import completes. Such design is out of scope for this paper, but some discussion in chapter 6 of performance limitations of the experimentanl system highlights where this system may be architected differently to be more suitable for such a cloud-based deployment.

The higher-level compositional architecture of the individual data processing stages can, of course, be altered independently of the design of those stages. The following sections will describe in greater detail those composable modules.

4.2 Avoiding Redundancy Across Multiple Experiments

The design of the data pipeline in chapter 3 would suggest an implementation with each stage implemented as a function converting a graph into a new, richer graph.

That is, while the different strategies illustrated in the maximal data pipeline in Figure 3.8 can be run in parallel, the extraction stage itself simply converts the identity graph described in section 3.3.2 to a single graph (after having taken the union of all the strategies).

In the experiment that is the subject of this paper, the intent was to compare each of the extraction strategies individually, but also all possible (union) combinations thereof. This presents at least two potential implementation strategies:

1. Build the whole data pipeline and machine learning system such that it is configurable which strategies are invoked and run an instance per configurable combination; or
2. implement the software to produce all possible outcomes along the pipeline.

The former approach is stronger if the aim is to build the system closer to how it would be implemented in an enterprise: only one set of clusters is needed

and even a production, enterprise system would be configurable if maintainers wished to enable or disable features as desired.

The latter strategy is arguably better for experimentation as every IRI fed into the source end of the pipeline is processed at the same time for every extraction and enrichment approach. This gives better assurance that the same input is used to evaluate each competing system.

Other operational reasons include being able to run the system on a single machine if necessary and that there is no repeated work: extraction by one means can be used in isolation, but also feed into a union with another technique without having to recalculate that graph. That is, if we have graphs A and B generated once each, then we can output A , B and $A \cup B$ for comparison. A parallel copy of each system would be calculating A and B twice each.

The limitation here is a production-ready implementation of the system would have to be built again from the ground-up, perhaps reusing functions and library code from the experimental version, as the application itself will be structured around this idea of multiple outputs for each input. This is likely to be the case for any experimental system and is arguably in line with Brooks' classic assertion to "Plan to Throw One Away"[4].

```
def all_extracted_graphs(iri):

    extraction_strategies = [
        dereference, extract_entities, find_links
    ]

    # This creates all 3 RDF Graphs only once
    graphs = [s(iri) for s in extraction_strategies]

    # Empty set removed from power set
    for idx, gs in enumerate(powerset(graphs) - [{}, {}]):
        # union defined elsewhere: list(graph) -> graph
        graph = reduce(union, gs)
        # Loop counter idx tells us from which technique
        # combination each graph comes
        yield idx, graph
```

Listing 4.1: Python function that generates all possible RDF Graphs

An illustrative Python function is shown in Listings 4.1 where each of the three extraction techniques is invoked only once and a power set function is used to generate all possible unions of those graphs and thus yield all possible

usages or non-usages of each strategy to generate RDF graphs. The details of the three extraction functions are covered in section 4.4.

4.3 Obtaining IRIs

It is a substantial undertaking to design, build and test a production-quality enterprise system that processing all content produced by a media organisation. An experimental system needs to focus on quick results and therefore is optimised to work only over a small sample of that content.

As introduced in section 1.1, all that content is also likely to be distributed across multiple databases, content management systems and other stores. While it is hypothesised in this research that semantics and linked data provide a good way to extract data about the total breadth of all content without any bespoke integration against internal systems, there still remains the enterprise integration problem of *discovery* of those content items.

Essentially, the data pipeline outlined in section 3.3 notably requires that known IRIs of content items are fed into it, but makes no statement about how those IRIs are acquired. This is a deliberate design decision to decouple the concepts of discovery from this extraction/enrichment workflow. Thus item may easily be re-ingested several times if it is updated (or simply periodically) and a modular approach like this defends against upstream systems changing and having to rebuild the triggers that notify when content is created or updated.

What follows it that the enterprise integration task has been reduced (we do not need to write bespoke code to extract basic data about every content item) but not wholly eliminated (some custom adaptors need to be created to notify the pipeline of creation or update events in each respective data store).

However creation of any such notification adaptors is out of scope for this research altogether, so a heuristic approach was employed where ten different, themed content aggregation pages on the BBC website¹ were polled for any new content promoted by editorial teams. This provided a way to find new items shortly after they are published and also ensured the data sample ultimately used focused on content that was deemed noteworthy or interesting in the last few months.

This is not an effective method for obtaining a large number of items quickly as it is entirely dependent on the rate these aggregate pages are updated. Running slowly over a long period yielded approximately ten thousand individual IRIs with little effort nor need for large amounts of integration work.

¹Including, among others, the BBC Homepage (<http://www.bbc.co.uk>), BBC Arts (<http://www.bbc.co.uk/arts>) and BBC Science (<http://www.bbc.co.uk/science>)

4.4 Extracting RDF Graphs

Listings 4.1 hinted at three individual functions capable of obtaining an RDF graph for a given IRI, all based on the extraction strategies outlined in section 3.3.3.

4.4.1 Dereferencing

Listings 4.2 shows how trivial a dereference function can be if we use the comprehensive RDFLib library for Python. The library can handle content type negotiation[9] to ensure it can happily dereference and parse any response that contains semantics, particularly RDFa (including embedded Turtle) and microdata within an HTML page.

```
from rdflib import Graph

def dereference(iri):
    g = Graph(identifier=iri)
    g.parse(iri)
    return g
```

Listing 4.2: Python function that generates all possible RDF Graphs

4.4.2 Entity Extraction

DBPedia Spotlight[7] was chosen to perform the entity extraction. A hosted version is available as a free service and it has been shown to be effective in many cases. A true comparative study of the merits of alternative entity extractors is out of scope for this paper.

```
import requests
from rdflib import Graph, URIRef, Namespace

FOAF = Namespace('http://xmlns.com/foaf/0.1/')

def extract_entities(iri):
    g = Graph(identifier=iri)

    text = requests.get(iri).text

    spotlight_response = requests.post(
        'http://spotlight.sztaki.hu:2222/rest/annotate',
```

```

        data={
            'text': text, 'confidence': 0.8, 'support': 20
        },
        headers={'Accept': 'application/json'},
        timeout=600)

    if spotlight_response.ok:
        r_json = spotlight_response.json()
        if 'Resources' in r_json:
            annotations = {
                resource['@URI']
                for resource in r_json['Resources']
            }
            if annotations:
                for entity in annotations:
                    g.add((
                        URIRef(iri),
                        FOAF.topic,
                        URIRef(entity)))

    return g

```

Listing 4.3: Python function that uses DBPedia Spotlight to extract entities from web pages

Listings 4.3 shows a basic implementation of a function that fetches a page and then feeds the content into a request to DBPedia Spotlight. All entities thus found are then fed in as objects to a series of `foaf:topic` triples.

There is much that can be tweaked in this implementation and the final version used in the experiment relied on a ad hoc whitelist of XPATH queries known to narrow down the content to the main article content on BBC pages. This is because the implementation shown in listings 4.3 does nothing to prevent entities being extracted from page chrome such as navigation links and other cross-site concerns.

In a given organisation, such an approach might well be sufficient to extract main article content from a controlled set of pages. In a production system, it may be more appropriate to consider readability systems such as that from Arc90.

4.4.3 Hyperlink Relationships

In listings 4.3, we see a simple Python function that uses the Beautiful Soup library² to search across all links in a document and infer a “related” property on the assumption that pages like to other pages that are in some way related.

```
import requests
from rdflib import Graph, URIRef, Namespace

DBPROP = Namespace('http://dbpedia.org/property/')

def find_links(iri):
    g = Graph(identifier=iri)

    text = requests.get(iri).text
    doc = BeautifulSoup(text)

    # For all <a> tags that have an href attribute...
    for a_tag in doc.find_all('a', attrs={
        'href': re.compile('.+')
    }):
        # ... handle href values being relative links ...
        other_iri = urljoin(
            iri, a_tag.attrs['href']
        ).strip()

        # ... infer triple if IRI is to another BBC page
        if bbc_url.match(url):
            g.add((
                URIRef(iri),
                URIRef(DBPROP.related),
                URIRef(other_iri),
            ))

    return g
```

Listing 4.4: Python function generates triples based on links to other pages

This falls foul of similar issues to entity extraction as described in section 4.4.2 in that site-wide navigation links and other supporting page elements may link to very general pages (e.g. a persistent link to “home” on every page).

²<https://www.crummy.com/software/BeautifulSoup/>

With appropriate feature selection, this may have no impact, but for this experiment a simple heuristic was employed to narrow down to the “interesting” part of BBC pages.

Another feature in listings 4.4 is a restriction to consider only links to other BBC pages. There may be a positive or negative effect in additionally noting external pages linked to from content pages, but that is left to future research to consider.

4.5 Enriching and not Enriching

The combinatorial consequence of the usages and non-usages of the three extraction techniques described so far is that the experimental system developed is already comparing seven (2^n less the case where no extraction is employed).

In order to maintain focus in the experiment, only one of the enrichment techniques described in chapter 3 was implemented and its usage and non-usage merely doubled the number of systems for comparison to fourteen.

This proved sufficient to give indicative results as to whether there is value added through any enrichment, but future research could certainly compare the merits of different enrichment approaches.

```
import rfc3987

def get_objects(graph):
    return {str(row.o) for row in graph.query(''
        SELECT DISTINCT ?o
        WHERE {
            ?iri ?p ?o .
        }
        '', initBindings={'iri': graph.identifier})}

def enrich(graph):
    new_graph = copy(graph)

    for o in get_objects(graph):
        if rfc3987.match(o, rule='IRI'):
            new_graph.parse(iri2uri(o))

    return new_graph
```

Listing 4.5: Python function that enriches a graph via dereferencing objects

Listings 4.5 illustrates a simple function to dereference all objects of triples where the current IRI is a subject. Note the convention to set the graph’s own identifier to that of the content item of interest.

Using SPARQL in this way opens up possibilities to perform multiple queries to choose IRIs to dereference. For example, we may wish to include semantics for objects reachable by following two predicates on the RDF graph and consider much more indirect data. Evaluating the utility of this is left for future work.

4.6 Feature Set Generation

The feature generation strategy employed was derived from a distilled portion of the approach introduced by Paulheim and Fürnkranz[18].

Listings 4.6 shows an illustrative, recursive function that “walks” the RDF graph starting with the content item’s IRI as the initial subject.

```
from rdflib Literal, URIRef

def generate(
    g, subject=None, depth=3, features=None, prefix=''
):
    if depth <= 0:
        return
    if not features:
        features = {}
    if not subject:
        subject = g.identifier
    for p, o in g.predicate_objects(subject=subject):
        if type(o) == URIRef:
            new_prefix = prefix + clean(p) + '_'
            features[new_prefix + clean(o)] = True
            generate(
                g,
                depth=(depth - 1),
                features=features,
                prefix=new_prefix,
                subject=o)
        elif type(o) == Literal:
            features[clean(p)] = str(o)

    return features
```

Listing 4.6: Python function that generates feature sets from RDF graphs

The `clean` function simply provides some cosmetic cleaning up of predicate IRIs to prefer CURIEs as they are more compact. A typical example feature might then be `foaf:topic_dbpedia:Albert_Einstein: true` where the leaf object is an entity or `ogp:title: "Gandhi: Reckless teenager to father of India"` if the leaf object is a literal.

4.7 Feature Selection

A simple selection heuristic was employed, again inspired by the work of Paulheim and Fürnkranz[18], to go some way to reduce potential noise in the subsequent machine learning phase.

In this experiment, all features that have the same value or entirely unique values were removed and values that occurred twice or more for a given feature had to make up over 5% of possible values for that feature. That is, if a feature had over 95% of its values being unique or all the same, then it was rejected.

4.8 Clustering Implementation

Hierarchical, agglomerative clustering was implemented by implementation of a `cluster` function that was merge the two “nearest” clusters on each invocation. This assumes that all content items not yet in a cluster are implicitly in a singleton cluster and the ability to merge one at a time allowed for control of when to cease merging.

The closeness of two potential, candidate clusters was calculated via a the complete linkage function as chosen in section 2.1.6. This made use of an implementation of the Jaccard distance as also justified in that same section.

4.9 Results Generation Strategy

With all of the components described so far in place, an experiment was run processing nearly 10,000 content items from the BBC website with each going into one of fourteen combination of extraction and enrichment approaches.

For each approach, hierarchical clustering was applied repeatedly until the next merge would produce a cluster with cohesion below 0.5. This is reasonably arbitrary as each technique will have different concepts of cohesion, but it

provided a strong basis on which to evaluate each approach on whether its cohesion meaningfully predicts whether a human would agree that cluster contains related items.

RESULTS AND ANALYSIS

In chapter 3, a data pipeline is derived that – at the logical maximum (see figure 3.8) could generate feature sets using any of 112 combinations of extraction and enrichment techniques. This is based on the product of using or not using any of three described extraction approaches (less the case where no extraction is performed) and enabled or disabling any of four distinct enrichment approaches (retaining the case where no enrichment is performed).

More practically, in chapter 4, the implementation of a real system for evaluating a subset of only fourteen combinations of approaches is described. Therefore there are fourteen resultant sets of clusters of the same BBC web content produced for comparative analysis.

In the following sections of this chapter, an objective and technical analysis of the clusters is performed, leading to a critical review of each individual extraction and enrichment approach, based on how each respective technique appears to contribute to the results.

In chapter 6, there is an evaluation of the overall system based on qualitative data gathered by a survey of real human users. That evaluation is more focused on the suitability of the holistic use of semantics and machine learning in the real world application of suggesting related media content to web users.

Conversely, in this chapter, we take a much narrower focus on the shape, size and quality of clusters themselves.

5.1 Comparison of Clusters Produced

In this section, we take a walkthrough of some of the clusters produced based on what seems interesting. Even reviewing a handful of the results shows some insights into how the different semantic extraction approaches have behaved

and we can see some clear evidence where the process is generally working and where it is making mistakes.

It is not feasible to analysis every result here in this way, but chapter 6 describes how every approach was evaluating against every other approach The sections following this one in this chapter try to give a summary of advantages and disadvantages we can see in each technique ahead of the qualitative evaluation.

The most stark difference between the results produced is the large range in terms of number of clusters produced for each approach respectively.

Table 5.1 shows the number of clusters produced by each combination of techniques. The range here is explained by some variants of the system produced few, very large clusters and some a large number of smaller clusters.

	Not enriched	Enriched
Deference	5	249
Entity Extraction	35	32
Hyperlink Relationships	2	56
Dereference and Entity Extraction	329	340
Entity Extraction and Hyperlink Relationships	199	233
Dereference and Hyperlink Relationships	53	117
All three extractions	184	223

Table 5.1: Number of clusters produced by each combination of approaches

5.1.1 Few, Large Clusters

Which of the two extreme outcomes is more suitable is arguably a matter for real evaluation, but it is perhaps reasonable to claim that clusters which are too large are less useful for choosing related content items to suggest to users. In the case of the unenriched graphs obtained via hyperlink relationships only, one of the two clusters produced contains 2,323 items – a number that risks “related content” suggestions being too erratic and random.

A deeper inspection of that largest cluster reveals every item was deemed to be related to an FAQ page on how to share BBC pages on social media websites – a page that appears to be linked to from every BBC programme information page or iPlayer catch-up video page. This is clearly not a good indication of the content of the page and raises two immediate issues:

1. the system would benefit from further heuristics that avoid inferring too many relationships from ancillary pages such as FAQs that are unrelated to the content itself; and

2. the nature of agglomerative, hierarchical clustering means that this system variant spent a large amount of time grouping all pages that link to this FAQ page at the expense of other, potentially useful clusters. This is a consequence of hierarchical clustering being a greedy algorithm.

Further discussion of the merits and problems with hyperlink relationships is covered in section 5.2.3.

5.1.2 More, Small Clusters

If we look at the other end of the spectrum, the system variant that produced the most clusters was the enriched union of dereference and entity extraction. With so many clusters, the distribution of sizes is better shown by the histogram in figure 5.1. Here we can see the results are dominated by clusters with 25 or fewer items.

An exploratory insight into the makeup of these clusters is shown in table 5.2 in which the ten most common features are shown for the one of the smallest, one of the biggest and one of the mean-sized clusters.

Smallest Cluster

The smallest cluster with 2 items in table 5.2 seems to contain two pages that mention BBC iPlayer (the `foaf:topic` predicate suggests this was found via entity extraction) and whose primary content is an item with `rdf:type` “RadioEpisode” in the Schema.org¹ vocabulary. This shows hints of a strong complement between semantic web data and entity extraction confirming that textual content on the page correlates with any semantics also embedded in the page.

Interestingly, this cluster is also strengthened by the fact that both pages have a common thumbnail (the `ogp:image` predicate indicates a thumbnail when used to share on Facebook). An examination of the two content pages in question confirms that they are two episodes of the same “5 Live Breakfast” programme on the *BBC Radio 5 live* radio channel.

The other two predicates for the small cluster are less clear without some explanation as to their origin. The `meta:twitter:card` predicate is a documented² HTML meta tag that to indicate a page has included further meta tags to control which metadata to include in the so-called *Summary Cards* Twitter generates as a summary of page a user is sharing in a post to the website. This

¹<http://schema.org/>

²<https://dev.twitter.com/cards/types/summary>

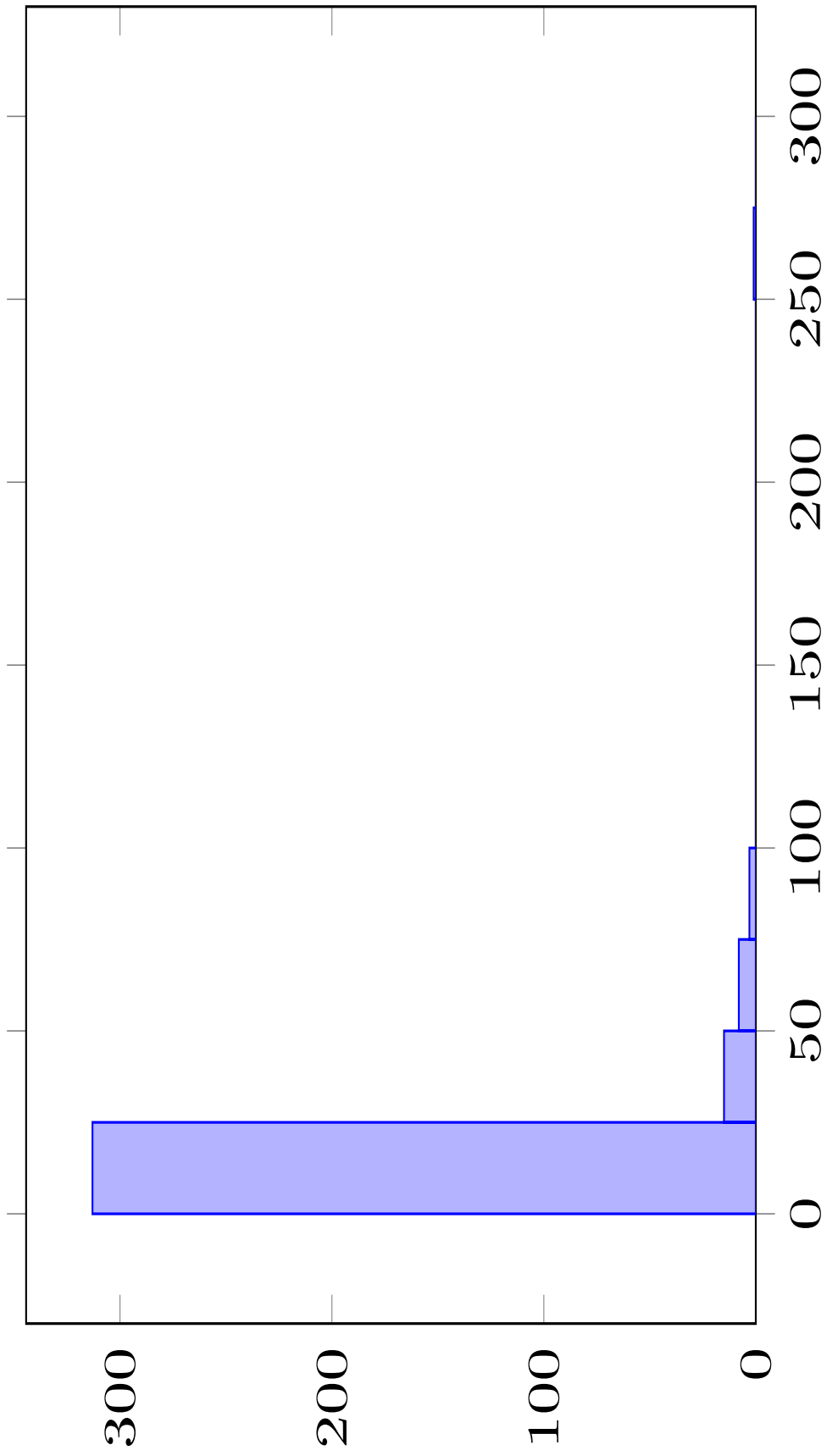


Figure 5.1: Distribution of cluster sizes produced by the enriched union of dereference and entity extraction

$N = 2$	$N = 9$	$N = 265$
ogp:image=" [...]"	rdf:type:schema:RadioEpisode=true	md:item_rdf:nil=true
foaf:topic_dbpedia:BBC_iPlayer=true	schema:url=" [...]"	foaf:topic_dbpedia:Digg
rdf:type:schema:RadioEpisode=true	foaf:topic_dbpedia:JavaScript	twitter:card:"summary_large_image"
rdfa:usesVocabulary_schema=true	meta:twitter:card="summary"	foaf:topic_dbpedia:LinkedIn
meta:twitter:card="summary"	foaf:topic_dbpedia:Listen_(Beyoncé_Knowles_song)"	meta:apple-mobile-web-app-title="BBC Sport"

Table 5.2: Ten most common features across the smallest, the largest and a mean-sized cluster produced by the enriched union of dereference and entity extraction

overlaps some of the features provides by the *Open Graph protocol*³ vocabulary used by Facebook for similar means.

This overlap between Facebook and Twitter highlights both:

- a failure for industry to adopt (or for academia to convince them to adopt) semantic web initiatives such as RDFa, Microdata, Microformats or Schema.org – designed to provide machine-readable semantics in ways richer than simple meta tags; but also
- a critical opportunity for research and development in semantics to build on top of the real, commercial pressure created by Facebook, Twitter, Google et al to enrich pages with semantic data so that content providers can control how their content is summarised when shared on their platforms and also how their content is analysed for searching and extrapolation of real time trends in social media conversation.

That predicates for Facebook and Twitter are appearing in this experiment so easily also shows evidence that the BBC is among the media organisations that now have content producers providing semantic enrichment alongside their content production or at least that automated generation of in-page semantics from metadata already present in content management systems is being prioritised alongside other work to develop features more visible to human users. It is not unreasonable to suppose this drive is at least partly driven by content producers’ and content promoters’ desire to control how content is displayed and discovered on third party social media platforms.

Mean-sized Cluster

Returning to the mean-sized cluster in table 5.2, we see a cluster where the most common items are identified as pages each for a single episode. There is no indication in the top five features that they are episodes of the *same* programme, however. This could well be a strength of this system variant in that it is able to suggest other radio programmes on the basis it has understood they all share a common type, but it is open to suggesting episodes of other programmes for greater diversity. In fact, this may be a necessary feature in any “related content” feature as it could be safely assumed that any BBC page for a single episode of a radio programme already contains clear and sufficient navigation links to find more episodes of the same programme; machine learning adds no value to the user here.

Again, there is potential to call out a real benefit in the combination of in-page semantics for this “hard” categorical data (i.e. the page’s content is of type

³<http://ogp.me/>

“Radio Episode”) with entity extraction for a looser, schema-less vocabulary of words that more qualitatively describe the topics covered in the content.

In this case, the topics extracted appear to be the JavaScript programming language and the song *Listen* by music artist Beyoncé Knowles. A manual review of the pages involved finds them to be radio episode pages again, but with no clear indication that they mention either topic. Deeper analysis of the HTML source for these pages finds two “mistakes” the system has made:

- the word JavaScript appears in the page only as part of the MIME type `text/javascript` in markup around JavaScript *code* supporting the page; and
- the word Listen appears on *every* BBC page concerning a radio programme due to the fact they all contain a “Listen” button allowing the user to listen to the live radio stream for that particular radio station. DBpedia Spotlight has assumed this word is a mention of a song titled *Listen*.

Largest Cluster

Finally, the largest cluster has unique quirks of its own. The most popular feature across all members was a rather strange `md:item.rdf:nil=true` whose original is unclear with some explanation. This triple appears to have originated in the RDFLib Python library as an artefact of the Microdata parser (run on any HTML response) having found no Microdata items in the page. This is likely to be a bug in the library where it may have been more useful not to say anything.

The result of this bug or unexpected behaviour is that variants of the data pipeline that use dereferencing as an extraction method will have this property for any page that does not use Microdata simply because of the choice of RDF parsing library. There appears to be enough mix of BBC content pages that do and do not use Microdata such that this feature passed the feature selection filter that should have removed any feature with the same value across the whole corpus.

This is part of a bigger behavioural pattern where embedded semantics appear to tell us a lot about how pages are built as well as describing the content contained therein. This is not necessarily a drawback and is discussed further in section 5.2.1.

Two other features in the five most common across the cluster suggest many of the content items mention the social network, LinkedIn, and news aggregator, Digg. These come from a similar issue with the *JavaScript* and *Listen* entities for the mean-sized cluster in that they are mentioned in the page as part of

controls inviting users to “share” the content on social media sites. These are also clear false positives that reinforce the importance of ensuring entity extraction is performed in relevant textual information. This is discussed in section 5.2.2.

The fifth most common feature for this cluster is genuinely something informative about the content in the page – it appears to be a meta tag informing of a title to use for the page on iOS devices. This is again likely to be an artefact of how the BBC Sport section of the BBC website is developed with requirements relating to iOS devices, but it also – perhaps inadvertently – tells us something semantic about the page in that it is part of BBC Sport.

This may not be ground-breaking insight as there are clearly more definitive ways to distinguish BBC Sport content (e.g. all the URLs paths start with the word “sport”), but it starts to showcase a potential advantage of unsupervised learning on semantics that it can use subtle clues based on how the pages are constructed to determine something about them – if this is deemed useful, that is.

It is also a showcase of how an unsupervised data mining process can be said to have “learned” that these are all BBC Sport articles without having to be instructed through bespoke business rules. This hints at some need for further research as to whether enterprises can truly adopt semantics and data mining to derive business rules that survive organisational and systems changes due to being less brittle than bespoke enterprise integration software based on static business rules (i.e. rules that are true today but need updating when the business context changes or risk breaking).

The more qualitative evaluation in chapter 6 will provide some idea of which properties ultimately end up actually being useful.

5.1.3 Impact of Noise

The previous section highlighted many cases of “false positives” and errors made by this experimental system. The intent of the designed system is to provide an initial baseline capable of processing any piece of media content, perhaps at the expense of the depth that would be achieved by explicit data adapters developed against an internal data API. Thus it is useful to analyse where the system performs less well because a goal for any initial, baseline application should be to evolve and grow it to adapt to errors as they find them.

An open question still for further research is whether these errors are real barriers to gaining useful insight via data mining. The open world assumption and loose nature of the RDF model lends itself well to embracing the patchy and noisy nature of the open web of data and that can be a strength even

across a single organisation’s own content – particularly in large and fragmented organisations.

In a rigid, closed-world approach, we may see bespoke data adapters fail altogether the first time a team responsible for a data API changes, say, the XML structure of its query responses without notifying all clients. We may also see data mining processes lacking the ability to find trends in the entire corpus since the data ingest written specifically for custom APIs has only been built for a subset of all the data stores in the organisation.

The nature of machine learning algorithms is they are intended to learn for themselves which data properties are useful and which are not. In a classification model, we would expect the learning to place more weight on features that produce the answers desirable by those that use the model and some of the noise naturally falls away.

In the current experiment around unsupervised clustering, not only was feature selection implemented to throw away features that do not vary and features that vary too much, but clustering algorithms should favour where items where they share a number of properties, not group content together simply because it shares one erroneous attribute.

Thus it can be concluded that the mere existence of noise is not enough to fault a particular configuration of our semantic data mining system, but there is a need to answer the question as to whether the noise is enough to overwhelm and confuse any machine learning attempts. The question we look to answer in this research is which of the variants of this experimental system are more or less susceptible to noise and errors and recommend how we might research overcoming any false positives that do arise.

At the very least, there are variants of the system that are clearly failing very quickly, e.g. the hyperlink relationships producing only two, unusably large clusters shows a clear need to overcome the causes of those problems before even considering using it in a real system.

5.2 Strengths and Weaknesses of Different Approaches

The analysis in the previous section walks through some exploratory reviews of a small number of clusters, whereas in this section an overview of how each approach appears to show strength and failures is given.

5.2.1 Embedded Semantics Extraction

Some of the analysis in section 5.1 touched on some of the side effects of semantics being tied to *how* a page was built rather than *what* the page is about. It was also shown semantics are being included due to pressures from social media organisations for content providers to describe summaries of their content for better display and discovery. Based on this and other observations in the clusters produced, clustering based on dereferencing URLs and reading their embedded semantics has the following advantages:

- Many media companies are providing semantic data for the purposes of display and other features in a social media context. This means there is a base level of metadata to be extracted without asking those building the pages to add in more semantic markup.
- Some parts of the BBC website have chosen to include much richer semantics. This is observed in section 5.1 where pages about radio episodes were described as such. Some parts of the BBC Sport website also mark up entities such as sport teams as well.

We can also observe the following challenges or drawbacks:

- There can be a lot of noise from meta information about the semantics, e.g. the RDFLib library declaring that a page contains *no* Microdata as observed in section 5.1 or RDFa declarations that inform that the page is using a particular vocabulary by default ⁴
- Some parts of the BBC website provide only basic metadata (e.g. for social media as above) and some have chosen to include far richer semantics. This leads to items varying substantially in terms of the size of the RDF graphs we can extract. The unbalance shows signs of causing a bias where clusters may not be likely to a mixture of such items, instead preferring to group the semantically-rich items together for example.
- There are very general-purpose assertions such as `ogp:site_name="BBC"` provided simply to tell Facebook that a given page is part of the overall BBC website. This is not useful if the whole corpus is from the BBC website, but does not get filtered out due to pages being built differently not all development teams behind individual parts of the website choosing to include that property. Thus the varied usage and non-usage of this feature implies to a machine learning algorithm there is information in the feature's presence or non-presence.

⁴The feature `rdfa:usesVocabulary.http://schema.org/=true` is very common

The last drawback above suggests a bigger question here as to whether there is a more general challenge with machine learning and the open world assumption of linked data and semantics. A classification model surely has to choose between non-membership or membership of a category with some degree of certainty, so will mistake the lack of knowledge of an attribute that would place it in a category as if that item genuinely lacks that defining feature.

Similarly, a clustering algorithm can only group items on what is known. Perhaps if features are lossy in a random sense, then other features will still link two related items, but if, say, a whole section of a website fails to provide semantics on genre classification of its content, then content items in that section will never be paired up with pages in another section of the site that does provide useful information above genres.

It should be noted that this is still a problem in trying to integrate information between two bespoke databases that follow a closed-world assumption. If one content management system encourages authors to categorise their work into genres and another does not, then we still cannot link up content. This situation is arguably worse in that two systems that *do* provide genre information, but using wholly different names for the properties and a different taxonomy of values, still cannot easily unify the data models without explicit and possibly extensive rules translating between the two.

It could be said that the Linked Data concept and by extension the idea of Linked Enterprise Data allows two different data sets to be developed independently for their own use cases so long as they (or a third party) is encouraged to provide additional semantics that link the vocabularies. This is even easier still if the two systems use different, but well-known vocabularies, as the mappings may already exist.

5.2.2 Entity Extraction

Inferring semantics from entity extraction has some clear advantages:

- Extracting real things from textual content gives a far stronger feel for the topics covered therein. Note this is essentially the basis of any keyword-driven search engine such as Google.
- Implementation in the enterprise is relatively simple given the vast number of technologies already available and the long history of research into entity extraction. Reuse of an existing solution – as implemented in this research – is sufficient for many use cases.

However, there are still many drawbacks and challenges to overcome:

- Entity extraction classically suffers from a disambiguation challenge (e.g. is it Paris, France or Paris, Texas?), but there is also much literature on solving and overcoming these problems. The naïve, simple usage of DBpedia Spotlight used in this experiment benefitted from no customisation of the parameters used nor from any attempts to solve ambiguity problems.
- It is less clear as to whether we can narrow down which are the primary topics or entities in a piece of content. Some search engines use heuristics such as preferring entities in titles and opening paragraphs, but this is still a fuzzy approach. In this research, a simple “topic” predicate from the FOAF vocabulary was used and thus gave equal status to all entities, assuming they are each equally a topic of the content. Better research in this area might provide more effective ways to discern a “topic” relationship from, say, a looser “mentions” relationship.
- All entity extraction technologies mentioned so far have focused around text content only. The ability to extract topics from audio or video content is much more complex and is the subject of whole other fields of research. Some very promising techniques were prototyped by Raimond et al.[19] to extract semantic data from the BBC World Service archive using a novel combination of text-to-speech analysis, machine tagging and crowdsourced user feedback at scale. There could be much opportunity to applying such research more generally, for example across BBC iPlayer catch-up content, which can then feed into better data mining.
- Effective extraction of the content “body” text must be performed to prevent entities being found in supporting page furniture such as site-wide navigation links. A single failure to remove an element common to multiple pages will result in all those pages being “tagged” with that concept.

The final drawback is worsened when elements are across just one class of pages (as observed with the *Listen* problem in section 5.1) as at least entirely global entities will not pass feature selection. When a navigation element only appears in part of the corpus, the system might erroneously decide this is an informative feature.

As noted in section 5.2.1 with semantics that expose the nature of the construction of the page, a supporting element on a particular class of pages might actually be useful information. To refer back to the *Listen* example – where a “Listen” button for radio stations on radio episode catch-up pages is mistaken for a song with that title – it can be argued that the clustering model “learned” something common between all these pages. It could be said that we need not

worry about the technically incorrect semantics that it “thinks” the pages are about that song if the end result is a useful feature that understands there is some commonality between radio episode catch-up pages and it is suitable to consider them as related content suggestions when a user starts on such a page.

This is an overall advantage to applying semantics to data mining: we do not need our machines to gain a perfect “understanding” of the content so long as the so-called understanding is *good enough* that applications of the models – such as suggesting related content – ultimately appear to be behaving intelligently in the average case.

This conclusion is reminiscent of John Searle’s famous *Chinese Room* thought experiment[24] that illustrates a computer programme’s potential to appear intelligent even when following deterministic rules and lacking the deep understanding and consciousness that we perceive as uniquely human.

5.2.3 Hyperlink Relationships

Exploratory analysis does not highlight any major strengths from hyperlink extraction alone. Common properties centre almost entirely around links to common pages such as FAQs, help pages, etc. due to the lack of constraints in the system implemented to narrow the extraction to “interesting” links from within the content itself.

This extraction technique might well perform better on a website such as Wikipedia where articles contain a large number of links to other articles, but BBC content employs links within article bodies very rarely. Other news websites such as The Guardian make more use of hyperlinks within articles to other articles and topic aggregate pages, so results for content from The Guardian website might look very different to those for BBC content.

5.2.4 Enrichment by Dereference

The most striking observation of all clusters from enriched RDF graphs is that they can have orders of magnitude more features than their unenriched counterparts. This was especially true in the case of enriched RDF graphs obtained via entity extraction. This is due to the fact that any lengthy article may yield ten to fifty entities, perhaps more. As DBPedia URLs were used for entity tags in this experiment and DBPedia can have very rich graphs for popular entities, it is not difficult to extrapolate an assumption that the final feature sets will be very large.

The size of these feature sets makes it challenging to analyse in an exploratory sense, but the comparative evaluation in chapter 6 hopefully proves

whether the size of the RDF graphs and resulting feature sets is ultimately harmful to the data mining process.

Enrichment via dereference was less dramatic for in-page semantics themselves extracted via dereference. While not called out specifically in section 5.1, a general trend was for those semantics exclusively to contain literals as values.

This is a consequence of relying on HTML meta tags and other such mechanisms for social media sites. Richer markup approaches such as RDFa and Microdata allow for entities identified by IRIs and URLs to be the objects of any triples, but since these were employed rarely in relation to metadata for social media, they appeared less often in the resulting clusters.

Finally, inferred semantics from hyperlinks would solely contain other BBC page URLs as objects (because the implementation explicitly filtered for BBC URLs only) and thus gained all the advantages and difficulties with extraction via dereference. A casual inspection of the clusters suggests that enrichment here did not therefore add as much additional value as was the case with entity extraction.

5.3 Recommendations for Production Use

It can be argued that building an experimental system full of flaws and drawbacks is not just more desirable, but essential for research and learning. However, if a similar system were to be built as a production-ready application delivering real benefits to customers in industry, there is clear need to do more work to overcome practical limitations.

Thus this section concludes this chapter with some recommendations based on all learnings so far on how a media organisation might want to start applying data mining of their content using semantics.

5.3.1 Embedded Semantics

The Semantic Web movement provoked some pragmatic scepticism[15] over the years, mainly focused around the expectation that content authors are unlikely to create alternative data for machines on top of their primary objective of creating content to be consumed by people.

The findings and analysis presented so far in this chapter suggest there are modern incentives around summarisation of content (e.g. Twitter “cards” when content is embedded in a post) and discovery (both Facebook and Twitter show trends in topics discussed in news items posted to their networks). Recognition of this shift in incentive and consequently the presence of more metadata than before does not appear to be noted so much in the academic literature.

Haas et al.[10] provided evidence in 2011 that fewer than four percent of pages retrieved via Yahoo US search contained RDFa markup. In a media organisation that has no culture of technical employees with an interest in the semantic web or linked data, there may be no pages with semantic metadata purposely added. However, if we embrace meta tags intended for social media websites, exploratory analysis of BBC metadata in this research suggests a ubiquity of such semantics driven entirely without the academic push behind the Semantic Web and Linked Data.

We can therefore see social media annotations as compromise between benefits of semantic markup and the pragmatic concerns that authors will not add hidden metadata without clear, immediate benefits. It is hoped that the results of this research show that there are some baseline benefits to an initial round of data mining on those semantics alone and gaps and failures can create the incentives for web page authors and engineers to improve their semantics and see immediate benefits (e.e. their pages get promoted more readily in pan-site signposting such as sets of “related content” suggestions).

In summary, the recommendation for the media industry here is to lead with building insights based on what data are already in place and look to improve over time once the incentives to do so are in place. Gaps to consider are where semantics are missing altogether and a large gap observed in BBC content alone is a lack of linked data between distinct areas of the website.

For example, programme information and catch-up pages are excellent at describing themselves as being TV or radio programmes and BBC News has the early stages of pages that aggregate News over a given topic, but there is no cross-linked data where concepts are covered both in a news article and in a programme. This will emerge in organisations where distinct teams and divisions work on very distinct parts of their output, so any data mining concerned with the whole corpus needs to highlight issues from lack of cross-linking as much as possible, particularly if that data mining is driving a real website feature that will see immediate improvement if such cross-linking is implemented.

5.3.2 Entity Extraction

The clearest requirement here is to ensure that entity extraction is run on only the main textual content of any page. With sufficient experimentation, an organisation might be able to tolerate the false positives on a more naïve implementation that processes the whole page. Over time, the system could evolve with bespoke content adaptors common in enterprise integration so as to extract the pure textual content directly from the source system and thus bypass the need to remove noise from around the article.

Also, there will be a need to spend time tuning and configuring the entity extraction to produce the right quantity and quality of entities for each content item. There is no clear single approach from this initial research alone and organisations will need to experiment on their own content.

5.3.3 Hyperlink Relationships

The only conclusion from this particular experiment is that hyperlink relationships are a poor indicator of the nature of the content in the BBC content corpus. An organisation might only want to make use of these relationships if its content authors habitually include links within articles to other articles or pages.

EVALUATION

This chapter builds on the more immediate analysis in chapter 5 of the clusters produced by evaluating the results across a group of people. The system designed and built is also a subject of evaluation, particularly any flaws or potential improvements that emerge from having run the software and reviewed its results.

A higher-level goal of this research was to perform some more qualitative evaluation of those clusters by obtaining human feedback on a potential application thereof. The application evaluated was a feature that would take a page a user is currently reading and suggest related content based on their being members of the same cluster. Mock-ups of such a feature were generated and evaluated via a survey as described in section 6.1.

The remaining sections of this chapter then discuss some issues with the design and difficulties arising during implementation respectively.

6.1 Qualitative Survey

An online survey was produced where a user is shown a sample page from the BBC website and for each cluster of which that page is a member, a row of up to four “suggestions” was presented to users.

In this section, some details around the design and sampling criteria for the survey are discussed initially, followed by analysis of the results. The section concludes with further qualitative feedback and observations that arose in survey responses.

6.1.1 Survey Design

An initial challenge for generating the survey was that it was necessary to present to users a view starting from a particular content item. This is effectively an inversion of the analysis from chapter 5 where a top-down overview of the clusters was performed, with some drill-down into more depth in some cases.

A reasonably arbitrary sample size of 20 content items was chosen for which it was therefore necessary to choose 20 *pages* that were known to be members of one or more clusters. It was also desirable to ensure that multiple clusters are evaluated in one survey question, so items that were placed into clusters by multiple instances of the data pipeline were preferable.

It was also important to ensure that the overall set of items chosen provided coverage across all permutations of the data pipeline and that some diversity of content was present (e.g. all items are not simply news articles without any representation of TV and video content).

A further additional property chosen for the sample set was that a diverse range of cluster *cohesion* values were present in the set. This arguably allows the survey to present for evaluation clusters that the machine learning applied itself believes to be poor as well as ones it believes to be cohesive. This controls for coincidences where only good clusters were chosen for one approach and another had its least cohesive results chosen. It also has potential not just to compare which approaches receive the most relevance votes, but also to look for where those approaches' results produce clusters whose cohesion measure correlate with anything meaningful to humans.

The above sampling heuristics were applied programmatically by first inverting the cluster data structures such that there is a known list of all content IRIs across the whole results set and the list of clusters of which they are members are keyed against those IRIs.

A composite uniqueness key was then created for each membership those content IRIs have in the form:

$$u(iri, cluster) = (approach, cohesion(cluster), category(iri))$$

where *approach* is a unique key referring to a particular permutation of the data pipeline being evaluated and *category* is a rough, heuristic function that tries to assess which part of the BBC website “owns” that content item, e.g. BBC News, iPlayer, Weather, Sport. Each item would have a uniqueness key attached to it for each cluster of which it is a member.

Content items were initially scored based on how many clusters of which they were a member:

$$score(iri) = 10 - |5 - |\{c \in C \mid iri \in c\}||$$

where C is the set of all clusters produced. This gives us a score of 10 when the number of clusters in which the item appears is the ideal value of five. The justification for this optimum is based on the lower end of the memory capacity limits suggested by Miller[16] (Miller’s Law).

The item is thus “punished” when it appears in only one cluster (thus the question would only be testing one approach and has less value as a question) or if the item appears in too many clusters (asking people to compare between too many items might be overwhelming and reduce the potential for people to answer accurately). As this is only a heuristic, the sampling code still chose some items nearer this extremes, thus an absolute cap was implemented in the survey itself to ensure a random sample of seven clusters was chosen for evaluation when items appeared in a number greater than seven.

Starting with the highest scoring so far, the sampling algorithm then updated each score based on the number of unseen unique keys it would introduce to the final sample if it were chosen:

$$score'(iri) = score(iri) \times \frac{15 - |keys(iri) \cap K|}{2}$$

where $keys(iri)$ is all uniqueness keys for an IRI:

$$keys(iri) = \bigcup_{c \in C} u(iri, c)$$

and K is the cumulative union of all keys so far generated by invocations of of the $keys$ function so far, with its initial value being the empty set.

Some of the constants used were tweaked based on what appeared to generated a desirable, mixed set of sample results such that they are a little better than arbitrary values. Once all IRIs were updated with the new scores, the final sample of results for evaluation was simply the content items with the twenty highest scores.

6.1.2 Survey Results

The survey was taken by 30 respondents with three having taken it following the think-aloud protocol[14] so that more information can be gathered around the motivation for the responses. Two of the think-aloud participants were experts in usability testing and user experience design and the remaining participant a normal website user.

Details of observations captured during the think-aloud responses are dis-

cussed in section 6.1.3.

A key metric generated from the responses was the proportion of times respondents selected a “related” set of items based on clusters generated from a particular data pipeline variant. A table of the responses is given in table 6.1.

Table 6.1: Success rate for each pipeline variant in generating related content suggestions

	Not enriched	Enriched
Deference	5%	44%
Entity Extraction	17%	37%
Hyperlink Relationships	8%	14%
Dereference and Entity Extraction	34%	37%
Entity Extraction and Hyperlink Relationships	16%	11%
Dereference and Hyperlink Relationships	26%	30%
All three extractions	23%	24%

A tabular form of the results is helpful for showing which techniques performed the best and whether enrichment improved or worsened the performance. However, it is difficult to derive absolute meaning from numbers taken from qualitative feedback over such a small sample.

In figure 6.1, each pipeline variant is visualised as a node in a directed graph. Note the nickname *RDFa* to represent dereferencing and extracting embedded semantics despite *RDFa* being only one of a few semantic markups extracted in this case. Also note the convention to suffix the variant name with *+* to indicate it has been enriched. The nodes on the far left represent each of the three extraction techniques used in isolation.

The edges of the graph represent introducing one new technique and re-running the experiment. For example, the edge from *RDFa* to *RDFa+* shows what happens to the performance if we introduce enrichment via dereference to data extracted also by dereference. The edges from e.g. *Entities* and *Links* point to the result of having used both of those techniques in data extraction (joining the graphs via set union).

Where a percentage increases (significantly), we can infer with some level of confidence that adding in a particular technique *improves* the performance of the overall system for choosing clusters of related content. Conversely, where the percentage drops a large amount, we can infer that introducing that technique has worsened the performance.

In the particular results depicted, there are a mix of insignificant and significant changes in performance when we alter one aspect of the system. Insignificant results include:

- In all but one case, the enrichment via dereference had very little effect.

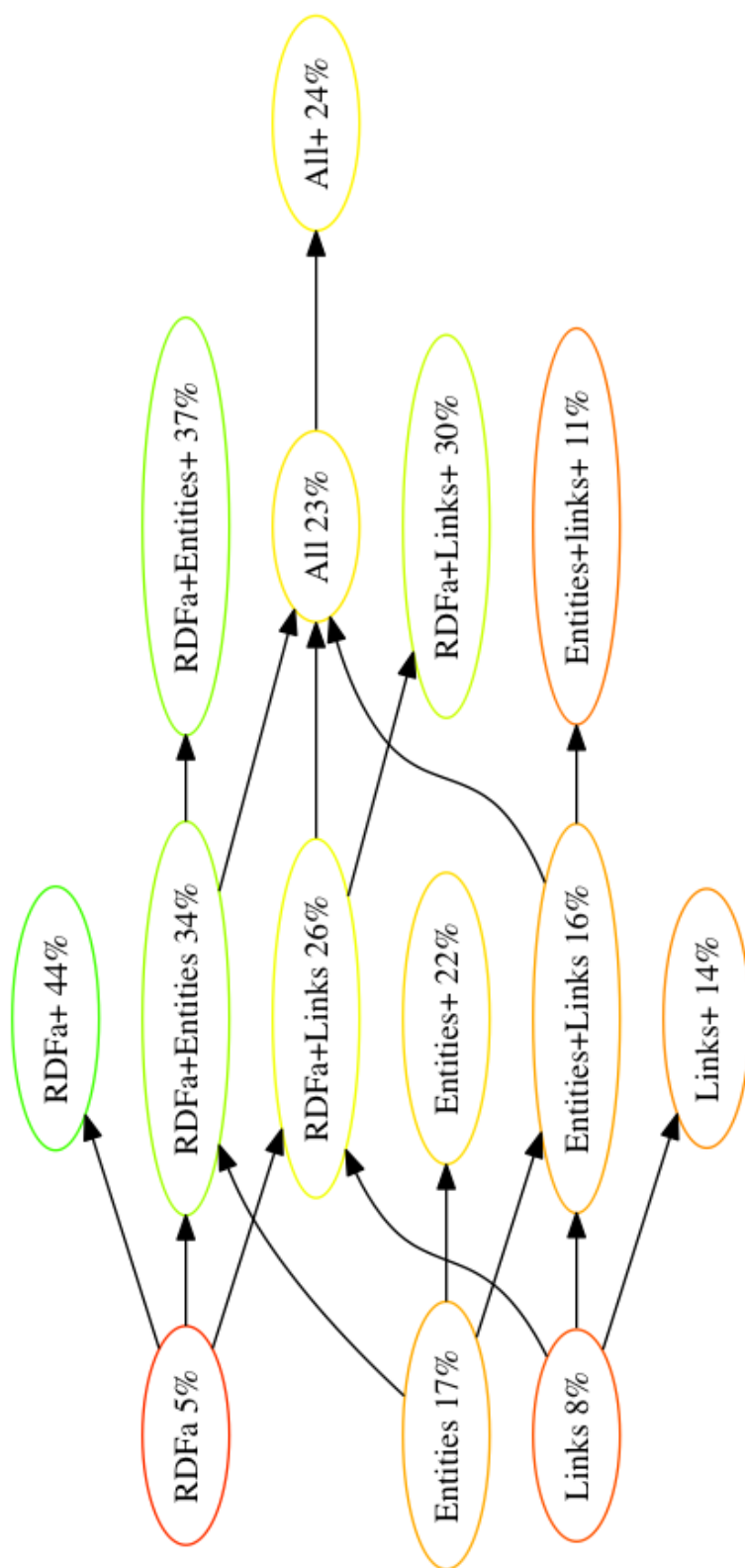


Figure 6.1: Visualisation of performance of each data pipeline variant

Changes between 1% and 5% do not stand out as large jumps in behaviour, particular with the small sample size of people being likely to make the error margins quite large.

- Extraction via entity extraction does not seem to improve nor degrade when adding in hyperlink relationships.
- The combination of dereference and hyperlink relationships does not perform very differently when entity extraction is added.

Some of the most significant results appear to be:

- Extraction via dereference only improves substantially when improved in *any* way. It benefits most significantly out of all variants from enrichment.
- Entity extraction benefits somewhat being combined with embedded semantics obtained via dereference, certainly more than it benefits from being combined with hyperlink relationships.
- Hyperlink relationships perhaps benefit a little from enrichment (but it might be bold to claim that), but more significantly we can see that extraction technique in performance when combined with either of the two other extraction approaches (or both).

The step change between embedded semantics in isolation and the enriched version thereof is so large it prompts a brief return to reviewing the clusters each variant produced.

If we refer back to table 5.1, we can see another significant step change in that the unenriched variant produced 5 (fairly large) clusters and that number drops to 249 when enrichment is introduced.

Considering also that this extraction approach performs the most poorly across all results, we begin to see support for the analysis in section 5.2.1 where it was observed that only very basic metadata is found embedded in many BBC pages. This appears to have created a sample of feature sets that have a very small number of features each. Further observations in section 5.2.1 stated that many of the semantics found had common values (e.g. `ogp:site_name="BBC"`). That many features thus did not pass feature selection (since they did not appear with enough value variation across the corpus) means that the few semantic properties found are stripped down even further.

Much of the performance gain by altering extraction via dereference might be explainable purely due to having added more data properties with which the machine learning algorithms can work. This starts to suggest a potential for a minimum feature set size below which clustering processes will struggle.

This is especially supported by the large performance increase from having simply enriched the data. Given the enrichment in a lot of cases just added more higher order properties describing the semantic properties themselves (e.g. `md:item_rdf:type_rdf:List` appeared in some cases, which tells us only that the `md:item` property found takes list objects as values), we can safely conclude much of the “enrichment” has not added information about the content, but just increased the triple count enough to make the clustering more effective.

Given the noise from page structure and meta-semantics like RDFS and OWL, it might be surprising that embedded semantics performed well at all. The strength that appears to have had the most impact is that the few times semantic properties are used in BBC pages, content producers are including basic categorical information such as what part of the BBC site we are on (e.g. `ogp:site_name="BBC Sport"`) and in some cases which section within that site (e.g. `article:section="Golf"`).

The basic categories seemed to be powerful enough to please many respondents who frequently approved of related content suggestions on the basis that the suggestions were from the same part as the BBC website. This may be an artefact of framing the survey in an artificial way as people validating the system by whether the pages are grouped by well-understand categories (e.g. football news, comedy TV, science articles) does not necessarily correlate with how those same users would have been tempted to follow links to suggested items as part of their own casual browsing of the website. This point was also raised in some of the think-aloud discussions with user experience experts, as discussed in section 6.1.3.

It seems reasonable to conclude that embedded semantics perform well enough to produce clustering that appears intelligent on casual inspect. Given that it is one of the simplest to implement (run a standard RDFa and Microdata parser such as `RDFLib` in Python), there is much to say for its cost-benefit ratio. It could be concluded this is a strong starting point for a first iteration of a real implementation of this experimental system.

Entity Extraction performed most strongly out of all extraction techniques in isolation. This result is even more promising when we consider that the parameters of the DBPedia Spotlight extraction used were arbitrarily chosen, so there is certainly scope for further work to find better performance with better tuning of the entity extraction alone.

The favourable discussion of both embedded semantics and entity extraction above is supported somewhat by two observations in the results visualisation: their combination appears to perform best out of all pairings of extraction techniques and adding hyperlink relationships to that pair reduces the performance. The joint occurrence of these two facts may not be coincidental and thus sup-

port the short analysis in section 5.2.3 where even brief review of the clusters provides little confidence in their utility. Some potential ways to improve this extraction were given at the end of section 5.3, but from this research alone we cannot conclude any benefit in extracting relationships in this way until those improvements are trialled.

It is also important to note conclusions from the lack of significant step changes and the most interesting one in these results is the lack of support for enrichment via dereference improving performance at all. This follows on from analysis in section 5.2.4 that suggests the use of dereference simply falls down on the same drawbacks as dereference as an extraction technique. The only case where enrichment makes a large difference is improving extraction via dereference, but this could be explained more by the latter performing so poorly in the first place, as discussed above.

In summary, there is much promise to consider starting with embedded semantics where the system will do little more than learn categorisation of content (in the case of BBC pages, that is) and look to bring in entity extraction in a controlled way so that the tuning of the extraction can be experimented with.

A production version of this system should aim to achieve an evolution from finding the “obvious” distinctions from the content (i.e. do we really need machine learning to tell us that BBC Sport articles are related to each other, but distinct from BBC Food recipes?) to finding more nuanced relationships based on entities and topics found within the content if it is monitored and tuned well. This difference between clear-cut differences and more topic-based relationships turned out to be a key theme from the think-aloud evaluation and consequent discussions with user experience experts. This is discussed in section 6.1.3.

6.1.3 Further Observations and Discussion

Further qualitative feedback was obtained in two ways: firstly by adding to the end of the survey some open-ended questions to invite some discussion:

- Do you feel that suggested links to promoted content is something you would use in general? Feel free to expand on your answer.
- Do you have any general observations on where the suggestions performed poorly or where they performed well?
- Please write any other comments or observations below.

Approximately half of respondents answered the first two and only three out of the 30 went on to give some additional comments. Many of those were user experience experts who felt they had much to contribute additional feedback.

The second phase of additional, qualitative feedback was notes taken during the “think-aloud” survey responses as described in the previous section.

In the think-aloud observations, non-expert responses were terser than those from experts and it seemed as though conclusions were reached more quickly about whether suggested content was relevant or related. The impression was that non-experts may act on some instinct that is hard to describe, whereas experts in user design are more experienced in some of the rationales and patterns they have observed across many user testing sessions. This more instinct-driven approach for non-experts is supported further from observations that thumbnail images were cited on more than one occasion as a motivator for determining content as being similar or not.

The expert think-aloud observations highlighted the key difference between content being similar due to being in the same categorisation groups versus being related by themes or topics, as discussed at the end of the previous section. The opinions from these user experience experts was that a topic-based similarity would be strongest for users to consider clicking through to the suggested content and this was vindicated on a number of occasions in non-expert responses two (in one example a respondent was disappointed that many suggestions offered next to a BBC News article were just “more articles” and not “articles on the same topic”).

The topic-based feedback gives more support for getting good quality meta-data *about* the content in far more fined-grained and nuanced ways than broad categories typically found in the embedded semantics in BBC pages. Entity extraction looks to be a strong candidate to support this if we cannot get more nuanced topic tags into the embedded semantics. This case is supported well by the analysis of the main responses in the last section.

The expert discussions raised some cases where “hard” categories for the content were necessary, however. In some cases the clustering processes had grouped content suitable for children with content not explicitly marked as such. For a media organisation like the BBC, where there is wide provision of content targeted at children, any promotional feature on the website needs to be very cautious about what it suggests. In the BBC, it is typical to create a strict separation between child and non-child content and a general-purpose data extraction pipeline has no automatic knowledge of this. In a real setting, it is likely a production version of this system would want to have some basic business rules to constrain its operation where these strict requirements exist.

Another case for hard categorisation came from BBC Bitesize pages with GCSE revision material for 14 to 16 year old British children. There was some approval where it suggested revision material for other subjects (relating GCSE French to GCSE English, for example) and even when it appeared to suggest

other content aimed at a younger audience (e.g. BBC Newsround news articles aimed at children), but it was raised whether it was appropriate to “distract” children revising for GCSE exams with entertainment content. This highlights more consideration for business rules.

It was also noted that GCSE revision material was sometimes grouped with material for even younger age groups (e.g. Key Stage 2 for 11 year olds) which is unlikely to be helpful. This is another drawback of trying to “learn” relationships without prior knowledge of strict categorisation of the UK National Curriculum structure. The BBC has however modelled this as a semantic ontology¹ which may be promising for future iterations of this research where we can incorporate more inference and enrichment based on ontologies.

The final case where strict separation of content is needed is where the system chose to cluster many British football teams together. Semantically, the system was behaving very well in identifying that all pages are published by BBC Sport and talk about a football team, its fixtures and its results. However, with proper domain expertise, a system should know not to suggest arbitrary, alternative football teams to a user who is on the page for their favourite team. It is unlikely they wish to read about teams they do not follow.

One last point raised in discussions with user experience experts was how they believe that users on a given part of the BBC site may be in different moods or have different goals depending on where they are. For example, users reading information and educational guides are believed to be more likely to be in a position to be suggested other informational content even if it’s only tangentially related because their focus will just be on reading interesting things. Conversely, people reading articles on BBC News might only wish to be suggested articles on the same topic or developing story.

These different moods or goals seem similar to some of the search and discovery modes proposed by Russell-Rose, Lamantia and Burrell[23], where they try to give names to different modes of behaviour exhibited by users when using search or navigation systems to find information. It is not immediately clear how we can infer these different modes or use cases based on the semantics of different content items, but there could be some consideration to how knowledge of user behaviour can feed in to any machine learning processes.

There is much useful feedback and discussion raised just from discussion with some user experience experts and also non-experts as they evaluated the system’s output in the survey. The open questions at the end of the survey prompted a large number of comments, which can be summarised as:

- Some liked where clear categorical grouping had occurred, e.g. news arti-

¹<http://www.bbc.co.uk/ontologies/curriculum>

cles grouped with news articles, perhaps from the same category. Areas of the site where clear categories are lacking from the embedded semantics were mentioned as performing less well.

- Others were less happy with suggestions being driven by broad categories only and felt they needed to relate by topic before they would follow the links.
- There were a range of opinions as to whether the results were overall good or bad.
- Two or three comments supported the idea that more weakly related content was better on the information sites, also supporting the idea that users are in a more exploratory “mode”.
- At least one comment noted that content was old. The clustering has no knowledge of what is current and what is older (which is very important for things like news).
- Comments generally supported the idea of having a related content feature at all, but many were quick to add that it had to be truly relevant otherwise they may ignore it in time or treat it as if it were spam or advertising.
- There were many comments, even from BBC employees about having discovered parts of the BBC site they were not previously aware of. Some of this was helped by the sampling heuristic deliberately choosing a diverse range of content for evaluation, but it does support the idea that users might need features driven by data in this way to suggest parts of the website they did not know about before.

A common theme from both this section and the previous section is this balance between structured, categorical data and topic and theme information both feeding into how content is grouped. This provides strong evidence again for the benefits of combining structured information from embedded semantics with fuzzier approaches like entity extraction.

The simple survey designed and given to only 30 people has raised a substantial amount of feedback on the variants of the system. In the next section, there is some evaluation of the software itself from a design perspective and some discussion of some of its shortcomings that a production version might wish to avoid.

6.2 Design Limitations

Throughout chapter 3, the design of the data pipeline and overall software architecture was outlined and known trade-offs and limitations were highlighted. Further design trade-offs due to the systems intended use to be experimental rather than production-quality in an enterprise were also covered.

This section highlighted some design issues that were noted only after the system was built and how research and industry alike might learn from these problems. Such problems might be addressed if the results of this experiment are to be researched further or indeed if such a system were to be built in a real media organisation. Such learnings for production use should follow on from the recommendations in section 5.3 around applying the data extraction techniques used and provide more general software design recommendations.

6.2.1 Performance

The experimental system ran far slower than would be acceptable in an enterprise system and even to the extent that it would limit developing this research to the scale where it is processing millions of items – a target that would be ideal for further proving the suitability of semantics and machine learning on real media content corpora.

A better-performing system might have allowed even this experiment to consider larger numbers of items, although even a relatively small sample size should sufficiently indicate which techniques look more promising for developing a more efficient system that focuses thereon (and save time by dismissing techniques that show no promise).

The performance difficulties that arose from the design and concept broadly break down into two problems:

1. lack of consideration for data structures for the feature sets and clusters;
and
2. network latency bottlenecks.

The first problem stems from the fact that the design was precise around the in-flight data in the pipeline, less consideration was given for how to store the resulting feature sets and also the clusters. The feature sets were stored as simple JSON objects on files on disk, which is perfectly fast for writing and reading, but there was no pre-calculated distance matrix between those objects. The clusters were also stored in a naïve fashion of larger JSON objects that embedded their members' data for quick display of those clusters and calculation of things like cohesion.

A distance matrix is a $O(n^2)$ operation in terms of computational complexity, which scales poorly, particularly for a continuous ingest of data where each new item invalidates the matrix. The design of the system implemented in this research was built around an assumption that we wish to have a continuously-running data pipeline that can update as new content is published. Recalculating the distance matrix on each new item would effectively push the complexity up to $O(n^3)$ which is clearly undesirable.

With this in mind, a cut-off for content ingest had to be determined so that the distance calculations and then the clustering could be invoked. The system implemented does not save any intermediate data such as distances, so adding in a single new item or cleaning out any duplicates found required all the results to be regenerated from the start.

A production version of this system would have to look at a distance matrix and cluster set structure that allows for real time updates of new and updated content, efficiently changing only parts of the matrix affected (e.g. a new item only needs to calculate its distances with each existing item and does not affect existing pairs). This could be a promising direction for further research.

The other issue of network latency became very apparent in particular when enrichment via object dereferencing was enabled. Whereas an enterprise integration effort between two different data stores operates on bespoke software engineered in a controlled network, extracting RDF data via a URL dereference is susceptible to network latency over the public Internet. Also, HTML pages with embedded semantics have a very poor ratio of semantic metadata to irrelevant information – a document DOM focuses a lot on marking up the content for web browsers.

There is still a compelling case for the *decoupling* achieved by using standards like RDFa and the *abstraction* HTML and HTTP provide over the underlying data stores, reducing the need for bespoke clients. However, any extraction of that data needs to tolerate or factor in the increased latency for this approach.

For extraction, the latency of a single HTTP request (or two or three if HTTP redirects are issued) will only cause a bottleneck if new content is published or updated at a rate faster than the pipeline can process. This seems unlikely even in an organisation like the BBC, particularly if the system implements structures such as queues to handle bursts of input, processing them in quieter intervals.

However, for enrichment via deference, an RDF graph produced might have hundreds of objects needing dereferenced via HTTP request. A simple cache layer might prevent the system repeatedly requesting for the same URL in a short period, but this kind of latency still means it could take of the order of minutes for a single item to get through the pipeline.

It is not clear that there is a single answer to handle this as it is likely a combination of factors need optimised to make this form of enrichment acceptable:

- It might be that hundreds of objects linked via predicates creates too much noise in general. If those objects have come mainly from entity extraction, should entity extraction be tuned to bring back only the “main” topics of a page?
- Chapter 5 discussed how many of the extraction techniques (particularly deference) produced a lot of irrelevant facts (e.g. about the page itself, not the content) all of which would be candidates for deference of the objects are IRIs. Effectively filtering out such noise would reduce the work spent enriching irrelevant things further.
- A simple architectural solution is to parallelise the HTTP calls as much as possible such that an item’s latency is only as long as the slowest response time. There are obvious limits to this (we should avoid overloading the server even if it is scaled for millions of visitors per day), but any parallelism is clearly better than a hundred sequential HTTP requests. Parallelism includes distributed architecture over multiple servers as much as concurrent programming paradigms.
- An organisation should probably ensure a system is physically near any servers serving HTTP requests to reduce the overall TCP packet latency. This optimisation will add up over time, but is a challenge for a large organisation such as the BBC with systems of varying ages distributed over multiple locations ²

Even with all the optimisations possible, it is inescapable that multiple HTTP requests to assemble an RDF graph is slower than a single query to a data store’s query engine (e.g. SQL) that returns all the information needed in a single response. The benefits of using semantics, HTTP and other standards – such as decoupling, simple enrichment, reuse of standard technologies – need to be effectively researched and promoted, otherwise enterprise organisations will continue to reach for the seemingly obvious solution of building software that queries one database to push to another.

²Industry has long outgrown the notion that enterprises like the BBC have a single “www” server as in the early days of the World Wide Web. However, the www hostname still needs to resolve to a single set of IP addresses for something that fronts the rest of the network like a load balancer. Effective caching in this front layer and ensuring our data pipeline lives close to that cache might be sufficient in this case. An example of a front cache might be something like the Varnish HTTP cache: <https://www.varnish-cache.org/>

6.2.2 Noise

The semantic web and more recently Linked Data are arguably built around the idea that they embrace the loose architecture of the World Wide Web. With that looseness – open world assumption, no schema constraints, etc. – we cannot assure strict quality and integrity of the data as would be possible in a closed-world database.

The data pipeline design in chapter 3 has no requirements nor consideration for how to handle facts that are erroneous, missing nor meaningless (e.g. see the discussion in section 5.2.1 of the system finding facts about the pages’ structure rather than content metadata).

In section 5.1.3, it is argued that noise might not have as much impact as one would assume given the fuzzy nature of machine learning in general. This argument is important to consider, but here we explore the issue of noise on the assumption that it *is* a problem as it is important to evaluate how noise fed into the system in the first place and how we might tackle it.

Erroneous facts may be non-trivial to distinguish from real facts, but there is scope for research on effective methods for reducing that noise. In an enterprise, we need not exclude the benefits of enterprise integration development to *support* this approach based on semantics and web standards.

While there is much gained from being able to reason about the entire breadth of an organisation’s content using semantics, it does not preclude writing bespoke business rules that strip out known, erroneous data or provides a framework against which to evaluate the likelihood of a fact being useful or true. At the very least, there could be some work to develop ontologies and schemas that detect inconsistencies in the data, but in a way that adds value to a working system rather than such modelling being a barrier to building the first iteration of the system.

Facts that are missing are arguably not a “noise” issue, but still a data integrity concern. If an item lacks key information, it may be categorised incorrectly. It should be noted that the data pipeline designed here did nothing to address this deliberately and the desire was to evaluate the open world characteristics of semantics without trying to fill in the gaps.

As with the erroneous facts discussion above, there is much case to be made for designing such a system so that it is extensible enough with customisations and bespoke software to aid where it appears to be struggling – once its initial behaviour is evaluated. In the case of the data pipeline designed in chapter 3, any in-house databases and APIs can be integrated as additional extraction techniques to be joined via union to more general approaches such as dereferencing.

Data being irrelevant might be the larger of the three concerns here as that greedy machine learning algorithms can get stuck on such noise. In section 5.1.1, we see how one approach caused the clustering to get stuck on the fact that all items linked to a common FAQ page.

Other data attributes such as the Twitter Cards metadata (see section 5.1.2) can contain very broad things that are declared on all pages that use this vocabulary (e.g. `card=summary` is always used to indicate that a given page is using these meta tags) might cause a greedy algorithm to focus too long on grouping together all pages that happen to choose to implement this Twitter feature with less concern about the more interesting properties.

CONCLUSIONS AND FUTURE WORK

This chapter lays out some conclusions from this research around the potential for semantics being used more in the enterprise, whether semantics combined with machine learning or data mining has potential in industry and how organisations should consider implementing this. Finally, some options and potential for future research are suggested.

7.1 Challenges and Opportunities for Semantics in the Enterprise

As discussed in section 5.3 and also more generally throughout chapter 5, there is much scope for enterprises to benefit from using semantics in public-facing pages that display their own content. This is particularly necessary in larger organisations where attempting to gain an overview of all the content metadata in a short timeframe would be a large enterprise integration effort.

The challenges amount to the issues raised around noise (semantic information not immediately relevant to the content), incomplete information (due to the open world assumption) and perhaps even erroneous information (embedded Semantic Web data is not always visible enough for publishers to spot errors.)

Even with these issues, the experiment performed in this research was still able to take place across a wide range of BBC content without any bespoke integration against internal data APIs nor a any significant code created to deal with a particular data source.

The power to use semantics and other web standards to gain a broad overview of a large set of content should be very appealing to a media organisation, even if there are issues with that data, assuming their application is in a use case

where less precision of that information is tolerable.

Even where data needed corrected, the software developed even in this experiment was able to adapt to broad patterns in the data that were problematic. there is also much indication that engineers in the enterprise would be to complement the breadth from extracting semantics with the depth of data obtained directly from data sources. This is achievable with the set-theoretic nature of RDF graphs and our ability to perform simple set union operations to join data sources.

As is evidenced by the pressure from social media and networks such as Facebook and Twitter, publishers will include better semantics if the right incentives are there. Perhaps the incentives promised by the earlier semantic web advocates (search engine optimisation, the development of clients that join up data between websites, etc.) were not strong enough for publishers, but the need to control how that content is summarised and discovered in places outside of the primary website is indeed a strong incentive.

There is much to be said for the argument that any enterprise that therefore creates applied features to make use of content metadata (promoting related content being just one example), that the organisation might create appropriate pressure internally for those publishers to "correct" or at least improve their semantic annotations when faced with clear evidence where improvements could be made and errors corrected.

7.2 Suitability for Semantics and Data Mining in Media Organisations

As noted in section 5.1.3, the fuzzy and noisy nature of linked data and the semantic web might find an ideal match in the world of machine learning – something that can operate on noisy and fuzzy data sets and still find patterns and insight. That machine learning and data mining builds upon the idea that data collected might be noisy or incomplete leads to a strong argument for its application being ideal for the RDF model of the semantic web.

Statistical methods like machine learning are clearly more tolerant of errors than more "hard" uses such as presenting concrete facts to users based on embedded semantics or inferring some hierarchical structure for a navigation feature. Even where the machine learning methods struggle in this particular research, it does not prevent further research that better tunes the learning methods used to produce even more useful results.

The question remaining from all of this for the media enterprise, is whether this combination of semantics and data mining has real application that is useful.

The results of the survey discussed in chapter 6 suggest the example application of driving related content suggests was successful enough to get positive feedback for certain permutations of the data pipeline. It was argued in analysis of the results that there is a strong cost-benefit justification in creating a general-purpose system capable of using embedded semantics on which a clustering process can at least learn basic categorical structure. This can then be made more nuanced and topic-drive over time with entity extraction, when introduced in a supervised way so that it can be tuned to behave desirably.

The development time on the extraction of embedded semantics is far less than a series of bespoke enterprise integration efforts against each data store and there are immediate results in some of the clusters it can produce.

There is still much need for further research to improve these extraction processes however. This is discussed in section 7.3.

7.3 Future Research

7.3.1 Better Enrichment

As discussed in chapter 6, enrichment by deference fell down on some of the drawbacks of extraction via dereference and did not seem to add much value to the clusters produced.

The data pipeline designed theoretically in chapter 3 described many more suggestions for how we might enrich RDF graphs in the middle of the pipeline, but this research only allowed time to experiment with the simplest to implement.

One idea that could have a lot of potential is using OWL and RDFS ontologies to infer facts not outright stated, which can find generalisations (e.g. an article about tigers and an article about lions are both about big cats even if we cannot find the word “cat” in their respective text content). Where the application in an enterprise may be truly powerful is how such reasoning opens up possibilities to include bespoke business rules to complement the basic inferences. Here, there are possibilities to find a balanced compromise from avoiding writing bespoke software to transform multiple types of content, but still allow for experts within the organisation to codify their knowledge and guide how the data is transformed and enriched.

7.3.2 Patterns for Reducing Data Noise

The idea of bespoke inference rules in the previous section can help reduce noise, but there may be great scope for experimental research into more generally-

applicable ways to strip out semantics we can broadly identify as not useful for machine learning.

There may be trends or patterns in which vocabularies provide the most useful data as well. The RDFS and OWL vocabularies focus on describing ontologies, class hierarchies and schemas, which is more abstract than describing the actual content and entities therein. Such research might be able to confirm this is the case and we can indeed cut back or filter out entirely such vocabularies in favour of, say, Schema.org that is well-used for describing web content.

7.3.3 Deeper Study of Machine Learning on Semantics

This research presented only clustering as the machine learning process used for experimentation as the focus was primarily on the data pipeline upstream of the machine learning itself. Further research could repeat the same data extraction processes, but explore which other machine learning algorithms can provide useful insight into an organisation's content.

Supervised learning techniques could start from known groups of related content and be trained to identify more of such groups. Association rule mining could find trends and patterns within the content.

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APPENDIX

A

PROPOSAL

Proposal for improving content discovery through combining linked data and data mining techniques

Ross Fenning

1 Context

Media companies produce ever larger numbers of articles, videos, podcasts, games, etc. – commonly collectively known as “content”. A successful content-producing website not only has to develop systems to aid producing and publishing that content, but there are also demands to engineer effective mechanisms to aid consumers in finding that content.

Approaches used in industry include providing a text-based search, hierarchical categorisation (and thus navigation thereof) and even more tailored recommended content based on past behaviour or content enjoyed by friends (or sometimes simply other consumers who share your preferences).

2 Problems

There are several technical and conceptual problems with building effective content discovery mechanisms, including:

- Large organisations can have content across multiple content management systems, in differing formats and data models. Organisations face a large-scale enterprise integration problem simply trying to gain a holistic view of all their content.
- Many content items are in fairly opaque formats, e.g. video content may be stored as audio-visual binary data with minimal metadata to display on a containing web page. Video content producers may not be motivated to provide data attributes that might ultimately be most useful in determining if a user will enjoy the video.
- Content is being published continuously, which means any search or discovery system needs to keep up with content as it is published and process it into the appropriate data structures. Any machine learning previously performed on the data set may need to be re-run.

3 Hypotheses

In this proposal, the following hypotheses are proposed for research:

- Research and software tools around the concept of *Linked Data* can aid us in rapidly acquiring a broad view (perhaps at the expense of depth) of an organisation’s content whilst also providing a platform for simple enrichment of that content’s metadata.
- We can establish at least a naïve mapping of an RDF graph representing a content item to an attribute set suitable for data mining. With such a mapping, we can explore applying machine learning – particularly unsupervised learning – across an organisation’s whole content corpus.
- Linked Data and Semantic Web *ontologies* and models available can provide data enrichment beyond attributes and keywords explicitly available within content data or metadata.
- We can adapt established machine learning approaches such as clustering for data published continuously in real time.

- Many content-producers currently enrich their web pages with small amounts of semantic metadata to provide better presentation of that content as it is shared on social media. This enables simple collection of a full breadth of content with significantly less effort than direct integration with content management systems.

4 Proposal

It is thus proposed to do the following research activities:

1. Create a simple software system that will fetch a content item by its URI, extract semantic data readily available in the page (RDFa, microformats, social media metadata) and store an RDF graph.
2. Define a simple mapping from these RDF graphs and experiment with unsupervised learning such as clustering. It should be possible to create a basic web page that visualises clusters of content as they emerge.
3. Experiment further with the effectiveness of each of the following:
 - Using established entity extraction on textual content to generate new attributes for a content item's RDF graph.
 - Using linguistic knowledge from taxonomies (e.g. hypernyms) to infer further attributes that are implicit (i.e. intuitive to humans, but not explicitly present in the content).
 - Using established ontologies and linked data to enrich a content item with transitive attributes from related entities (e.g. the birth place of an actor that appeared on a television programme).
 - Identifying opportunities to apply domain knowledge from experts.

A desired outcome is an ecosystem of software services that can receive notifications of newly-published content, produce highly-enriched RDF graphs, perform real-time data mining and drive a single web page that allows navigation of any machine learning insights.

That there is little in the literature around combining linked data and machine learning indicates that this research could point to the need for deeper exploration of one or more of the research activities above. It is hoped that this work will at least provide a good indication of which approaches appear to give the best opportunities for content metadata enrichment and insights.

It is also hoped that this work provides a good balance of opening up further research opportunities around data mining of linked data graphs along with some practical tools and techniques that media organisations could apply immediately to get a little more effective at providing navigation and discovery of their content.

APPENDIX

B

ETHICS FORM

COMPUTING PROJECT ETHICS CHECKLIST

This checklist is designed to help you to decide whether or not ethics approval is required and, if required, to decide on the appropriate ethics review procedure – please read Annex 0 and 1 on page 5 before you complete this form

Please Note:

- α) This Checklist should be completed for **all** projects.
- β) All questions on this checklist should be completed.
- χ) Contact details (email address) should be given for supervisor and student.
- δ) Supervisors should read and sign this checklist (in the correct box – EITHER/OR – not both boxes) BEFORE it is submitted to the Ethics Administrator for sign off by the Chair of the Research Ethics Panel.
- ε) Guidance on the 2 different ethics review procedures that together make up the University's Ethics Review System (i.e. 'University' and 'NHS') is available on the University Ethics website.
- φ) If your project will involve human tissue/biological fluids you should contact the UoB Designated Individual for the HTA licence, Dr Sue Boyce for advice (s.g.boyce@bradford.ac.uk or on 01274 235879)
- γ) **If this Checklist is NOT correctly completed, it will be returned to you unauthorised.**

Project Title: Improving content discovery through combining linked data and data mining techniques

Name of Supervisor: Dhavalkumar Thakker

Contact Details – D.Thakker@bradford.ac.uk

Department/School Faculty of Engineering and Informatic

Name of Student : Ross Fenning

Contact Details – ross.fenning@bbc.co.uk

Has student attended appropriate ethics training (Project Ethics lecture): Yes

Please give summary of project (max 150 words): *to be typewritten*

A study into using tools of the semantic web and linked data to extract sufficient information about BBC content via the public website such that we can use machine learning to group related content together.

Q1	<p>Is the proposed project an <u>empirical research project</u> involving people?</p> <ul style="list-style-type: none">• will the project include primary data collection from human subjects, their data or their tissue?• Will it constitute an ‘investigation undertaken in order to gain knowledge and understanding’? (this includes work of educational value designed to improve understanding of the research process) <p>If you answer ‘Yes’ to Q1 ethical approval may be required, move to Q2.</p> <p>If you answer ‘No’ to Q1 then a research ethics review is <u>not</u> required and you are not required to submit this checklist. You should still complete the form as Appendix B of your dissertation.</p> <p><i>Note: there may be occasions where a project is not defined as research but still raises ethical issues – please submit for review if you think this is the case.</i></p>	No No No
Q1a	<p>Is the proposed project an <u>audit</u> involving humans?</p> <p>A more detailed definition of Research, Audit and Service Evaluation is available on the University Ethics website.</p> <p>If you answered ‘Yes’ to Q.1a then ethical review is required.</p>	No
Q2	<p>Will the project involve the <u>NHS</u>?</p> <p>see Research Ethics and Governance in NHS and Social Care page of the website</p> <p>If you answer ‘No’ to Q2 move on to Q3</p>	No

	If you answer 'Yes' to Q2 ethical approval will be required by NHS Research Ethics Committee (REC)	
Q3	<p>Will the project involve any of the following in the UK:</p> <p>Testing a medicinal product Investigating a medical device Taking samples of human biological material (e.g. blood, tissue) Prisoners or others in custodial care (e.g. young offenders) as participants Adults with mental incapacity as participants Other vulnerable groups (e.g. vulnerable children) as participants</p> <p>If you answer 'Yes' to Q3 ethical approval will <i>usually</i> be required through Ethical Tissue or NHS Research Ethics Committee (REC) or where the project includes participants which need approval under the Mental Capacity Act approval will be required by the Social Care REC.</p> <p>If you wish to source material from Ethical Tissue at the University, they can be contacted on 01274 235897 or visit www.ethicaltissue.org</p> <p>See information specific to research in Social Care on the University Ethics website</p> <p><i>If you answer 'No' to Q3 move on to Q4</i></p>	No
Q4	<p>Will the project involve human participants and/or human data (<u>but not accessed through the NHS</u>)?</p> <p><i>If you ticked 'Yes' please give details of:</i></p> <ol style="list-style-type: none"> <i>1. Interviews (how many, how long will they last),</i> <i>2. who you intend to interview,</i> <i>3. where interviews will take place and</i> <i>4. attach interview guidelines or the questions you intend to ask:</i> 	No
Q5	<p>Will the project involve <u>human tissue (but not requiring NHS approval – see Q3)</u>?</p> <p>If you answer 'Yes' to Q5 University ethical approval is required</p> <p>If you require advice on human biological material please contact Human Tissue Act (HTA) Designated Individual: Dr Sue Boyce [s.g.boyce@bradford.ac.uk] on ext 5897 or visit www.ethicaltissue.org</p> <p>If you answered 'Yes' to Q5, is the human material over 100 years old and archaeological?</p>	No
Q5a	<p>If 'YES' please refer to the Biological Anthropology Research Centre (BARC) guidelines at http://www.barc.brad.ac.uk/BARC_human_remains_policy.pdf</p>	No
<p>If you answer 'No' to Q5 and have answered 'No' to Q2, Q3 and Q4 ethical approval is not required.</p>		

PLEASE COMPLETE and SIGN ONE of the two boxes below

(in the case of a student project, we do require a Supervisor's signature in whichever box is relevant, before we can have the checklist signed off by the Research Ethics Panel):

1. I have discussed this project with my student AND/OR
2. I confirm that there are no ethical issues requiring further consideration.

(Any subsequent changes to the nature of the project will require that the Panel are informed of all changes)

Signed by (Supervisor):

Signature: Date:

PLEASE PRINT NAME ...DHAVALKUMAR THAKKER.....

Signed by (Student):

Signature: Date:

PLEASE PRINT NAMEROSS FENNING.....

OR

I confirm that there are ethical issues requiring further consideration and will either:

1. refer the proposal to Ethical Tissue, or,
2. fill in and submit a full ethics application to be considered by the appropriate Research Ethics Panel.

Signed by (Supervisor):

Signature: Date:

PLEASE PRINT NAME

Signed by (Student):

Signature: Date:

PLEASE PRINT NAME

APPENDIX

C

ARTICLE

Improving content discovery through combining linked data and data mining techniques

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ABSTRACT

A comparative study of multiple approaches for extracting linked data from web content published by the BBC for the purposes of applying machine learning to cluster related content.

This project designs and implements a process by which semantic data about any piece of online media content can be extracted into RDF models in multiple ways and feature sets for machine learning can be generated from that data. The clusters produced by fourteen different permutations of techniques are evaluated and a potential application of suggesting related content is mocked up for qualitative evaluation.

It is concluded organisations can very easily make use of embedded semantics within web pages due to better semantic properties being made available in recent years because of pressure from social media sites such as Facebook and Twitter. These embedded semantics provide a good baseline for simple learning that can group content based on broad categorisation.

A simple application of entity extraction also shows promising results in evaluation and is highlighted as an area for organisations to explore tuning to provide a powerful complement to embedded semantics.

1. INTRODUCTION

Media companies produce ever larger numbers of articles, videos, podcasts, games, etc. – commonly collectively known as “content”. A successful content-producing website not only has to develop systems to aid producing and publishing that content, but there are also demands to engineer effective mechanisms to aid consumers in finding that content. Examples include providing a text-based search, hierarchical categorisation and tailored recommended content based on past behaviour.

1.1 Problems

- Content across multiple content management systems, in differing formats and data models.
- Content items are in fairly opaque formats, e.g. video and audio content.
- Content is being published continuously, so any analytical process that operates over all content (e.g. machine learning) may need to be run periodically or in an incremental fashion.

1.2 Hypothesis

- Research and software tools around the concept of *Linked Data* can aid us in rapidly acquiring a broad view of an organisation’s content.
- We can establish at least a naïve mapping of an RDF graph representing a content item to an attribute set suitable for data mining.
- Linked Data and Semantic Web *ontologies* and models available can provide data enrichment beyond attributes and keywords explicitly available within content data or metadata.
- We can make use of semantic metadata added to pages to provide better presentation of that content as it is shared on social media.

2. BACKGROUND

Data mining activities such as machine learning rely on structuring data as *feature sets*[1] – a set or vector of properties or attributes that describe a single entity. The process of *feature extraction* generates such feature sets from raw data and is a necessary early phase for many machine learning activities.

The RDF graph is a powerful model for metadata based on representing knowledge as a set of subject-predicate-object *triples*. The query language, SPARQL, gives us a way to query the RDF graph structure using a declarative pattern and return a set of all variable bindings that satisfy that pattern.

For a large content-producer, there is a more general problem where many content items do not have a relational representation and the content source is a body of text or even a raw HTML page. However, the feature generation from Paulheim and Fürnkranz proves to be a promising strategy given we can acquire an RDF graph model for content items in the first place.

3. DESIGN

An experimental system was designed and built around the following high-level requirements:

1. gathering (meta)data about all of an organisations content items;
2. further enriching that metadata with information not explicitly present in the content item itself; and

3. applying machine learning to that content metadata to gain new insights about that content.

The system was also designed with the end goal of being able to present users with alternative content items deemed similar to any given item they are currently ready or watching. This provided a focus to ensure some industrial application of the experiment and also a means by which to evaluate the results in that results can be scored on how they perform at driving such a website feature.

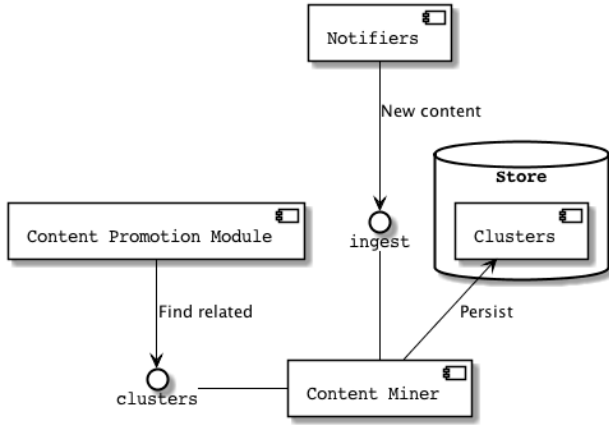


Figure 1: High-level component diagram with interfaces for each use case

Figure 1 shows a high-level view of a “Content Miner” software application. A set of “notifier” applications can be created to connect different content production and management systems to the data mining system such that it is notified when new content is created. The notification need only be an *IRI* that uniquely identifies that content item. Once the application has meaningful clusters of content, we can imagine another system that can query this miner application to provide some view of related content given some initial content item.

3.1 Data Pipeline

This input side of the miner was conceptually modelled as a data “pipeline” that takes an *IRI* identifying a piece of web content at the source end and produces feature sets at the other end. In this pipeline, the three primary data structures employed are the *IRI*¹ (in many cases the public URL for the content’s primary page is sufficient), the *feature set* (modelled as a schema-less set of key-value pairs) and the *RDF graph* as an intermediate structure for manipulating along the pipeline.

The data pipeline was then designed inductively, introducing potential methods for creating *RDF* graphs from web content and also enriching those graphs.

Listings 1 shows a SPARQL query inspired by Paulheim and Fürnkranz[2]. This query generates a boolean **true** value for any properties that match and implies **false** for those that do not and we then flatten this into a simple feature format: `?p_?o=true`, e.g. `rdf:type:schema:Article=true`

¹<http://tools.ietf.org/html/rfc3987>

```
SELECT ?p ?o
WHERE { ?iri ?p ?o . }
FILTER isIRI(?o)
```

Listing 1: Generates field `content_?p_?v` with value **true**

Note that this ignores triples whose objects are literals, for which case the similar strategy as shown in listings 2 was employed to produce features of the form: `?p=?v`.

```
SELECT ?p ?v
WHERE { ?iri ?p ?v . }
FILTER isLiteral(?o)
```

Listing 2: Generates field `content_?p_?v` with value **true**

With a feature generation strategy in place, we can inductively build up the pipeline of how we create *RDF* graphs for that generation.

```
{
  "@id": "http://example.com/entity/1",
  "@graph": []
}
```

Listing 3: Identity graph for a content item in JSON-LD syntax

With the knowledge only of a content item’s *IRI*, we are arguably only able to produce an empty named *RDF* graph. Such a graph for an example *IRI* `http://example.com/entity/` is illustrated in JSON-LD syntax in Listings 3. This provides our base case in the inductive design. This enables a *null* pipeline as shown in Figure 2 that only produce feature sets with a single property containing the item’s *IRI*.

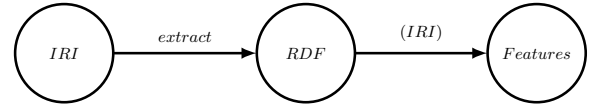


Figure 2: Null feature generator

We can then add in, one-by-one, the following potential extraction techniques:

- Extraction by dereference of the *IRI*, parsing any *RDFa* or microdata semantics found embedded in the response.
- Use entity extraction such as DBpedia and infer triples of the form $(IRI, rdf:about, Entity)$
- Infer a relationship between pages if they have hyperlinks to each other: $(IRI_1, ex:related, IRI_2)$

We also propose enrichment techniques such as the following:

- Dereference every object *IRI* for triples of which the given content item is the subject.
- Infer facts based on *OWL/RDFS* ontologies and schemas, e.g. infer an item is about animals if the entity *Dog* is found and we have an ontology that states that *Animal* is a superclass.

This could lead to a theoretical maximum pipeline as depicted in Figure 3.