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Testing Ontology Embedding Visualization

July 2022

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Submitted in partial fulfillment of the requirements for the degree of MSc in Information Science.

1. ABSTRACT

This dissertation presents an experiment conducted with human participants on human-information interaction with visualizations of ontologies. The research question is whether embedding visualizations or graph based visualizations lead to better task performance for human-information interaction. A literature review of word embeddings, information retrieval applications, cartesian and radial visualizations, and knowledge graph visualizations is conducted. This literature review is grounded in a facet analysis of the intersecting topics of the central research question. The context of embeddings as used for information retrieval in the 20th century, as opposed to more recent 21st century inventions such as Google's word2vec is explored. A training ontology, the African Wildlife Ontology (AWO) was selected. It was extended using public lexical resources taken from the internet to include classes of common African plants and animals. This ontology was then visualised both as vectorspace embeddings and as a classical graph visualization. Participants were presented with one of four different knowledge graph visualizations: WebVOWL, OntoGraf, SquareVis and CircleVis and had to perform a specific information retrieval task. This task was to record as many African animals as they could find on the chart. The results are analyzed in terms of precision, recall, spam and average time. Although ultimately the results do not reject the null hypothesis, there is an opportunity for further research in the visualization of embeddings of knowledge graphs, especially for information retrieval.

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****NOTE THAT SOME OF THE APPENDIX FILES ARE QUITE LARGE. FOR EASE OF ACCESS, THEY HAVE ALSO BEEN UPLOADED TO THIS GITHUB REPSITORY:** HTTPS://GITHUB.COM/JACKKAUSCH/KGS

2. INTRODUCTION

Information ontologies are logically precise hierarchies which semantically structure data in RDF <subject, predicate, object> triples and logical axioms. Ontologies can be realised as a set of logical propositions, as a series of rows in a relational database, or as nodes and edges in a graph database. It is the last one which is typically used to visualise an ontology as it depicts the relationships between entities in an explicit, readable way which logical propositions do not readily do. Graph structures have the advantage of expressing either hierarchical trees or networks, and in the case of RDF and OWL the graph structure is directed.

However, there are other ways of visualising ontologies. In recent years the creation of word embeddings has become popular in the artificial intelligence and natural language processing community. Word embeddings take a corpus of documents and produce vectors for those words within a multidimensional semantic space. Due to the ease with which these technologies can be used to train machine learning algorithms they have been adapted for ontologies, as the purpose of an ontology is to create high quality data for artificial agents to operate over.

The vectors which embeddings produce are multidimensional, often having more than one hundred dimensions. Such vectors are very hard, if not impossible, to visualise in any conventional way. Thus, statistical dimensionality reduction techniques, such as principal component analysis (PCA) are used to reduce the dimensions of the vectors down to two or three dimensions. These vectors are then easily visualised using the conventional cartesian coordinate system.

Very few experiments have been conducted on visualising knowledge graphs in this way, although a few tools have been produced to create embeddings of them. One such tool is OWL2Vec[1], which is based on Google's word2vec and produces embeddings of an ontology written in the OWL language. While there are many experiments which have been conducted in the past on information interactivity with visualizations of embeddings, there have been none so far as the author knows conducted on ontology embeddings.

In addition, while many studies have been done comparing polar coordinate visualizations to cartesian visualizations, there have been no studies which test whether changing the coordinate system impacts how users interact with embeddings of ontologies specifically. There has been much investigation of radial visualizations of knowledge graphs and ontologies, but these have been limited to radial visualizations of trees or graphs with a node-edge structure. A radial visualization of a knowledge graph embedding has not yet been attempted, and that is what is tested in this report.

The use of embeddings, the visualization of embeddings, and ontologies all have implications for both information science and linguistics or natural language processing. Indeed, although the use of embeddings has a long history in information science, the newer methods being used today derive from linguistics. In particular, OWL2Vec, the method tested to make the embeddings, is one of the newer methods. Thus, in order to understand how information science and natural language processing have historically interacted in this field, a literature review of the history of embeddings and data visualizations in both information retrieval and natural language processing is necessary.

[1] OWL2Vec was developed by a team which included Ernesto Jimenez-Ruiz, the supervisor of this dissertation. The code used to create the Embeddings can be found at this github repository: https://github.com/KRR-Oxford/OWL2Vec-Star

3. SCOPE, RESEARCH QUESTION, AND DEFINITIONS

The research question this dissertation sets out to answer is **(rq1)**: *are embedding visualizations or graph visualizations of ontologies better for information retrieval and user interactivity?*

The secondary question is **(rq2)**: *of classical methods, are graphs or trees easier for users to interact with, and of embedding methods, do polar coordinate or cartesian visualizations give better results?*

Whether a given visualization is "better" than another is defined as having higher precision and recall. The time taken to complete the task is also taken into account.

Two classical methods are tested and two embedding visualization methods are tested. The two classical methods are an image of a non-hierarchical graph (WebVOWL[2]), and an image of a tree (OntoGraf). The two embedding methods are cartesian coordinates (SquareVis) and polar coordinates (CircleVis) respectively.

The hypothesis is that classical graph visualizations will perform better than embedding visualizations, and that of these the tree visualization will perform better than the graph visualization. Of the embedding visualizations, the hypothesis is cartesian will lead to better participant performances than polar coordinates. The reasoning behind this hypothesis is that participants are likely to have the easiest time performing an information retrieval task if the graph is clearly demarcated, rather than as a scatterplot of entities whose proximity implicitly represents "semantic" relations.

The author has an interest in data visualization, and in particular radial (circular) visualizations which use polar coordinates. However, the practical utility of such visualizations is often questionable. Therefore one of the aims of this dissertation is to empirically test whether a radial visualization improves performance on an information retrieval task, or reduces performance. The hypothesis is that it will reduce performance. Performance is measured in terms of precision, recall and time on an information retrieval task, as described in section 7. RESULTS.

The term **ontology** refers to a logical formalisation of knowledge in a given domain, which is expressed as a graph in the OWL language and the RDF format. For the purposes of this dissertation, the term ontology and the term **knowledge graph** will be used interchangeably as synonyms.

The term **word embeddings** refers to a set of multidimensional vectors which represent the semantics of a word. These vectors usually consist of a few hundred dimensions, and thus contain a few hundred numbers. The embedding file used in this experiment is contained in Appendix 9. Embeddings file .txt format. The literature review also discusses **document embeddings** which are multidimensional vectors of entire documents, but these methods are not tested in the experiment.

The term **count based** embeddings is used synonymously with **matrix** due to the matrix multiplication used to create them. This is a method for creating **document embeddings** which involves counting the occurrences of word in a document, rather than using machine learning.

The terms **distributional semantics** and **statistical semantics** are used synonymously to refer to the linguistic theories which underly word embeddings.

The term **data visualization** or **visualization** refers to the act of interpreting data as geometry and visualising them in an aesthetically or interpreable pleasing way.

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[2] WebVOWL is an online version of the VOWL plugin for Protege that can be found here: http://vowl.visualdataweb.org/webvowl.html

The term **information retrieval** refers to the act of looking for and seeking information. It also has a secondary meaning of systems which facilitate information retrieval. When the experiment is said to test how participants interact with information in terms of information retrieval, the first sense of this term is what is meant.

The term **polar coordinates** or **radial visualization** refers to a coordinate system which is constructed in terms of the unit circle, and where vectors are defined by the coordinates (r, θ) as opposed to (x,y) where r is the radius of a circle, and θ is its angle in either radians or degrees. The antonym to this term is **cartesian coordinates** which refer to the classical (x,y) coordinate system, where vectors are based on squares, rather than circles.

Where individual tools, computer programs, algorithms, or statistical visualization methods are summarised by an acronym, the full name of the method is used followed in parentheses by the acronym (x). Following their introduction, sometimes the full name or the acronym is used.

4. LITERATURE REVIEW

The following literature review was conducted by doing a facet analysis of the research question. This facet analysis is based on the terms defined in 3. SCOPE, RESEARCH QUESTION, AND DEFINITIONS. The facets were identified as:

1. word embeddings
2. knowledge graphs/ontologies
3. data visualization
4. information retrieval
5. polar coordinates

These facets were developed in an ad hoc fashion, not in line with any structure like PMEST or PiCO, but with the metaphor of intersecting sets. The five facets were then expanded using the following synonymous terms:

1. embedding OR vectorspace OR "word embedding" OR "distributional semantics" OR "statistical semantics"
2. "knowledge graph" OR ontology
3. "data visualization" OR "information visualization" OR visualization OR visualization
4. "information retrieval" OR "visual search"
5. "polar coordinates" OR radial OR cartesian

Rather than using a successive fractions or building blocks search strategy, the literature review has been structured based on a series of strategic searches which explore different intersections of the five facets. Each of the six sections, linked here, explore different facets.

4.1 HISTORY OF WORD EMBEDDINGS: facets 1 AND 4,
4.2 WORD EMBEDDINGS IN KNOWLEDGE GRAPHS: facets 1 AND 2,
4.3 WORD EMBEDDINGS IN DATA VISUALIZATION: facets 1 AND 3,
4.4 DATA VISUALIZATION FOR INFORMATION RETRIEVAL: facets 3 AND 4
4.5 USE OF RADIAL VISUALIZATIONS: facets 3 AND 5
4.6 DATA VISUALIZATIONS OF KNOWLEDGE GRAPHS: facets 2 AND 3

Following this, citation searches were run on the most-cited papers to gauge their influence. This facilitated a pearl-growing search which expanded the search results further, carried out to a depth of 1 citation link apart. The searches were conducted on Google Scholar due to the ability to easily gather accurate bibliographic metadata from the search engine, and the expedient citation search feature which facilitated the assessment of influence for each paper.

This approach explores the intersecting facets by separating them into distinct searches. Within the literature, there have been several precedents to the research question this dissertation investigates, and a wide range of work relevant to the experiment conducted. However, this work is spread across several domains, some of which are not aware of each other. In particular, this literature review examines the two different approaches taken to vectorspace embeddings taken by the information retrieval and natural language processing communities. Although the experiment conducted is an information science experiment, the tested tool OWL2Vec comes from the more recent NLP systems derived from word2vec. There are also relevant studies from the knowledge graph and data visualization communities.

The “intersecting sets” metaphor of this facet analysis allows the literature review to be structured around an examination of each part of the research question, before culminating in a review of the tool Stunning Doodle, which is a system that was produced to visualise knowledge graphs which combines all facets. Along the way, several user experience centric studies from cognitive science and information retrieval will be reviewed with similar research methods to the one conducted here.

Finally this facet analysis was constructed as an ontology in Protege, and visualized with the tool OntoGraf, and included below to give the reader an intuitive, visual representation of how these facets fit together (Figure 1: Visualization of the facet analysis as an ontology with OntoGraf).

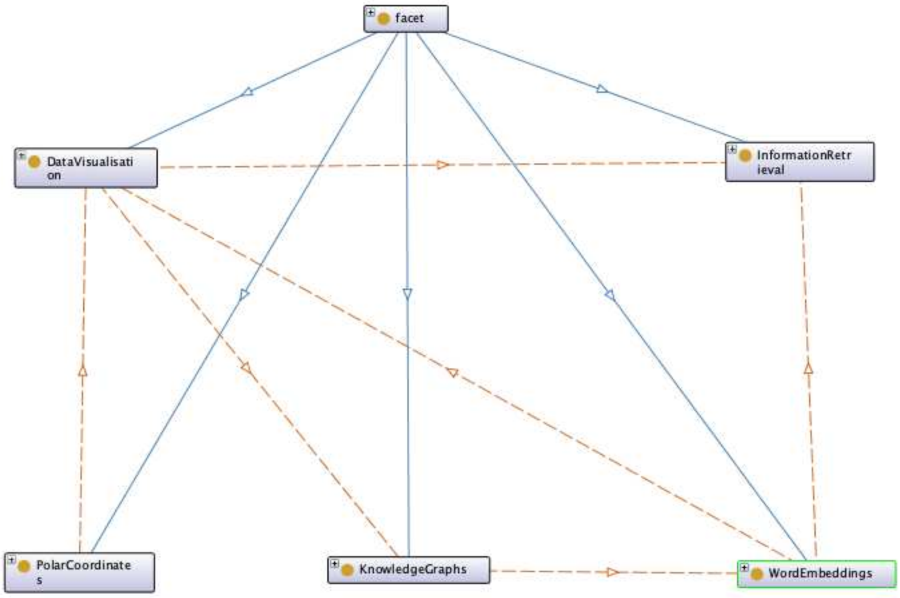

Figure 1: Visualization of the facet analysis as an ontology with OntoGraf

4.1 HISTORY OF WORD EMBEDDINGS

Word embeddings, and embeddings generally, have a history which predates their use in natural language processing and machine learning applications today. Kalgren and Sahlgren (2016) make a distinction between word embeddings and document embeddings in their history of the topic.

Document embeddings have historically been associated with the field of information retrieval. Word embeddings are associated with linguistics. In computational linguistics, the preffered term is distributional semantic model.

4.1.1 Distributional Semantics in Theory

Distributional semantics is summarized by John Firth in the aphorism "a word is characterized by the company it keeps." (Firth, 1957) This is a statistical view of linguistic semantics. (Weaver, 1955) Statistical semantics captures the distributional context of a word, out to a certain depth n. Semantically similar words tend to be used in similar linguistic contexts. By measuring the context, a representation of the meaning of the word in terms of how it is used can be created. This may be similar to the way in which children and second language learners acquire new words, an idea that has been tested in cognitive science (Mcdonald and Ramscar, 2001). John Firth, William Weaver, Zellig Harris, and Wittgenstein were all at the forefront of distributional semantics in the early 20th century (Kalgren and Sahlgren, 2016).

Zellig Harris, the teacher of Noam Chomsky, was an early pioneer in the field of distributional semantics (Kalgren and Sahlgren, 2016). Harris' goal was to transform linguistics into applied mathematics. While his ideas anticipated Chomsky's, Harris believed that semantics was contained in syntax. Chomsky would take some of Harris' ideas, such as the idea of generative grammar, which was first propsed in Harris' *Methods in Structual Linguistics* (1951). However, in his articulation of the theory of deep structure and surface structure, Chomsky would use concepts from mathematical logic (ultimately derived from Rudolf Carnap) to create a different transformational idea of universal grammar (Chomsky, 2014 p.16).

It would not be long, however, before Chomsky's own students would differentiate themselves from their teacher in a similar manner. As documented in R. A. Harris' book *The Linguistics Wars*, students such as George Lakoff would criticize Chomsky for attempting to reduce semantics to syntax, and create cognitive linguistics from the premise that the underlying representation of language (its deep structure) was entirely semantic, and therefore representable solely by mathematical logic (Harris, 2021 p. 73).

These theoretical issues are connected to the technical issues of distributional semantics. Distributional semantics, by reducing the meaning of a word to the the context it appears in (its adjacent words) implicitly assumes, like Zellig Harris, that semantics is contained in syntax. This is in contrast to the increasingly formal approach advocated by Chomsky and his descendants. This distinction is particularly relevant to knowledge graphs and ontologies, as the semantic assumptions of the standards they depend on, such as RDF, are formalized in first-order logic. The use of word-embedding models in contemporary natural language processing and machine learning, as opposed to knowledge graphs and ontologies, mirrors these two approaches to semantics found in the history of linguistics.

Distributional semantic models lend themselves to formalization with linear algebra and matrices. Relations between words in a document can be represented as very large multidimensional vectors of an arbitrary depth. Since the 1960s, a number of applications of the theory of distributional semantics have been made in computational linguistics and information retrieval, leading up to their current popularity in machine learning.

4.1.2 Information Retrieval and the Count-Based Model

Almeida and Xexeo (2019) divide distributional semantic models into two main categories: prediction-based models, derived from neural networks, and count-based models, derived from matrices. Research has shown that both approaches yield similar results (Levy and Goldberg, 2014) (Osterland et al. 2015). The count-based models originated in the information retrieval community.

Charles Osgood should be mentioned, because his work on semantic differentials and feature analysis had an influence on the attempt to represent distributional semantics in a vectorspace (Osgood, 1957). Osgood explicitly crafted his features, and labelled axes in a semantic vectorspace with them. This was one of the influences which lead to the idea of using linear algebra to model distributional semantics, although later models would not explicitly label the coordinates of their vectorspaces.

Salton (1975) created a vector model for automatic indexing, that makes use of document embeddings to calculate similarity for information retrieval. This paper is usually held to be the first to create the idea of mapping the semantic similarity scores of documents to a vectorspace represented by the unit sphere, with more similar documents clustering together. Rather than representing natural language the technique was used to create an index of documents.

Latent Semantic Analysis (LSA) was patented in 1988 as an information retrieval tool. It uses a count-based model to create a term-document matrix. In the matrix, rows represent each word, and columns represent each document, with a count of how many times each word occurs in each document. (Deerwester, 1990) Singular value decomposition is then used to reduce the matrix to a more manageable size while preserving essential relations between documents. While the vectors produced are typically document vectors, word level vectors can also be produced by relying only on the rows of the matrix (Almeida and Xexeo, 2019).

The primary application for LSA was in information retrieval, where a query of terms are translated into vectors and matched to the position of documents in a low-dimensional space. LSA was also used in cognitive science and psychology to study semantic memory in human beings (Harris, 1999).

Hyperspace Analogue to Language (HAL) was developed a few years after Latent Semantic Analysis (Lund and Burgess, 1996). HAL was explicitly created to study semantic memory in humans. They produce a matrix of word occurences by taking a count of co-word occurrences in a corpus of documents. Unlike LSA, HAL creates vectors only for words, not documents.

4.1.3 Natural Language Processing and the Prediction-Based Model

Around the same time that LSA was being developed, models using artificial neural networks were also being invented (Kohonen, 1988). Kohonen created a model called Self Organizing Maps (SOM) which operates as an artificial neural network which takes data represented as feature vectors to produce a semantic space. SOM can be seen as another form of Principal Component Analysis (PCA), which is important for the visualization of semantic vectorspaces (Gorban, 2008 p. VII).

Like most neural approaches, SOM is not limited to linguistic or document-based information. Training the model automatically produces clusters of similar entities in a topological vectorspace. Those vectorspace representations could correlate to many different kinds of similarity, and are not necessarily linguistic. They have even been used for the creation of artwork (Frenzel, 2017). Nevertheless, they are also useful for natural language processing and produces a semantic vectorspace.

Simple Recurrent Networks (SRN) are another popular neural form created during the 1990s, and have since become the basis of all language models. (Kalgren and Sahlgren, 2016). Elman (1990) creates a three-layer network with context units in order to solve problems related to representing time spatially. Their goal is to represent time implicitly instead, and along the way they create a number of syntactic and semantic ways to represent and encode language as feature vectors. Many of Elman's assumptions about how time is represented are based on linguistic or psycholinguistic theories, particularly the failure of a purely syntactic representation to capture sequential time in utterances. Elman is also skeptical of the existence of discrete linguistic features such as phonemes and morphemes outside of the utterance itself. Thus an application of the statistical approach, in the form of a recurrent neural network, leads Elman to a model where (reminiscent of Zellig Harris) content and form are treated as one.

Jordan (1997) also creates an SRN, approaching similar problems that Elman does. Jordan attempts to make a theory of learned sequential behavior by focusing on co-articulatory phenomena in speech. Jordan networks are almost the same as Elman networks with a slight difference in which layer the context units are fed from.

The development of prediction-based language models was hampered by computational efficiency for a long time (Almeida and Xexeo, 2019). It was not until Bengio et al. (2003) that the first large language models began to be produced. Increasing the efficiency and performance of language models was for many years an intractable problem. In addition, earlier language models were not interested in embeddings in their own right, treating them instead as interesting byproducts of natural language understanding tasks. In the present era, computational efficiency has been effectively solved, and the perfomance of large language models like GPT-3 demonstrates that scale can (at least in some cases) generate good results. As the machine learning revolution took off, there have also been breakthroughs in embedding natural language vectors using the prediction-based approach.

4.1.4 Use of Word2Vec, BERT, and similar models today

The word "embedding" simply refers to the projection of raw language vectors into the second layer of neural language model; the second layer is embedded in the first, and so are the vectors produced by the model (Almeida and Xexeo, 2019). While the computational problems of machine learning have been solved in our time, the structure of embedding models are not that different from SRNs. The most famous of these models, word2vec, consists of two simple layers.

In two papers published in 2013, (Mikolov et al., 2013a, 2013b) Mikolov's team at Google put word embeddings on the map as a topic of study for the natural language processing community. Word2vec takes a corpus of documents as an input and returns an embedding for each word within a semantic vectorspace. Most surprising in their results from (2013a) were the semantics of some the vectors. Famously, the distance between KING and QUEEN vectors showed that there was a semantic relationship to their distribution which seemed to be related to gender.

Following this, Mikolov's team released two models for producing word embeddings of text: SkipGram (SG) and Continuous Bag of Words (CBoW). These two models are inverses of each other. CBoW aims to predict a word based on its context, whereas SG aims to predict the context based on its word.

A few years later, another team at Google lead by Devlin et al. (2018) produced a model called Bidirectional Encoder Representations from Transformers (BERT). The advance over word2vec that BERT offers is the additional calculation of context. Word2vec generates one vector for each word, essentially flattening polysemous strings into a single dimension, and creating an ambiguous vector representation. BERT, on the other hand, creates context based vectors for each use of a word, allowing it to capture subtle distinctions in the connotations of words, including polysemy. BERT also generates new embeddings for every sentence, rather than creating a lexicon like dictionary of single word-vector pairs (Gupta, 2022).

One of the problems word2vec and other large language models face is compositionality (Mikolov et al. 2013b). The principle of compositionality in linguistics is that the meaning of a sentence is composed of its constituent parts. This means that words hierarchically modify other words. Due to the inherently syntactic bias of distributional semantics, these hierarchical relations are not modelled in the way they would be in a knowledge graph or ontology. Some of these barriers are inherent to the problems of using large language models to attempt to solve tasks which require reasoning (Scagliarini, 2022).

In this context, knowledge graphs and ontologies provide a potential solution to how to model compositionality. The original purpose of the Semantic Web was to create high quality data for artificial agents to operate over. Knowledge graphs, representing the deep structure rather than the surface structure of language, offer forms of information closer to the meaning of words. Thus, some have proposed solving the problems of compositionality faced by combining the two approaches and using distributional semantic technologies to make embeddings of knowledge graphs. Most of these approaches have been explicitly based on word2vec, rather than BERT. It is these attempts which are investigated in **4.2**, in an examination of how knowledge graphs projected into distributional semantic vector spaces can be used.

4.2 WORD EMBEDDINGS IN KNOWLEDGE GRAPHS

4.2.1 Early attempts to transform KGs into vector spaces

Knowledge graphs and ontologies emerged from the Semantic Web community, and depend on the stack of standards created by the W3C, particularly the RDF framework and SPARQL. Data that is formulated in the <subject, predicate, object> structure of RDF can be interpreted as propositions in first order logic (FOL), as tables in a relational database, or as nodes and edges in a directed graph. While SPARQL exists to query data stored in the RDF framework, feature extraction from knowledge graphs for machine learning applications can prove challenging (Ristoski, 2016) (Grover and Leskovec, 2016).

Creating embeddings of knowledge graphs can be a potential solution for feature extraction. Grover and Leskovec (2016) discuss using a count-based method for creating embeddings, similar to classical methods such as Principal Component Analysis. However they find these to be too computationally expensive, especially with very large modern knowledge graphs. Another approach to generate embeddings for knowledge graphs is to create "embeddings in an end-to-end manner, iteratively adjusting the vectors using an optimization algorithm to minimize the overall loss across all the triples" (Chen et al., 2021). This is also called the "translational" method by Bordes et al. (2013) who created a method called TransE to model the relations of knowledge graphs.

The stated motivation behind TransE is that knowledge graphs contain hierarchical relationships, and the creators of TransE believe translations are the best way to represent these entities. They regard relations between mother nodes and daughter nodes as translations, which has the added effect of keeping sibling nodes close to each other (Bordes et al., 2013). Wang et al. (2014) and Lin et al. (2015) take a similar approach, extending the original TransE model to make TransH and TransR respectively. The technique uses a global loss function to model all of the entities as vectors simultaneously. This means that even an embedding from a single entity/relation encodes information about the entire graph (Wang et al., 2014). Wang et al. extend the method by using two vectors, and translating the entities on "hyperplanes" (essentially two dimensional vectors).

Lin et al. extend the method further with TransR, to create embeddings which exist in multiple spaces, to capture the different aspects of the entities modeled. In their method there is an embedding space and a relation space, and each entity exists in both spaces. This means that clustering can be performed on entities that are close to each other in the graph, and also entities which share similar relations (Lin et al., 2015).

Yang et al. (2015) extend all of these results to create DistMult, a method which combines TransE with a technique called NTN — developed by Socher et al. (2012) as a way to model semantic compositionality in a vector-space — to create one model which unifies the translational knowledge graph embedding techniques which existed at that time, and worked to improve performance. An interesting application these researchers make with their technique is to use DistMult to take learned embeddings to produce new logical rules. They demonstrate that such rules can be extracted from embeddings, which is of particular interest when one considers OWL2vec (see below, section 4) which makes embeddings of logical propositions and axioms.

4.2.2 Node2vec, graph2vec and the use of embeddings for networks

As word2vec became more well known in the community new methods for transforming knowledge graphs into vector spaces were developed based on the Skipgram and CBoW models. Node2vec is among the first of these algorithms created, and manages to achieve similar results to early embedding methods with much less compute (Grover and Leskovec, 2016). Node2vec is not specifically dedicated to knowledge graphs, although there is a particular emphasis placed on that domain: node2vec can also be applied to social networks and network analysis in general. Similar to applications involving knowledge graphs, link prediction is one dividend of creating a model of a graph or network using embeddings.

One of the challenges of node2vec is creating a way to create the embeddings which maintain the "neighborhood" effect, such that nodes which are similarly located in the graph have the same location in the vector space. This is because Skipgram and CBoW architectures take document-like entities as inputs, and simply giving them a set of statements may not preserve the "neighborhood" relations found in the graph (Grover and Leskovec, 2016). The solution node2vec implements is to conduct random walks over the graph. These random walks essentially translate the graph into a document of "sentences" which preserve a node's location in a graph by expressing both nodes and edges as clauses, depending on the parameters used. This document is treated as though it were a text of syntactic natural language, the Skipgram model from word2vec is then used on it. One of the benefits of random walks is that they are computationally efficient as compared to other methods. They also have less time complexity.

While node2vec is semi-supervised, Narayanan et al. (2016) present subgraph2vec, an unsupervised learning method which generates embeddings of graph structures. They achieve this by modifying the Skipgram model itself so that it can understand a "radial" context of a word, rather than the linear context common to text in documents. This modification allows them to embed sub-graphs in a vectorspace. Following this, Narayanan et al. (2017) produced graph2vec, which creates an embedding of an entire graph, rather than just a subgraph. They do this by borrowing from Le and Mikolov's (2014) method doc2vec which creates neural document embeddings. Doc2vec generates vectors for sentences, paragraphs and whole documents, and not just single words. Thus, similarly to Grover and Leskovec, they choose to treat the entire graph as though it were a document.

However, unlike with node2vec, Narayanan et al. build on their previous work to consider the graph as being composed of subgraphs, and then treat the subgraphs as though they were words in a document. They argue that the non-linear structure of their approach related to subgraphs captures the multi-relational nature of graphs better than the node2vec version which uses linear random walks to compose the document. In this application they use a typical Skipgram architecture to generate the embeddings similar to doc2vec, and instead capture the nonlinear relationships when they define as subgraphs before generating the embeddings (Narayanan et al.,2017). Regardless of which method used, modern embedding tools based on word2vec for graph structures must have some way to segment the graph into smaller parts.

4.2.3 RDF2Vec

While these models work well to generate embeddings for networks and graph structures, they are not tailored to the RDF framework in particular, and thus miss some of its subtleties. In particular, RDF graphs are directed graphs, which is not an assumption made by node2vec (Chen et al. 2021).

In 2017, in a PhD thesis for the university of Mannheim, Petar Ristoski introduces RDF2Vec, a method based on word2vec for generating embeddings of Semantic Web data (Ristoski, 2017a). Ristoski treats the problem of feature generation from RDF graphs as a problem he calls "propositionalization" (Ristoski, 2016, 2017a). Features are usually binary (true/false), nominal or symbolic, which makes

RDF data a challenge, as it is in graph format, and it must be transformed into one of these data types. Propositionalization is essentially the same problem Grover and Leskovec and Narayanan et al. derive solutions for in section 2. However, Ristoski treats the problem of transformation as a data-mining problem, one for which SPARQL applications may potentially have a role in specifying features. He presents RapidMiner, a system which allows users to make SPARQL queries to select certain subgraphs from which features are then derived.

However in the presentation of the RDF2vec system itself he falls back onto similar solutions used by the creators of node2vec and graph2vec. One of his proposed methods is to conduct random walks (Ristoski, 2016). Another solution is similar, but not identical, to the subgraph2vec approach, which uses the Weisfeiler-Lehman algorithm to construct subtrees RDF graph kernels. Ristoski also tests both the Skipgram and CBoW models once documents are generated from the RDF graphs. They also test the approach on multiple datasets, including Wikidata and DBpedia. Ristoski settles on biased graph walks as being superior to kernels for generating embeddings of RDF graphs (Ristoski, 2017a)(Cochez 2017). He also experiments with adjusting the weights for the random walk, creating some versions based on Google's PageRank algorithm, and others based on logical and semantic considerations.

Ultimately Ristoski finds that RDF2Vec outperforms then-existing state of the art graph embedding models. In addition, PageRank and other weighting algorithms perform well for the learning methods employed, but unweighted edges are also competitive. He also finds that Skipgram is superior to CBoW for generating RDF embeddings. For Ristoski embeddings represent a superior form of "propositionalization" to the data mining techniques he has also examined, developed and tested. Similar to other researchers who have experimented with generating embeddings from networks, Skipgram is preferred to CBoW.

An interesting application of RDF2vec is the use of embeddings to automatically predict class subsumption in taxonomies (Ristoski, 2017a, 2017b). This unsupervised model predicts class membership of entities based on their position in the vector space. Inan and Dikenelli (2017) apply RDF2vec to word disambiguation tasks. The use of RDF embeddings has profound semantic and logical implications. However, in some cases using just the RDF framework alone may not capture all of the relations which exist in an ontology, which also consists of a set of logical axioms, as well as being a graph.

4.2.4 OWL2Vec

Similar to the relation RDF2vec has to node2vec and graph2vec, OWL2vec was developed by Chen et al. (2021) to handle some of the unique features of the OWL language which are not present in RDF. While the RDF framework consists of <subject, predicate, object> triples, OWL ontologies also include logical constructors, "such as class disjointness, existential and universal quantification" (Chen et al., 2021). There are also metadata elements included in an OWL ontology, especially tags under the rdfs:label and rdfs:comment relations.

Previously to OWL2vec, there were a number of approaches which sought to generate embeddings of OWL ontologies. Kulmanov et al. (2019) created a method which created embeddings for description logic EL++, but did not include metadata. Garg et al. (2019) created a method to embed ontologies with description logic ALC, but also did not include metadata; OWL2vec is the first to consider both the logical structure of axioms and the lexical information contained in the metadata. OWL2vec embeds the description logic SROIQ.

Hao et al. (2021), Guan et al. (2019), Moon et al.(2017) and Zhou et al. (2019) create embedding techniques which seek to go beyond simple RDF data in a graph format to model semantic spaces.

However, they do not take embeddings of the OWL language and rely on large training data sets to derive their principles, making minimal assumptions about taxonomies.

Other approaches, such as Onto2Vec or Opa2vec, created by Smaili et al. (2018a, 2018b) treat the ontology as a document of axioms, rather than treating it as a graph. They then use the Skipgram model on the document of axioms, treating the logical propositions as natural language. Unfortunately, according to Chen et al. (2021) this approach fails to consider the relations *between* axioms which are captured in the graph structure.

OWL2vec, takes an approach similar to RDF2vec and node2ved in that it conducts random walks in order to develop its document(s). In order to capture the different kinds of information, including lexical metadata, logical axioms, and graph structures, three different documents are generated: one consisting of graph structures and logical propositions, one consisting of lexical information, and one mixed document of all three. It then uses the Skipgram model to transform these entities into embeddings.

One problem OWL2vec must solve is how to translate an ontology written in OWL into the RDF framework. Chen et al. (2021) propose two solutions to this. One involves the original OWL to RDF mapping as defined by the W3C. The second strategy involves a series of projection rules which were written by the creators to transform axioms into RDF triples. This has the advantage of avoiding the use of blank nodes in the projected RDF graph, which reduces noise when the random walks are conducted. However, it also makes the graph less logically rigorous.

OWL2vec has been applied to clustering tasks, in order to aid with information retrieval (Ritchie et al., 2021).

4.3 WORD EMBEDDINGS IN DATA VISUALIZATION

4.3.1 Techniques to reduce Dimensionality: PCA and t-SNE

Typically, the vectors created in the embedding process are very large, although their dimensionality is arbitrary (usually around 300 dimensions) (Liu et al. 2017). This means that entities are represented as vectors with a very large number of dimensions, many of whose numerical values have no explicit meaning. This makes them impossible for humans to understand; it also makes them impossible to visualize. Multidimensional scaling methods serve the purpose of taking these large vectors and scaling them down to two or three dimensions, making it possible to visualize them in coordinate plane with x, y and occasionally z axes.

The classical method to reduce dimensionality is Principal Component Analysis (PCA), invented by Karl Pearson in 1901 (Pearson, 1901). Principle Component Analysis operates by reducing a data-set to a set of vectors orthogonal to each other, with each generated vector “best fitting” the data-set, for a given number of dimensions. A best fitting vector is defined as one which minimizes the Euclidean distance between itself and the rest of the data-set. The method is structured in such a way that, with each new principal component, a best fitting vector is generated on the data which remains. This means that PCA can be used to model up to any level of dimensionality, but for visualizations usually only two or three principal components are used, to represent the dimensions of the coordinate plane. The method has the advantage of mostly preserving distributional properties of the dataset, and thus the semantic relations embodied by the n-dimensional vectors, unreadable by humans, are reduced.

There are other methods of dimensionality reduction used. Roweis and Saul (2000) pioneer a non-linear method which uses manifolds to approximate the linear features of multidimensional vectors. Tenenbaum (1997) also takes a manifold approach to non-linear dimensionality reduction. Roweis would later go on to develop t-distributed stochastic neighbor embedding (t-SNE) (Hinton and Roweis 2002). It makes use of probabilistic methods to reduce the data to lower dimensionality, although there is an alternative version which uses the Euclidean distance. They calculate the probability that neighbors in a vector space will be similar, or the probability that a given entity would pick another entity as its neighbor. One of the stated advantages of their approach is that unlike PCA it can handle one to many embedding mappings, which allows it to be useful for modeling polysemy. For instance, the word "bank" which is highly polysemous, can have several realizations in the lower dimensional space with their method. Interestingly enough, they test t-SNE on a document embedding created with the count-method in order to demonstrate this principle.

Liu et al. (2017) on the other hand find that non-linear methods, most notably t-SNE, have the unintended side effect of distorting the semantic relations between words found in modern, post-word2vec embeddings. For this reason they prefer PCA to create data visualizations because the direct semantic relations between points are more faithfully preserved. A version of PCA has recently been implemented in the Python library sci-kit learn and it is this version which is used in the experiment.

4.3.2 Issues with visualization, including uncertainty

Liu et al. (2017) explore the visualization of semantic relations using PCA. They find that any method for the dimensionality reduction of embeddings leaves a lot to be desired, and that there is always a loss of semantic features. They contrast this with the problem of uncertainty in data visualization. Brodlie et al. (2012) provide a review of uncertainty in data visualization across several domains.

They devote their study to two problems: the uncertainty of visualization, and the visualization of uncertainty. The data visualization pipeline involves taking data, performing an operation on it to transform it into geometry, and creating an aesthetic visualization of that data. The uncertainty of visualization is when the process of visualization generates distortions. They divide this process into three stages: filter, map and render, with unique possibilities for the generation of uncertainty at each stage. The visualization of uncertainty, on the other hand, occurs when the data which has been collected is inherently uncertain.

In the case of creating visualizations of vector-space embeddings of natural language, documents, or graphs we can see that both kinds of uncertainty investigated by Brodlie et al. (2012) apply. The data is uncertain due to the theoretical reasons explored in 4.1.1 Distributional Semantics in Theory, because the theoretical assumption that semantics and meaning can be determined by a word's context does not always produce accurate results. Simultaneously, applying dimensionality reduction to make the embeddings human-readable distorts the data, no matter whether the method is linear or nonlinear, which means that there is also uncertainty in the visualization phase.

Schnabel et al. (2015) propose a number of methods to evaluate the semantics of word embeddings using data visualizations. They divide these into two types: extrinsic evaluation, which measures how well a downstream task does trained on the embeddings, and intrinsic evaluation. Extrinsic evaluation does not always produce results which can definitively reflect on the quality of the semantics of the data. Intrinsic evaluation involves the construction of a group of target words, called a *query inventory.* Query inventories have been used in psycholinguistics and information retrieval (Finkelstein et al., 2002). Unfortunately query inventories are often subjective, and Schnabel et al. (2015) propose a number of methods to improve their construction. Notably they find that different methods of embedding the same data, while judged against a query inventory, produce vastly different semantic results.

This is very concerning for the level of uncertainty present in the creation of semantic visualizations. Gladovka and Drozd (2016) ask how these results can be improved, and whether methods of analyzing the semantics of embeddings with intrinsic evaluation can be made more objective. A problem they point out is that linguistics does not offer an alternative semantic evaluation other than the construction of semantic similarity datasets based on the intuitions of human respondents, and subject to the ambiguity of words.

Liu et al. (2019), taking these uncertainty problems in stride, attempt to create visualizations which can circumvent these issues using t-SNE to represent the ambiguous properties of words in multiple dimensions.

4.3.3 Ways to make embeddings less uncertain

Oubenali et al. (2022) conduct a literature review of studies which evaluate how visualizations of word embeddings can aid in analyzing the unstructured data contained in electronic health records. They conduct a literature search which, due to the nature of their criteria, only retrieves seven studies published between 2018 and 2021. This is due to the fact that studies of visualizations of embeddings in a clinical setting remains a largely unexploited domain. They find that, similar to the problems Schnabel et al. (2015) and Gladovka and Drozd (2016) discover, there is not always a systematic way to formally evaluate the semantics of word embedding visualizations intrinsically.

However, they state that this may not be a problem for embeddings as a whole, as they are often used instrumentally to perform a downstream task. They recommend that visualizations of embeddings, due to their issues in information loss during dimensionality reduction, and the fact that different embedding methods generate different neighborhoods, should not be considered as systematic or objective. However, they may be useful in an "exploratory" way, allowing users to examine a geometric depiction of semantic relations, so long as these relations are not taken as absolute. They recommend that the creators of embeddings be explicit about whether it is intended to be used in an instrumental way to be utilized by an algorithm, or whether it should be used in an exploratory way for domain experts to extract information.

Liu et al. (2019) propose Latent Space Cartography (LSC) as a way to resolve this "exploratory" problem. LSC allows the user to choose attribute vectors which they can map to the data. They can also change the resolution of the number of dimensions the data is embedded in. This allows the user to explore semantic relations at different levels of dimensionality, potentially removing the visualization of uncertainty. They also label the attribute vectors with emoji, which are transformed according to the semantic features the attribute vector picks up. This helps the user interpret what is happening in the dataset. For instance, a data set with a gendered difference will have a vector labeled with an emoji gradually transforming between male and female. The ability to navigate between different dimensions, and having attribute vectors with predefined semantics which map to the data, goes a long way to reduce the uncertainty. It is notable that in their conclusion, Liu et al. propose defining semantic axes to structure the space as the next level beyond defining attribute vectors, an approach eerily reminiscent of Osgood's original feature vectors features from the 1960s. (See 4.1.2 Information Retrieval and the Count-Based Model)

4.4 DATA VISUALIZATION FOR INFORMATION RETRIEVAL

4.4.1 Semantic axis visualization in information retrieval

As discussed in section 4.1.2 Information Retrieval and the Count-Based Model, the field of information retrieval has an independent history of creating document embeddings, using count-based models derived from explicit matrices rather than implicit prediction-based models. In the field of UI/UX design for visual search independent techniques have been developed for the visualization of document embeddings. Yi et al. (2002) face several of the same problems in multidimensional scaling which the NLP community would later face in visualizing word embeddings. While they also discuss PCA, the explicit, count-based nature of document embeddings means that they are able to explore other visualization techniques with explicit semantic axes. As usual with modern work on embeddings in the NLP community, work in the information retrieval community has already invented solutions which potentially augments LSA (Li et al., 2019).

One technique is parallel coordinates, which allow data to be plotted in multiple dimensions simultaneously (Johnson, 2000). A set of parallel axes represent the different variables, and each entity is plotted along all of them simultaneously. The advantage of this is that there is almost no dimensionality distortion, at the cost of removing orthogonality of data-plotting, and confusion of entities, making it harder to perceive specific relations which exist in the data. Johnson attempts to circumvent this by plotting the parallel coordinates in a cartesian plane as though they were a single vector.

Another technique for multivariate visualization proposed by the IR community is star coordinates (Kandogan, 2002). Star coordinates build on Johnson's work bringing multidimensional vectors to a single coordinate plane. They function by adding a new set of axes to a two dimensional plane to represent each dimension in the data. These axes are added at regular angles from the origin, subdividing the coordinate plane into regular "stars" depending on the number of dimensions. This has the advantage of visualising all the dimensions simultaneously, while making the relations between the dimensions explicit. The other advantage is that the coordinate axes do not necessarily have to be orthogonal to each other, which saves space in the projection. Then, in a manner similar to how Johnson plots parallel coordinates in a single plane, Kandogan concatenates the vectors along multiple angles to form a "spiral" vector whose final position represents the location of the point in the space.

Because all the dimensions are represented explicitly, Kandogan claims that there is less loss of information in the projection of the multivariate points into their coordinate system. They also provide multiple ways that data can be transformed, and investigate how users interact with it. Their coordinate system can also be realised as either radial or cartesian coordinates, and lends itself well to rotations and translations. They claim that such operations are what make it helpful to the user and aid in the knowledge discovery process.

Another technique Yi et al. (2002) examine is a scatterplot matrix, which allows the user to examine the entire permutation of scatterplots formed by pairs of dimensions across all the different axes. It is essentially a matrix of two-dimensional plots, which allows the users to see all the relations explicitly but may not help them in finding relations between them.

4.4.2 The "dust and magnet" metaphor

Yi et al. (2002) build on the earlier work in the IR visualization community by making use of the metaphor of a magnet. The magnet metaphor is itself a reimagination of another metaphor pioneered by Olsen et al. (1993), the point of interest (POI). The origin of the POI is the metaphor of a stack of documents in an office. Olsen et al. create a system called VIBE, where POIs are used to establish a coordinate system in a vector space. Each POI is a query, and it attracts the documents in the vector space which are most relevant. Every time a new query is created a new point of interest is defined, giving the user the ability to see how their various queries interact over a group of documents, and what potential relations exist between them.

Yi et al. reimagine POIs as magnets, and documents are particles of dust. They create a system called Dust and Magnets (DnM) which takes points of interest a step further in how they attract particles: some magnets attract particles more than other, as opposed to POIs which all have equal attraction. The DnM system allows users to modify the "magnitude" of certain points of interest and attract some documents to it at a greater rate (Yi, 2010).

DnM also allows the user to change other parameters of the data visualization, such as the size and colour of the particles. The metaphor of the magnet also serves to make interaction intuitive for users. Magnets have four features which determine the magnitude of attraction a given document has to them: the assigned attribute of the magnet, the value of the matched attribute of the Dust particle, the magnitude of the magnet, and the repellent threshold of the magnet. These four parameters work together to create a more user-friendly way to explore document relations than with POIs. The system also operates based on a star-coordinate system, but is more intuitive for users because they are confronted with the metaphor of a magnet to describe a query, rather than the abstract multidimensional vectors.

However, DnM also has reproducibility problems. The amount of data required to store all the transformations a user makes on the data is immense. The intent of the authors was to develop a way to save configurations of information although it is not clear if this was ever completed. The tradeoff in DnM is for greater interactivity, at the loss of precision in how movements in the system are recorded.

Dai et al. (2015) update DnM with new user interface technology, including the touchscreen. They design the interface to be multitouch, which allowed multiple users to move magnets on a large display simultaneously. Because physically moving magnets was tiring, they updated the system to have the dust move automatically, rather than every time a user shakes a magnet. They also added in an option for the dust particles to automatically repel each other. Similarly to the original creators of DnM, they found a lack of precision in the visualization technique, and mention that there is a need to improve this factor.

4.4.3 Radial Search and polar coordinate visualizations

Nitsche and Nurnberger (2006) develop QUEST, a system for visual search with a more streamlined UI than VIBE or DnM. It is inspired by Cousins et al. (1997) who developed an intuitive UI approach for bibliography which visualised documents in circular charts. However the UI of QUEST is simpler, with all the controls located in one window.

The QUEST system expands upon the DnM metaphor by adding a radial coordinate system which grounds the magnets in a pre-existing coordinate space. The radial system correlates to a measurement of relevance: the user is able to control how relevant they think a magnet is by positioning it closer to the centre. The system was designed under the premise of *vague query formulation,* which is that users with an information need do not always know what they are seeking. It is also designed to be a multi-user system.

The use of radial design for the relevance coordinate system is significant, as is its combination with the dust and magnet interface. As Nitsche and Nurnberger (2006) mention, most radial visualizations have fixed positions for entities in the coordinate system. The advantage of their variation of the DnM system is that users can place queries wherever they want. The users thus do not need to specify a concrete position on the screen as the system supports it with non-determined precision. The closer a query is to the centre, the more relevant a query is. This can be seen as a visualization of the “magnitude” parameter in Yi et al. (2002).

This makes a system which is more streamlined and interactive, with dust particles being automatically distributed near queries in a radial relevance space. The radial visualization is also intuitive, with the single dimension of relevance well-captured by the metaphor of “centring.”

Unfortunately, while Nitsche and Nurnberger provide a mathematical definition of how they calculate relevance in the space, they are not transparent about how the multivariate visualization of the dust particles map onto the polar coordinate space of the relevance mapping. This is important because Yi et al. (2002) were transparent in how their work built on both parallel and star coordinate systems to create a two-dimensional mapping of documents. While it is clear that QUEST builds on the work of DnM, Nitsche and Nurnberger are not transparent in how they map these multivariate positions into a polar coordinate space.

This is relevant because to convert from a cartesian system of (x,y) to a polar system of (r, θ) it is necessary to transform the coordinates using the simple transformation: r = √x^2+y^2, and θ = tan−1(y/x). Both the parallel coordinates of Johnson (2000) and the star coordinates of Kandogan (2001) involve concatenating vectors of different dimension, and while these will ultimately give a simple set of (x,y) coordinates even for a very high number of dimensions, it would still be useful if they were transparent about how they created their coordinate system from previous work. As will be discussed in **4.5** a transformation from cartesian to polar coordinates offers yet another opportunity for dimensionality distortion and uncertainty of visualization to creep into the process.

4.5 USE OF RADIAL VISUALIZATIONS

4.5.1 History of Radial Visualization

While the term “radial visualization” was coined by Hoffman et al. in the 1990s (1997), like many popular data visualizations the practice was first pioneered by William Playfair in the early 19th century (Draper et al, 2009)(Playfair, 1801). Playfair’s *The Statistical Beviary* displayed the different countries of Europe by population, depicting the statistics as the size of the radius in the visualization. Spence (2005) writes that Playfair took inspiration from earlier radial diagrams, particularly Venn diagrams, could have emerged from the tradition of Ramon Llull, Giordano Bruno, Leibniz, and Euler, from whom William Playfair may have taken influence via his brother John. Whatever the case may be, radial diagrams have a history in representations of mathematical logic which stretch back a considerable distance.

The next great development in the pie chart would come from Florence Nightingale, who created a pie chart in 1850 to communicate the poor sanitary conditions faced by the British army during the Crimean War (Nightingale, 1987). This visualization was notable for making use of the form of the circle to represent the twelve months of the year, and the cyclical conditions the army faced.

Draper et al. (2009) discuss a number of common radial visualization strategies in their review of the subject. One of these is star plots, which we saw before pioneered in the information retrieval community in (Kandogan, 2002) — they note that one of the common uses for radial visualization is the display of search results. Another is tree plots, which are a useful way for representing taxonomic data, such as knowledge graphs. The 20th century use of radial visualization they trace to sociometry (Northway, 1952). Interestingly, Northway also discusses a peg-board radial display of social relations, which is an analog realisation of a radial data visualization.

Draper et al. (2009) also mention four usage domains which are commonly appropriate for a radial approach: tree diagrams, which we shall see again in 4.6 DATA VISUALIZATIONS OF KNOWLEDGE GRAPHS, relationships among multidimensional data as we saw in 4.3 WORD EMBEDDINGS IN DATA VISUALIZATION, search results as we saw in 4.4 DATA VISUALIZATION FOR INFORMATION RETRIEVAL, and finally cyclical data, such as Nightingale's report of hospital conditions. They claim that these uses, while not exhaustive, are fit domains for a radial visualization, and it is important to keep this in mind as radial displays can often be misused.

One aspect Draper et al. also stress is the extent to which radial visualizations lend themselves to interactivity. A major benefit of radial visualizations is that they are accessible. Users tend to find them aesthetically pleasing and easy to use. Particularly, they cite a number of studies which show that for visualization of tree charts they can be more effective than classical, cartesian forms of visualization. They also expect that in the future there will be more interactivity in radial visualization. Similar to the DnM system, a theme in the literature about radial visualization seems to be that they are an incredibly accessible and popular user interface; also like DnM this has some downsides in terms of precision.

4.5.2 Issues with Radial Visualization

Rodden (2020) writes an Observable which demonstrates some of the proper uses of radial visualization. In doing so they also discuss some of the issues with radial visualization. Precisely because radial visualizations are accessible and aesthetically pleasing, they are often chosen by novice designers.

One of the central issues of radial visualization is the proper comparison of quantities. Edward Tufte, in the Visual Display of Quantitative Information, emphasises Visual Integrity as one of the founding principles of data visualization ethics (Tufte, 1985). This means that the depiction of quantities geometrically should be to scale, and the magnitude should reflect the numerical values without distortion. Radial visualizations can unintentionally distort magnitudes the further away one moves from the centre. Rodden discusses how this can impact sunburst visualizations, where quantities further from the centre will appear to be larger than they are. This also applies to Florence Nightingale's stacked bars.

Another issue is less associated with ethics but have to do with how humans judge relative quantity. Using the example of a pie chart, Rodden demonstrates how the relative magnitudes of each quantity are easier to perceive in a linear rather than an angular form: that is, a bar chart is simple and intuitive to read, and the viewer can instantly perceive which values are greater or lesser. Especially when the values are closer together, and the viewer needs to differentiate subtle changes in quantity, a pie chart will make those differences appear almost identical.

It is interesting to note that these two distortions are due to the nature of polar coordinates. Blocks with a greater radius ***r*** will take up more area than smaller radius blocks or bars, and it is harder for the eye to perceive magnitude differences between arcs with differing θ values than between linear segments. A transformation from a cartesian to a polar coordinate system necessarily entails some distortion, with the exception of the use cases Draper et al. list in 4.5.1 History of Radial Visualization. (Indeed, Rodden is particularly enthusiastic about tree visualizations in radial design.)

This distortion is mathematical and has to do with the properties of lines and circles. While circles remain mathematical objects which inspire us with a sense of aesthetic awe, π remains a transcendental and mysterious number, and our more limited minds are better able to reason when confronted with lines and squares. This fundamental mathematical fact may account for the reason most designers are wary of people who use radial visualization solely for aesthetic impact. It can certainly be said, following Rodden, that if the sole reason a visualization has been chosen is for this aesthetic effect, and user accessibility, it will not lead to results which Tufte would consider ethical (Burch and Weiskopf, 2014). However, a case can also be made for the use of radial designs for all the domains surveyed here, particularly both embeddings and knowledge graphs, in simultaneously the explicit, tree-based form of taxonomic relations, and in their implicit multidimensional form.

4.5.3 Radial Visualizations in Prototype Theory

A theme of this dissertation is that work on embeddings in linguistics, cognitive science, and natural language processing would benefit from an examination of previous techniques used in information retrieval. In this instance, there is an area where the field of information visualization could benefit from an examination of linguistics and cognitive science. One of the central problems in word-sense disambiguation and language in general is polysemy. It is also well-known that even representations of the meaning of words in formal logic fail to capture the intension of a word or proposition. These theoretical considerations have been reviewed in section 4.1.1 Distributional Semantics in Theory.

Following these considerations, the work of cognitive linguists, particularly Lakoff, has made a contribution to lexicography explicitly based on a radial approach to understanding polysemy (Lakoff, 1987). Such an approach to visualising polysemy should be considered particularly relevant due to the use of radial star-coordinates to represent multidimensional semantic data. However, in the case of Lakoff's prototype theory, the polysemous senses are formal, rather than syntactic, and their relations are intended to operate by means of metaphor and metonymy (Halas, 2016).

The senses of words are inherently difficult to formalise, due to problems of vagueness and the nature of sets (Sorensen, 2018). One proposed solution to this problem is prototype theory, which defines the lexical meaning of a word according to a prototype. One sense of the word is held to be the most important in the lexicon, and other sense of the words are seen as "less prototypical". The way Lakoff proposes to visualise this is radially.

As the radius increases different properties such as metonomy and metaphor are modelled, which depict the transition of a term from its essential meaning to more derivative ones. Interestingly, one of the issues Halas points out for radial visualization of lexicography is that it can give the impression that the relationship between senses is more hierarchical than it actually is. The tree diagram element of radial visualizations, and its application to lexicography for categorical thinking may make the sense relations between words appear more taxonomic than they truly are.

The prototype theory radial model of a lexeme thus presents the viewer with an interesting application halfway between a tree diagram and a multidimensional visualization of word semantics, albeit one which is more semantically motivated than word embeddings, and has none of the underlying technologies. Prototype theory models are built by cognitive linguists as purely theoretical models to understand the meanings of very specific terms. Unlike word embeddings, they are not based on any mathematical formulation.

However, Evans (2005) does propose four criteria for selecting which sense of a word should be centred as prototypical: 1) from etymology, the earliest attested sense of a term, 2) which sense is most frequently attested in the network (an approach similar to count based methods of information retrieval matrices) 3) how predictable the other senses of the word are based on that sense (it is perhaps a stretch to claim any similarity to the prediction based model of word embedding in a formal or mathematical sense, but it is a similar idea) and 4) a purely phenomenological level based on subjective experience, which is an entirely valid way to deal with the meanings of words, but is not always the most mathematisable.

4.5.4 Studies of the Effectiveness of Radial Visualization

While it is the general opinion of experts that radial visualizations are not always the best choice to represent data, a number of scientifically rigorous studies on the subject have always been conducted, comparing how users interact with data presented in both cartesian and polar coordinates.

Stasko et al. (2000) conduct a study comparing a cartesian Treemap to a Polar Sunburst diagram of the same data, measuring both how well participants perform at a given task and also the time it takes them to complete said task. They found that the circular method more frequently aided task performance. Burch et al. (2008) find the opposite. In their study they test Timeline Trees, a cartesian visualization, and Time Radar Trees, a radial one. They also use eye-tracking to collect another type of data to their results, which revealed an interesting fact: although their cartesian participants performed better, polar coordinates did not lead to the "blinders effect" because their participants looked everywhere and they were more likely to inspect the periphery of the visualization.

Burch et al. (2011) expand on the importance of eye-tracking experiments in gathering accurate data on the differences between cartesian and radial visualizations. They also discover that radial visualizations are hard to read, with the added finding from the eye tracking equipment that participants were reviewing the location of labels on the radial diagram, perhaps implying it was harder for participants to remember the position of information on radial visualizations.

Diehl et al. (2010) also test how well users remember the location of entities in both cartesian and radial coordinate planes. For this study they generated an n x n matrix to simulate a cartesian space, and then created a similarly segmented circle. Users had to perform tasks of both recalling which segment had been highlighted, and also move highlighted blocks around in both systems. In general they find a slight advantage to user performance on cartesian visualizations in the tasks of their experiment, although there is no statistically different amount of time it took the participants to complete the tasks.

Burch and Weiskopf (2014) remark in a literature review of the available studies that there are few who have conducted studies on the performance of users on information retrieval tasks in both cartesian and polar coordinate visualization systems. It should be noted that, in spite of evidence that cartesian systems tend to outperform radial ones, most of the studies reviewed here came from the same lab. The sole exception to this from Stasko et al. (2000) found a superior performance for polar coordinates. What the team which included Burch, Weiskopf and Diehl did was to find ways to control for variables across both data visualizations. It is possible that comparing a TreeMap to a Sunburst diagram, rather than two roughly analogous tree diagrams or matrices in the different realisations, added a level of complexity which confused users for the TreeMap, and improved results for the Sunburst diagram.

4.6 DATA VISUALIZATIONS OF KNOWLEDGE GRAPHS

4.6.1 Indented tree visualizations

The most basic form of ontology visualization is using an indented tree, similar to the interface in Windows Explorer. An indented tree is a compact way to represent a hierarchy which supports user find-ability. The most popular ontology editors, most notably Protege, offer an indented tree visualization for navigating an ontology, and Kaon, WebProtégé, OBOEdit, structOntology, OntoEdit and OntoRama offer an interface similar to Protege's (Katifiori et al., 2007(Fu et al., 2013). In addition, ontology browsers such as VectorBase, libraries such as BioPortal, and ontology mapping tools like BioPortal all make use of indented trees (Ibid).

Indentation indicates super- and sub-class relations and there is only a single path between a given pair of nodes (Fu et al., 2013). For this reason, indented lists are useful for providing a simple and legible representation of the content of a taxonomy, but are not as good at representing its structure (Johnson and Schneiderman, 2021). It takes the user time to parse the list, and without lines showing graph relations between nodes there is no straightforward way for a user to apprehend a taxonomy's structure.

One place where this manifests is with the visualization of multiple inheritance (Katifiori et al., 2007). Multiple inheritance (nodes having multiple parents, or classes that are subclasses of multiple superclasses) is sometimes encouraged in ontologies because it allows complex relationships and logical conjunctions to be modelled (Noy et al., 2002). In a graph visualization multiple inheritance relations can be apprehended instantly by examining the edges which connect a given node, and the relations they are labelled with. In an indented tree visualization, nodes with multiple inheritance will be listed as twice as entries under both parents. This means that in order to perceive the relationship the user will have to exhaustively examine all subclasses in order to determine which nodes have multiple inheritance, if any.

For these reasons Noy et al. (2002) and Eades et al. (1993) propose the use of nested boxes to represent sub-class and super-class relations instantly as a treemap, allowing users to instantly apprehend taxonomic relationships. Similarly, Parsia et al. (2005) propose CropCircles which use nested circles, similar to Venn diagrams to represent tree structures. They state that their approach is similar to a treemap, and notably state that their approach has an aesthetic appeal, which echoes the general motivation for the adoption of radial visualizations discussed in section 4.5.2 Issues with Radial Visualization.

In order to more accurately represent trees Noy et al. recommend the delineation of connections between parent and child nodes, which quickly evolves into a graph view. While the use of treemaps or crop circles can make complex relations like multiple inheritance explicit and readily accessible to the eye, in the case of CropCircles Parsia et al. (2005) add in directed edges to visualise relations between different classes depicted by the system. Because these graph visualizations serve to make the structure of the taxonomy more explicit they are often included in with Protege and other editors as plugins (Katifiori et al., 2007).

4.6.2 Node-link tree and graph visualizations

Katifiori et al. (2007) define node-link tree and graph visualizations as those which use nodes and edges to present the taxonomy typically with a top-down or right-to left layout. There are a number of studies on finding the best algorithms to generate readable node-link diagrams, going back to Klein and Wood (1989). Protege offers several extensions that visualize a graph as an ontology, including OWLViz, NavigOWL, TGVizTab, OWLPropViz, OntoViz, OntoGraf and WebVOWL. Other, third party graph visualizations also exist, such as IsaViz, SpaceTree, OntoTrack, GoSurfer, and GOBar.

One of the great advantages of graph visualization is the ability to represent object properties and data properties alongside class and instance relations, which is not as apparent in an indented tree visualization. Protege includes object and data properties in separate panes when viewing them in the indented tree. In the graph visualization these relations can be shown as directed edges, enabling full visual exploitation of the RDF structures OWL runs on. Herman et al. (2000) argue that the point of graph visualization is to answer the question for the user "where am I?"

On the other hand, when graphs become too large, usability and view-ability suffers. When there are too many nodes and edges clustered together it becomes impossible to differentiate edges, which appear as a mass (Ibid). Usability can suffer even before this visual threshold, and there is an inverse relationship between how usable a graph is and how large it is. As Herman et al. mention, ever since Euler first set out to solve the bridge problem in Konigsberg, how a graph is reasoned over or mathematically defined has often been connected to how it it visualised.

Battista et al. (1994) write a literature review of techniques for visualizing aesthetically pleasing graphs. They review hundreds of papers on the subject, ranging over a wide array of visualization subjects in graph theory, but notably — and explicitly — avoiding the subject of embeddings. Among the aesthetic considerations for graphs they review the foremost is that none of the edges of the graph should cross each other. Another interest is the proper representation of symmetry. They also mention standards for the proper distance to separate levels in a hierarchy of nodes and the correct distance for sister nodes. Their recommendation is that the width of the drawing should remain as small as possible.

In addition they review algorithms for constructing radial visualizations of trees. Graph visualizations provide several advantages over indented tree visualizations, but most of them are based on the holistic aspect of viewing a graph. Users can very quickly see relations between nodes, with the caveat that the graph cannot become too complex. For ontologies there is the added problem of labelling edges. If the labels intersect they may become unreadable, making the most essential aspect of a knowledge graph, its semantics, obscured.

For this reason some programs make use of three dimensions for visualizing graphs, in order to increase the potential for interactivity, and also to provide a more efficient use of space.

4.6.3 Three-dimensional visualizations

There are a number of tools developed which visualise an ontology as a graph in three dimensions. Reikmoto and Green (1993) use transparency to present Information Cube, a tool which visualises categories in an ontology as nested cubes. Andrews et al. (1997) present Information Pyramids, which represents the hierarchy as a series of pyramids with flat tops. Subcategories are secondary pyramids placed on top of the broader categories.

OntoSphere (Bosca et al., 2005) uses a spherical visualization to represent graph relations. It represents the upper level classes of the ontology as boxes located on the surface of a sphere. Zooming in shows property relations between different classes. ConeTree (Robertson, et al., 1991) visualises taxonomic relations using cones, with the top of the cone being a parent node and the bottom of the cone being a child. 3D Hyperbolic Tree visualizes a tree in three dimensions, placing the nodes at the edge of a sphere. TreeViewer (Kleiberg et al., 2001) takes a more creative approach, and visualises tree diagram as though they are botanical trees, with files being represented graphically as either fruit or pinecones, automatically generated. They use this approach to visualise file path hierarchies, however they state that the pinecones could be used to represent any list of items in another application.

These visualizations use three dimensional geometry to add an extra layer of interactivity to the visualization of a graph. However, some studies have shown that three-dimensional visualizations are not superior to two dimensional ones, and may in fact lag behind their flat counterparts in terms of interactivity. Hicks et al. (2003) run an experiment which require participants to perform information retrieval and comparison tasks on a two dimensional plot, a three dimensional plot, and a three dimensional helix. They find that response times were significantly lower on the three dimensional plot, and performance was worse on the helix.

Cockburn and McKenzie (2002) run an experiment where they construct six interfaces. Three of the interfaces are physical realizations with printed photographs, and three are virtual interfaces with digital photographs. Of these two groups, there are two and three-dimensional visualizations, and also a two and a half dimensional visualization, which consists of photographs arranged on a sloping line. Their experiment investigated the ability of participants to use spatial memory. Similar to Hicks et al., they discovered that an increase in the number of dimensions substantially increased the amount of time it took to complete the task. They also found that subjects had trouble remembering where they placed objects in the three dimensional visualization.

Similar to radial coordinates, despite the aesthetic appeal of three-dimensional visualization, it is not always as practical as its two-dimensional counterparts. Visualizations of graphs may benefit from being able to use space more efficiently by adding another dimension, and are better able to keep to Battista et al.'s (1994) recommendations. However, these visualizations may not be as usable as two dimensional ones when it comes to interactivity.

4.6.4 Usability of ontology visualizations and combinations of approaches

There have not been many papers written comparing different kinds of ontology visualizations in user response tasks. Noy et al. (2002) test user response times for indented tree visualizations against graph based visualizations. The test was a usability test which asked participants to judge an alignment between two ontologies by interacting with visualizations of those ontologies. The participants corrected incorrect mappings and added missing ones. They found that indented trees had a higher success rate, while graph visualizations had a higher efficiency of task completion.

As stated at the outset of this literature review, the research question of this dissertation investigates a question which cuts across several facets of data visualization and knowledge graphs and ontologies. As far as the author knows there is only one tool which has been developed which visualizes a knowledge graph and its embeddings simultaneously, and that is Stunning Doodle, developed by Ettore et al. (2022).

Stunning Doodle aims to fill a gap in visualization analysis of knowledge graphs. It creates a graph visualization tool which allows the user to view the nodes connected via the explicit knowledge graph edges, and simultaneously to see which nodes are closest to it in an embedding view. The program requires that the user upload an ontology file in the turtle format and a csv file of embeddings. These two files coordinate to create a graph view of both structures. Most embedding visualization tools examined here place the entities within a continuous coordinate plane: Stunning Doodle is unique in creating a secondary graph which shows the nearest entities in terms of similarity score out to a certain threshold with a node/edge structure.

However, while many papers exist which evaluate different visualizations of knowledge graphs for information retrieval, no studies have been done which evaluate graph and indented tree-based visualization of knowledge graphs against embeddings of those graphs made with the new word-embedding technology. In the following sections the research goals of this dissertation will be clarified, and a study which incorporates OWL2Vec, OntoGraf and WebVOWL will be conducted with human participants.

5. METHODS

5.1 Extending the African Wildlife Ontology

In order to keep the experiment simple, it was necessary to choose an ontology which covered a domain which was common knowledge. Because the Pizza Ontology, typically used as the tutorial ontology, could be rather abstract, the African Wildlife Ontology, an alternate ontology developed by Keet et al. (2020) was selected. The African Wildlife Ontology (AWO) was developed to create a tutorial ontology without some of the issues of the Pizza and Wine tutorial ontologies. Most of these shortcomings concern modelling practices or styles.

For the purpose of this experiment maintain modelling best practices are not as important as selecting an ontology with an accessible domain. The African Wildlife Ontology was chosen because it was a domain which would be common knowledge to all participants, the entities listed were accessible and un-intimidating, and it was possible to create a very general information retrieval query from its classes that was simple for participants to understand and carry out.

The task for participants was to select all animals from a data visualization of the ontology. Because the ontology was not going to visualise instances of individual animals, classes of African animals needed to be added. Originally the ontology contained the classes 'Lion', 'Elephant', 'Giraffe', 'Impala' and 'Warthog.' These classes were too sparse, so the ontology was extended with the classes of seven other animals, bringing the total up to twelve. Originally, the intention was to use exhaustive taxonomic data-sets of flora and fauna of Africa, and extend the ontology programatically. However, on investigation, most of these data-sets make use of the Linnaean Classification system, and the experiment is intended for members of the general public, not domain experts.

Thus, informal resources were used to extend the ontology. For extending the animals, "A-Z Animals.com" was used. Some of these animals were already present as classes in the ontology. Of those that were not, unique exemplars were chosen ('Wild Dog' for instance, being modified by 'Wild' was not chosen for the ontology). The classes added to the original ontology were 'Python', 'Ostrich', 'Shark', 'Mosquito', 'Zebra', 'Hippopotamus', 'Buffalo'.

These classes were created as subclasses of the relevant categories in the ontology, such as 'Herbivore', 'Omnivore' and 'Carnivore.' While this would only be visible to participants in the Graph and Tree visualizations of the ontology, the position of classes in relevant subclasses would impact the random walks OWL2Vec makes over the graph, and thus indirectly informs the embedding position of a node.

To maintain consistency, plant species were taken from 'A List of African Plants' on GardenGuides.com, and ten African trees were added from EarthTouchNews.com. This was to add similar elements to the ontology which were not animals, in order to test participants' ability to successfully differentiate in the information retrieval task. The classes added were 'Baobab', 'DragonBloodTree', 'FeverTree', 'Leadwood, 'MarulaTree', 'MopaneTree', 'QuiverTree', 'SausageTree', and 'SycamoreFig.'

Finally, while some object properties were initially added to the ontology to contain information about which animal eats what, this practice was abandoned because object properties are not visualised by embeddings, while they are in a graph visualization. This had the potential of adding unnecessary visual data to the experiment. The original object properties were left in the ontology, but no attempt was made to exhaustively model all the object property relations between classes, as this was not necessary for the visualization task. All modelling was done using the Protege software.

5.2 Creating Visualizations in WebVOWL and OntoGraf

To visualise the ontology as a graph, two pre-existing programs were used. One of these was WebVOWL, designed by Lohman et al. (2014) to visualise ontologies as a graph based on Open Web standards. It implements the Visual Notation for Owl Ontologies, or VOWL. WebVOWL creates an interactive force-directed graph out of an ontology file or an ontology IRI. Because the visualization is interactive it is possible to move the nodes of the graph around as the user explores the connections. However, in order to remain consistent, no interaction with the graph was conducted, and the graph was saved as an SVG file to use in the experiment.

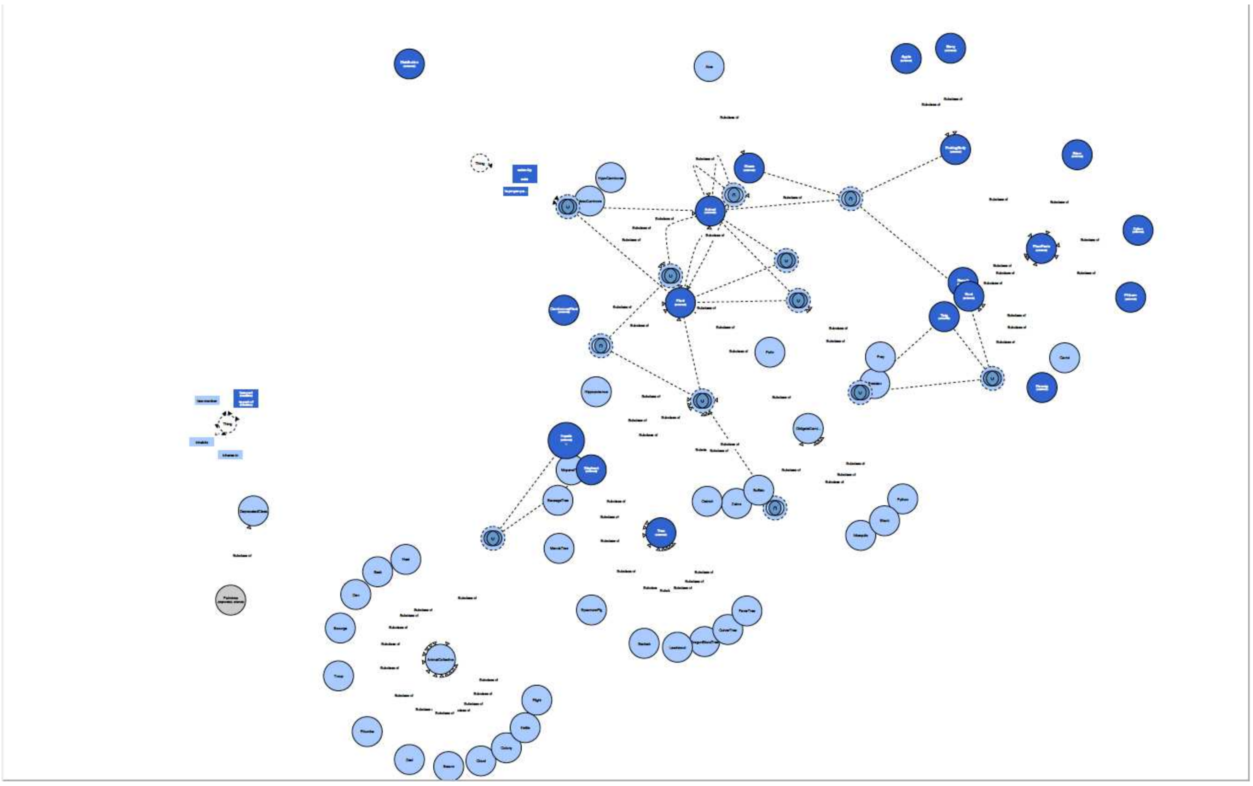

Figure 2: The Extended African Wildlife Ontology visualised with WebVOWL

The other visualization tool used was OntoGraf, which is an extension for Protege. OntoGraf has the advantage of allowing the user to automatically transform the graph into a tree structure, oriented either horizontally or vertically. It also allows the user to select which classes are to be visualised, and automatically depicts property relations between them. To create this visualization all classes were selected, and then a top-down hierarchical tree structure was suggested. Like with WebVOWL the user has the option to move the nodes of the graph to explore its structure. Similarly to WebVOWL, no interaction was done with the graph, and the visualization was saved as an image after being automatically generated.

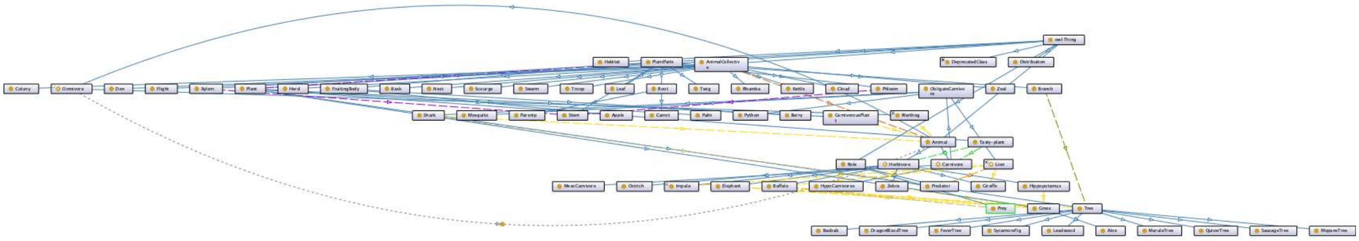

Figure 3: The Extended African Wildlife Ontology visualised with OntoGraf

5.3 Using OWL2Vec and mattplotlib

In order to generate the embeddings of the ontology, OWL2Vec was used. The latest version of the tool was downloaded from the GitHub and installed, and run via a Jupyter notebook. The parameters for the tool were set to not use the projected ontology, project only taxonomic relations, avoid multiple labels, avoid OWL constructs, and to save the embedding as a document of sentences. However, when the document of embeddings was produced, the data still needed to be cleaned in order to visualise it.

Several terms were included that were just OWL terms, that when visualised would appear to users as an incoherent stream of numbers and letters. These were removed. In addition, one of the advantages of OWL2Vec is that it creates embeddings for metadata, such as tags under the rdfs:label property, which in the African Wildlife Ontology contained long sentences, sometimes whole paragraphs, which the python implementation built for visualization would have trouble parsing. These were removed. Finally, a number of animals not contained as classes in the ontology were mentioned as entities in metadata rdfs:label tags. In order to create a systematic, controlled, TREC style standard for information retrieval, where animals were mentioned that were not present in the added classes of the ontology, they were removed.

Visualising the ontology was done using a python implementation of principle component analysis (PCA) from the scikit-learn library. The ontology embeddings were reduced to a data frame containing two dimensions. These were then visualised using the matplotlib library to create the cartesian embeddings.

In order to create polar coordinate embeddings, the two columns in the dataframe were treated as (x,y) cartesian coordinates. Then the simple formula to convert cartesian coordinates to polar coordinates was performed: **$r=\sqrt{x^2+y^2}$, $\theta=\tan^{-1}(yx)$**; which created a dataframe with the position of each dimensionally reduced point represented as the coordinates (r,θ). These were then visualised in a radial plot in the matplotlib library.

One of the difficulties faced in creating this visualization was readability of labels. Although for both cartesian and radial visualization a distribution was created which showed where the entities were located in a semantic space, the labels were often illegible, because they overlapped each other. In order to make the text readable, first the font size was adjusted. However, in order to reach an adequate font size that no labels overlapped each other, the font would have to become so small that it was also unreadable. Thus, instead of altering the font size, the size of the canvas was changed.

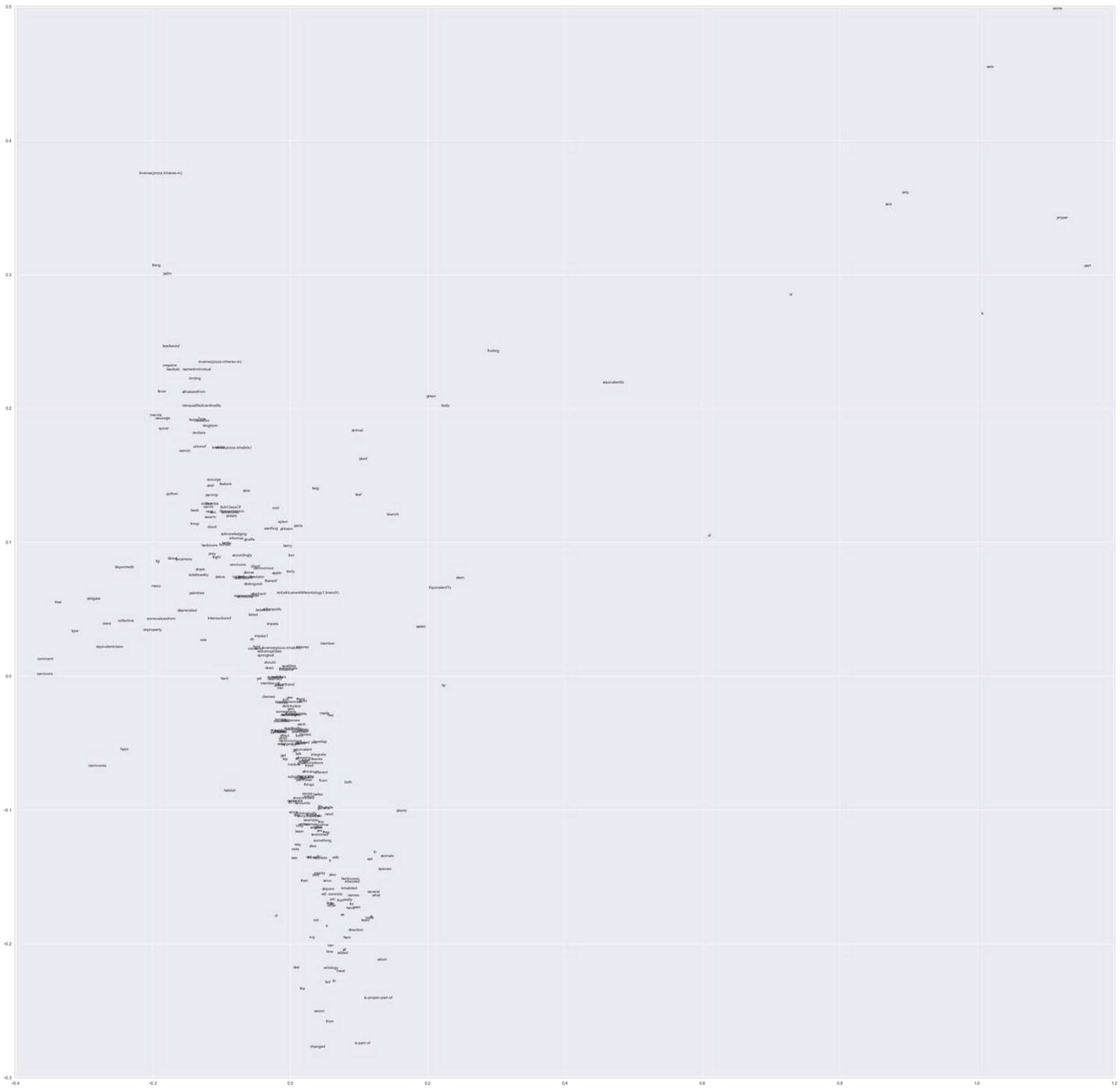

Figure 4: The SquareVis visualization of the ontology, created with OWL2Vec and Matplolib

For the cartesian visualization, altering the canvas size was trivial, and did not create many real distortions in user experience. It was possible to create a visualization which looked roughly the same and was also readable. For the radial visualization, this was more complicated. Adjusting the window on a radial visualization did not produce a circle, instead creating a pie wedge, or a section of a circle. While this changed the overall aesthetic impact of the visualization, the relations between the points in the display remained unchanged. Thus, users were presented with a pie-wedge section of a radial chart with a semantic distribution, rather than a complete circle.

Figure 5: The CircleVis visualization of the ontology, created with OWL2Vec and Matplolib

5.4 Experiment Design

In order to conduct the experiment, a Qualtrics survey was created for participants. Each of the four images was uploaded to a different url at a domain owned by the author. Participants were instructed to view the image and enter all the animals they could see in the provided form. Each participant was only shown one image out of the four.

They were prompted with a format with which to enter the information, but they were given no information about what animals they were looking for, or how many animals there were. Participants were recruited using the Amazon Mechanical Turk (AMT) marketplace and were given fifteen minutes to accomplish the task (the average time of completion for the task was seven minutes.) No personal information was collected from the participants, but all participants nonetheless signed a consent form. Each participant was reimbursed $1 United States Dollar for their time.

As no personal information was collected it is impossible to know the demographics of the participants, but they were all employees of the Amazon Mechanical Turk marketplace. “Master” status, as offered by AMT, was not required for this experiment. Each participant was also given a unique id generated from the Qualtrics survey to enter into the AMT portal to confirm completion of the experiment, and to qualify themselves for payment.

In order to make sure that only one image out of four was shown to each participant, a randomizer was used. This mostly distributed results evenly across the four categories, but it was not an even proportion of data. In order to make sure that the same amount of responses were collected for each category, a second round of experiments was done calling for an explicit amount of participants for both OntoGraf and the radial visualization on AMT, in order to bring up the total number of participants for each category to roughly 30. In total, 113 participants were recruited for the experiment.

6. ETHICS

As someone who works as a data labeler, it was important to me that participants were reimbursed for their time. I was not able to pay them much, but in order to make it worthwhile for workers on AMT I also endeavored to keep the experiment short. Workers on AMT are very exploited, with some of them not making minimum wage due to the nature of the platform. My goal was for the experiment to take about five minutes, thus paying participants within a rate of $12/hour and staying within my personal budget. I was happy that the average task completion time was seven minutes, which was close to this goal. Part of the motivation for keeping the experiment short and simple was not just to make it understandable for participants, but also to use their time effectively, as AMT workers spend most of their time "shopping" for tasks.

No personally identifying information was collected of any participants, and all results were kept in password protected spreadsheets on my computer.

7. RESULTS

Of the 113 participants, there was a wide range of inputs in how they approached the task. Although effort was made to make the instructions as simple and straightforward as possible, a significant minority of participants misunderstood the task. However the manner in which participants misunderstood the task differed. One participant submitted a dictionary of African animals they found from another website. Another participant shared their personal opinions about the structure of the experiment.

Other participants understood the task, but submitted animals not contained in the ontology, while others selected entities in the ontology, but ones which were not animals. In order to better understand the results, especially for the calculation of recall, the answers were divided into four categories:

1. Correct answer that is actually in the list
2. Incorrect answer that is actually in the list
3. Incorrect answer that is not in the list
4. SPAM/Did not understand the task

Some participants understood the task and returned correct answers, but also added in animals as guesses from their own memory not present in the ontology. These answers were understood as Category 1, because the participants had had enough understanding of the task to accomplish it to some degree. Although the inclusion of their own answers lowered the precision of those responses, the bar for getting into Category 1 was to submit a single correct answer. Mis-spelled answers which clearly were names of animals included in the target set were also counted as Category 1. The process by which each response was scored involved manual coding for each entry. In entries from Category 3 and 4 where responses did not come from the ontology, the denominator for precision and recall was kept at 0, and the score for both metrics was understood to be a zero. For responses in Category 1 and 2, precision was calculated as number of correct entries over number total entries, and recall was counted as number of correct entries over total number of classes which were subclasses of the animal set (12).

	SPAM
WebVOWL	2
OntoGraf	0
SquareVis	7
CircleVis	12
Average	**5.25**

Table 1: Spam Results

The average recall was initially calculated from the individual recall from each participant for each visualization (see Table 2). However, it was then decided that arguably spam results from Category 4 were emblematic of participants who did not understand the task, and in similar data visualization studies done on Amazon Mechanical Turk these were eliminated so they did not contaminate the results (see Literature Review). Recall Reduction 1 is the average recall calculated without any of the results in Category 4. This was then expanded to include Category 3 and 4 for Recall Reduction 2, where the inclusion of data that is not present in the table is considered a kind of spam, as the participant is clearly not engaging with the experiment and merely supplying their own guesses about what African animals might be present in the ontology (Figure 6).

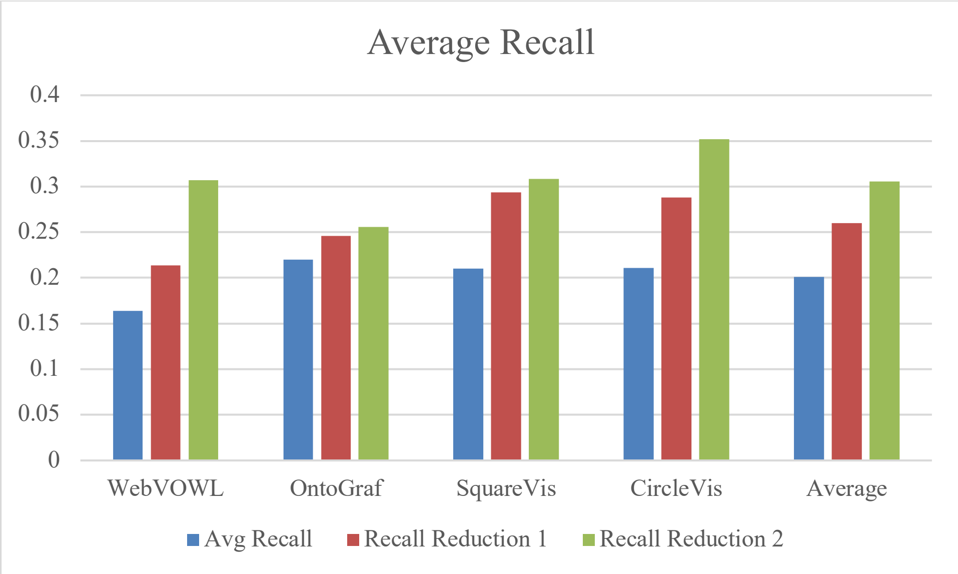

Figure 6: Average Recall

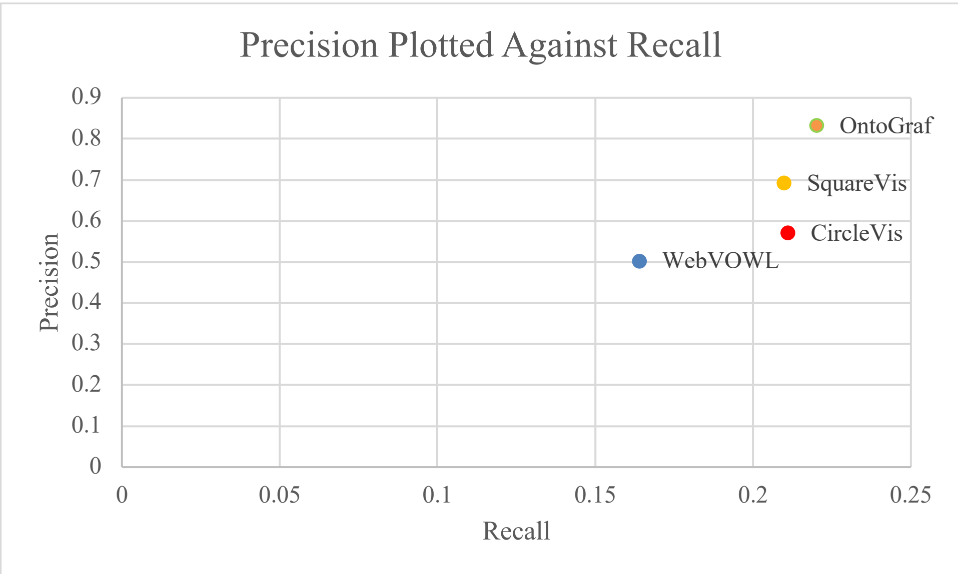

Figure 7: Precision Plotted Against Recall

Similarly precision was calculated for all categories, and with reductions eliminating Category 4 and Category 3 and 4. It should be noted that with this method, precision and recall appear much higher for the embedding visualizations, SquareVis and CircleVis. However, there also was a much higher proportion of spam, particularly for the CircleVis, which had almost 60% more spam than SquareVis. Thus, the reduced numbers favour the embeddings, and they arguably give more information about spam than about actual recall. (Figure 9) Indeed OntoGraf, which had no spam responses, suffers the most from recall reduction 2, while having the highest recall overall without any reductions. For this reason, when calculating statistical significance, the base recall number was used, from the first column of Table 2.

	Recall	Recall Reduction 1	Recall Reduction 2	Precision	Duration (s)
WebVOWL	0.16388889	0.213768116	0.307291667	0.50277778	240.48
OntoGraf	0.2202381	0.245650183	0.25547619	0.83293651	243.010309
SquareVis	0.20987654	0.293650794	0.308333333	0.69230769	244.90625
CircleVis	0.21111111	0.287878788	0.351851852	0.57047619	254.923077
Average	**0.20127866**	**0.26023697**	**0.305738261**	**0.64962454**	**245.829909**

Table 2: Results

Another point to note is the relationship between precision and recall (Figure 7). The two variables are often seen as inverses of each other, and when plotted on axes against each other in Figure X this relationship can generally be seen with the exception of WebVOWL, for reasons addressed in the Discussion. (WebVOWL scored lower on both recall and precision.)

Other than WebVOWL, OntoGraf, SquareVis and CircleVis all had similar base Recall scores within two percentage points of each other. The duration of all the tasks was likewise similar, with average duration falling within the fifteen second range from 240 to 255. Precision varied a great deal, with the highest being OntoGraf at 83, and the lowest being WebVOWL at around 50, with SquareVis and CircleVis coming in second and third.

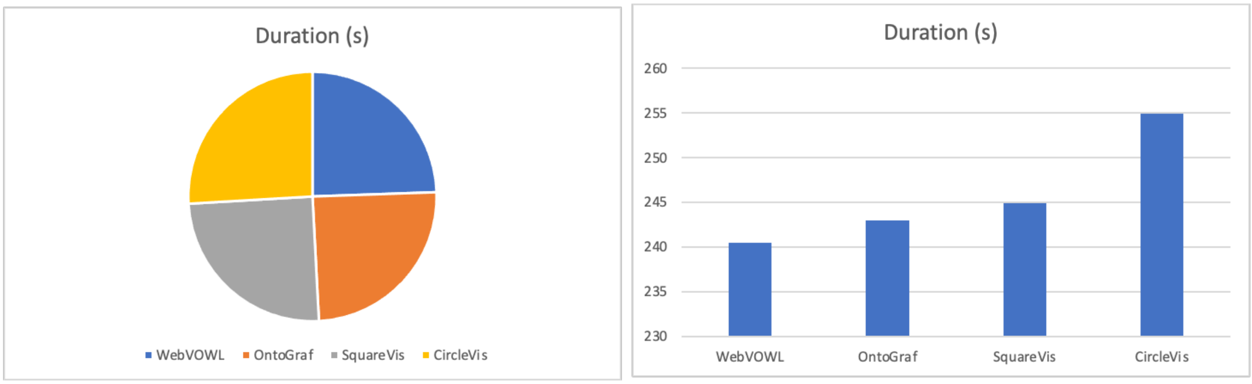

Figure 8: Duration visualised radially and with a bar chart

Figure 8 visualises duration in both a pie chart and a bar chart in order to take advantage of the unique properties of radial and cartesian visualizations. From the pie chart on the left it can be seen that the durations are more or less the same, while the bar graph on the right allows the reader to observe differences in duration among the four visualizations.

8. DISCUSSION

p-values	Embedding Precision	Embedding Recall
Graph Precision	0.6665	
Graph Recall		0.6374

Table 3: Statistical Significance Tests

The results do not reject the null hypothesis for research question 1 (Table 3). The null hypothesis is that there is no difference in user interactivity between visualising an ontology as a graph or as projection of semantic embeddings. Table 3 was created by taking the average of recall and precision of WebVOWL and OntoGraf combined, and comparing it to the average recall and precision of CircleVis and SquareVis combined. The cut-off for statistical significance was a p-value of 0.05. The test used to arrive at these results was an unpaired t-test, from which the two-tailed p-value was derived.

The lack of statistical significance suggests that this experiment was insufficient to answer research question 1. The p-values are very large for both precision and recall, suggesting no real difference between the two groups. However, when the analysis is expanded to comparing each method and each metric with an unpaired t-test, there are some interesting implications for research question 2,

Precision p-values				
	WebVOWL	OntoGraf	SquareVis	CircleVis
WebVOWL		0.0135	0.1743	0.7698
OntoGraf			0.269	0.0283
SquareVis				0.2832
CircleVis				

Table 4: Statistical Significance of Precision Comparison Across Methods

Table 4 shows that in terms of precision OntoGraf participants score significantly better than WebVOWL and CircleVis. For SquareVis, on the other hand, the null cannot be rejected. This is a demonstration of the usefulness of tree shaped graph visualizations over radial visualizations and non-hierarchical graphs. Precision varied much more than recall, and as Table 5 shows, there no comparisons between the methods was statistically significant. The average recall scores ranged between 16% - 22%, and with roughly equivalent sample sizes it is not surprising that the null could not be rejected. When calculated the standard deviation of recall, the original recall scores were used and note the recall reduction scores.

Recall p-values				
	WebVOWL	OntoGraf	SquareVis	CircleVis
WebVOWL		0.4456	0.4742	0.5542
OntoGraf			0.9782	0.8739
SquareVis				0.8739
CircleVis				

Table 5: Statistical Significance of Recall Comparison Across Methods

The fact that a difference in precision was statistically significant for OntoGraf in two instances suggests that it may be more readable than other methods. The fact that recall is not statistically significant in any instance may suggest that all visualizations are equally difficult for participants to achieve complete task fulfillment, but not equally difficult in terms of specificity of perceiving results. What this could mean is that participants find the tree diagram less ambiguous and are less likely to input incorrect results, although it is equally hard for them to holistically perceive all of the animals. With a bespoke (non-automatic) tree generation perhaps user performance could be improved in this regard.

In spite of the fact that much of the data gathered could not reject the null hypothesis, the results could still yield some interesting insights. At the very least, potential confounds and reasons why the experiment did not yield as many results as it could can be discussed. The hypothesis was that the tree visualization would be easiest to read, followed by graph visualizations, followed by cartesian visualizations, and finally polar visualizations. For the most part this was true, with the notable exception of WebVOWL's underperformance relative to every other technique. This can be explained by the difficulty in reading graphs when the edges are crossed over each other. WebVOWL is a force-directed graph interface, allowing the user to manipulate the nodes and edges. In order to keep the experiment consistent an image of the ontology was created without manipulating the interface. Because of this, participants may have had trouble viewing a static image of a tangled graph which normally they would have been able to manipulate. However, since the other visualizations were static this was maintained to control the variation in the experiment, and only an image of WebVOWL was given to participants. In addition, to make the experiment consistent all images were made in PDF format. This lead to a loss of some edges in the graph which were present in the SVG format for WebVOWL.

OntoGraf had an option to automatically sort the nodes into a tree-structure, which meant that many of the issues WebVOWL had were taken care of automatically: nodes were already organised hierarchically, and the edges were already set in a way that they would not cross over each other. This result was in line with the hypothesis. Figure 7 shows the plot of average precision against average recall for all visualization methods. Typically, recall and precision are understood to have an inverse relationship in information retrieval. Therefore it is notable that the tree diagram had higher precision and recall, and the non-hierarchically structured graph had lower of both. Both embedding methods had similar recall, but the square visualization had higher precision.

The circular visualization performs better on recall when spam results are removed. Indeed, the circular visualization is so far superior on recall reduction two that initially this was seen as overturning the hypothesis that circular visualizations are harder to read than cartesian ones. However, when looking at the difference between recall reduction one finds it correlates exactly with how many spam results each visualization technique receives. Thus, the tree visualization, which received no spam results, suffers the most from the recall reduction. While it helps to show what each visualization's results would have been had there been no spam, the spam results conceivably reflect the difficulty that participants are having reading the visualizations. Thus, as expected they are higher for cartesian visualizations, and highest for the radial visualization, which, with its pie-wedge shape of a circular graph may not have been intuitive for participants to navigate. The spam results are closely in line with the original hypothesis.

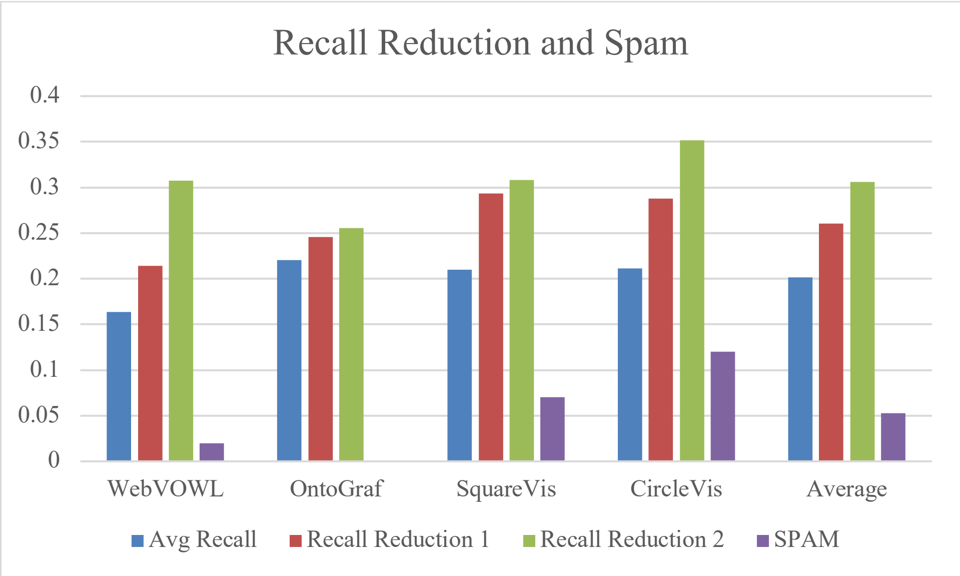

Figure 9: Recall Reduction and Spam

The precision metric shows incredibly high precision with OntoGraf, slightly lower with SquareVis, and lower with both CircleVis and WebVOWL. WebVOWL is again the lowest. Particularly with OntoGraf, SquareVis and CircleVis, all three had recall scores within two percentage points of each other. Even WebVOWL had a score that was within four percentage points of the mean. For precision, on the other hand, there is much more variation. Also, interestingly enough, the results suggest precision does not seem to relate exactly to spam: WebVOWL had the lowest precision score, but the second lowest count of spam answers.

The central research question was whether embedding visualizations could hold their own against classical graph based visualizations, and the second research question was whether radial visualizations could stand up to cartesian ones. The results here cannot confirm research question one, nor can they answer research question two. The only statistically significant result is that OntoGraf is superior to WebVOWL and CircleVis for precision. This is in line with previous research into the proper way to construct graphs, and that tree diagrams with edges which do not intersect are the easiest for users to read and understand.

While the radial visualization did have very high recall when spam answers were screened out, it also had the highest number of spam answers. While average recall was more or less the same among all methods, precision varied widely. The results do not suggest whether cartesian or radial visualization methods are superior in terms of precision or recall as the averages for both these visualizations was incredibly close.

However, despite the fact that they could not reject the null, one interesting line of research these results suggest is that embedding visualizations could possibly be superior to graph visualizations, *if* those visualizations are disorganised. Graph visualization is seen as the primary mode of ontology visualization in the industry. Many researchers may not follow best practices for the construction of graphs, and force-directed graphs are often automatically generated. Encouraging researchers to use embedding models in addition to graph models may be a fruitful line of research in the future. Further work could also be done testing hybrid models, such as Stunning Doodle.

There are a number of confounds which may have influenced these results. First of all, the two graph visualization programs were extensions to Protege, chosen because they were well-established in the industry. The two embedding visualizations were based on OWL2Vec and used the mattplotlib python module. A more sophisticated embedding visualization software (the kind which, to the best of my knowledge, does not exist for ontologies at the present time) might give better visualization results for both kinds of embeddings. In addition, some of the greatest advantages of OWL2Vec over other ontology embedding methods may have proved to be its biggest issues for information visualization. This is because OWL2Vec picks up information contained in the rdfs:label tag and metadata in addition to OWL constructs. The creators of the African Wildlife Ontology added information about classes into the rdfs:label tag not contained within the ontology. This lead to the creation of animal names that appeared in the embedding visualizations which had to be edited out manually, although other rdfs:label material was retained. This kind of information, which is really an advantage to the OWL2Vec approach, may have over-complicated the embedding visualizations and made them harder for users to understand. Future studies could either add metadata into graph visualizations as nodes, or use a version of OWL2Vec which does not embed metadata.

Another confound comes from the method used to gather participants, Amazon Mechanical Turk (AMT). AMT was chosen because it gave an ethical way to reimburse participants. In addition, no personal information on participants was collected. However, that also creates a data-set of people who are professional data labellers, who might have more experience with information retrieval tasks than the general public. Collecting personal or demographic information was not in the remit of the research question and was not considered ethically necessary, however without that information it is not clear whether the sample is representative of the general population. The general public might have a different experience interacting with these data visualizations.

9. REFLECTION

The experiment proceeded mostly how I envisioned it in my original proposal. However, the biggest challenge was the high number of spam results I got in my survey. I tried to make the information retrieval task as simple as possible from the outset. This is why I used the African Wildlife Ontology, which modelled a domain I thought was more accessible than the Pizza Ontology. Indeed, I had the idea to create an ontology of animals using African wildlife independently, and then discovered that Keet et al. (2020) had already done so for the same reason. However, despite the fact that I laboured to make the instructions as clear as possible and the task simple, many participants submitted responses that were incoherent. I paid these participants for their time (although Amazon does allow for responses on AMT to be rejected) both for the reasons of ethics and consistency: spam results are still useful scientific information, so even in cases where participants fully misunderstood the task or input incoherent answers, they were reimbursed.

I initially approached this research question because I enjoy making radial data visualizations. I already had an inkling that they probably would not perform as well in my experiment, but as I conducted research for the literature review I discovered that there is a general consensus in the data visualization literature that radial displays are not as effective as cartesian ones, except for certain applications. This caused me to question my own commitment to radial visualization. I realised that I was committed to radial visualizations because I liked their aesthetic qualities, like many other novices. The experiment caused me to reconsider the utility of radial visualization, although I was pleased to discover previous research in visual search for information retrieval which made good use of them.

Both the research and the experiment caused me to question my assumptions about data visualization and information retrieval. The other big surprise that came from this dissertation was from my research on the history of embeddings, especially star coordinates and the work of Charles Osgood. I hope to apply these older ideas from information science to natural language processing in future data visualization work.

During the process of creating this dissertation my research and results were live-tweeted. I also plan to disseminate this dissertation by uploading it to humanities commons, and including a link to it on my academia.edu profile.

10. CONCLUSION

The proper embedding visualization technique for knowledge graphs has not been discovered yet. The use of polar coordinates to create a radial visualization was one possible technique for visualising embeddings tested here. While radial visualization techniques have worked for the information retrieval community in the past, although the results of this experiment could not reject the null, they are possibly in line with previous research that combining them with word embeddings PCA leads to visualizations which are inferior to cartesian ones. More research would need to be done to conclusively say that cartesian visualizations are superior to radial ones. However, tree diagrams may be useful for participants, as evidenced by the high performance of the OntoGraf visualization method. Embeddings also should not be rejected in favour of explicit, graph-based models, as the inferior performance of WebVOWL shows.

This dissertation has surveyed a number of other methods however which may be useful for further research. In particular, the use of older techniques from information retrieval, whether these are Charles Osgood's feature axes, star coordinates or Dust and Magnet interfaces may help the natural language processing community in the future. The count-based approach to embeddings (not investigated in this experiment) could also be a worthwhile place for further research, particularly for creating a user interface which would allow users to explicitly manipulate items in a graph database.

OWL2Vec uses newer, natural language processing methods based on statistical semantics to create embeddings of knowledge graphs, rather than the older methods from information retrieval. While the new methods based on word2vec offer a great deal in terms of computational simplicity as opposed to the massive matrices produced by the count based method, there is still a need for a contribution from information retrieval to the creation of embedding technologies for ontologies today. Indeed, the nature of ontologies and their connection to information science would make such an approach intuitive.

While radial visualizations (barely) underperformed cartesian ones, the experiment only tested a PCA based visualization, and avoided older, more explicit methods such as star coordinates. A star coordinate system combined with a radial display such as the one used for radial search could also be an interesting thing to test. The question of how to visualise embeddings of ontologies is constrained by "uncertainty of visualization" and the "visualization of uncertainty." In the case of the polar coordinate visualization, the results were confounded by both factors. A count-based method could serve to make the embedding of the knowledge graph more explicit, and a method using star coordinates could replace PCA, which is a black box, with an explicit way to represent multidimensional spaces. Then it would be easier to isolate whether users are having trouble with polar or cartesian coordinates.

Embedding technologies are not going away, as they are increasingly a part of artificial intelligence applications. It will be necessary to find ways to visualise them not just to make information more interactive, but to provide ways for humans to understand the processes artificial intelligences are conducting by revealing the data. Ontologies, being one of the most semantically structured forms of information around, will doubtless have a role to play in this process, and there is a fruitful field of future work on their visualization awaiting.

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Appendix 1. Glossary and Thesaurus

cartesian coordinates the classical (x,y) coordinate system, where vectors are based on squares, rather than circles. Antonyms: **polar coordinates, radial visualization.**

count based a method for creating **document embeddings** which involves counting the occurrences of word in a document, rather than using machine learning. Synonymous with **matrix based.**

data visualization or **visualization** refers to the act of interpreting data as geometry and visualising them in an aesthetically or interpreable pleasing way.

distributional semantics the linguistic theories which underly word embeddings. Synonyms: **statistical semantics.**

document embeddings multidimensional vectors of entire documents. Related terms: **word embeddings.**

information retrieval 1) the act of looking for and seeking information. 2) systems which facilitate information retrieval. When the experiment is said to test how participants interact with information in terms of information retrieval, the first sense of this term is what is meant.

knowledge graph a logical formalisation of knowledge in a given domain, which is expressed as a graph in the OWL language and the RDF format. Synonyms: **ontology.**

ontology a logical formalisation of knowledge in a given domain, which is expressed as a graph in the OWL language and the RDF format. Synonyms: **knowledge graph.**

polar coordinates a coordinate system which is constructed in terms of the unit circle, and where vectors are defined by the coordinates (r, θ) as opposed to (x,y) where r is the radius of a circle, and θ is its angle in either radians or degrees. Synonyms: **radial visualization** Antonyms: **cartesian coordinates.**

radial visualization a coordinate system which is constructed in terms of the unit circle, and where vectors are defined by the coordinates (r, θ) as opposed to (x,y) where r is the radius of a circle, and θ is its angle in either radians or degrees. Synonyms**: polar coordinates** Antonyms: **cartesian visualization.**

word embeddings a set of multidimensional vectors which represent the semantics of a word. These vectors usually consist of a few hundred dimensions, and thus contain a few hundred numbers. Related terms: **document embeddings.**

Appendix 2. Dissertation Proposal

Working Title: Can Polar Coordinate Embeddings of Knowledge Graphs Aid Information Retrieval Tasks?

Introduction: This goal of this project is to test how word-embedding based visualizations of knowledge graphs can be used in information retrieval. Vector-space embeddings of knowledge graphs are becoming increasingly popular as part of their wider adoption by the machine learning community. While systems like Word2Vec and BERT are commonly used in NLP to train models, principal component analysis can also lead to an application of word embeddings to data visualization. Because embeddings are created with positional probabilities they serve only to emulate the semantics of words, which means that in practice visualizations may contain some errors (Liu et al, 2017). However, even though the visualization may contain errors, it is still possible to gain general semantic insights from visualizations, especially with clustering.

Radial design for embedding visualization has the advantage of making the cosine similarity between vectors explicit due to the trigonometric nature of the coordinate system. The hypothesis is that it may be easier for participants to understand relationships like synonymy and antonymy based on position, and that radial designs will lead to slightly better performance, as compared to classical cartesian designs. On the other hand, in certain instances previous studies have found cartesian designs to better facilitate differentiation of information (Burch et al, 2008). Work needs to be done on whether semantic information from knowledge graphs does, or does not benefit from a radial visualization. Inspiration is also taken from radial search methods, such as that pioneered by Nitsche and Nürnberger (2006). In order to test participant performance against a control, visualizations in graph and simple tree form will also be tested.

Aims and Objectives: The aims are to test whether different configurations of a semantic vector space or more traditional knowledge graph visualization affect the way users interact with and retrieve information. The aim is especially to continue previous research evaluating the usefulness of embeddings on the one hand, and radial displays of information more specifically, to support information retrieval tasks for users. The objective is to determine the specific way different visualizations impact user interaction along two metrics: terms retrieved, and time taken. The four visualizations tested will be tree diagram, graph diagram, cartesian coordinate embedding, and polar coordinate embedding.

Scope and Definition: The term “knowledge graph” and “ontology” will be used interchangeably in this project. Technically an ontology is a set of logical relationships for structuring data, while a knowledge graph is a graph-database application for representing semantic information. However, in practice, the word “ontology” refers to applications built in the OWL framework running on RDF, and thus the term is often used interchangeably with the term “knowledge graph.” “Embeddings” will refer to vectors produced by the tool OWL2Vec, based on word Word2Vec but for the OWL language. In other contexts, “embeddings” can also refer to the production of other language models such as RDFVec, and those created by information retrieval document models. “Information retrieval” here refers to a predefined task done by the participant: participants are not asked to generate a query themselves, but are given one at the outset of the experiment.

The scope of the project is limited to investigating a simple information retrieval task based on a visualization of an ontology. The ontology to be visualised will be based on the African Wildlife Ontology, which will be extended with concrete examples. The task required will be limited to finding all instances of a class as visualised. The experiment will be carried out with an anonymous online survey on Qualtrics. Visualizations of unstructured data are not tested here, only visualizations of knowledge graphs. Likewise, while polar and cartesian embeddings will be tested, more traditional means of visualising knowledge graphs will also be tested as part of the experiment.

Research context/literature review: Word embeddings have a long history, and are based on the premise that contextual information alone provides information about the meaning of a word. This idea has its theoretical roots in the work of Ludwig Wittgenstein, John Firth and Zellig Harris (Kalgren and Sahlgren 2016). In contrast, knowledge graphs and ontology are based on formal logic. They come from an interpretation of language in line with the tradition of formal linguistics represented by Chomsky, or more accurately his students such as Lakoff (Harris, 2021). This distinction between a contextual model which uses a distributional semantic space, and a symbolic representation of language has become increasingly important recently in the debate over whether large language models should be based on a solely machine learning approach or have a symbolic dimension (Scagliarini, 2022).

Embeddings of knowledge graphs are one way to reach this hybrid approach. The subject, predicate, and object structure of RDF triples, as in RDF2Vec, are treated as words in sentences similar to Google's Word2Vec algorithm (Ristoski, 2016)(Inan and Dikenelli, 2017). This leads to URIs and literals represented as "words" within a vector space. The creation of RDF2Vec extended the possibility of distributional semantic models to the application of knowledge graphs, such as in the work of Wang et al. (2021), Schlichtkrull et al. (2018), Cochez et al. (2017). Taking this work a step further, the OWL2Vec tool extends this to apply to the OWL language and to represent logical relations in a similar way, by "lexicalizing" them (Chen et al. 2021). This allows ontologies themselves, and not just RDF graph structures, to be transformed into embeddings.

While this will have increasing importance for artificial intelligence in coming years, another application for embeddings is data visualization. Performing principal component analysis on the data can be a useful way to reveal semantic similarity and make relations explicit to the viewer by means of dimensionality reduction, which can then be represented on a plot of either two or three dimensions. However, Liu et al. (2017) find that there are often errors in the visualizations produced and that they can create misleading results. Oubenali et al. (2022) review 417 studies in the biomedical domain to assess whether embedding visualizations of unstructured data can aid understanding of semantic relations; while they find that visualizations can help explore results they do not find that they convey all the information in the original embedding model. Liu et al. (2019) propose "latent space cartography" as a potential solution to this problem, and discuss how subtle variations in domain knowledge and human judgement can impact an interpretation.

While embeddings have exploded in use in the NLP community over the past decade, such techniques have been used in the information retrieval community for a long time (Kalgren and Sahlgren, 2016). Distributional document semantic models have almost as long a history as distributional word-level semantic models. In this period of time, visualizations of embeddings have also been applied to visual search interfaces. For instance, Yi et al (2005) use a “dust and magnet” metaphor to take a multivariate embedding visualization of documents for information retrieval, and transform it into a user interface for visual search. This approach went on to implement many succeeding information retrieval implementations, such as Dai et al. (2015) and Castro and Lopez (2009). Nitsche and Nürnberger (2006) take it a step further and create a radial interface, where relevance of a document is depicted as distance to the centre.

Radial visualizations are a common form of data visualization for several domains. Radial designs have a long history in data visualization, going back centuries to early statistical graphics (Draper et al, 2009). However, despite the aesthetic appeal of such designs, there are also advantages to cartesian visualizations of multivariate data, such as a more efficient use of rectangular screen space (Burch and Weiskopf, 2013) (Burch et al, 2008) . As in the case of Nitsche and Nurnburger (2006), the aesthetic aspect of radial data visualization can lend it to an application for an intuitive user interface. However, as Diehl et al. (2010) found, cartesian data visualizations often lead to significantly faster response times when users are given a task to retrieve visual information.

Other visualizations of knowledge graphs rely on more explicit approaches to representing the taxonomy. Indented tree visualizations are the ones usually given to novices, but Fu et al. found that graph visualizations are more intuitive and less redundant. Katifori et al. (2007) perform an inventory of then-existing ontology visualizations and find that there are several interesting ways to visualise trees and taxonomies (some of them radial) and some of them in a three dimensional virtual space. They find there is not one specific method which is appropriate for all applications. Many tools have been produced to perform ontology visualization, and some are categorised by Katifori et al. in their analysis, shown in Figure 1 below.

Retraction and Expansion of nodes/Pruning	Movement and/or rotation of the graph	Movement and/or rotation of the viewpoint	Zooming	Overview Window	History/Back and Forward	Animated Transitions
Class Browser, OntoViz, SpaceTree, OntoTrack, GOBar, GOSurfer, Cone Tree, fsviz, Recon-figurable Disk Tree, Information Slices, TGVizTab, BiFocal Tree, TreePlus	Tree Viewer, BiFocal Tree, OntoSphere, BeamTrees, TGVizTab, 3D Hyperbolic Browser	Class Browser, OntoViz, IsaViz, SpaceTree, OntoTrack, Cone Tree, fsviz, Reconfigurable Disk Tree, OntoSphere, Jambalaya, Information Pyramids, TGVizTab, Gopher VR, Harmony Information Landscape, fsn	OntoViz, IsaViz, SpaceTree, OntoTrack, Cone Tree, fsviz, Reconfigurable Disk Tree, Tree Viewer, OntoSphere, Grokker, Jambalaya, Information Cube, Information Pyramids, CropCircles, TreeMap, SequioaView, BeamTrees, TGVizTab, Gopher VR, Harmony Information Landscape, fsn	OntoViz, IsaViz, OntoTrack, Information Pyramids, Jambalaya, TreePlus	Jambalaya, Information Pyramids, CropCircles	SpaceTree, OntoTrack, Cone Tree, fsviz, Recon-figurable Disk Tree, Jambalaya, TGVizTab, OZONE, BiFocal Tree, 3D Hyperbolic Browser, TreePlus

Figure 1: Visualization Methods Categorised According to Interactive Features
taken from Katifori et al. (2007)

Finally, the application of all of these techniques, specifically to knowledge graphs, has not been explored deeply. While Katifori et al. (2007) explore radial designs, embeddings of knowledge graphs were not yet a topic in the community. Recently however, Ettore et al. (2022) have proposed Stunning Doodle, a tool for visualising knowledge graphs with embeddings. Stunning Doodle combines a regular knowledge graph visualization in graph form with a visualization of embeddings. Next to this typical visualization will be displayed the closest node from either the cosine or the euclidean distance. This allows the user to view both types at once, simultaneously an embedding model and a graph/tree model. This solution for data visualization is similar to the one called for in machine learning generally, especially in the need to unify discrete knowledge graphs with neuro-continuous computation (Smolensky et al, 2022). Ultimately an approach that combines embeddings with a traditional graph-based one may be the most fruitful.

Methodology: The methodology used for gathering data will be a questionnaire methodology. The African Wildlife Ontology will be extended with data from data.world, as well as with manual modelling. Four Observable Notebooks will be created with different visualizations of the same produced ontology in four configurations: tree diagram, graph diagram, cartesian embedding visualization, and polar coordinate embedding visualization. Participants will be recruited from Amazon Mechanical Turk. Each participant will be given one and one only visualization of the ontology (four tasks on Amazon Mechanical Turk will be created). Amazon Mechanical Turk syncs and partners with Qualtrics Surveys, which City, University of London also partners with. Participants are given a simple task to select all entities which are animals. Participants will select their responses in a Qualtrics Survey from a predefined set of animals, some of which are present in the visualization, some of which are not. The data that are collected are: of the set of animals, how many does the participant correctly select? And how long does it take them to complete the task? The data will be stored in a Google Spreadsheet. Participants will be paid.

Dissemination: This dissertation will be published on humanities commons. It may also be uploaded on academia.edu. Tweets about the research, especially images of the visualizations, will be ongoing, as they generate interest in the field in general. In addition, Observable is a public platform for the open source publication of data visualization. All code produced to create the visualizations will be licensed as open source, and other users can fork the code for use in their own visualizations.

Work plan:

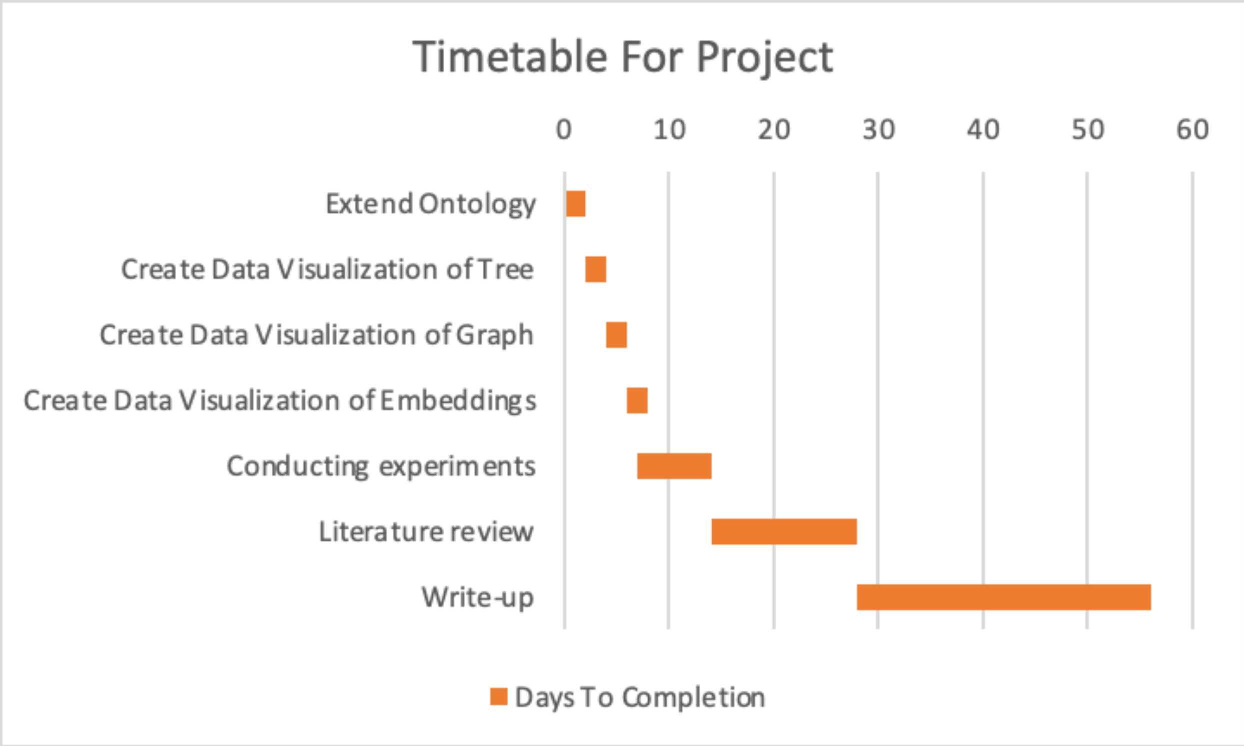

Figure 2: Gantt style diagram of work plan

Transcribed Schedule:

27 May - 29 May Extend Ontology
29 May - 31 May Create Tree Visualization
1 June - 3 June Create Graph Visualization
3 June - 5 June Create Embedding Visualization
5 June - 14 June Conduct Experiments
14 June - 31 June Literature Review
31 June - 10 July Write-up
Break for Summer Program in July (cleared with supervisor on 31 March)
1 August - 21 August Write-up

Resources: Estimated costs at about $50 United States Dollars to pay 100 participants 50 cents for a 5 minute task.

Ethics: Ethics form attached. Participants are paid and no personal information will be collected.

Confidentiality: No personal information will be gathered from participants in this experiment. All data collected from this experiment will be stored in Qualtrics

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Appendix 3. Visualization Code

The following code was based on this principle component analysis tutorial: https://www.datacamp.com/tutorial/principal-component-analysis-in-python and this k-means tutorial: https://jakevdp.github.io/PythonDataScienceHandbook/05.11-k-means.html. Also included is a second script previously published by the author on GitHub "polarCoordinateEmbeddings.py" which is original work, but based on a script written by Ernesto Jiminez-Ruis to query embeddings of knowledge graphs such as DBpedia. This can be found at https://github.com/JackKausch/KGS/blob/main/polarCoordinateEmbeddings.py.

Visualization.py

```
# %%
import matplotlib.pyplot as plt

# %%
import seaborn as sns; sns.set()  # for plot styling


# %%
import numpy as np


# %%
from sklearn.datasets import make_blobs


# %%
X, y_true = make_blobs(n_samples=300,centers=4, cluster_std=0.60, random_state=0)


# %%
plt.scatter(X[:, 0], X[:, 1], s=50);

# %%
from sklearn.cluster import KMeans
kmeans = KMeans(n_clusters=4)
kmeans.fit(X)
y_kmeans = kmeans.predict(X)

# %%
plt.scatter(X[:, 0], X[:, 1], c=y_kmeans, s=50, cmap='viridis')

centers = kmeans.cluster_centers_
plt.scatter(centers[:, 0], centers[:, 1], c='black', s=200, alpha=0.5);

# %%
from sklearn.datasets import make_moons
X, y = make_moons(200, noise=.05, random_state=0)

# %%
labels = KMeans(2, random_state=0).fit_predict(X)
plt.scatter(X[:, 0], X[:, 1], c=labels,
            s=50, cmap='viridis');
```

```
# %%
from sklearn.cluster import SpectralClustering
model = SpectralClustering(n_clusters=2, affinity='nearest_neighbors',
                           assign_labels='kmeans')
labels = model.fit_predict(X)
plt.scatter(X[:, 0], X[:, 1], c=labels,
            s=50, cmap='viridis');

# %%
import pandas as pd


# %%
file = pd.read_csv('./ontology.embeddings.txt', header=None, sep=' ')


# %%
rep = list(file[0])

# %%
file = file.drop(columns=0)
print(file)

# %%
centroids = kmeans.cluster_centers_

# %%
from sklearn.decomposition import PCA


# %%
pca = PCA(n_components=2)

# %%
principal_components = pca.fit_transform(file)

# %%
principal_components_df = pd.DataFrame(data = principal_components
             , columns = ['x', 'y'], index = rep)

# %%
polardf = principal_components_df.drop(columns = 'x')
polardf = polardf.drop(columns = 'y')
principal_components_df = principal_components_df.drop(columns = 'phi')
principal_components_df = principal_components_df.drop(columns= 'ro')
print(polardf)

# %%
kmeans = KMeans(n_clusters=4).fit(principal_components_df)


# %%
```

```
kmeans2 = KMeans(n_clusters=4).fit(polardf)


# %%
#phi = np.arctan(principal_components_df.loc[:,"x"]*principal_components_df.loc[:,"y"])
#r   = np.power( np.power(principal_components_df.index,2) +
np.power(principal_components_df.columns,2), 0.5 )

principal_components_df["phi"] =
np.arctan(principal_components_df["x"]*principal_components_df["y"])
principal_components_df["ro"] = np.power( np.power(principal_components_df["x"],2) +
np.power(principal_components_df["y"],2), 0.5 )


# %%
font = {
'size': 6}

plt.rc('font', **font)

fig = plt.figure()
ax = fig.add_subplot(projection='polar')
theta = 2 * np.pi * np.random.rand(315)
#c = ax.scatter(polardf['phi'], polardf['ro'], c=theta,  s=(50), cmap='hsv', alpha=0.75)
plt.axis([-.4,1.3, -0.4, 0.4])
plt.rcParams["figure.figsize"] = (50,50)


#c=kmeans2.labels_.astype(float),

for k, v in principal_components_df.iterrows():
    plt.annotate(k, v)


# %%
print(principal_components_df)

# %%
centroids = kmeans.cluster_centers_


# %%
font = {
'size': 7}

plt.rc('font', **font)

#plt.scatter(principal_components_df['x'], principal_components_df['y'], c=
kmeans.labels_.astype(float), s=50, alpha=0.5)
#plt.scatter(centroids[:, 0], centroids[:, 1], c='red', s=50)
plt.axis([-0.5,1.3, -0.4, 0.4])
#plt.rcParams({'font.size': 12})

for k, v in principal_components_df.iterrows():
```

```
    plt.annotate(k, v)

x_data = principal_components_df['x']
y_data = principal_components_df['y']

txt_height = 0.04*(plt.ylim()[1] - plt.ylim()[0])
txt_width = 0.02*(plt.xlim()[1] - plt.xlim()[0])
text_positions = get_text_positions(x_data, y_data, txt_width, txt_height)
text_plotter(x_data, y_data, text_positions, ax, txt_width, txt_height)
plt.rcParams.update["figure.figsize"] = (50,50)

#plt.ylim(0,3610)
#plt.xlim(4.3,6.5)



# %%
#plt.scatter(centroids[:, 0], centroids[:, 1], c='red', s=50)
#plt.annotate("Hello", (0.2, 0.2))


# %%
import string

# %%
file.drop(0, inplace=True, axis=1)

# %%
fig, ax = plt.subplots()

principal_components_df.plot('x', 'y', kind='scatter', ax=ax,
c=kmeans.labels_.astype(float), s=50, alpha=0.5)
plt.scatter(centroids[:, 0], centroids[:, 1], c='red', s=50)
plt.axis([1,1.1, 0.25, 0.35])

for k, v in principal_components_df.iterrows():
    ax.annotate(k, v)

fig.set_figheight(20)
fig.set_figwidth(20)
```

polarCoordinateEmbeddings.py

```
'''
Created on 19 Jan 2021

@author: ejimenez-ruiz
'''
import requests
import json
import numpy as np
import pandas as pd
```

```
from sklearn.preprocessing import StandardScaler
from sklearn.decomposition import PCA

#This script takes precomputed kg embeddings from DBpedia and uses principle component
analysis
#to express each uri as a single polar coordinate vector.

def cart2pol(x, y):
    rho = np.sqrt(x**2 + y**2)
    phi = np.arctan2(y, x)*(180/np.pi)
    return(rho, phi)

def getEmbeddings():

    #Check http://www.kgvec2go.org/

    print("\nPolar coordinate vector embedding for the resource %kg_entity (format: r,
theta):")

   # directory = []
   # with
open("/Users/jackkausch/Documents/Artistic/UCL/Language/panlex_swadesh/swadesh110/eng-
000.txt") as file:
    #    for line in file:
   #         for word in line:
    #            directory.append(word)

    #http://dbpedia.org/resource/Chicago_Bulls
    kg_entity = "Earth"
    kg_entity2= "Air"
    kg_entity3= "Fire"
    kg_entity4= "Water"

    #vector_array = []
    #for word in directory:
    #    r = requests.get('http://www.kgvec2go.org/rest/get-vector/dbpedia/' + word)
    #    print(r.json())
        #vector_array.append(r.json()["vector"])

    r = requests.get('http://www.kgvec2go.org/rest/get-vector/dbpedia/' + kg_entity)
    print(r)
    r2 = requests.get('http://www.kgvec2go.org/rest/get-vector/dbpedia/' + kg_entity2)
    r3 = requests.get('http://www.kgvec2go.org/rest/get-vector/dbpedia/' + kg_entity3)
    r4 = requests.get('http://www.kgvec2go.org/rest/get-vector/dbpedia/' + kg_entity4)
    uri = r.json()["uri"]
    uri2 = r2.json()["uri"]
    uri3 = r3.json()["uri"]
    uri4 = r4.json()["uri"]
    v = r.json()["vector"]
    print(v)
    v2 = r2.json()["vector"]
    print(v2)
    v3 = r3.json()["vector"]
```

```
    v4 = r4.json()["vector"]
    vector_array=list(zip(v,v2,v3,v4))
    print(vector_array)


    #Load the vector in a dataframe
    dataframe = pd.DataFrame(vector_array).transpose()
    print(dataframe)


    #Take the principle components of the vector
    pca = PCA(n_components=2)
    principal_components = pca.fit_transform(dataframe)

    principal_components_df = pd.DataFrame(data = principal_components
             , columns = ['principal component 1', 'principal component 2'])

    print(principal_components_df)
    vector_list = []
    for n in range(4):
        vector_small = principal_components_df.iloc[n].tolist()
        vector_list.append(vector_small)

    polar_list = []
    #Convert the output into polar coordinate
    for i in vector_list:
        polar_vector = cart2pol(i[0],i[1])
        polar_list.append(polar_vector)
    print(polar_list)



#Query pre-computed knowledge graph embeddings
getEmbeddings()

print("\nTests successful!!")
```

Appendix 4. The extended African Wildlife Ontology in rdf/xml

The original version used was version 4, which can be found on Maria Keet's website, here:
http://www.meteck.org/swdsont.html .
Other animal and plant classes to add to the ontology were taken from these informal resources:
https://a-z-animals.com/animals/location/africa/
https://www.gardenguides.com/13428511-a-list-of-african-plants.html
https://www.earthtouchnews.com/natural-world/natural-world/top-10-iconic-african-trees/
The ontology and all scripts can also be downloaded from GitHub.


```
<?xml version="1.0"?>
<rdf:RDF xmlns="xml:base#"
     xml:base="xml:base"
     xmlns:p1="#"
     xmlns:owl="http://www.w3.org/2002/07/owl#"
     xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
     xmlns:xml="http://www.w3.org/XML/1998/namespace"
     xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
     xmlns:owl2="http://www.w3.org/2006/12/owl2#"
     xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
     xmlns:owl2xml="http://www.w3.org/2006/12/owl2-xml#"

xmlns:AfricanWildlifeOntology1="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#">
    <owl:Ontology
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl">
        <rdfs:comment>African Wildlide Ontology, Semantic Web Primer, 4.3.1 pages 119-
133</rdfs:comment>
        <rdfs:comment>AfricanWildlifeOntology0.owl was then modified by Maria Keet (classes and
object properties added, more comments added, updated the uri etc) and renamed into
AfricanWildlifeOntology1.owl.
This is still an ontology just for tutorial purposes, so take it with a grain of salt</rdfs:comment>
        <rdfs:comment>CC-BY licence (do with it whatever you like, just give the author
credit)</rdfs:comment>
        <rdfs:comment>MK downloaded this file from
http://www.iro.umontreal.ca/~lapalme/ift6281/OWL/AfricanWildlifeOntology.xml, changed the
extension to .owl and appended the name with Web. That ontology give a load error in protege due to
the use of Collection in the definition of Herbivore, so the AfricanWildlifeOntology0.owl has that piece
removed.</rdfs:comment>
        <rdfs:comment>Version 4 has some things cleaned up and added toward a slight bit more science-
y, more OWL langauge features are used, and some educational explanations and questions for further
exploration have been added in annotation fields</rdfs:comment>
    </owl:Ontology>



    <!--
    ///////////////////////////////////////////////////////////////////////////////////////
    //
    // Annotation properties
    //
```

```
    ///////////////////////////////////////////////////////////////////////////////////////
     -->




    <!-- http://www.w3.org/2000/01/rdf-schema#comment -->

    <owl:AnnotationProperty rdf:about="http://www.w3.org/2000/01/rdf-schema#comment"/>



    <!--
    ///////////////////////////////////////////////////////////////////////////////////////
    //
    // Object Properties
    //
    ///////////////////////////////////////////////////////////////////////////////////////
     -->




    <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#eaten-by --
>

    <owl:ObjectProperty
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#eaten-
by">
        <owl:inverseOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#eats
"/>
    </owl:ObjectProperty>



    <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#eats -->

    <owl:ObjectProperty
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#eats">
        <rdfs:range>
            <owl:Class>
                <owl:unionOf rdf:parseType="Collection">
                    <rdf:Description
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Anima
l"/>
                    <rdf:Description
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Plant"/
>
                    <owl:Restriction>
```

```
                    <owl:onProperty
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#is-
proper-part-of"/>
                    <owl:someValuesFrom
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Ani
mal"/>
                </owl:Restriction>
                <owl:Restriction>
                    <owl:onProperty
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#is-
proper-part-of"/>
                    <owl:someValuesFrom
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Pla
nt"/>
                </owl:Restriction>
            </owl:unionOf>
        </owl:Class>
    </rdfs:range>
    <rdfs:comment>Note: cf AWO1, the axiom changed from is-part-of to is-proper-part-of, which is
what was really intended</rdfs:comment>
    <rdfs:comment>domain is not specified, as it is used in one of the exercises (declaring it to be
Animal makes the CarnivorousPlant unsatisfiable)</rdfs:comment>
  </owl:ObjectProperty>



  <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#has-part -->

  <owl:ObjectProperty
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#has-
part">
    <owl:inverseOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#is-
part-of"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#TransitiveProperty"/>
  </owl:ObjectProperty>



  <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#is-part-of --
>

  <owl:ObjectProperty
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#is-part-
of">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#TransitiveProperty"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ReflexiveProperty"/>
  </owl:ObjectProperty>
```

```
   <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#is-proper-
part-of -->

   <owl:ObjectProperty
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#is-
proper-part-of">
       <rdfs:subPropertyOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#is-
part-of"/>
       <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#IrreflexiveProperty"/>
   </owl:ObjectProperty>



   <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#has-
member -->

   <owl:ObjectProperty
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#has-
member">
       <rdfs:comment>intended to be the same as the membership relation in the taxonomy of part-whole
relations. Added here for playing with animals and their collectives</rdfs:comment>
   </owl:ObjectProperty>



   <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#inhabits -->

   <owl:ObjectProperty
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#inhabit
s"/>



   <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#inheres-in -
->

   <owl:ObjectProperty
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#inheres
-in">
       <rdfs:comment>to relate dependent to indpendent entities</rdfs:comment>
   </owl:ObjectProperty>



   <!--
   ///////////////////////////////////////////////////////////////////////////////////////
   //
   // Classes
   //
   ///////////////////////////////////////////////////////////////////////////////////////
    -->
```

```
    <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Animal -->

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Anima
l">
        <owl:disjointWith
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Pla
nt"/>
    </owl:Class>



    <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Apple -->

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Apple"
>
        <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Frui
tingBody"/>
    </owl:Class>



    <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Berry -->

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Berry"
>
        <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Frui
tingBody"/>
    </owl:Class>



    <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Branch -->

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Branch
">
        <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Pla
ntParts"/>
        <rdfs:subClassOf>
            <owl:Restriction>
```

```
                <owl:onProperty
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#is-
part-of"/>
                <owl:someValuesFrom
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Tre
e"/>
            </owl:Restriction>
        </rdfs:subClassOf>
        <rdfs:comment>Branches are parts of trees.</rdfs:comment>
    </owl:Class>



    <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Carnivore -
->

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Carniv
ore">
        <owl:equivalentClass>
            <owl:Class>
                <owl:unionOf rdf:parseType="Collection">
                    <owl:Restriction>
                        <owl:onProperty
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#eats
"/>
                        <owl:allValuesFrom
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Ani
mal"/>
                    </owl:Restriction>
                    <owl:Restriction>
                        <owl:onProperty
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#eats
"/>
                        <owl:allValuesFrom>
                            <owl:Restriction>
                                <owl:onProperty
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#is-
proper-part-of"/>
                                <owl:someValuesFrom
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Ani
mal"/>
                            </owl:Restriction>
                        </owl:allValuesFrom>
                    </owl:Restriction>
                </owl:unionOf>
            </owl:Class>
        </owl:equivalentClass>
        <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Ani
mal"/>
```

```
        <owl:disjointWith
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Her
bivore"/>
        <owl:disjointWith
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Om
nivore"/>
        <rdfs:comment xml:lang="en">Note: cf AWO1, the axiom changed from is-part-of to is-proper-
part-of, which is what was really intended</rdfs:comment>
        <rdfs:comment xml:lang="en">This informal definition does not really hold; see also the
subclasses added and their descriptions. How to revise the ontology accordingly?</rdfs:comment>
        <rdfs:isDefinedBy>Carnivores are exactly those animals that eat only
animals.</rdfs:isDefinedBy>
    </owl:Class>



    <!--
http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#CarnivorousPlant
-->

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Carniv
orousPlant">
        <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Pla
nt"/>
        <rdfs:subClassOf>
            <owl:Restriction>
                <owl:onProperty
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#eats
"/>
                <owl:someValuesFrom
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Ani
mal"/>
            </owl:Restriction>
        </rdfs:subClassOf>
        <rdfs:comment xml:lang="en">they do exist (https://en.wikipedia.org/wiki/Carnivorous_plant).
Added in the ontology mainly to play with inconsistencies on domain and range axioms, like the
&quot;only animals eat something&quot;, yet the carnivorous plant (disjoint from animals) also eats
animals (insects and arthropods, mainly)</rdfs:comment>
    </owl:Class>



    <!--
http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Distribution -->

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Distrib
ution">
        <rdfs:comment xml:lang="en">Distribution of the individuals of a species</rdfs:comment>
```

```
        <rdfs:comment xml:lang="en">This class obviously should not be a top class, but somewhere else
in a hierarchy of qualities etc.</rdfs:comment>
    </owl:Class>



    <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Elephant --
>

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Elepha
nt">
        <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Her
bivore"/>
        <rdfs:subClassOf>
            <owl:Restriction>
                <owl:onProperty
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#eats
"/>
                <owl:someValuesFrom
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Gra
ss"/>
            </owl:Restriction>
        </rdfs:subClassOf>
        <rdfs:subClassOf>
            <owl:Restriction>
                <owl:onProperty
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#eats
"/>
                <owl:someValuesFrom
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Tre
e"/>
            </owl:Restriction>
        </rdfs:subClassOf>
    </owl:Class>



    <!--
http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#FruitingBody -->

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Fruitin
gBody">
        <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Pla
ntParts"/>
    </owl:Class>
```

```
   <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Giraffe -->

   <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Giraffe
">
       <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Her
bivore"/>
       <rdfs:subClassOf>
           <owl:Restriction>
               <owl:onProperty
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#eats
"/>
               <owl:allValuesFrom>
                   <owl:Class>
                       <owl:unionOf rdf:parseType="Collection">
                           <rdf:Description
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Leaf"/
>
                           <rdf:Description
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Twig"/
>
                       </owl:unionOf>
                   </owl:Class>
               </owl:allValuesFrom>
           </owl:Restriction>
       </rdfs:subClassOf>
       <owl:disjointWith
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Lio
n"/>
       <rdfs:comment>Giraffes are herbivores, and they eat only leaves.</rdfs:comment>
       <rdfs:comment>they also eat twigs</rdfs:comment>
   </owl:Class>



   <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Grass -->

   <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Grass"
>
       <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Pla
nt"/>
   </owl:Class>



   <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Habitat -->
```

```
    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Habita
t">
        <rdfs:subClassOf>
            <owl:Restriction>
                <owl:onProperty>
                    <rdf:Description>
                        <owl:inverseOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#inha
bits"/>
                    </rdf:Description>
                </owl:onProperty>
                <owl:minQualifiedCardinality
rdf:datatype="http://www.w3.org/2001/XMLSchema#nonNegativeInteger">2</owl:minQualifiedCardi
nality>
                <owl:onClass>
                    <owl:Class>
                        <owl:unionOf rdf:parseType="Collection">
                            <rdf:Description
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Anima
l"/>
                            <rdf:Description
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Plant"/
>
                        </owl:unionOf>
                    </owl:Class>
                </owl:onClass>
            </owl:Restriction>
        </rdfs:subClassOf>
        <rdfs:comment xml:lang="en">Acknowledging extremophiles, in the scope of African Wildlife,
each habitat is inhabited by at least two plants or animals</rdfs:comment>
        <rdfs:comment xml:lang="en">See, e.g., The ENVO Environment ontology, that has habitats
since the 2016 edition (textmined from the Encyclopedia of Life). A few have been added here for the
sake of example. Can you generate a habitat module form teh ENVO and integrate it with the AWO? Is
their notion of habitat the same as used here?</rdfs:comment>
        <rdfs:comment xml:lang="en">the &quot;inverse (inhabits)&quot; amounts to inhabited by,
showing the use of the inverse feature</rdfs:comment>
        <rdfs:seeAlso xml:lang="en">https://en.wikipedia.org/wiki/Habitat</rdfs:seeAlso>
    </owl:Class>



    <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Herbivore -
->

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Herbiv
ore">
        <owl:equivalentClass>
            <owl:Class>
                <owl:unionOf rdf:parseType="Collection">
                    <owl:Restriction>
```

```
                    <owl:onProperty
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#eats
"/>
                    <owl:allValuesFrom
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Pla
nt"/>
                </owl:Restriction>
                <owl:Restriction>
                    <owl:onProperty
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#eats
"/>
                    <owl:allValuesFrom>
                        <owl:Restriction>
                            <owl:onProperty
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#is-
proper-part-of"/>
                            <owl:someValuesFrom
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Pla
nt"/>
                        </owl:Restriction>
                    </owl:allValuesFrom>
                </owl:Restriction>
            </owl:unionOf>
        </owl:Class>
    </owl:equivalentClass>
    <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Ani
mal"/>
    <owl:disjointWith
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Om
nivore"/>
    <rdfs:comment>Herbivores are exactly those animals that eat only plants or parts of plants
</rdfs:comment>
    <rdfs:comment xml:lang="en">Note: cf AWO1, the axiom changed from is-part-of to is-proper-
part-of, which is what was really intended</rdfs:comment>
</owl:Class>



<!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Impala -->

<owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Impala
">
    <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Her
bivore"/>
    <rdfs:comment>An african antelope http://en.wikipedia.org/wiki/Impala</rdfs:comment>
</owl:Class>
```

```
   <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Leaf -->

   <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Leaf">
       <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Pla
ntParts"/>
       <rdfs:subClassOf>
           <owl:Restriction>
               <owl:onProperty
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#is-
part-of"/>
               <owl:someValuesFrom>
                   <owl:Class>
                       <owl:unionOf rdf:parseType="Collection">
                           <rdf:Description
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Branch
"/>
                           <rdf:Description
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Twig"/
>
                       </owl:unionOf>
                   </owl:Class>
               </owl:someValuesFrom>
           </owl:Restriction>
       </rdfs:subClassOf>
       <rdfs:comment>Leaves are parts of branches.</rdfs:comment>
   </owl:Class>



   <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Lion -->

   <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Lion">
       <owl:equivalentClass>
           <owl:Class>
               <owl:intersectionOf rdf:parseType="Collection">
                   <owl:Restriction>
                       <owl:onProperty
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#eats
"/>
                       <owl:someValuesFrom
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Her
bivore"/>
                   </owl:Restriction>
                   <owl:Restriction>
                       <owl:onProperty
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#eats
"/>
```

```
                    <owl:allValuesFrom
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Her
bivore"/>
                  </owl:Restriction>
                </owl:intersectionOf>
              </owl:Class>
            </owl:equivalentClass>
            <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Obl
igateCarnivore"/>
            <rdfs:subClassOf>
              <owl:Restriction>
                <owl:onProperty
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#eats
"/>
                <owl:someValuesFrom
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Gir
affe"/>
              </owl:Restriction>
            </rdfs:subClassOf>
            <rdfs:subClassOf>
              <owl:Restriction>
                <owl:onProperty
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#eats
"/>
                <owl:someValuesFrom
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Imp
ala"/>
              </owl:Restriction>
            </rdfs:subClassOf>
            <rdfs:subClassOf>
              <owl:Restriction>
                <owl:onProperty
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#eats
"/>
                <owl:someValuesFrom
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Buf
falo"/>
              </owl:Restriction>
            </rdfs:subClassOf>
            <rdfs:subClassOf>
              <owl:Restriction>
                <owl:onProperty>
                  <rdf:Description>
                    <owl:inverseOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#inhe
res-in"/>
                  </rdf:Description>
                </owl:onProperty>
                <owl:someValuesFrom
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Pre
dator"/>
```

```
            </owl:Restriction>
        </rdfs:subClassOf>
        <rdfs:comment>Lions are animals that eat only herbivores.</rdfs:comment>
        <rdfs:comment xml:lang="en">Note cf v1: I changed the &apos;only&apos; to
&apos;some&apos; in the &quot;eats some herbivore&quot;, and made into equivalent class cf
subclass, so I can get my lion1 be classified as an instance of Lion. and &apos;closed&apos; the
axiom.</rdfs:comment>
    </owl:Class>



    <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Omnivore -
->

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Omniv
ore">
        <owl:equivalentClass>
            <owl:Class>
                <owl:intersectionOf rdf:parseType="Collection">
                    <owl:Restriction>
                        <owl:onProperty
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#eats
"/>
                        <owl:someValuesFrom
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Ani
mal"/>
                    </owl:Restriction>
                    <owl:Restriction>
                        <owl:onProperty
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#eats
"/>
                        <owl:someValuesFrom
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Pla
nt"/>
                    </owl:Restriction>
                    <owl:Restriction>
                        <owl:onProperty
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#eats
"/>
                        <owl:someValuesFrom>
                            <owl:Class>
                                <owl:unionOf rdf:parseType="Collection">
                                    <owl:Restriction>
                                        <owl:onProperty
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#is-
proper-part-of"/>
                                        <owl:someValuesFrom
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Ani
mal"/>
                                    </owl:Restriction>
                                    <owl:Restriction>
```

```
                                <owl:onProperty
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#is-
proper-part-of"/>
                                <owl:someValuesFrom
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Pla
nt"/>
                            </owl:Restriction>
                        </owl:unionOf>
                    </owl:Class>
                </owl:someValuesFrom>
            </owl:Restriction>
        </owl:intersectionOf>
    </owl:Class>
  </owl:equivalentClass>
  <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Ani
mal"/>
  <rdfs:comment xml:lang="en">An animal that eats both plants and animals (or parts
thereof)</rdfs:comment>
  <rdfs:comment xml:lang="en">Note: cf AWO1, the axiom changed from is-part-of to is-proper-
part-of, which is what was really intended</rdfs:comment>
</owl:Class>



<!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Palmtree --
>

<owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Palmtr
ee">
  <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Dep
recatedClass"/>
  <rdfs:subClassOf>
    <owl:Restriction>
      <owl:onProperty
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#has-
part"/>
      <owl:someValuesFrom>
        <owl:Class>
          <owl:complementOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Bra
nch"/>
        </owl:Class>
      </owl:someValuesFrom>
    </owl:Restriction>
  </rdfs:subClassOf>
  <owl:disjointWith
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Tre
e"/>
  <owl:deprecated xml:lang="en">it&apos;s a palm or a tree, not palm tree</owl:deprecated>
```

```
    </owl:Class>



    <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Parsnip -->

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Parsni
p">
        <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Roo
t"/>
    </owl:Class>



    <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Phloem -->

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Phloe
m">
        <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Pla
ntParts"/>
        <rdfs:subClassOf>
            <owl:Restriction>
                <owl:onProperty
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#is-
proper-part-of"/>
                <owl:someValuesFrom
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Ste
m"/>
            </owl:Restriction>
        </rdfs:subClassOf>
    </owl:Class>



    <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Plant -->

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Plant"
>
        <rdfs:comment xml:lang="en">&apos;plant&apos; is here a shorthand for plant
kingdom</rdfs:comment>
        <rdfs:comment>Plants are disjoint from animals.</rdfs:comment>
    </owl:Class>



    <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#PlantParts -
->
```

```
    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#PlantP
arts">
        <rdfs:subClassOf rdf:resource="http://www.w3.org/2002/07/owl#Thing"/>
        <rdfs:subClassOf>
            <owl:Restriction>
                <owl:onProperty
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#is-
proper-part-of"/>
                <owl:someValuesFrom
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Pla
nt"/>
            </owl:Restriction>
        </rdfs:subClassOf>
        <rdfs:comment xml:lang="en">Generally deemed easier to talk of in the &apos;from part to
whole&apos; direction, but ontologically, the other direction is better. e.g., in the normal course of
things, all plants have as part roots, but not all roots need to be part of some plant.</rdfs:comment>
    </owl:Class>



    <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Root -->

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Root">
        <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Pla
ntParts"/>
        <rdfs:comment xml:lang="en">note that this is different from a tuber (enlarged stem, like
potato)</rdfs:comment>
    </owl:Class>



    <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Stem -->

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Stem"
>
        <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Pla
ntParts"/>
    </owl:Class>



    <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Tasty-plant
-->
```

```
    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Tasty-
plant">
        <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Pla
nt"/>
        <rdfs:subClassOf>
            <owl:Class>
                <owl:intersectionOf rdf:parseType="Collection">
                    <owl:Restriction>
                        <owl:onProperty
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#eate
n-by"/>
                        <owl:someValuesFrom
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Car
nivore"/>
                    </owl:Restriction>
                    <owl:Restriction>
                        <owl:onProperty
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#eate
n-by"/>
                        <owl:someValuesFrom
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Her
bivore"/>
                    </owl:Restriction>
                </owl:intersectionOf>
            </owl:Class>
        </rdfs:subClassOf>
        <rdfs:comment>Plants eaten both by herbivores and carnivores</rdfs:comment>
    </owl:Class>



    <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Tree -->

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Tree">
        <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Pla
nt"/>
        <rdfs:comment>Trees are a type of plant.</rdfs:comment>
    </owl:Class>



    <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Twig -->

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Twig"
>
```

```
        <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Pla
ntParts"/>
    </owl:Class>



    <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Warthog --
>

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Warth
og">
        <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Om
nivore"/>
        <rdfs:subClassOf>
            <owl:Class>
                <owl:intersectionOf rdf:parseType="Collection">
                    <owl:Restriction>
                        <owl:onProperty
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#eats
"/>
                        <owl:someValuesFrom
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Ani
mal"/>
                    </owl:Restriction>
                    <owl:Restriction>
                        <owl:onProperty
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#eats
"/>
                        <owl:someValuesFrom
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Frui
tingBody"/>
                    </owl:Restriction>
                    <owl:Restriction>
                        <owl:onProperty
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#eats
"/>
                        <owl:someValuesFrom
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Gra
ss"/>
                    </owl:Restriction>
                    <owl:Restriction>
                        <owl:onProperty
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#eats
"/>
                        <owl:someValuesFrom
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Roo
t"/>
                    </owl:Restriction>
                </owl:intersectionOf>
```

```
        </owl:Class>
      </rdfs:subClassOf>
      <rdfs:comment>Warthogs are mostly herbivourous but sometimes eat meat
http://en.wikipedia.org/wiki/Warthog</rdfs:comment>
  </owl:Class>



  <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Xylem -->

  <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Xylem
">
      <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Pla
ntParts"/>
      <rdfs:subClassOf>
        <owl:Restriction>
          <owl:onProperty
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#is-
proper-part-of"/>
          <owl:someValuesFrom
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Ste
m"/>
        </owl:Restriction>
      </rdfs:subClassOf>
  </owl:Class>



  <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Aloe -->

  <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Aloe">
      <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Gra
ss"/>
  </owl:Class>



  <!--
http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#AnimalCollective
-->

  <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Anima
lCollective">
      <rdfs:subClassOf>
        <owl:Restriction>
```

```
            <owl:onProperty
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#has-
member"/>
            <owl:allValuesFrom
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Ani
mal"/>
         </owl:Restriction>
      </rdfs:subClassOf>
      <rdfs:comment xml:lang="en">There are more listed on:  https://safarisafricana.com/collective-
nouns-animals-birds-africa/</rdfs:comment>
      <rdfs:comment xml:lang="en">There is some &apos;overlap&apos; at least in English, in that
some collective names are for several species and some species have several collective names (in
general, or for a particualr configuration). How will that affect the representation?</rdfs:comment>
   </owl:Class>



   <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Baobab -->

   <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Baoba
b">
      <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Tre
e"/>
   </owl:Class>



   <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Bask -->

   <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Bask"
>
      <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Ani
malCollective"/>
      <rdfs:comment xml:lang="en">of crocodiles</rdfs:comment>
   </owl:Class>



   <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Buffalo -->

   <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Buffal
o">
      <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Her
bivore"/>
      <rdfs:subClassOf>
         <owl:Restriction>
```

```
            <owl:onProperty
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#eats
"/>
            <owl:someValuesFrom
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Gra
ss"/>
         </owl:Restriction>
      </rdfs:subClassOf>
      <rdfs:subClassOf>
         <owl:Restriction>
            <owl:onProperty
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#inhe
res-in"/>
            <owl:someValuesFrom
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Pre
y"/>
         </owl:Restriction>
      </rdfs:subClassOf>
   </owl:Class>



   <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Carrot -->

   <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Carrot
">
      <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Roo
t"/>
   </owl:Class>



   <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Cloud -->

   <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Cloud"
>
      <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Ani
malCollective"/>
      <rdfs:comment xml:lang="en">of insects, gnats, grasshoppers</rdfs:comment>
   </owl:Class>



   <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Colony -->

   <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Colon
y">
```

```
        <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Ani
malCollective"/>
        <rdfs:comment xml:lang="en">of ants</rdfs:comment>
    </owl:Class>



    <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Den -->

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Den">
        <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Ani
malCollective"/>
        <rdfs:comment xml:lang="en">of snakes</rdfs:comment>
    </owl:Class>



    <!--
http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#DeprecatedClass -
->

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Deprec
atedClass">
        <rdfs:comment xml:lang="en">For those classes on their way out...</rdfs:comment>
    </owl:Class>



    <!--
http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#DragonBloodTree
-->

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Drago
nBloodTree">
        <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Tre
e"/>
    </owl:Class>



    <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#FeverTree -
->

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#FeverT
ree">
```

```
        <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Tre
e"/>
    </owl:Class>



    <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Flight -->

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Flight"
>
        <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Ani
malCollective"/>
        <rdfs:comment xml:lang="en">of butterflies, dragons</rdfs:comment>
    </owl:Class>



    <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Herd -->

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Herd"
>
        <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Ani
malCollective"/>
        <rdfs:subClassOf>
            <owl:Restriction>
                <owl:onProperty
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#has-
member"/>
                <owl:someValuesFrom>
                    <owl:Class>
                        <owl:unionOf rdf:parseType="Collection">
                            <rdf:Description
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Elepha
nt"/>
                            <rdf:Description
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Impala
"/>
                        </owl:unionOf>
                    </owl:Class>
                </owl:someValuesFrom>
            </owl:Restriction>
        </rdfs:subClassOf>
        <rdfs:comment xml:lang="en">The current axiom with just Elephant or Impala will have to be
updated at some point. What about declaring it the other way around instead, like that elephants are
member-of a herd etc.?</rdfs:comment>
        <rdfs:comment xml:lang="en">of elephants, cattle, impala, springbok, zebra</rdfs:comment>
    </owl:Class>
```

```
    <!--
http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Hippopotamus -->

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Hippo
potamus">
        <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Her
bivore"/>
        <rdfs:subClassOf>
            <owl:Restriction>
                <owl:onProperty
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#eats
"/>
                <owl:someValuesFrom
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Gra
ss"/>
            </owl:Restriction>
        </rdfs:subClassOf>
    </owl:Class>



    <!--
http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#HypoCarnivores --
>

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#HypoC
arnivores">
        <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Car
nivore"/>
        <rdfs:comment xml:lang="en">their diet diet consists of at least 30 pct meat. practically can be
considered to be omnivores...</rdfs:comment>
    </owl:Class>



    <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Kettle -->

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Kettle"
>
        <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Ani
malCollective"/>
        <rdfs:comment xml:lang="en">of vultures whilst circling</rdfs:comment>
    </owl:Class>
```

```
    <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Leadwood
-->

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Leadw
ood">
        <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Tre
e"/>
    </owl:Class>



    <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#MarulaTree
-->

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Marula
Tree">
        <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Tre
e"/>
    </owl:Class>



    <!--
http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#MesoCarnivore --
>

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#MesoC
arnivore">
        <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Car
nivore"/>
        <rdfs:comment xml:lang="en">their diet diet consists of at least 50 pct meat</rdfs:comment>
    </owl:Class>



    <!--
http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#MopaneTree -->

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Mopan
eTree">
```

```
        <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Tre
e"/>
    &lt;/owl:Class&gt;



    <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Mosquito -
->

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Mosqu
ito">
        <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Obl
igateCarnivore"/>
    &lt;/owl:Class&gt;



    &lt;!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Nest --&gt;

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Nest">
        <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Ani
malCollective"/>
        &lt;rdfs:comment xml:lang="en"&gt;of vipers&lt;/rdfs:comment&gt;
    &lt;/owl:Class&gt;



    <!--
http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#ObligateCarnivore
-->

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Obliga
teCarnivore">
        <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Car
nivore"/>
        &lt;rdfs:comment xml:lang="en"&gt;their diet diet consists of at least 70 pct meat&lt;/rdfs:comment&gt;
    &lt;/owl:Class&gt;



    &lt;!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Ostrich --&gt;

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Ostric
h">
```

```
        <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Her
bivore"/>
    </owl:Class>



    <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Palm -->

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Palm"
>
        <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Pla
nt"/>
    </owl:Class>



    <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Predator --
>

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Predat
or">
        <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Rol
e"/>
    </owl:Class>



    <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Prey -->

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Prey">
        <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Rol
e"/>
    </owl:Class>



    <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Python -->

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Python
">
        <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Obl
igateCarnivore"/>
    </owl:Class>
```

```
    <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#QuiverTree
-->

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Quiver
Tree">
        <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Tre
e"/>
    </owl:Class>



    <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Rhumba --
>

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Rhum
ba">
        <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Ani
malCollective"/>
        <rdfs:comment xml:lang="en">of rattlesnakes</rdfs:comment>
    </owl:Class>



    <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Role -->

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Role">
        <rdfs:subClassOf>
            <owl:Restriction>
                <owl:onProperty
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#inhe
res-in"/>
                <owl:someValuesFrom>
                    <owl:Class>
                        <owl:unionOf rdf:parseType="Collection">
                            <rdf:Description
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Anima
l"/>
                            <rdf:Description
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Plant"/
>
                        </owl:unionOf>
                    </owl:Class>
                </owl:someValuesFrom>
            </owl:Restriction>
```

```
        </rdfs:subClassOf>
        <rdfs:comment xml:lang="en">to distinguish between the animal or plant and the role(s) they play
(e.g., turning out to be something else&apos;s dinner)</rdfs:comment>
    </owl:Class>



    <!--
http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#SausageTree -->

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Sausag
eTree">
        <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Tre
e"/>
    </owl:Class>



    <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Scourge --
>

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Scourg
e">
        <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Ani
malCollective"/>
        <rdfs:comment xml:lang="en">of mosquitos</rdfs:comment>
    </owl:Class>



    <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Shark -->

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Shark"
>
        <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Obl
igateCarnivore"/>
        <rdfs:subClassOf>
            <owl:Restriction>
                <owl:onProperty
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#eats
"/>
                <owl:someValuesFrom
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Ani
mal"/>
            </owl:Restriction>
        </rdfs:subClassOf>
```

```
        <rdfs:subClassOf>
            <owl:Restriction>
                <owl:onProperty
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#inhe
res-in"/>
                <owl:someValuesFrom
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Pre
dator"/>
            </owl:Restriction>
        </rdfs:subClassOf>
    </owl:Class>



    <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Swarm -->

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Swarm
">
        <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Ani
malCollective"/>
        <rdfs:comment xml:lang="en">of locusts, bees</rdfs:comment>
    </owl:Class>



    <!--
http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#SycamoreFig -->

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Sycam
oreFig">
        <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Tre
e"/>
    </owl:Class>



    <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Troop -->

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Troop"
>
        <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Ani
malCollective"/>
        <rdfs:comment xml:lang="en">of lions</rdfs:comment>
    </owl:Class>
```

```
    <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Zeal -->

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Zeal">
        <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Ani
malCollective"/>
        <rdfs:comment xml:lang="en">of zebra</rdfs:comment>
    </owl:Class>



    <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Zebra -->

    <owl:Class
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#Zebra"
>
        <rdfs:subClassOf
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Her
bivore"/>
        <rdfs:subClassOf>
            <owl:Restriction>
                <owl:onProperty
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#eats
"/>
                <owl:someValuesFrom
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Gra
ss"/>
            </owl:Restriction>
        </rdfs:subClassOf>
    </owl:Class>



    <!-- http://www.w3.org/2002/07/owl#Thing -->

    <owl:Class rdf:about="http://www.w3.org/2002/07/owl#Thing"/>



    <!--
    ///////////////////////////////////////////////////////////////////////////////////////
    //
    // Individuals
    //
    ///////////////////////////////////////////////////////////////////////////////////////
     -->
```

```
    <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#impala1 -->

    <owl:NamedIndividual
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#impala
1">
        <rdf:type
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Imp
ala"/>
    </owl:NamedIndividual>



    <!-- http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#lion1 -->

    <owl:NamedIndividual
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#lion1"
>
        <AfricanWildlifeOntology1:eats
rdf:resource="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology4.owl#imp
ala1"/>
    </owl:NamedIndividual>



    <!--
    ///////////////////////////////////////////////////////////////////////////////////////
    //
    // General axioms
    //
    ///////////////////////////////////////////////////////////////////////////////////////
     -->

    <rdf:Description>
        <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#AllDisjointClasses"/>
        <owl:members rdf:parseType="Collection">
            <rdf:Description
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Branch
"/>
            <rdf:Description
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Leaf"/
>
            <rdf:Description
rdf:about="http://www.meteck.org/teaching/OEbook/ontologies/AfricanWildlifeOntology1.owl#Twig"/
>
        </owl:members>
    </rdf:Description>
</rdf:RDF>



<!-- Generated by the OWL API (version 4.5.9.2019-02-01T07:24:44Z)
https://github.com/owlcs/owlapi -->
```

Appendix 5. Qualtrics Survey

The following is the downloaded version of the Qualtrics Survey presented to participants. The urls lead to pdf versions of each visualization, still present at those addresses at the time of submission. Participants saw only one of each of the four questions, selected randomly.

Default Question Block
CONSENT FORM
Name of principal investigator/researcher:
John Kausch
Title of study:
Visualising Knowledge Graphs
Please tick the box "I consent" to confirm the following statements are true.
1.I have had the opportunity to consider
the information and ask questions which have been answered satisfactorily.
2. I understand that my participation is voluntary and that I am free to withdraw withoutgiving a reason without being penalised or disadvantaged.
3 I understand that I will be able to withdraw my data up to the moment I submit thesurvey.
4 I agree to City recording and processing this information. I understand that thisinformation will be used only for the purpose(s) explained in the participant informationand my consent is conditional on City complying with its duties and obligations under theGeneral Data Protection Regulation (GDPR).
5 I agree to take part in the above study.
INSTRUCTIONS:
Below there is a link to an image file.
Click on this link or copy it into your browser.
The image is a data visualization of the names of African wildlife.
Your task is to record
all
the names of
animals
you see in this image.
I consent
I do not consent

THERE ARE MANY ANIMALS IN THE IMAGE SO PLEASE INPUT MORE THAN ONE

You may need to zoom in to read the names.
The file is saved in pdf format. You may need pdf reader software.
Enter the names of the animals
in the field supplied in the form below
in the following format: "[name] , [name] , [name]..." etc.
No other information is necessary.

1.Go to this url: http://www.renpet.net/AfricanWildlifeOntology.pdf
Return to this page and enter the
names of the animals
in the field below:

2.Go to this url: http://www.renpet.net/tree-diagram-ontoAfrican.pdf
Return to this page and enter the
names of the animals
in the field below:

3.Go to this url: http://www.renpet.net/SquareViz.pdf
Return to this page and enter the
names of the animals
in the field below:

4.Go to this url: http://www.renpet.net/CircleViz.pdf
Return to this page and enter the
names of the animals
in the field below:

Here is your ID number: ${e://Field/RandomID}

Appendix 6. Ethics Form and Participant Information Sheet

The participant information sheet was posted in the description field of the Amazon Mechanical Turk task created for the experiment. The ethics form was attached to the Qualtrics survey in Appendix 5.

Research Ethics Review Form: CityLIS dissertation projects

A.1 If you answer YES to any of the questions in this block, approval will be needed from an appropriate external ethics committee for approval. Consult your supervisor if you think this may be the case.		*Delete as appropriate*
1.1	Does your research require approval from the National Research Ethics Service (NRES)? *e.g. because you are recruiting current NHS patients or staff?* *If you are unsure try - https://www.hra.nhs.uk/approvals-amendments/what-approvals-do-i-need/*	**NO**
1.2	Will you recruit participants who fall under the auspices of the Mental Capacity Act? *Such research needs to be approved by an external ethics committee such as NRES or the Social Care Research Ethics Committee - http://www.scie.org.uk/research/ethics-committee/*	**NO**
1.3	Will you recruit any participants who are currently under the auspices of the Criminal Justice System, for example, but not limited to, people on remand, prisoners and those on probation? *Such research needs to be authorised by the ethics approval system of the National Offender Management Service.*	**NO**
A.2 If you answer YES to any of the questions in this block, approval will be needed from the Senate Research Ethics Committee. Consult your supervisor if you think this may be the case.		*Delete as appropriate*
2.1	Does your research involve participants who are unable to give informed consent? *For example, but not limited to, people who may have a degree of learning disability or mental health problem, that means they are unable to make an informed decision on their own behalf.*	**NO**
2.2	Is there a risk that your research might lead to disclosures from participants concerning their involvement in illegal activities?	**NO**
2.3	Is there a risk that obscene and or illegal material may need to be accessed for your research study (including online content and other material)?	**NO**
2.4	Does your project involve participants disclosing information about special category or sensitive subjects? *For example, but not limited to: racial or ethnic origin; political opinions; religious beliefs; trade union membership; physical or mental health; sexual life; criminal offences and proceedings*	**NO**
2.5	Does your research involve you travelling to another country outside of the UK, where the Foreign & Commonwealth Office has issued a travel warning that affects the area in which you will study? *Please check the latest guidance from the FCO - http://www.fco.gov.uk/en/*	**NO**
2.6	Does your research involve invasive or intrusive procedures? *These may include, but are not limited to, electrical stimulation, heat, cold or bruising.*	**NO**
2.7	Does your research involve animals?	**NO**

2.8	Does your research involve the administration of drugs, placebos or other substances to study participants?	**NO**
A.3 If you answer YES to any of the questions in this block, then approval will be needed from the Computer Science /Library and Information Science Research Ethics Committee (CSREC). Consult your supervisor if you think this may be the case.		*Delete as appropriate*
3.1	Does your research involve participants who are under the age of 18?	**NO**
3.2	Does your research involve adults who are vulnerable because of their social, psychological or medical circumstances (vulnerable adults)? *This includes adults with cognitive and / or learning disabilities, adults with physical disabilities and older people.*	**NO**
3.3	Are participants recruited because they are staff or students of City, University of London? *For example, students studying on a particular course or module.* *If yes, then approval is also required from the Head of Department or Programme Director.*	**NO**
3.4	Does your research involve intentional deception of participants?	**NO**
3.5	Does your research involve participants taking part without their informed consent?	**NO**
3.5	Is the risk posed to participants greater than that in normal working life?	**NO**
3.7	Is the risk posed to you, the researcher(s), greater than that in normal working life?	**NO**
A.4 If you answer YES to the following question and your answers to all other questions in sections A1, A2 and A3 are NO, then your project is of minimal risk. **If this is the case, then you can apply for approval through your supervisor under PROPORTIONATE REVIEW. You do so by completing PART B of this form.** **If you have answered NO to all questions in the checklist, including question 4, then your project does not require ethical approval. You should still include the form in your dissertation proposal.**		*Delete as appropriate*
4	Does your project involve human participants or their identifiable personal data? *For example, as interviewees, respondents to a survey, or participants in testing.*	**YES**

PART B: Ethics Proportionate Review Form

If you answered YES to question 4 and NO to all other questions in sections A1, A2 and A3 in PART A (checklist) of this form, then you should complete PART B of this form to submit an application for a proportionate ethics review of your project. Your supervisor has delegated authority to review and approve this application under proportionate review. Your proposal, including this ethics application, must be approved by your supervisor before beginning the planned research.

If you cannot provide all the required attachments (see B.3) with your project proposal (e.g. because you have not yet written the consent forms, interview schedules etc), you must submit the missing items to your supervisor for approval prior to commencing these parts of your project.

Your supervisor may ask you to submit a full ethics application through Research Ethics Online, if they are unable to give approval.

B.1 The following questions must be answered fully.		*Delete as appropriate*
1.1.	Will you ensure that participants taking part in your project are fully informed about the purpose of the research?	**YES**
1.2	Will you ensure that participants taking part in your project are fully informed about the procedures affecting them or affecting any information collected about them, including information about how the data will be used, to whom it will be disclosed, and how long it will be kept?	**YES**
1.3	When people agree to participate in your project, will it be made clear to them that they may withdraw (i.e. not participate) at any time without any penalty?	**YES**
1.4	Will consent be obtained from the participants in your project? Consent from participants will be necessary if you plan to involve them in your project or if you plan to use identifiable personal data from existing records. “Identifiable personal data” means data relating to a living person who might be identifiable if the record includes their name, username, student id, DNA, fingerprint, address, etc. *If YES, you must attach drafts of the participant information sheet(s) and consent form(s) that you will use in section B.3 or, in the case of an existing dataset, provide details of how consent has been obtained.* *You must also retain the completed forms for subsequent inspection. Failure to provide the completed consent request forms will result in withdrawal of any earlier ethical approval of your project.*	**YES**
1.5	Have you made arrangements to ensure that material and/or private information obtained from or about the participating individuals will remain confidential?	**YES**

B.2 If the answer to the following question (B2) is YES, you must provide details		*Delete as appropriate*
2	Will the research be conducted in the participant’s home or other non-University location? *If **YES**, you must provide details of how your safety will be ensured.*	**NO**

B.3 Attachments **All of the following documents must be provided to supervisors if applicable. If they are not available when the proposal is submitted, they must be approved by the supervisor later.**	***YES***	***NO***	***Not Applicable***

Details on how safety will be assured in any non-University location, including risk assessment if required (see B2)			**x**
Details of arrangements to ensure that material and/or private information obtained from or about the participating individuals will remain confidential (see B1.5) *Any personal data must be acquired, stored and made accessible in ways that are GDPR compliant.*			**x**
Full protocol for any workshops or interviews**			**x**
Participant information sheet(s)**			**x**
Consent form(s)**	**x**		
Questionnaire(s)** *sharing a Qualtrics survey with your supervisor is recommended.*	**x**		
Topic guide(s) for interviews and focus groups**			**x**
Permission from external organisations or Head of Department** *e.g. for recruitment of participants*			**x**

CONSENT FORM

Name of principal investigator/researcher

John Kausch

Title of study

Visualising Knowledge Graphs

Please tick or initial box

1	I confirm that I have read and understood the participant information dated 12-05-2022 Version 01 for the above study. I have had the opportunity to consider the information and ask questions which have been answered satisfactorily.	
2.	I understand that my participation is voluntary and that I am free to withdraw without giving a reason without being penalised or disadvantaged.	
3	I understand that I will be able to withdraw my data up to the moment I submit the survey.	
4	I agree to City recording and processing this information. I understand that this information will be used only for the purpose(s) explained in the participant information and my consent is conditional on City complying with its duties and obligations under the General Data Protection Regulation (GDPR).	
5	I would like to be informed of the results of this study once it has been completed and understand that my contact details will be retained for this purpose.	
6	I agree to take part in the above study.	

____________________ ____________________________ _____________

Name of Participant   Signature   Date

____________________ ____________________________ _____________

Name of Researcher   Signature   Date

When completed, 1 copy for participant; 1 copy for researcher file.

PARTICIPANT INFORMATION SHEET

Title of study

Visualising Knowledge Graphs

Name of principal investigator/researcher

John Towler Kausch

Invitation paragraph

We would like to invite you to take part in a research study. Before you decide whether you would like to take part it is important that you understand why the research is being done and what it would involve for you. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. You will be given a copy of this information sheet to keep.

What is the purpose of the study?

The purpose of this study is to see how different kinds of data visualization impact how people interact with information

Why have I been invited to take part?

You have been invited because you are on the Amazon Mechanical Turk platform.

Do I have to take part?

Participation in the project is voluntary, and you can choose not to participate in part or all of the project. You can withdraw at any stage of the project without being penalised or disadvantaged in any way. It is up to you to decide whether or not to take part. If you do decide to take part you will be asked to sign a consent form. If you decide to take part you are still free to withdraw at any time and without giving a reason.

Once you have submitted your answers on the Qualtrics survey, your anonymous answers cannot be altered and they will be stored.

What will happen if I take part?

You will participate in a single survey which should take an estimated five minutes of your time. You will be given a data-visualization which contains many different names on it. Your task will be to identify all the animals in the visualization, and select them in the survey. None of your personal information will be collected. The exact time it took you to complete the survey and your answers will be collected.

What do I have to do if I take part?

Click on a link, view the data visualization, and take the survey.

What are the possible disadvantages and risks of taking part?

This exercise involves staring at a screen. If you have already been doing so for a long period of time, your eyes may experience strain. The task should take roughly five minutes.

What are the possible benefits of taking part?

You may learn something about animals.

Expenses and Payments

You will be reimbursed $1 for a five minute task, equivalent to being paid at the rate of $12/hour.

What should I do if I want to take part?

If you would like to take part, please click on the continue button to go to the Qualtrics Survey.

Will my taking part in the study be kept confidential?

All personal data will be kept anonymous.

What will happen to the results?

The results will be published online in the Open Access Humanities Commons.

Who has reviewed the study?

This study has been approved by City, University of London Research Ethics Committee.

What if there is a problem?

If you have any problems, concerns or questions about this study, you should ask to speak to a member of the research team. If you remain unhappy and wish to complain formally, you can do this through City's complaints procedure. To complain about the study, you need to phone 020 7040 3040. You can then ask to speak to the Secretary to Senate Research Ethics Committee and inform them that the name of the project is Visualising Knowledge Graphs.

You can also write to the Secretary

at: John Montgomery

Research &

Enterprise Office City,

University of London

Northampton Square

London, EC1V 0HB

Email: j.montgomery@city.ac.uk

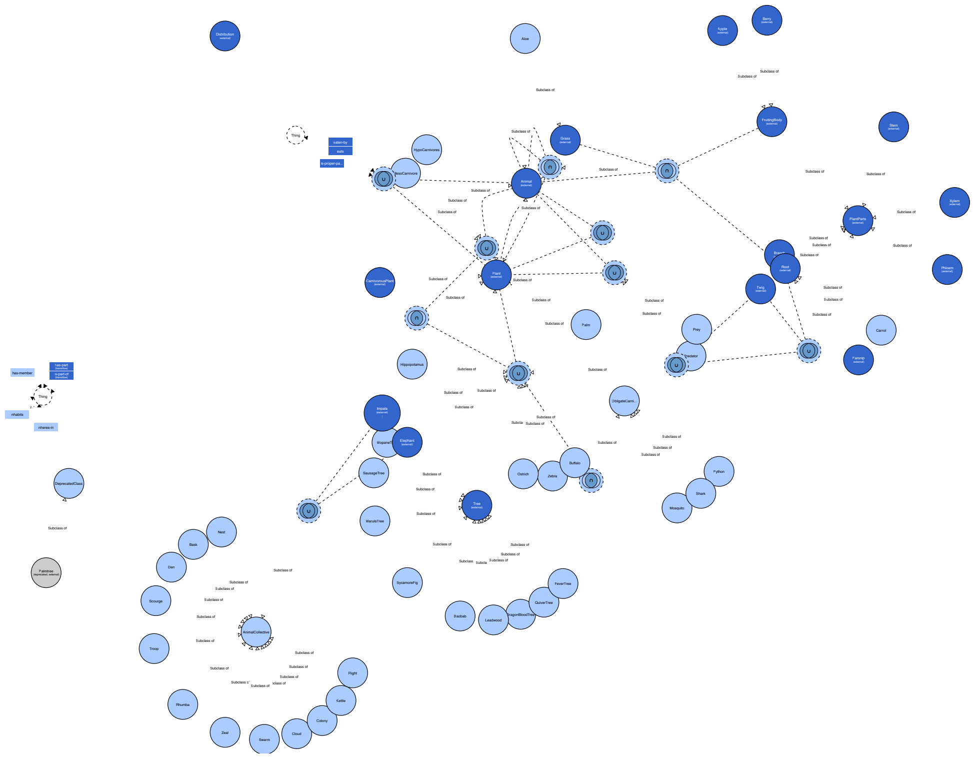
Further information and contact details

If you have any questions about this study, please contact either John Kausch at Jack.Kausch@city.ac.uk or Ernesto Jimenez-Ruiz at Ernesto-Jimenez-Ruiz@city.ac.uk

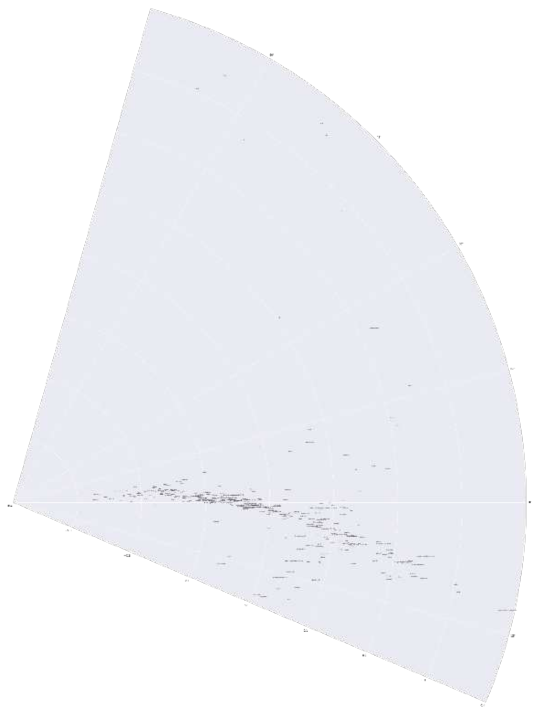
Thank you for taking the time to read this information sheet.

Appendix 7. Visualizations of the African Wildlife Ontology

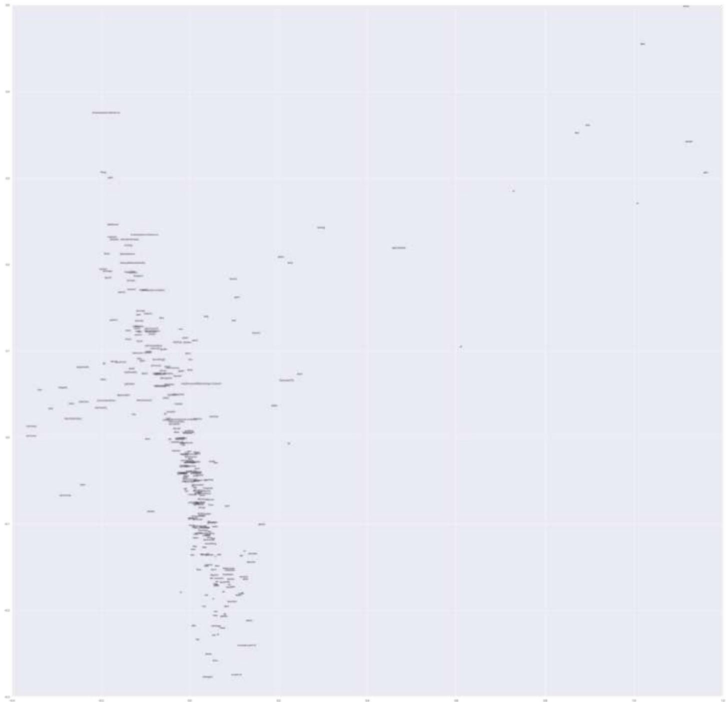
For higher quality versions of these files, please follow the links in the Qualtrics survey or check the GitHub repository https://github.com/JackKausch/KGS



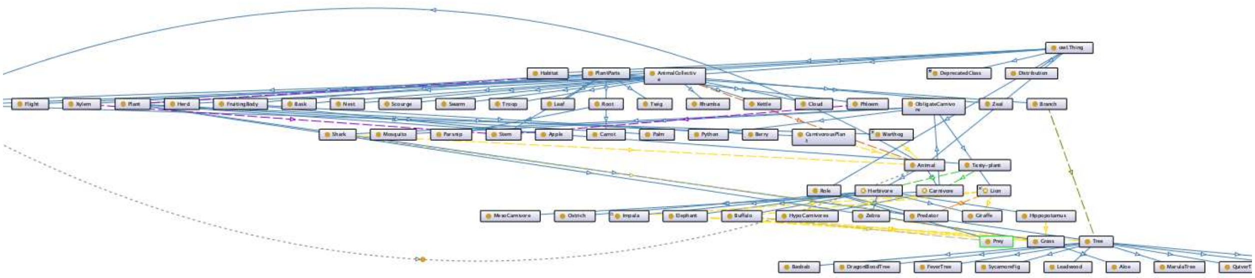
AfricanWildlifeOntology.pdf



CircleViz.pdf



SquareViz.pdf



tree-diagram-onto-African.pdf

Appendix 8. Results as a .csv file

Each line of the file represents a different participant response.

WebVOWL
"zebra,lion,shark,paithon,griff,elephant,mosquiti,buffalo"
We keep some pet animals at home. We look after them to
buffalow zebra shark
Buffalo
"Hippopotamus, Impala, elephant, ostrich, zebra, buffalo, "
"zebra,buffalo,ostrich,elephant,shark,python,mosquito"
lion
Monkey
African wildlife
African wildlife
A. African Buffalo. Albatross. Alligator. Alpaca. American Bison. Ant. Antelope. Ape ; B ¬∑
Baboon.
dog
"Shark,Phython,Buffalo"
"EEPHANT,ZEBRA,OSTRITCH,HIPPOPOTAMUS,BUFFALO"
Ostrich Buffalo Zebra Mosquito Shark Python Elephant Impala Hippopotamus
ELEPHANT
"Elephant, Impala, Ostrich, Zebra, Buffalo, Hippopotamus"
buffalo
"tiger.lion, elephant,kangaroo,bear,monkey,panda,"
MONKEY
"xylemy, phloem"
stam
"Hippopatamus, zebra,Ostrich, Buffalao,"
African wildlife
cat
Lion
tiger
AfricanWildlifeOntology
"[Zebra], [Buffalo], [Hippopotamus]"
Animal

OntoGraf
"""Buffalo , shark, zebra, Elephant, Lion"""
"ELEPHANT,BUFFALO,ZEBRA,LION"
Elephant
"Zebra, Lion"
"""[camel],[tiger],[lion],[shark],[elephant]"""
shark
Lion
tiger

"ELEPHANT,BUFFALO,ZEBRA,OSTRITCH,HIPPOPOTAMUS"
cat
[shark][Mosquito]
"buffalo ,zebra, lion,giraffe, elephant ,hippopotamus"
"""[elephant],[zebra],[lion],[buffalo]"""
"elephant, zebra, paffalo, lion"
"LION, ELEPHANT,BUFFALO,ZEBRA,"
"lion, elephan , buffalo, zebra"
Lion
TREE
LION
GROW
lion
"zebra, buffalo, elephant"
Ostrich Impala Elephant Buffalo Zebra Predator Giraffe Hippopotamus Lion
"shark, elephant , zebra"
lion
"Tiger, Lion"

SquareVis
[Dog] [lion][tiger]
"zebra,elephant,paithon,shark,giraffe,lion,"
""" Buffalo, lion zebra, Elephant"""
"ostrich, python, hippopotamus, giraffe, lion, buffalo, shark, zebra, elephant, "
ZEBRA
no animal name in the field
giraffe
"zebra, lion, shark, python, graffe, astrich"
tiger
no animal name in the box
Zebra
griaffe
rat
nothing
African wildlife
"impala, giraffe"
"shark,python,zebra,giraffe,lion,"
[ZEBRA] [BUFFALO] [PYTHON] [GIRAFFE] [ELEPHANT] [SHARK]
"lion, python, ostrich, zeal, buffalo, fig, impala, whale, shark, zebra, elephant, abes"
ostrich
"Elephant, lion, giraffe, hippopotamus,buffalo,zebra"
DOG
ELEPHANT
"python, giraffe, zebra, elephant, lion, buffalo"
[ZEBRA] [BUFFALO]
lion

dog

CircleVis
[zebra] [giraffee] [lion] [python] [ostrich] [shark]
Dog
"Buffalo,Zebra,Ostrich,Elephant,Impala"
"lion, zebra, shark,python,graffe,astrich"
"zebra,shark,graffe,python,lion,astrich"
buffalow zebra elephant
no animals name
cat
NO ANIMALS
African wildlife
shapes
CAT
"giraffe,impala"
African wildlife
"Elephant,lion,giraffe,hippotamous,zebra,buffalo"
dog
lion
African wildlife
"beavers, zebra, mole, giraffe, python, whale, elephant"
"lion,tiger"
"elephant, zebra, shark, giraffe, python, ostrich"
snake
"elephant, shark, buffalo"
"python, giraffe, elephant, impala, zebra, shark, arthropods"
"""[lion], [giraffe], [elephant], [buffalo]"""
[Giraffe] [Cat] [Zebra] [Shark]
Make sure all words are spelled correctly. Try different keywords. Try more general keywords. Try fewer keywords.
"horse, cat, impala, whale, warthog, elephant, buffalo, giraffe, shark, python"
ELEPHANT
elephant

Appendix 9. Embeddings file .txt format

This is a text version of the embeddings of the ontology generated by OWL2Vec.

subclassof -0.062460095 0.19492513 -0.07846462 -0.22278558 0.07477594 0.11467287 0.052410536 0.37799686 -0.13911961 0.060448498 -0.3327301 0.32666242 0.41048446 0.16534092 -0.14779122 0.024128046 0.02211025 -0.39419258 -0.021592548 -0.30903503 0.02408975 0.21312957 0.08991588 0.1383791 0.09853955 -0.057764668 -0.061904054 0.15525675 0.06659513 0.048018288 0.053933363 -0.0560743 0.10064336 0.12104543 0.22914264 -0.0141393235 0.22024284 -0.11554784 -0.09642223 0.21269923 0.14676753 0.14941813 0.22777414 -0.10428731 0.056049027 0.18027644 0.22051492 0.17379257 0.24920513 -0.08771824 -0.046895456 -0.17791025 0.091334246 -0.017762683 0.2976726 0.07084731 0.06498229 0.14799337 -0.0920353 0.3444047 0.012568041 -0.12339888 -0.24281602 0.20851849 -0.05868948 0.12598033 0.0015363574 -0.40889636 -0.14903164 0.101263694 -0.079954974 -0.145569 -0.09847681 0.027027143 -0.049093463 -0.22145963 -0.07773825 -0.01375398 0.03801429 -0.002655605 -0.07100854 -0.05146735 0.041317087 0.074882716 -0.29648438 0.15974538 -0.115726344 -0.2978375 -0.11303914 -0.116624676 -0.21994609 0.42688605 -0.027852103 -0.2754112 0.11534989 -0.22876099 0.016392991 -0.004346011 -0.34539348 -0.24066342
type -0.06983806 0.20418784 -0.09790937 -0.21065044 0.094834544 0.097196534 0.082783535 0.38135514 -0.1329259 0.08478268 -0.31916407 0.31055343 0.40081474 0.14847624 -0.13565683 -0.024786498 -0.012494934 -0.38213137 -0.036376435 -0.30587333 0.0009836059 0.18997763 0.09642328 0.13075623 0.09790421 -0.07789647 -0.082439475 0.13110779 0.091637485 0.026636483 0.02846499 -0.040273845 0.09709463 0.122857474 0.22497873 0.03401384 0.23105974 -0.09135202 -0.08554905 0.18376029 0.13959007 0.15397204 0.19735788 -0.11029244 0.08440758 0.16203487 0.24513191 0.15358227 0.24278544 -0.110041626 -0.090669155 -0.13692452 0.08470409 -0.01185621 0.2858608 0.094051786 0.05111808 0.1218967 -0.12366424 0.305482 -0.009472636 -0.15633003 -0.21438076 0.20853908 -0.053604305 0.12966199 -0.011182475 -0.40486482 -0.16141924 0.10565335 -0.09921377 -0.17050931 -0.09556786 0.049568508 -0.07433811 -0.20009124 -0.09214863 0.022415722 0.020656096 -0.0071233353 -0.066731155 -0.042197853 0.057283636 0.06475745 -0.30700406 0.13614479 -0.109708965 -0.25240064 -0.09362213 -0.11567359 -0.2149152 0.40633667 -0.036505062 -0.29031253 0.11328016 -0.21413857 0.04025585 -0.008405553 -0.37387177 -0.22380748
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Appendix 11. Modified OWL2Vec Jupyter Notebook

The code used for OWL2Vec comes from this Github repository: https://github.com/KRR-Oxford/OWL2Vec-Star

Some modifications were made to the jupyter notebook included there, and that code is included below. Please note that the ontology was renamed to the name "pizza" due to compatability issues. The file pizza.owl in this case represents the extended African Wildlife Ontology.

```
from owl2vec_star import owl2vec_star


#Parameters:
# ontology_file
# config_file
# uri_doc
# lit_doc
# mix_doc
gensim_model = owl2vec_star.extract_owl2vec_model("./case_studies/pizza/pizza.owl",
"./default.cfg", True, True, True)

output_folder="./cache/output/"

#Gensim format
gensim_model.save(output_folder+"ontology2.embeddings")
    #Txt format
gensim_model.wv.save_word2vec_format(output_folder+"ontology2.embeddings.txt",
binary=False)
 from gensim.models import KeyedVectors

#Embedding vectors generated above
model = KeyedVectors.load("./cache/output/ontology.embeddings", mmap='r')
wv = model.wv

#vector = wv['pizza']  # Get numpy vector of a word
print("Vector for 'pizza'")
#print(vector)

#cosine similarity
#similarity = wv.similarity('pizza', 'http://www.co-
ode.org/ontologies/pizza/pizza.owl#Pizza')
#print(similarity)

#similarity = wv.similarity('http://www.co-
ode.org/ontologies/pizza/pizza.owl#Margherita', 'margherita')
#print(similarity)
```

```
#Most similar cosine similarity
#result = wv.most_similar(positive=['margherita', 'pizza'])
#print(result)

#Most similar entities: cosmul
result = wv.most_similar_cosmul(positive=['lion'])
print(result)
```

Appendix 10. Visual-Meta

The information in very small type below allows software to provide rich interactions with this document.
See Visual-Meta.info for more information.

This is what we call Visual-Meta. It is an approach to add information about a document to the document itself on the same level of the content. The same as would be necessary on a physically printed page, as opposed to a data layer, since this data layer can be lost and it makes it harder for a user to take advantage of this data. ¶ Important notes are primarily about the encoding of the author information to allow people to cite this document. When listing the names of the authors, they should be in the format 'last name', a comma, followed by 'first name' then 'middle name' whilst delimiting discrete authors with ('and') between author names, like this: Shakespeare, William and Engelbart, Douglas C. ¶ Dates should be ISO 8601 compliant. ¶ The way reader software looks for Visual-Meta in a PDF is to parse it from the end of the document and look for @{visual-meta-end}. If this is found, the software then looks for {@{visual-meta-start} and uses the data found between these marker tags. ¶ It is very important to make clear that Visual-Meta is an approach more than a specific format and that it is based on wrappers. Anyone can make a custom wrapper for custom metadata and append it by specifying what it contains: For example @dublin-core or @rdfs. ¶ This was written Summer 2021. More information is available from https://visual-meta.info or from emailing frode@hegland.com for as long as we can maintain these domains.

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It is typically written in the OWL language. ¶
An ontology typically consists of classes, which describe specific entities as instances of a given class, and object properties which define different facets of how those classes relate to each other. ¶
The term ontology is closely linked with the term knowledge graph, although they are not identical. A knowledge graph tends to refer more to a graph database which contains information in the RDF framework. However, there is a great deal of overlap in how the terms are used. For the purposes of this dissertation, the terms ontology and knowledge graph are treated as identical. },¶}
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