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Fachbereich 4: Informatik

WeST People and Knowledge Networks
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Enrichment of ontological taxonomies using a neural network approach

Bachelorarbeit

zur Erlangung des Grades einer Bachelor of Science (B.Sc.)
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vorgelegt von
Alex Baier

Erstgutachter: Prof. Dr. Steffen Staab
Institute for Web Science and Technologies

Zweitgutachter: Max Mustermann
Institute for Web Science and Technologies

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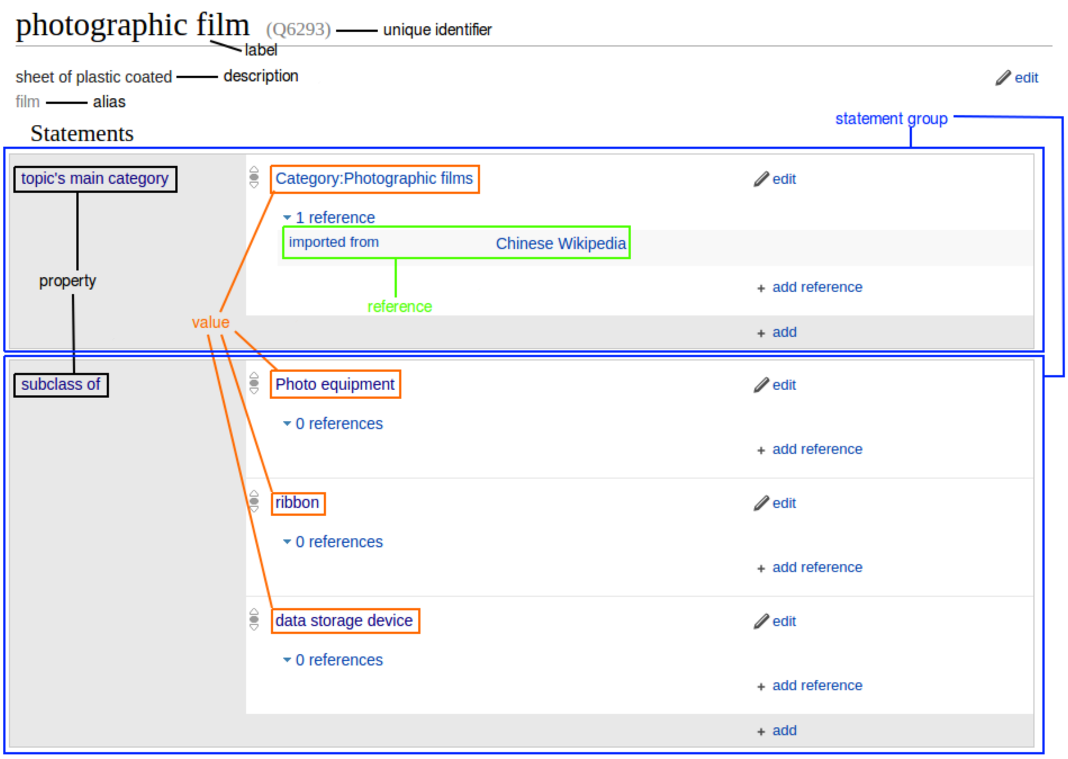

Figure 1: Example of Wikidata class: photographic film (Q6239)

1 Introduction

Motivation. Related work. Solution. Evaluation.

2 Foundations

2.1 Wikidata

TODO: Define entity in Wikidata, how are classes identified, etc. Galárraga [11] Wikidata is a open, collaborative and user-driven knowledge base. Its main purpose is to serve as a structural knowledge store for other Wikimedia projects like Wikipedia.

2.2 Taxonomy

Ontologies are sets of concepts and relations, which formally define how knowledge can be related and ordered in a context. Additionally it is possible for ontologies to contain axioms used for validation and constraint enforcement. In comparison, a knowledge base like Wikidata can be seen as an instantiation of such an ontology,

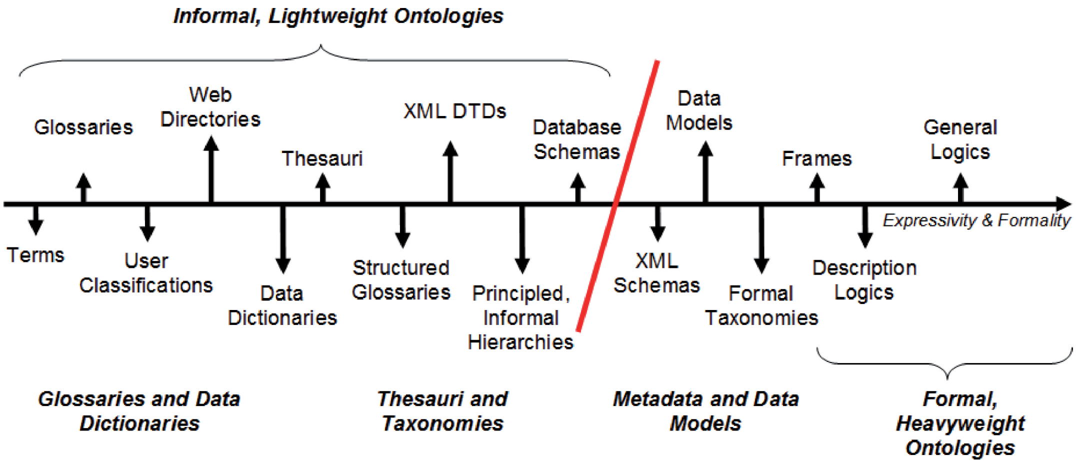

Figure 2: The spectrum of ontology kinds. [23]

since every knowledge base has to be conceptualized by an ontology [23]. Different types of ontologies can grouped by their level of formality and expressiveness. Wong et al. [23] differentiates ontologies as lightweight and heavyweight ontologies (see Figure 2). *Taxonomies* are concept or class hierarchies. They typically represent a parent-child structure, which can be formalized with a single relationship called for example *subclass-of* in the case of Wikidata. The observed taxonomy in Wikidata belongs to the category of lightweight ontologies, specifically *principled, informal hierarchies*, as the only enforced rule for the subclass-of relation is that it should connect two entities [1].

For the purpose of developing a formal definition of the thesis' problem statement the notion of taxonomy needs to be formalized. Cimiano [6] defines a heavyweight ontology, which includes a taxonomy, as follows:
"

Definition (Ontology). *An* ontology *is a structure*

$$\mathcal{O} := (C, \leq_C, R, \sigma_R, \leq_R, \mathcal{A}, \sigma_\mathcal{A}, \mathcal{T})$$

consisting of

- *four disjoint sets C, R, $\mathcal{A}$, and $\mathcal{T}$ whose elements are called* concept identifiers, relation identifiers, attribute identifiers *and* data types, *respectively,*
- *a semi-upper latice $\leq_C$ on C with top element $root_C$, called* concept hierarchy *or* taxonomy,
- *a function $\sigma_R : R \to C^+$ called* relation signature,
- *a partial order $\leq_R$ on R, called* relation hierarchy, *where $r_1 \leq_R r_2$ implies $|\sigma_R(r_1)| = |\sigma_R(r_2)|$ and $\pi_i(\sigma_R(r_1)) \leq_C \pi_i(\sigma_R(r_2))$, for each $1 \leq i \leq |\sigma_R(r_1)|$, and*

- *a function $\sigma_{\mathcal{A}} : \mathcal{A} \rightarrow C \times \mathcal{T}$, called* attribute signature,
- *a set $\mathcal{T}$ of datatypes such as strings, integers, etc.*

Hereby, $\pi_i(t)$ is the i-th component of tuple t. [...] Further, a semi-upper lattice $\leq$ fulfills the following conditions:

$$\forall x x \leq x \text{ (reflexive)}$$
$$\forall x \forall y (x \leq y \land y \leq x \implies x = y) \text{ (anti-symmetric)}$$
$$\forall x \forall y \forall z (x \leq y \land y \leq z \implies x \leq z) \text{ (transitive)}$$
$$\forall x x \leq top \text{ (top element)}$$
$$\forall x \forall y \exists z (z \geq \land z \geq y \land \forall w (w \geq x \land w \geq y \implies w \geq z)) \text{ (supremum)}$$

So every two elements have a unique most specific supremum. "

A taxonomy can be modeled as a semi-upper lattice. This induces two important assumptions about the structure and to some degree completeness of the observed taxonomies. First, there is only one *root class*, top element of the lattice, of which every other class is (transitively) a subclass. Second, because of the supremum property, the taxonomy is fully connected, which means each class, but the root class, has a superclass. Wikidata's taxonomy does therefore not fulfill the definition by Cimiano [6], as it is not fully connected.
In the following, new definitions will presented, which attempt to model an incomplete taxonomy based on the already presented data model and structure of Wikidata. First, basic concepts of graphs will be introduced.

Definition 1 (Directed graph). *A* directed graph *G is an ordered pair $G = (V, E)$, where V is a set of vertices, and $E = \{(v_1, v_2) \mid v_1, v_2 \in V\}$ is a set of ordered pairs called directed edges, connecting the the vertices.*

Definition 2 (Predecessor). *Let $G = (V, E)$ be a directed graph. $v_1 \in V$ is a* predecessor *of $v_2 \in V$, if there exists an edge so that $(v_1, v_2) \in E$. Let $v \in V$ be a vertice of G, then $pred_G(v) = \{w \mid (w, v) \in E\}$ is the set of predecessors of v.*

Definition 3 (Successor). *$v_1 \in V$ is a* successor *of $v_2 \in V$, if there exists an edge so that $(v_2, v_1) \in E$. Let $v \in V$ be a vertice of G, then $succ_G(v) = \{w \mid (v, w) \in E\}$ is the set of successors of v.*

Definition 4 (Walk). *Let $G = (V, E)$ be a directed graph. A* walk *W of length $n \in \mathbb{N}$ is a sequence of vertices $W = (v_1, \ldots, v_n)$ with $v_1, \ldots, v_n \in V$, so that $(v_i, v_{i+1}) \in E \; \forall i = 1, \ldots, n-1$.*

Definition 5 (Cycle). *A walk $W = (v_1, \ldots, v_n)$ of length n is called a* cycle, *if $v_1 = v_n$.*

Definition 6 (Directed acyclic graph). *A directed graph G is called* directed acyclic graph, *if there are no cycles in G.*

In Wikidata, a class can have multiple superclasses, therefore a tree structure is not sufficient to model the taxonomy. However a directed acyclic graph, can model the taxonomy. The acyclic constraint is necessary to ensure that no class is transitively a subclass of itself.

Definition 7 (Taxonomy). *A* taxonomy $T = (C, S)$ *is a directed acyclic graph, where* C *is a set of* class identifiers, *and* S *is the set of edges, which describe the* subclass-of relation *between two classes. such that* c_1 *is the subclass of* c_2*, if* $(c_1, c_2) \in S$.

Definition 8 (Subclass-of relation). *The transitive binary relation* $\lhd_T$ *on the taxonomy* $T = (C, S)$ *represents the subclass relationship of two classes in* T*. Given* $c_1, c_2 \in C$, $c_1 \lhd_T c_2$*, if there is a walk* $W = (c_1, \ldots, c_2)$ *with length* $n \geq 1$*, which connects* c_1 *and* c_2. $\lhd_T$ *is transitive,* $\forall c_1, c_2, c_3 \in C : c_1 \lhd_T c_2 \land c_2 \lhd_T c_3 \implies c_1 \lhd_T c_3$.

If the taxonomy defined by Cimiano [6] is mapped on this graph-based taxonomy model, the following assumption is true, for $T = (C, S)$:

$$|\{c \in C \mid \neg\exists s \in C : c \lhd_T s\}| = 1$$

Only one class in this taxonomy has no superclasses. This class is called *root class*. However in the case of Wikidata, this assumption does not hold true. The following state is the case:

$$|\{c \in C \mid \neg\exists s \in C : c \lhd_T s\}| > 1$$

There are classes other than the root class, which also have no superclasses. These classes will be called *unlinked classes*.

Definition 9 (Root class). *Given a taxonomy* $T = (C, S)$*, the* root class $root_T$ *is a specific, predefined class with no superclasses in* T*. For* $root_T$, $|succ_T(root_T)| = 0$ *applies.*

Definition 10 (Unlinked class). *Given a taxonomy* $T = (C, S)$ *with a root class* $root_T$*, a class* $u \in C$ *is called* unlinked class, *if* $u \neq root_T \land |succ_T(u)| = 0$.

In Wikidata, the root class is *entity (Q35120)* [2]. All other classes, which are not subclasses of *entity (Q35120)*, are therefore either unlinked classes, or subclasses of unlinked classes. **TODO: Something is missing here maybe. The problem statement could follow here, but the required definition of similarity is missing. Maybe switch the order of similarity and taxonomy.**

2.3 Similarity

- semantic similarity e.g. distributional similarity
  Lin [17]
  Rodríguez and Egenhofer [21]

- geometrical similarity e.g. distance based-similarity, cosine similarity

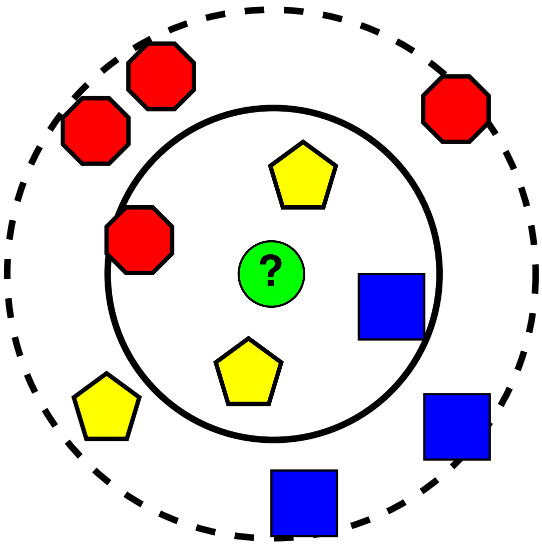

Figure 3: Example for k-nearest neighbors for 3 classes with k=4 and k=10.

For the task of ontology learning [14] as well as classification, e.g. k-nearest-neighbors, the concept of similarity is of importance. A basic intuition of similarity is for example given by Lin [17]. Similarity is related to the commonalities and differences between two objects. More commonalities implies higher similarity. Vice versa, more differences implies lower similarity. Two identical objects should have the maximum similarity. In addition, only identical objects should be able to achieve maximum similarity. Typically, similarity can be defined as a binary function, which maps two objects to a value in the interval $[0, 1]$. A value of 1 represents identical input objects. For this thesis, semantic and vector similarity measures will be used.
Vector similarity.
Semantic similarity measures are needed when comparing structures, which cannot be sufficiently represented as vectors. These are for example words and classes in ontologies **citations needed**. Rodríguez and Egenhofer [21] develops a semantic similarity measure for comparing entity classes in ontologies. Entity

2.4 Similarity-based classification

Chen et al. [4]
Zhang and Zhou [24]

Explain how kNN works. Nearest-neighbors classification is a lazy method, as it does not require training before testing. This is useful for applications with high amounts of data, large numbers of classes, and changing data [24]. For the considered use case of classification in Wikidata, these are very important strengths, as the number of classes in the taxonomy is very high and Wikidata is being constantly edited.

2.5 Text processing

- N-Gram
  Jurafsky and Martin [15]
- Skip-Gram
  Guthrie et al. [13]
- Counting-based word representations
  Levy et al. [16]
- Predictive word representations
  Levy et al. [16]

2.6 Problem statement

The task of this thesis is the classification of unlinked classes in Wikidata. In other words a function is needed, which given an unlinked class u of a taxonomy $T = (C, S)$ with a root class $root_T$, find an appropriate superclass for T. Doan et al. [9] suggests that for the task of placing a class into an appropriate position in T, either finding the most similar class, most specific superclass, or most general subclasses of u, are sensible approaches. This induces that the appropriate superclass for an unlinked class u is either the most similar class $c \in T$, or one of the superclasses of $succ_T(c)$. Therefore we can define the problem, as follows:

Definition 11 (Problem definition)**.** *Given a taxonomy $T = (C, S)$ with root class $root_T$ and a similarity function sim over T, find a function f, which, given an unlinked class $u \in C$, returns a class $s = f(u)$, fulfilling the following criteria:* ***TODO: define as the parents of the most similar class? for example german would be similar to english, therefore the superclass for german should be language and not english***

$$\neg(s \lhd_T u) \text{ no child} \tag{1}$$

$$s = \max_{c \in C}(sim(u, s)) \text{ most similar class} \tag{2}$$

3 Analysis of the Wikidata taxonomy

4 Ontology learning

General concepts. Classification of considered problem in the task of ontology learning. Related work.
Cimiano et al. [5]
Wong et al. [23]

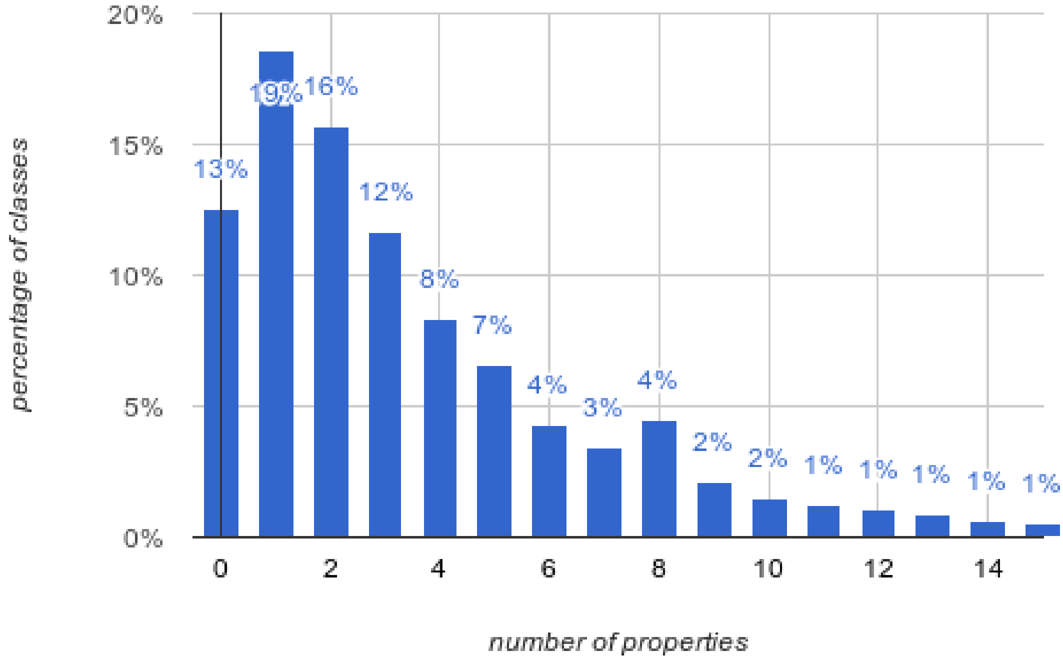

Figure 4: Percentage of unlinked classes with a specific amount of unique properties. Wikidata (2016-11-07)

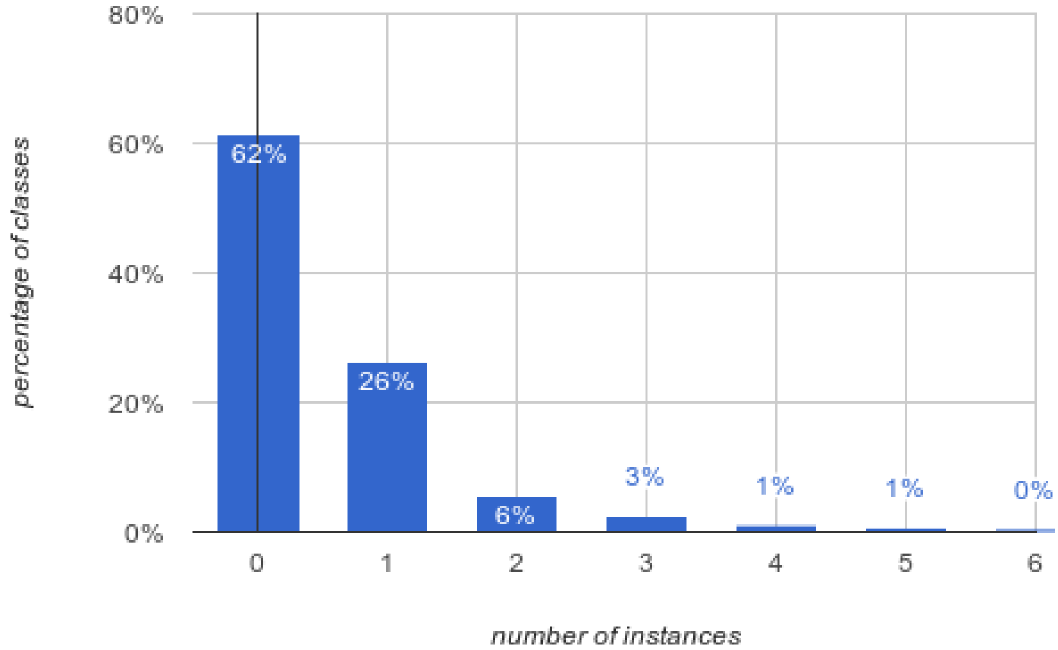

Figure 5: Percentage of unlinked classes with a specific amount of instances. Wikidata (2016-11-07)

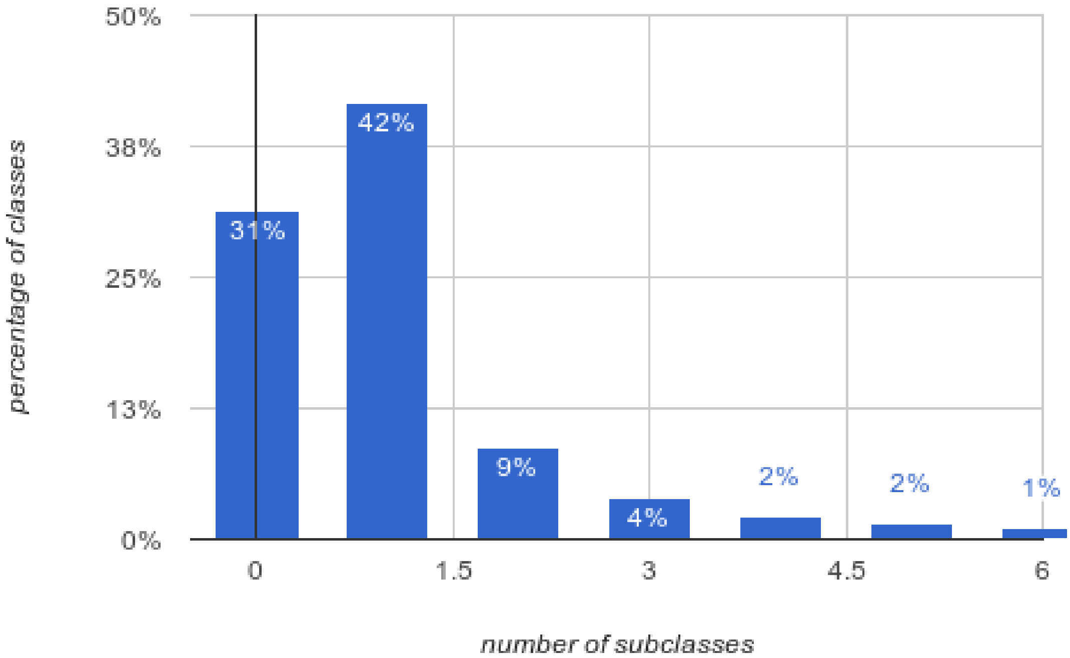

Figure 6: Percentage of unlinked classes with a specific amount of subclasses. Wikidata (2016-11-07)

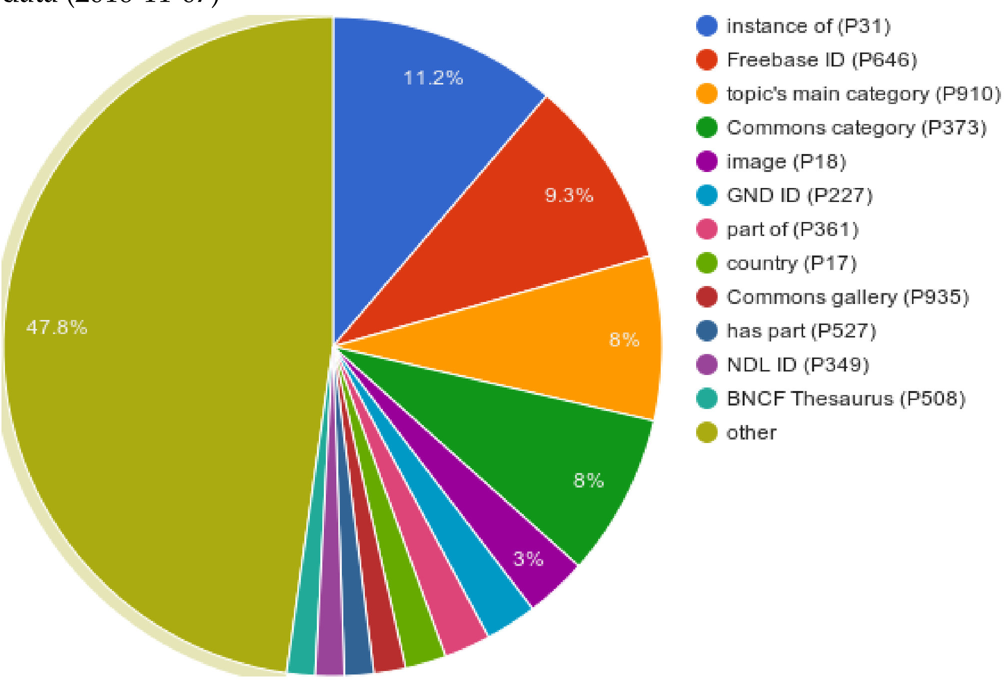

Figure 7: Frequency of properties in unlinked classes. Wikidata (2016-11-07)

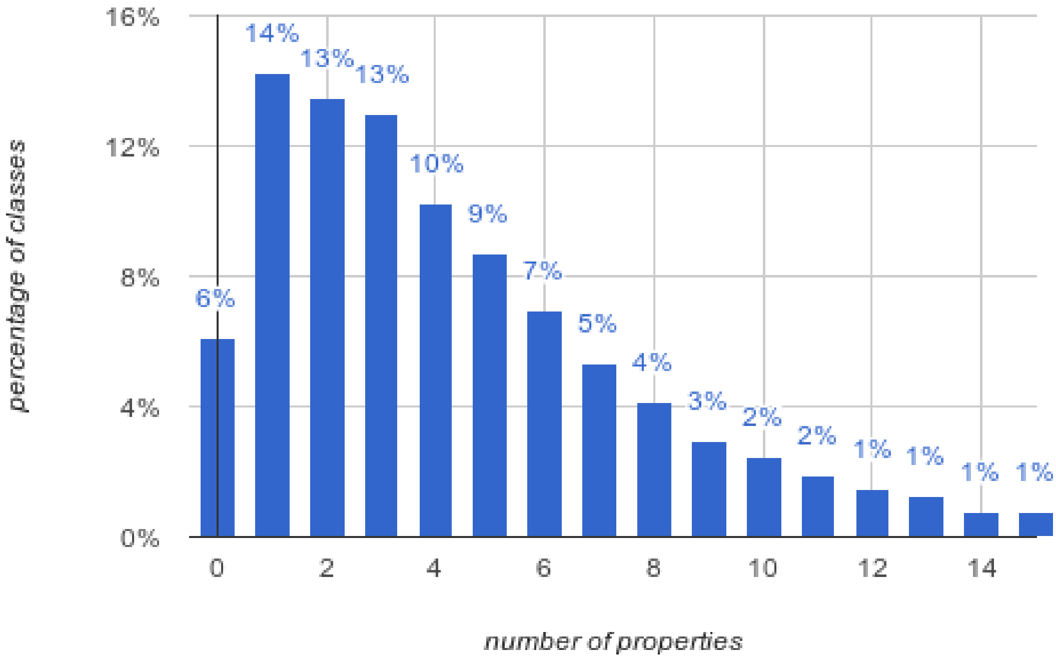

Figure 8: Percentage of unlinked, labeled, instantiated classes with a specific amount of unique properties. Wikidata (2016-11-07)

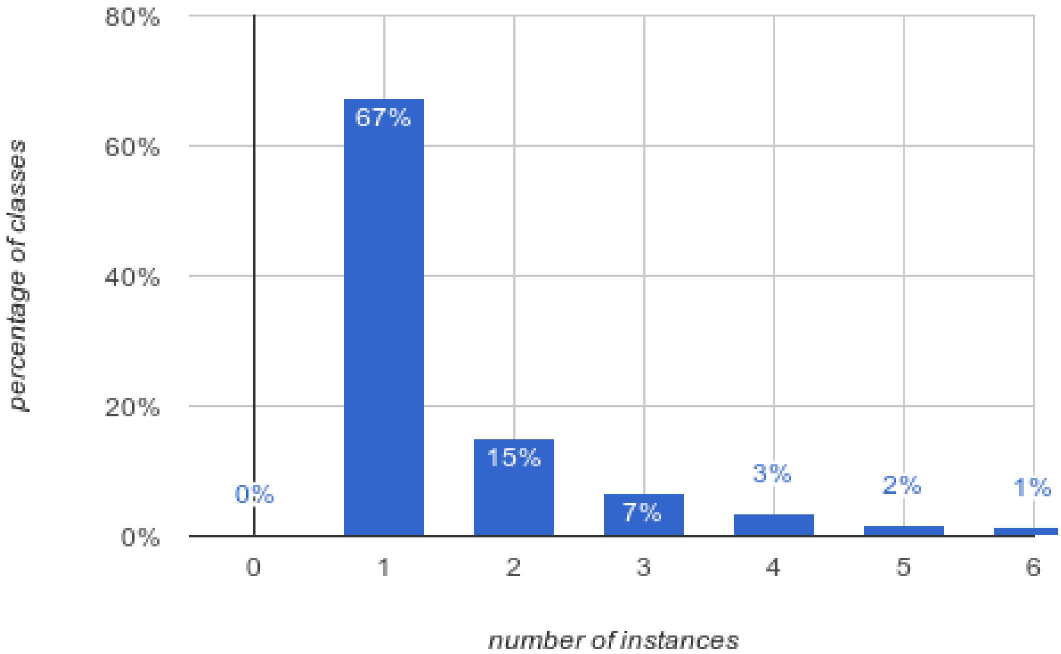

Figure 9: Percentage of unlinked, labeled, instantiated classes with a specific amount of instances. Wikidata (2016-11-07))

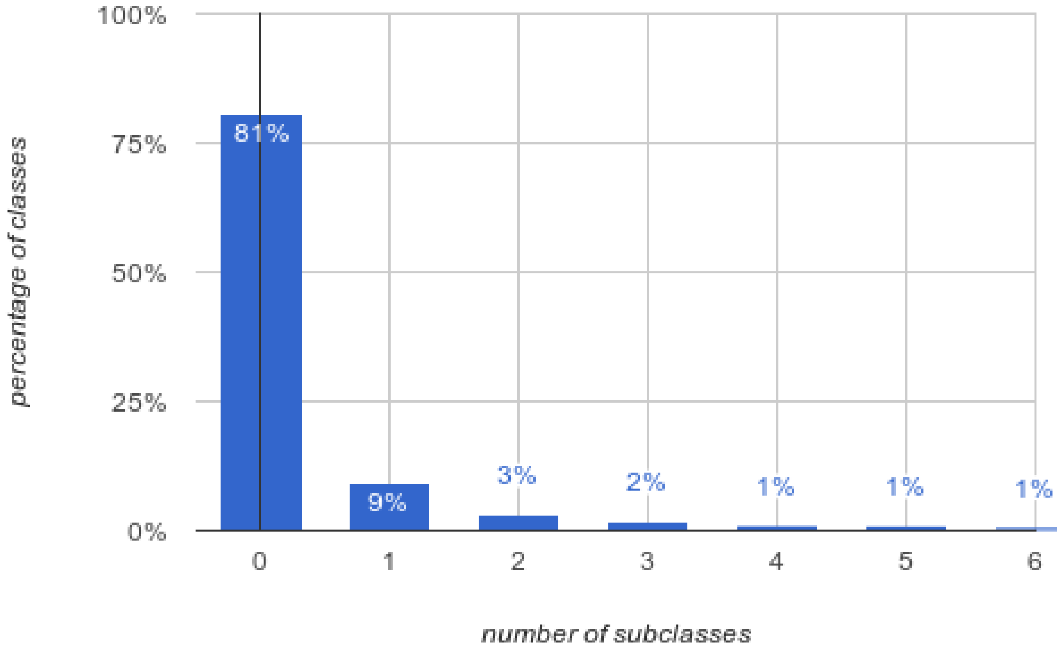

Figure 10: Percentage of unlinked, labeled, instantiated classes with a specific amount of subclasses. Wikidata (2016-11-07)

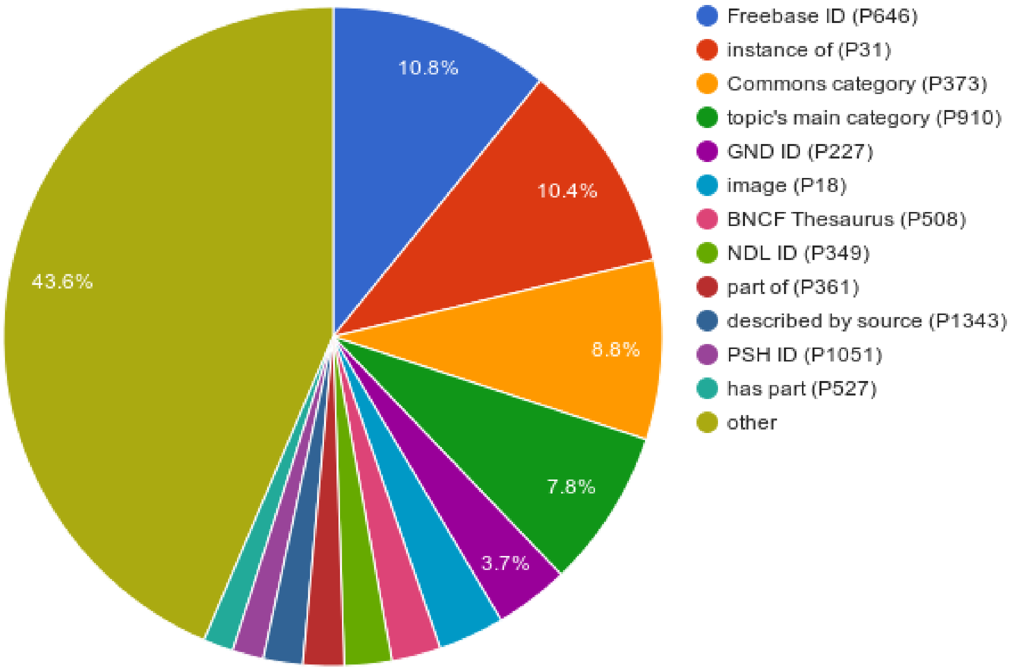

Figure 11: Frequency of properties in unlinked, labeled, instantiated classes. Wikidata (2016-11-07))

d'Amato et al. [7]
Petrucci et al. [19]
Fu et al. [10]

5 Neural networks

Notion of neural networks will be introduced.

5.1 Recursive neural networks for graph representation

Scarselli et al. [22]

5.2 Deep neural networks for graph representation

Cao et al. [3]
Raghu et al. [20]

5.3 Continuous Bag-of-Words

Mikolov et al. [18]

5.4 Skip-gram with negative sampling

Mikolov et al. [18]
Levy et al. [16]
Goldberg and Levy [12]

5.5 Comparison

6 Algorithm

6.1 Baseline

- Hyper parameters
- Training data

6.2 Supplementing with other resources

e.g. Wikipedia

7 Evaluation

7.1 Method

Dellschaft and Staab [8]

7.2 Generation of gold standard

7.3 Results

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