First Steps Toward a Digital Database of Aristotelian Diagrams

Wouter Termont
Center for Logic and Philosophy of Science, KU Leuven
wouter.termont@kuleuven.be

Lorenz Demey
Center for Logic and Philosophy of Science, KU Leuven
lorenz.demey@kuleuven.be

Hans Smessaert
Department of Linguistics, KU Leuven
hans.smessaert@kuleuven.be

ABSTRACT

Aristotelian diagrams occupy an important place within the broader cultural heritage that accompanies the discipline of logic. In recent years, logical geometry has begun to study these diagrams as objects of independent interest. We are currently developing a comprehensive digital database, which aims to provide easy online access to the thousands of Aristotelian diagrams that have been used across history and across disciplines. The aim of this paper is to report our first steps in this development process, emphasizing our choice for using Semantic Web standards. In particular, we discuss Linked Open Data, the Resource Description Framework, RDF Schema and the Web Ontology Language, and show their (expressive and inferential) advantages for our particular purposes.

CCS CONCEPTS

• **Applied computing** → **Arts and humanities**; • **Theory of computation** → *Logic*; • **Human-centered computing** → Information visualization.

KEYWORDS

Aristotelian diagram, Semantic Web, RDF, RDF Schema, OWL, Linked Open Data, logical geometry, logic, automated reasoning

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1 INTRODUCTION

An *Aristotelian diagram* is a compact visualization of a set of concepts or expressions, and certain logical relations holding among them. Throughout history, these diagrams have found numerous applications in philosophy and logic, and have thus come to occupy an important place within the broader cultural heritage that accompanies these academic disciplines. Furthermore, in the past decade, it has become clear that Aristotelian diagrams can also be fruitfully studied as objects of independent interest, thus giving rise to the burgeoning research area of *logical geometry*.

Aristotelian diagrams translate the abstract subject matter of logic into the concrete realm of visual space, and often even have clear aesthetic properties. Consequently, they can play an important role in the popularization of logic and its history. Furthermore, in light of the diversifying usage of Aristotelian diagrams today, it is important that researchers from one discipline can easily check whether a given diagram already occurs in other disciplines (to avoid reinventing the wheel). Finally, if logical geometry is not to become a pure armchair enterprise, its theoretical investigations should have a sound basis in the actual Aristotelian diagrams found in the literature. In light of these various reasons, we are currently developing a comprehensive digital database, which aims to provide easy online access to the thousands of Aristotelian diagrams that have been used across history and across disciplines. The aim of this paper is to report our first steps in this development process.

The paper is organized as follows. In Section 2 we briefly sketch the background and wide variety of applications of Aristotelian diagrams, emphasizing their role within broader cultural heritage. In Section 3, we propose the Semantic Web standards as the preferable approach to build a database of these diagrams. Sections 4, 5 and 6 look into the different (expressive and inferential) advantages of these standards: the fine-grained (internal and external) accessibility of Linked Open Data, the reusability and extensibility afforded by RDF Schema and OWL, and the semantic integration of these technologies in automated reasoning. In Section 7, we briefly address some challenges of these standards. Finally, Section 8 summarizes our argumentation and illustrates it by means of a more substantial example.

2 SCIENTIFIC & CULTURAL BACKGROUND

An Aristotelian diagram visualizes a set of expressions, and certain logical relations holding between them. In their simplest form, these relations are defined in terms of truth and falsity:[1] two statements are said to be

- *contradictory* iff they cannot be true together and they cannot be false together,
- *contrary* iff they cannot be true together but they can be false together,
- *subcontrary* iff they can be true together but they cannot be false together,
- in *subalternation* iff the first one entails the second one (i.e. whenever the first one is true, the second one is also true) but not vice versa.

The oldest and most well-known example of an Aristotelian diagram is the so-called *square of opposition* for the categorical statements from syllogistics — which was historically also the first logical system that was developed. A modern example of a square

[1] For more mathematically precise definitions, cf. [7].

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of opposition is shown in Fig. 1. Next to the square, there exist many larger, more intricate Aristotelian diagrams, such as hexagons and octagons, and even 3D diagrams, such as cubes and rhombic dodecahedra. Today, all these diagrams (and their interrelations) are systematically studied in logical geometry [7, 8].

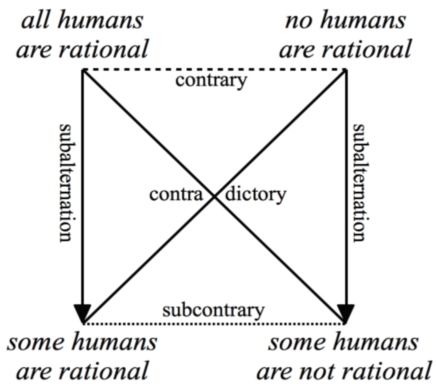

Figure 1: Square of opposition for the categorical statements from syllogistics.

Aristotelian diagrams have been used throughout the history of philosophy and logic, by distinguished authors such as William Ockham, John Buridan, Gottlob Frege, Hans Reichenbach and Arthur N. Prior. After a decline in popularity in the first half of the 20th century,[2] they are nowadays used very frequently again, often in rather unexpected areas, such as the philosophy of religion [10]. Furthermore, because of the ubiquity of the relations that they visualize, Aristotelian diagrams are currently also used in many other disciplines that are concerned with logical reasoning, such as psychology, linguistics, legal theory and computer science. For example, Fig. 2 shows an extension of the square, viz. a *cube of opposition*, that is used by AI researchers working on the knowledge representation formalism of graded possibility theory [9].

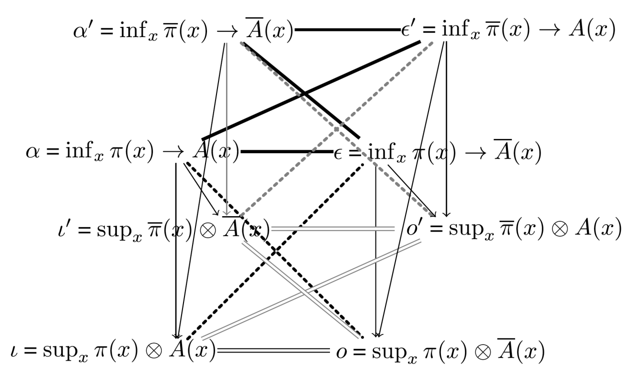

Figure 2: Cube of opposition in graded possibility theory [9].

Because of their tremendous popularity in philosophy and logic, Aristotelian diagrams have also come to occupy an important place within the broader cultural heritage that accompanies these academic disciplines. For example, by the early 13th century, the square of opposition had become so popular among logicians that it could be used as a visual metaphor for the entire discipline of logic — just like the astrolabe was an 'icon' of astronomy. For example, Fig. 3 shows a fragment from a manuscript[3] of Thomasin von Zerclaere's epic poem *Der Wälsche Gast* from around 1420 [23]: on the right we see a woman that represents the discipline of logic (*dialectica*), on the left we see the best and most famous practitioner of this discipline (Aristotle); together, these two characters are holding up the square of opposition that we see in the middle.

Figure 3: Square in *Der Wälsche Gast* [23].

Other, perhaps even more exotic examples of Aristotelian diagrams can be found carved in the plaster walls of a 13th-century Swedish church building [15], in a stained glass window from 1521 at Eton College [2] and in large educational posters (so-called 'broadsides'), such as Philander Colutius's *Logicae universae typus* (1606; 73.3 × 48.5 cm) [1]. Finally, to illustrate the great care but also the artistic freedom that authors took in producing Aristotelian diagrams, Fig. 4 shows a 'circular' square of opposition for the categorical statements (recall Fig. 1) that is due to Augustinus Vandungen, a student at the University of Leuven in 1759 [14].[4]

3 THE SEMANTIC WEB

Given the interdisciplinary aims explained above, a key factor of the proposed database should be its usefulness for researchers from a diverse range of interests (logic, computer science, psychology, historiography, cultural heritage, etc.). This breadth entails a minimum level of comprehensiveness needed, both in absolute numbers and in the relative amount of data relevant to each field of interest. One way in which this aspect can be promoted is to enable researchers to contribute data to the database: new Aristotelian diagrams, annotations of existing diagrams, or (at a later stage) even corrections of mistakes in the existing annotations.

Furthermore, it follows from the interdisciplinary nature of the database that the format in which the data are (or can be) represented or added cannot be tailor-made to a specific approach. Great care should therefore be taken in designing the online interface to

[2] See [6, 13] for the broader cultural background of this temporary decline.

[3] Heidelberg, Universitätsbibliothek, Cod. Pal. germ. 330, f67v.

[4] Brussels, Royal Library of Belgium, ms. II 3212, f104v.

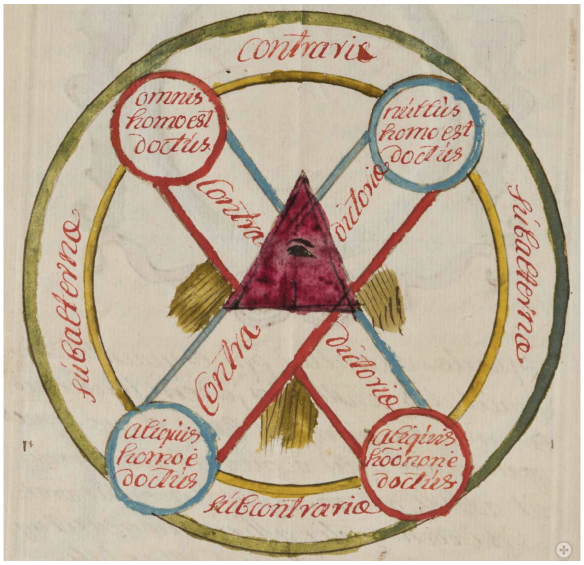

Figure 4: ‘Circular’ square of opposition [14].

the database, providing equally good accessibility to researchers from any of the various disciplines. One solution could be to start from a non-field-specific core format, and provide the option to view the data in any of a number of representational transformations of this common format.

To further accommodate the various research needs, much added value could come from the ability to extend the diagram data with more field-specific annotations, or link and combine them with other data sources. In order to provide this kind of extensibility, the raw data should be accessible independently of the interface, in a format that can be processed by external tools.

The above considerations have led us to adopt certain Semantic Web standards to format and represent the data. These standards, promoted by the World Wide Web Consortium (W3C), provide a framework of data formats and exchange protocols that facilitate sharing, reusing and integrating data across different applications and systems [31]. Their ultimate goal is to represent semantically structured knowledge that is machine-readable[5] in a *Web of Data* — as a complement to the current *Web of Documents*. This knowledge can manifest itself as additional semantic markup inserted in existing documents or as a separate data store supplementing or replacing those documents. The Semantic Web standards developed for these purposes rest most heavily on the fundamental Resource Description Framework (RDF) [30], an extremely simple abstract language, with multiple concrete syntactic formats,[6] for expressing data and data models based on a system of triples. Each triple describes a subject resource as having a certain relationship (a.k.a. ‘property’ or ‘predicate’) with an object resource.

These Semantic Web standards have only gradually found their way in Digital Humanities. Surely, there are some large central projects, like the Dublin Core Metadata Initiative (DCMI) ontologies for metadata design [5]; the many bibliographic description models of the US Library of Congress Linked Data Service [3]; or the Conceptual Reference Model (CRM) of the ICOM International Committee for Documentation (CIDOC) [12], aimed at cultural heritage documentation and used, for example, by the Oxford Linked Open Data project (OXLOD) [24]. Some smaller tools also exist, like the Historic Event Markup and Linking Project (Heml), which proposed a switch to RDF in 2009 [18]; or Recogito, the online collaborative document annotation platform of the Pelagios Commons geodata community [17]. However, the Semantic Web ideas never became popular enough in the Humanities to populate the envisioned Web of Data with all available the data. On their webpage, Pelagios introduce the Semantic Web idea of Linked Open Data as “an old idea that is slowly coming of age.”

Because of this slow uptake of Semantic Web standards, projects in Digital Humanities tend to stay with the tried and true: relational databases (RDBs). This methodology has been the standard for ages, and has definitely proved its worth. Moreover, tools are available to make existing RDBs accessible via the same Semantic Web interfaces native to RDF. Vice versa, relational data can equally well be stored in RDF as in RDBs. Because of these close similarities, it can be hard to choose between both approaches. In Sections 4, 5 and 6, we will therefore describe in more detail three clusters of the advantages of RDF, that we believe to tip the scale.

4 LINKED OPEN DATA AND THE IRI

A first cluster of advantages lies in its design as the core framework of the Semantic Web. In order to reach this envisioned Web of Data, RDF has the same linking structure as the current (non-semantic) Web of Documents, forming a directed, labelled graph of links between resources. Data with this structure are called *Linked Data* — and under an open license this becomes *Linked Open Data* (LOD) [28]. To make Linked Data workable on the huge scale of the Web, both the data and their relationship links should be identifiable in a standardized way.

RDF grounds this identification in Internationalized Resource Identifiers (IRIs) [25]. Since every piece of data in RDF is a triple, this means that every subject resource, predicate and object resource is identified by such a unique string of characters (with the exception of blank nodes in the graph and objects that contain literal data, i.e. text, numbers, etc.). IRIs are a generalization of URIs (Universal Resource Identifiers) that add support for non-ASCII characters. The best known and most used of these URIs are URNs (Universal Resource Names) like DOI and ISSN numbers, and URLs (Universal Resource Locators), which additionally allow for each resource to be located on some server. For example, each Web address is a URL and thus an IRI.

Consider an Aristotelian diagram by the 14th-century French philosopher John Buridan, a scan of which could, for example, be stored on the database’s server as `http://logicalgeometry.org/buridan.jpg`. For ease of notation, RDF allows us to shorten IRIs with prefixes, so if `lg` stands for `http://logicalgeometry.org/`, this becomes just `lg:buridan.jpg`. Now the database of diagrams could contain some knowledge about this diagram, for example the RDF triple

[5]While ‘machine-readable’ literally means ‘can be processed by machines’, within the aims of the Semantic Web it clearly means ‘can be processed by machines and humans alike’.

[6]Most prominently RDF/XML, N3, Turtle, RDFa and JSON. In this paper, Turtle is used to express the examples.

`lg:buridan.jpg lg:origin lg:summulae` where `lg:origin` stands for the relation between scans and the work from which they originate, and `lg:summulae` stands for Buridan's work *Summulae de Dialectica*.

This use of IRIs within RDF triples might seem trivial, but it shows an immediate advantage over relational databases: individual resources are not just *internally* identifiable, but also *externally*; they are linkable. While the diagram database will contain much detailed information about different diagrams, e.g. their logical and geometric similarities and differences, it will contain fewer details about the sources they originate from. Other researchers might be in exact opposite situation, when they are working on medieval manuscripts, for example. Due to the power of IRIs, both groups of researchers can now easily refer to each separate diagram or manuscript in each other's databases, e.g. `ms:summulae ms:contains lg:buridan.jpg`, where `ms` is the prefix of a manuscript database. Human readers and machines alike can then simply follow the link between the two databases to find detailed information on both the manuscript *and* the diagram it contains. These two directions of fine-grained data references thus form a first strong advantage compared to RDBs. In concreto, the above could be realised for some of the medieval diagrams by referring to the manuscripts in the library of digitized historic literature of the University of Heidelberg [22]. For example, their digitized version of Buridan's manuscript in the Biblioteca Apostolica Vaticana, Pal. lat. 994, has the IRI `urn:nbn:de:bsz:16-diglit-107614`. Plugging this IRI in the example above, it becomes: `urn:nbn:de:bsz:16-diglit-107614 ms:contains lg:buridan.jpg`.

Another way in which the diagram database could benefit from IRI references is for the representation of the diagrams' logical content. The concepts and relations represented in an Aristotelian diagram make up a logical graph [7]. The Content Dictionaries of the OpenMath [21] project provide a standardized reference to symbols used to formulate mathematical expressions. At the time of writing, they only provide a crude symbolic representation of graphs (at the IRI `https://www.openmath.org/cd/graph1.html#graph`), but they allow for the proposal of extensions. In light of the diagram database, we could therefore propose a more detailed set of symbols to represent graphs by IRI reference.

5 SCHEMATA AND ONTOLOGIES

On top of these data-level possibilities, a second group of advantages can be found in the extensibility of RDF's higher-level semantics. More specifically, RDF allows us to theoretically ground the data in RDF Schema (RDFS) [27] and the Web Ontology Language (OWL) [29].

5.1 RDF Schema

Extending RDF with a number of semantic concepts, RDF Schema — another W3C-recommended Semantic Web standard — provides a generalized way for the description of custom vocabularies and basic ontologies (e.g. taxonomies). RDF itself already allows us to represent class–instance relationships with `rdf:type`; for example: `lg:buridan.jpg rdf:type lg:AristotelianDiagram`.[7] This `rdf:type` relation is also used, for example, to indicate which resources are themselves relations: `lg:origin rdf:type rdf:Property`. However, the expressive power of these constructs is not sufficient to represent in a standardized way the complex hierarchies that are often present in data. Therefore, RDFS adds, amongst others, `rdfs:subClassOf`, allowing us, for example, to add a superclass `lg:LogicalDiagram` to which other (classes of) logical diagrams (e.g. `lg:DualityDiagram`) could be added in the future: `lg:AristotelianDiagram rdfs:subClassOf lg:LogicalDiagram`.[8]

While the use of RDFS to construct taxonomies of data already supersedes relational databases in its flexibility, the real advantage lies in its combination with the uniquely identifiable references described earlier. This introduces a whole new level of reusability and extensibility. A number of interesting vocabularies have therefore grown to be central names in the Semantic Web.[9]

A useful example for the diagram database is the Friend Of A Friend (FOAF) vocabulary [16]. It defines a vocabulary of concepts about people, documents, and the links between them. It can, for example, be used as a Linked Open Data interface between social networks, or to represent other structures of interpersonal connections (real or fictional). While the real purpose of FOAF is to model such connections between people with the `foaf:knows` relationship, for the purpose of the database it is most useful to represent the authors of Aristotelian diagrams in a simple, reusable way. For example, medieval authors were/are often known under many different names. With FOAF, we can represent this as follows:[10]

```
Individual: lg:buridan
     Types: foaf:Person
     Facts: foaf:name “John Buridan”@en
            foaf:name “Johannes Buridanus”@la
            foaf:name “Jean Buridan”@fr
            foaf:made lg:buridan.jpg
```

The precise semantics of these concepts, as defined by the FOAF project, is not needed for the advantage of using them: adding links to the FOAF vocabulary indicates that some of the things the diagram project is concerned with are precisely the kind of things that also concern other projects linking to FOAF, with exactly the same semantic value. For example, everything stated to be a `rdf:type foaf:Image` (in any database of any data project), belongs to the same semantic class — in casu, an `rdfs:subClass` of `foaf:Document` that `foaf:depicts` something.

Another much-used RDFS vocabulary that could function in a similar way is the Dublin Core Schema by the Dublin Core

[7] Here the convention is used to start class names with a capital letter. Notice also that the prefix `rdf` is used to refer to the space where the W3C RDFS concepts are to be found.

[8] RDFS also adds some elements that are especially interesting for the human aspect of data projects: `rdfs:label` and `rdfs:comment` to provide a human-readable names and descriptions for the resources, as well as `rdfs:isDefinedBy` and `rdfs:seeAlso` to additionally provide defining and informative resources.

[9] RDFS's power in expressing taxonomies is itself extended by the popular Simple Knowledge Organization System (SKOS) [26].

[10] For ease of notation, code blocks will be written in in OWL's Manchester Syntax.

Metadata Initiative (DCMI) [5]. It defines a set of metadata terms to describe digital and physical resources somewhat more detailed than FOAF (but lacking representation for the connections between people). For example, we can add that `lg:summulae rdt:type dcterms:BibliographicResource` and `lg:buridan.jpg dcterms:source lg:summulae`.

While the DCMI vocabulary in itself still lacks the detail needed to fully describe resources in a bibliographic way (e.g. by semantically representing their complete BibTeX records), since November 2018 they took up responsibility for maintaining the Bibliographic Ontology (BIBO) [4]. In BIBO we can, for example, represent the Codices Palatini Latini as `lg:pal-lat rdft:type bibo:Collection` and locate the manuscript in it:

```
Individual: lg:summulae
     Types: bibo:Manuscript
     Facts: bibo:isPartOf lg:pal-lat ,
            bibo:locator "994"
```

Given the large user-base of the DCMI, we can expect BIBO to become a standard in the next years. It is therefore a good choice, although possible alternatives do exist, e.g. the BIBFRAME ontology of the US Library of Congress Linked Data Service [3].

5.2 The Web Ontology Language

Where RDFS succeeds in describing simple hierarchical structures, the Web Ontology Language (OWL) extends it even further. It allows for axioms to specified for on the individuals, classes and properties of RDF(S).[11] In the earlier examples, we suggested to link to external manuscript resources instead of using our own representation of the manuscripts. Up till now, this would mean changing existing data triples, which might have unexpected consequences in complex ontologies, just like updating a relational database. In OWL, however, we can simply leave the data untouched, and add the statement `lg:summulae owl:sameAs urn:nbn:de:bsz:16-diglit-107614`.[12] The same can be done for classes with the `owl:equivalentClass` relation. For properties, we can also indicate how they relate to each other. A lot of semantic value can be gained, for example, by stating for the properties of the manuscript example that `lg:origin owl:inverseOf ms:contains`.

OWL also enables complex class constructors, which allow us to define a class by simply describing its restrictions. A traditional Aristotelian square of opposition (cf. Fig. 2), for example, could be described as follows:

```
     Class: lg:AristotelianSquare
SubClassOf: lg:AristotelianDiagram ,
            lg:hasShape some geo:Square
```

The `some` indicates the property restriction that the class only contains individuals that stand in the `lg:hasShape` relation with at least one `geo:Square`. Similar restrictions also exist for cardinalities: we could, for example, state that each diagram `lg:visualizes exactly 1 lg:LogicalGraph`. In the example above, the prefix geo refers to the geometric ontology of the Department of Astronomy at the University of Maryland [20].

One last useful property introduced by OWL is `owl:imports`. Up till now, reusability was described as the possibility to use IRIs of existing data, for example in detailed reference to a resource in some other database (cf. Section 4). The facts about those resources, however, are still stored somewhere else. What if we want our own database to include these facts as well? With the above property, OWL allows us to import — or rather: allows us to *state* that we import — an entire other dataset or ontology into our own. Such an import can be useful, for example, to reason about reused statements *locally* (i.e. without having to retrieve them from somewhere else first).

6 AUTOMATED REASONING

All of the advantages described in Sections 4 and 5 are broadly about the static expressive power of the Semantic Web standards. The biggest advantage of these specifications, however, is of a dynamic nature: they make the data machine-readable. A machine reasoner can semantically understand the diagrams, situate them within the ontology, and infer new information about them (e.g. two distinct diagrams sharing a non-trivial feature).

One could argue that machines can also do the same with relational databases. However, in the case of RDBs, the semantic interpretation of the resources is hard-coded in the reasoning program itself. The semantics of each term is constructed precisely in function of what the program does with it. RDF(S) and OWL, on the other hand, provide the semantics independent of program interpretation. These standards allow every reasoner to infer the same additional information based on the data that are explicitly provided. The semantics is thus integrated in the data itself.

To continue the example from Section 5.2, as soon as we state that a diagram is an `lg:AristotelianSquare`, a basic reasoner will infer that it is also an `lg:AristotelianDiagram` that `lg:hasShape some geo:Square`.

Using the constructs explained in this section, OWL reasoners can compute subtle and powerful consequences. This power is not always an advantage, since OWL in its full expressivity (OWL Full) is undecidable (i.e. some questions in it cannot be answered in a finite amount of computational time). To circumvent this, OWL can be limited to a number of interesting sublanguages, each optimized for a certain computational task. Without going into detail, the most interesting for the diagram data is OWL QL, a 'query language', optimized for questions pertaining to a large number of data described by a relatively small ontology.[13]

7 CHALLENGES OF THE SEMANTIC WEB

The last three sections have listed some key advantages of choosing Semantic Web standards over a traditional approach with relational databases. For these reasons, we have chosen to adopt the Semantic

[11] OWL also introduces some extra syntaxes: a high-level functional one, that closely follows its abstract definitions, but also a new XML syntax (OWL/XML) and the Manchester Syntax, the latter with a strong focus on human readability. Of course, all RDF syntaxes can still be used, since the whole of OWL is based on that framework.

[12] Similarly, we can state the opposite with `owl:differentFrom`.

[13] Two other subset are OWL EL, optimized for existential questions pertaining to larger ontologies with a smaller number of entities per ontology class, and OWL RL, a sublanguage optimized for rule-based modelling.

Web approach in developing the database of Aristotelian diagrams. No technology is perfect, however, and thus there are also certain challenges to using these standards.

A first challenge was already indicated in Section 3: the general uptake of the Semantic Web within Digital Humanities is slow, and only a handful of larger authoritative ontologies have grown popular enough to leverage the power of an interlinked Web. Given that the traditional approach already lacks these abilities to begin with, however, this challenge should be seen as one to rise up to, by publishing new, interesting and well-authored ontologies for other research to reuse and expand.

Another challenge might be a more technical one, and is mostly due to the maturity of the traditional approach. Relational databases, after all, have been around for decades longer than the Semantic Web, and have through the years been optimized to the point of perfection. These performance issues, however, should only concern data projects with extremely large datasets — genuine 'Big Data'. Benchmark studies already show good performance for Semantic Web technologies on datasets with billions of entries [11, 19]. For the purposes of a diagram database, differences in this order of magnitude have no application: even on a very enthusiastic estimate, the number of diagrams in the extant literature only runs into the (tens of) thousands.

8 CONCLUSION

The goal of this paper has been to describe our first steps in developing a database of Aristotelian diagrams, which are an important part of the cultural heritage of logic. We proposed Semantic Web standards as the preferable approach. They allow for a more accessible, reusable and extensible model than a traditional relational database, and enable automated semantic reasoning on the dataset.

To conclude our argumentation, we provide a more substantial illustration that shows how the various examples discussed above could be integrated to (partially) describe the many aspects of the Aristotelian diagram in Fig. 3.

```
Individual: lg:Vandungen001.jpg
Types: lg:AristotelianDiagram ,
       lg:hasShape some geo:Circle ,
       dcterms:source some ( bibo:Manuscript that
         bibo:isPartOf some ( bibo:Collection that
           bibo:title value “Magister Dixit” ) ,
         and bibo:locator “ms. II 3212” ,
         and dcterms:title “Dialectica”@la ,
         and dcterms:creator some (foaf:Person that
           foaf:name value “Augustinus Vandungen” ) ,
         and dcterms:created 1759 )
Facts: lg:isEmbellished true ,
       lg:directedEdges false ,
       lg:hasVertex “omnis homo est doctus”@la ,
       lg:hasVertex “nullus homo est doctus”@la ,
       lg:hasVertex “aliquis homo est doctus”@la ,
       lg:hasVertex “aliquis homo non est doctus”@la
```

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