The wind in our sails: Developing an accessible, transparent, reusable, and maintainable knowledge graph in the field of Dutch maritime data

MSc Thesis by Stijn Schouten

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Abstract. to-do
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1 Introduction

Digital humanities research is a multidisciplinary field in which computer science and complex social questions are combined. Digital humanities researchers utilize computational processing power to create and present insights that were not possible before in traditional humanities research. [1] Due to large-scale digitalization efforts in recent decades, the volume of digitally available records is enormous. [2] For instance, the Amsterdam Archives has scanned over 8 million pages in its archive at the moment of writing.[1] Another example, one more relevant to this project, is the VOC databases and their digital records. The Vereenigde Oostindische Compagnie (VOC) was a large trading company founded in 1602 in the Netherlands. [3] The VOC created and curated several written logbooks. These logbooks covered, for instance, the sailors who ventured on the journey to the East Indies and who might never return[2]. The logbooks also cover the

[1] https://alleamsterdamseakten.nl/overhetproject/ retrieved at: 17-04-2021
[2] https://www.nationaalarchief.nl/onderzoeken/zoekhulpen/voc-opvarenden retrieved at: 17-04-2021

cargo shipped by these journeys. Some relatively innocent, such as spices, while others less so[3]. These logbooks were eventually converted to a digital format by efforts of archives and research institutes.

However, these digitalization projects come at a cost. Lora M. Hughes describes that digitizing, storing, and publishing data is a costly endeavor. The usefulness of such projects is not apparent immediately. [4] It takes time for researchers to compose stories about the people who lived then or to incorporate the digitized data in some greater coherent theory. Therefore, the focus in digitizing projects are becoming more result-driven. [2]

Research questions

In this research project, a knowledge graph is iteratively designed and developed. The design and development are some of the more practical goals of this research. Moreover, the owners/curators of the data would be interested in the designed artifact, a useful knowledge graph. This artifact, which will be discussed in the next section, can be used by digital humanities researchers and other enthusiasts to 'accelerate' their research projects. Meaning, the artifact can be seen as a tool that can drive result-driven research and help answer the research questions of these digital humanities researchers.

The wind in our sails project is a research project. Therefore, the process of creating the artifact is heavily monitored and curated. The decisions made during the process are described and weighed against the alternatives. The process of creating a sustainable knowledge graph could be helpful in other conversion and extension projects. Furthermore, the implementation should be replicable and applicable for other projects. These theoretical and practical implications are boiled down to the following research question:

RQ: How can a sustainable knowledge graph be developed which is useful for researchers in the field of Dutch maritime data?

The main research question aims to create an artifact, the knowledge graph, that fulfills the set requirements of sustainability and usefulness. The chosen approach is an iterative design science method that involves two design and test cycles. This unique approach allows for multiple rounds of feedback during the research project.
There are two characteristics found in the main research question. First, the result and the approach should be *sustainable*. Second, the designed artifact should be *useful* for researchers. These characteristics are captured in the following sub-research questions:

SRQ1: What is a sustainable method of developing a knowledge graph related to Dutch maritime data?

[3] http://resources.huygens.knaw.nl/boekhoudergeneraalbatavia retrieved at: 17-04-2021

SRQ2: How can a useful knowledge graph be developed for Dutch maritime history and how can that be measured?

Measuring en determining the most sustainable approach can be subjective. Therefore, four quality attributes are defined that can be used to measure, steer, and can lead the design to a sustainable solution. These design requirements are set in cooperation with the project stakeholders and are as follows:

- *Transparency:* Clear and well-described design decisions and rules.
- *Accessability:* Results and intermediate results should be accessible.
- *Re-usability:* Re-usable methods and semantic models.
- *Maintability:* Future-proof knowledge graph in technology and extendability.

The usefulness variable of the second sub-research question is also challenging to describe and measure. In this research project, competency questions are used as a derivative of the usefulness variable. The term' scientific competency question' is first coined by Azzaoui, K. et al. [5] in their research of LOD in the domain of pharmaceutical data. These questions were used to prioritize datasets, build the ontology, and evaluate the validity of the designed artifact. The gathered competency questions are explored in the methodology section of the thesis.

2 Background & Related work

To complete research questions and research projects, digital humanities researchers need access to rich and available knowledge sources. Publishing and managing these sources in an open, available, and structured manner boasts the feasibility of such research projects. [4] Data can be shared in several procedures, such as an email containing CVSs of data or a central SQL database that hosts numerous tables. The user is responsible for collecting the different datasets, interpreting, refining, and finally creating the queries and filtering operations needed to answer their research question. This complex process is not always straightforward; some researchers can interpret variables differently from others, and combining different datasets can take up much time. [6] Another concern with traditionally sharing data is the problem of machine interoperability. A computer can not access the data directly in most cases. The user first has to download and load it into the application of choice. Moreover, a computer can not easily construct and define relations between two data entries. Thus, the human researcher is responsible for much of the intelligence behind the data-engineering.

2.1 Knowledge Graph

A knowledge graph can alleviate these problems. In the semantic journal [7] a knowledge graph is defined as follows:

> "Knowledge graphs are large networks of entities, their semantic types, properties, and relationships between entities."

The entities in this definition are the things in the world around us—for instance, the city of Amsterdam. The semantic type of Amsterdam is that of a city. This classification means that Amsterdam falls in the same class as Berlin, for instance. Amsterdam has a certain amount of residents; that number is a property of the instance of Amsterdam. The Netherlands, as a country type, is also an entity. Two entities can be related to each other via a relationship. In this case, we can define the relationship "hasCapital" and link The Netherlands to Amsterdam.

Instances are connected via a property or a relationship to some object. This serialization of three distinct data points is called a Resource Distribution Framework (RDF) triple and is the backbone of most knowledge graphs. The reasoning engine within a knowledge graph also plays a vital role. The reasoning engine takes RDF triples and an ontology and creates implicit statements. An ontology is considered a formal and explicit definition of a particular domain's shared conceptualization. [8] It describes the relation between semantic types, properties, and relationships. For instance, an ontology could describe that the property of "hasCapital" is the inverse of "isCapitalOf". After all, this holds as Amsterdam is the capital of the Netherlands. It further implies Amsterdam as a Capital City due to the domain (starts at) and range (ends at) functionality of reasoning languages. The reasoning engine creates these implicit RDF triples in the graph without user interference. This notion of explicit and implicit is illustrated in figure 1.

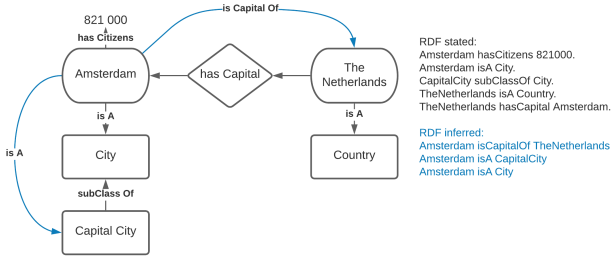

Fig. 1. Visualization of a knowledge graph and its reasoning engine

2.2 Semantic Web

A knowledge graph can be of great assistance in structuring data in a uniform way while also making it computer interpretable. However, the shareability problem would not be inherently solved as only the format changed. This shareability issue is solved by web-transforming the knowledge graph. A web-enabled knowledge graph is also known as a semantic web database. In the semantic

web database, instances are expressed in Uniform Resource Identifiers. For instance, Amsterdam is identified as https://dbpedia.org/resource/Amsterdam in the DBpedia knowledge graph.[4] Anyone in the world can now re-use and connect to the instance of Amsterdam by simply absorbing the URI in their semantic web database.

To instantly browse and connect to other semantic web databases on the web, SPARQL endpoints can also be traversed. SPARQL endpoints function as gateway ports to and from the semantic web database. With the use of SPARQL endpoints, multiple semantic web databases can be queried simultaneously.[9]

In short, knowledge graphs and semantic web technology drastically reduce the time a researcher has to spend browsing and preparing different datasets. Queries can be answered almost instantly, even with the most complex questions. The semantic web enables a more open infrastructure in which knowledge graphs can point to other knowledge graphs and query results due to standard SPARQL endpoints. Creating a knowledge graph and making it available on the web can solve many of the previously stated challenges of digital humanities research. The advantages of following this approach are illustrated in figure 2.

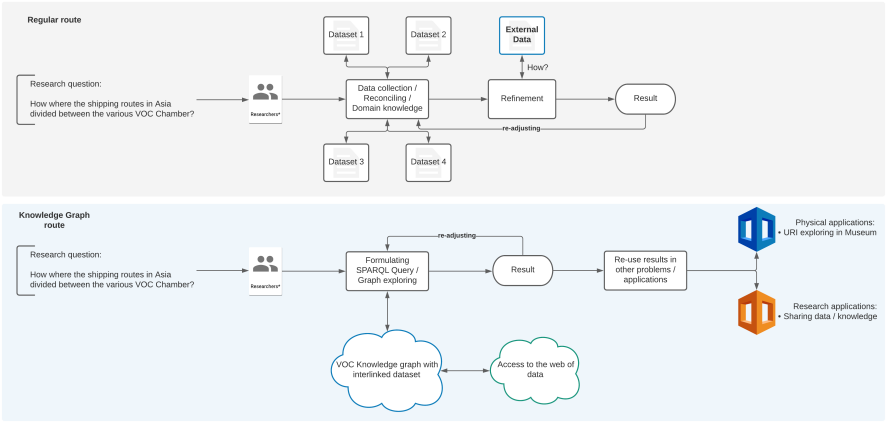

Fig. 2. Visualization of utilizing knowledge graphs in research

2.3 Literature review

Developing an accessible, transparent, reusable, and maintainable knowledge graph in the field of Dutch maritime data can be challenging. Therefore, existing work and literature are used to understand and build knowledge of the development of such artifacts. First, the four requirements are examined. The accessible,

[4] http://wikidata.dbpedia.org/about

transparent, reusable, and maintainable design guidelines appear closely related to the FAIR principles. The FAIR principles describe four principles that serve as guidelines for data and research publishers. The guidelines describe that publishers should provide Findable, Accessible, Interoperable, and Reusable (FAIR) data and research results. Adhering to this principle entails that the added value of research projects is significantly increased after publishing.[10] Researching similar development projects which adhere to the FAIR principle, or a relative of, can provide insightful knowledge for The wind in our sails research project.

The research project "Wikidata as a FAIR knowledge graph for the life sciences" of Waagmeester et al.[11] describes the development of knowledge graph (extension) on the Wikidata platform. In the research project of Waagmeester et al., existing data from other research is used to enrich biomedical graphs within Wikidata. Wikidata provides many interactivity methods for researchers, both graphically and computationally, thus making the solution *accessible* and *interoperable*. The solution is released under a creative commons zero agreement, making the graph freely available for any use. However, that does not automatically entail that the solution is *reusable*. Poor design decisions could be made during the process, rendering the solution poorly *reusable*. Finally, an interesting observation is made regarding the sustainable growth of the artifact after project completion. The authors presume that further growth of biomedical graphs within Wikidata is reliant on community efforts.

The work of Waagmeester et al. did not dive into the technical side of the implementation. Anastasia Dimou, with her work "The creation of knowledge graphs", does provide multiple approaches.[12] In short, Dimou compared dedicated mapping languages and restructured mapping languages for converting datasets to knowledge graphs. These mapping languages provide a general, albeit challenging, approach to converting multiple datasets into knowledge graphs. The languages and applications discussed are not extensive. Therefore it can be fruitful re-do some of the analysis of the discussed tools and other tools alike for The wind in our sails research project.

In an attempt to encompass both the higher-level properties of knowledge graph engineering and the detailed, technical side of these projects, Milos Jovanovik proposes a new Linked Data application development methodology.[13] This methodology is, in the study, compared to other existing Linked Data methodologies. The methodology focuses on allowing data- and domain engineers to produce high-quality linked data aligned with the semantic web. Furthermore, the methodology is centered around the re-usability of methods and conversion methods utilizing a modular approach.

In conclusion, the design guidelines of developing an accessible, transparent, reusable, and maintainable knowledge graph are close related to the FAIR[10] principle. The work of Waagmeester et al.[11] provides us with tips and pointers on how to develop a knowledge graph according to the FAIR principle. Dimou[12]

dives more into the technical side of knowledge graph engineering and inspires further research and comparison of these approaches. Finally, Jovanovik[13] brings it together with his linked data application development methodology, which focuses both on FAIR principles and the technical implementation.

2.4 Related projects

In the literature review, general high-over projects are discussed. [11, 12] However, these projects are of a different domain than maritime history. In this subsection, two relevant projects are examined in more detail.

De Boer et al. [14] started in 2014 with Dutch Ships and Sailors (DSS). In this project, the researchers harmonized four different datasets to unify the scattered Dutch maritime data. [14] Additional work in this domain has been completed by Entjes [15] in 2015. Although Entjes did not explicitly mention the use of competency questions within his research, the research is driven by a similar methodology.

The work of Entjes[15] and De Boer et al.[14] is reflected upon by utilizing the defined design guidelines. The projects are both designed with a high level of *transparency* and *accessibility*. All the design decisions made during the Dutch Ships and Sailors (DSS) projected are stored on the project website [5] and include information such as datasets conversions, methodologies, and much more. By including the project team's thought process, the decisions can be followed and understood, even as an outsider. Furthermore, the project website also hosts a semantic server that can be used to access the knowledge graph directly. All graphs in the database can even be downloaded separately.

However, the other guidelines should be considered as well. In DSS, multiple general-purpose ontologies and models are used, and a specific model is created for the maritime activities. This design decision has definite upsides as it is generally recommended to re-use as many models and ontologies to enable interoperability with other graphs on the web. [6] Still, these general-purpose ontologies are, as the name describes it, general-purpose. Thus, concepts as naming or things as actors can be captured well. But, domain-specific concepts are not captured in these models. This design decision makes the re-usability of DSS regarding the semantic web high (due to the utilization of general-purpose ontologies) but regarding domain-specific projects low as it is unlikely that the concept of Ship in DSS is used between projects outside of the DSS sphere.

The third implementation of this domain has been completed during the 2019 Time Machine conference.[7] During this conference, Beretta et al.[16] presented the OntoMe application.[8] As part of the presentation, the Dutch maritime datasets were selected and converted to a knowledge graph. Like the work of De Boer et al.[14] and Entjes[15], the work of Beretta et al.[16] is also reflected upon

[5] https://dutchshipsandsailors.nl
[6] https://www.w3.org/standards/semanticweb/ontology
[7] https://digital-strategy.ec.europa.eu/en/events/time-machine-conference-2019
[8] `http://ontome.net`

according to the design guidelines. The project is designed with a high level of maintainability as the poster proposed a method of maintaining and distributing ontologies for digital heritage projects. Furthermore, the selected ontology, an adapted version of the CIDOC CRM, is a widely accepted and highly detailed model for digital heritage. Concepts in this model, such as voyages, have a better chance of being re-used in other semantic web projects, thus offering great alignment possibilities. However, it has to be noted that unlike DSS, which used widely accepted conventions for naming things (SKOS, DCTerms, etc.), the OntoMe implementation sticks to CIDOC CRM conventions. This design decision can lead to better interoperability possibilities with related projects but lower connectedness with the semantic web cloud.

Nevertheless, the transparency and accessibility design principles can be improved. Design decisions are not openly published, making it difficult for outsiders to understand and follow the thought process during the design. However, the adjusted semantic model is posted and accessible on the OntoMe platform.[9] During the interview with the domain expert from the Huygens, it was apparent that the knowledge graph was challenging to access. No direct download links are provided while the SPARQL endpoint seems to be in beta as of writing.

In conclusion, the discussed projects have their strength and weaknesses. Some design decisions can be re-used for this research project, such as the transparent methodology of DSS or the model maintainability of the OntoME project. The lessons learnt are summarized in the table below.

	DSS and its extension	OntoME implementation	*Wind in our sails*
Transparency	Good, clear process.	To be improved.	*Improve on previous iterations.*
Accessibility	Good, easy access.	To be improved.	*Improve on previous iterations.*
Re-usability	To be improved.	Good, encompassing model.	*Improve on previous iterations.*
Maintainability	To be improved.	Good, ontology management.	*Improve on previous iterations.*

Table 1. Overview of previous implementations

2.5 Related tools

The work done by de Boer et al.[14] and Entjes[15] provides an insight into the linked data development of maritime history. Furthermore, the work of Dimou[12] and Jovanovik[13] discusses several approaches briefly. However, it would be beneficial to reflect and explore the approaches discussed and used as a lot can change in software. [17, 18]

The first approach consists of tools based around the RDF Mapping Language (RML). This mapping language is discussed in the work of Dimou[12] as well. Applications built on top of this technology include, but are not limited to,

[9] `http://ontome.net/project/28`

CARML[10], RMLEditor[11], and Yarrrml (matey)[12]. The RML based editors have their function when a researcher has to combine multiple, differently structured datasets and map entities between the sets.[19] However, all RML-based applications lack a workable visual or GUI representation. This downside makes the recommendation to use such an approach difficult for users outside computer and information science. The keyword 'workable' is of importance here, the RMLEditor[13] is a graphical editor, but it currently limits the user to twenty connections and a file size limit of 2 MB. An email requesting a more extensive version of the application is so far not met with a reply.

In the next category, we have the tools of the DataLegend ecosphere.[14] These tools allows domain experts to (semi)-automatically convert tabular data into RDF. [20] The tooling is well capable of quickly producing high volumes of RDF data with minimal user input. Modeling the data according to a strict ontology and even linking entities within a dataset is more difficult due to the mapping file workflow.

GraphDB is developed by the commercial company Ontotext.[15] This approach is mentioned by Jovanovik as well.[13] GraphDB is, like the name suggests, a database system for knowledge graphs. Later installments of GraphDB are preinstalled with OntoRefine[16], a tool for cleaning, reconciling, and converting tabular data into RDF. The user can do the complete data-processing work within the GraphDB application. These relatively easy-to-use data cleaning and management tools provide a solid workflow in preparing data for RDF conversion.
In The wind in our sails project, the GraphDB application is used for the conversion. The tool is transparent due to its interface. Users can directly intuitively influence the mapping. The tool is reusable due to the ability to import and export mapping tables between projects. Maintainability also scores high due to the active development of the application.[17] The only criticism it faces is the lower accessibility. A commercial company develops the application. Thus, it makes sense that large-scale implementations are paid. It is not necessarily a bad thing. In return, support and active development are provided. Something that is not certain with the use of open-source (free) solutions.

2.6 Related ontologies and models

The Dutch Ships and Sailors (DSS) project and the "Archangel & Elbing" extension share the same ontology. Meaning, an instance of the class ship has the

[10] https://github.com/carml/carml
[11] https://rml.io/tools/rmleditor/
[12] https://rml.io/yarrrml/matey/
[13] https://rml.io/tools/rmleditor/
[14] `https://iisg.amsterdam/en/clariah`
[15] https://www.ontotext.com/products/graphdb/
[16] https://openrefine.org
[17] `https://graphdb.ontotext.com/documentation/standard/release-notes.html`

same meaning across the different research projects. In previous sections, the up-and downsides of using the ontology of DSS are discussed. In the third related project, the OntoMe implementation, a different ontology is used. In this project, an extended version of the CIDOC Conceptual Reference Model (CRM) is used. The CRM is a high-level formal ontology for integrating cultural heritage datasets around the world.[18] A high-level ontology is an ontology that can capture a wide range of phenomena by avoiding detailed definitions.

In The wind in our sails project, the CRM is selected as the ontology of choice. The CRM is a safe choice; it has been proven to work for the OntoME implementation. There exist other high-level ontologies as well, such as DOLCE[19] or COSMO[20]. It could be that these ontologies are also suitable for maritime datasets. However, comparing and developing these different conversions would take considerable time and does not fit the research question. Finally, some of the concepts of the OntoMe implementation can be re-used in The wind in our sails project.

3 Methodology

Design science is selected as the central methodology, as the primary goal of the thesis is the development of an artifact: the knowledge graph. In Design Science research, several research methods and frameworks exist.[21, 22] The main takeaway of these theories is the design-test cycle. In this iterative cycle, the researcher uses the designed artifact to solve the given problem while grounding the artifact in a social-technical foundation. The artifact is evaluated and the evaluation results are used in the second iteration of the design-test cycle. The cycle continues until a certain predefined threshold is met.

In The wind in our sails project, two cycles are completed. Two cycles allow for a review and evaluation period while still being time-efficient. Before initiating the first design cycle, it is essential to build the foundation. The foundation, which is explored in the previous section, consists out of three parts. The first layer is the literature review. Here, we have a birds-eye view of the problem- and solution space. Then, on top of that, we have the related projects: a more zoomed-in vision and review of previous iterations. Finally, the practical foundation is built by reviewing the related tools and ontologies.

In the design-test cycle, the approach of Jovanovik[13] is implemented. With the goal to re-use some of the steps during the second design-test cycle. Furthermore, an open and unstructured interview is conducted with a domain expert from the Huygens during the first design-test cycle. The domain expert is responsible for some and involved in most of the curations of datasets used during the research project. An interview does not only help with understanding the datasets but also creates an understanding of the use case. How are domain experts planning on using the artifact and what are the expectations. Not all

[18] urlhttp://www.cidoc-crm.org/version/version-7.1.1
[19] `http://www.loa.istc.cnr.it/dolce/overview.html`
[20] `http://ontolog.cim3.net/wiki/COSMO.html`

questions can be asked and answered during a single interview; some questions may arise during the cycle. Therefore, close contact was kept via email. Working together at one of the offices was not possible due to the ongoing pandemic. Finally, the used datasets are well described by the authors, as well as by the researchers of the previous iterations. The study of these descriptions and works is captured in desk research.

The first review period has two goals. First, the design is reviewed and errors, shortcomings, and other issues are discussed. Second, the review period enables the start and direction of the second design iteration. An unstructured discussion session with digital humanities experts and the domain expert underlines the review period.

Finally, the design is tested once again in the second review period. In this review period, a workshop is conducted with several stakeholders from the Huygens ING. In this workshop, the developed artifact can be user-tested, thus validating the research results. Aside from the workshop, a short data story is written to illustrate the usefulness of the created knowledge graph. The researcher will act as the historian and tries to utilize the knowledge graph in the composition of a story. A summary of the research methodology is captured in figure 3.

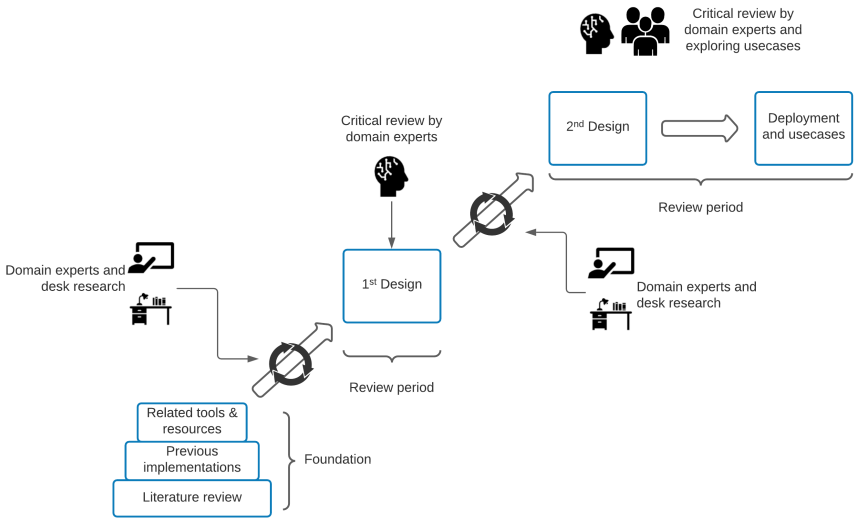

Fig. 3. Visual representation of the thesis methodology

Completing the constructed design framework aims to answer the main- and sub-research questions. The /emphsustainability aspect can be fulfilled by evaluating the design and approach with the design guidelines. *Usefullness* can be measured with the completion of the competency questions. [5] In this research project, the competency questions are derived from two sources: the Huygens

ING domain expert and a related project.[15] The competency questions are listed below along a source indicator (D for domain expert and R for related project):

- (D) Which VOC Chamber was accountable for the highest number of slaves transported?
- (D) How were the shipping routes in Asia divided between the various VOC chambers (for example, did ships from a specific chamber only sailed on certain routes)?
- (D) What was the average value of cargo on VOC return voyages per crew member/ship's ton, and how did this evolve over time?
- (D) To what extent was the value per ships' ton on return voyages correlated with the skipper's track record (how much experience, i.e., how many previous voyages / how quickly did a ship get to Asia on an outbound voyage)?
- (R) How did the price of goods changed over time?
- (R) Search for specific information in large datasets, such as names.
- (R) "Can external factors, such as war, be linked to the intensity of shipping?"

4 Initial design

The first and second design processes follow the same structure. In the first design cycle, the analysis of the domain knowledge will take more time and effort than the second design iteration. Documenting challenges and other factors contributing to the learning curve can lower the barrier for further design iterations in future work. The structure of the iterations is derived from, as discussed in the methodology, the work of Jovanonik. [13] The final two steps of the process are not completed entirely, as the results are not hosted on the web. This detail is brought up later in the discussion and future work section.

4.1 Domain and data knowledge

In the first step of the process, Jovanonik describes two distinct actions. First, the researcher has to understand the data and its context. Second, the researcher has to develop an understanding of ontologies and models used in the domain. As the second part has already been discussed in previous sections, this step will focus merely on comprehending the data and its context. Three VOC related datasets are included in the first design iteration and are addressed below:

Dutch Asiatic Shipping (DAS)

The Dutch Asiatic Shipping (DAS) dataset is a large dataset containing over 8700 voyages from the Netherlands to the Dutch Indies and back. The core details are noted from every voyage, such as the VOC Chamber who outfitted and

contracted the ship or the departing and arrival date of the ship at the ports.[21] This dutiful noting of events during the voyages and the eventual digitalization resulted in a vast normalized dataset of 72 columns spread out over nine tables. Most of the columns and values could be interpreted directly due to the logical naming schematic—for instance, the departing date of a ship is denoted with the column "voyDepartureEDTF". Other, more challenging, columns could be answered by interviewing one of the domain experts. The availability of two voyage IDs in the dataset (voyId and voyNumber), is an example of a challenging attribute. At first, the choice was made to use the latter voyNumber as the indicating value for the voyage, but it was pointed out that the voyId would be more relevant as it appeared in other datasets. Furthermore, ships also had two identifiers, but for another reason. It was explained that the same ship could change names in between or even during voyages. A remark denoted this event: "Ship was renamed on its third voyage from Barbara Theodora to Torenvliet." This possibility means that the ship's name is not persistent and thus should not be used in any identification. A final striking attribute of the DAS set is the onboard category. In this table, different categories listing from onbI to onbVI are linked to the voyage and are counts of crew and passengers during specific events. These events include, but are not limited to, boarding, disembarking, and even casualties. These events are not directly understandable from the column names, but an explanation was provided.[22]
The core concepts of the DAS dataset can be summarized in a couple of points:

- Voyages are leaving and arriving on a specific date from and to a specific port. Some voyages are recorded to call at the port of The Cape of Good Hope (SA) for refilling supplies and crew;
- During these voyages, events occurred, such as a storm or a capture of an enemy vessel. These events are stored in the voyParticulars column;
- Voyages partook on ships, and these ships can have different names over time, have different types, have several masters responsible over different voyages, were built at shipyards, and were outfitted by VOC Chambers.

These assumptions are verified in line with domain experts.

Bookkepper-General Batavia (BGB)

The following dataset that is added to the iteration is the Batavia Bookkeeper-General(BGB). In Batavia (now Jakarta ID), the bookkeeper and its clerks kept track financially of the goods coming into the Dutch Indies and leaving the Dutch Indies. These records were mainly lost over the years. However, a sizeable portion of the books was retrieved and eventually digitized and published [23]

There are overlapping features between the previously discussed DAS and the current BGB dataset. There are also recorded voyages from one particular port

[21] http://resources.huygens.knaw.nl/das retrieved at: 13-05-2021
[22] http://resources.huygens.knaw.nl/das/help/onboard retrieved at: 13-05-2021
[23] https://bgb.huygens.knaw.nl

to another port on a particular date in this dataset. Aside from these voyages, the core of the BGB is the cargo transported on these voyages. As the goal of the BGB was to track the movements and transactions of ships financially, extensive detail has been put into the cargo record. It includes the specific item transported, its value, its unit of measurement, and even some specific detail about the item. These details range from unordinary things to fascinating details, such as "intended for the kings of Cheribon".

Due to the earlier 'practice' on the DAS dataset, knowledge about the BGB set could be acquired more easily. Nevertheless, some columns and values remained ambiguous. It seemed that during voyages, multiple entries of the same good could be transported. It was explained that this due to fiscal responsibilities. Consequently, the 'carOrder' (the order of goods within a transport) should be used to uniquely identify goods on the ship to overcome duplicates. Another unusual aspect of the BGB set was that the duplication of two or more ships used on the same voyage. At first, it was thought to be an error of some sort. However, it was explained that ships could be used in convoy from one port to another. To keep it 'simple', the bookkeepers lumped together the different cargo of the ships. A final intriguing aspect of the BGB dataset is that the value of the goods is stored in two currencies. The currency used in the Republic at that time was the Gulden. However, the trading partners in Batavia and its surroundings preferred quality silver coins more than in Europe at that time. The bookkeepers in Batavia gradually increased the value of Guldens until the currency was outbalanced between the two regions. As a counter-measure, a different variant of the Gulden was introduced in Batavia, the so-called 'light' Guldens, while the regular Guldens were dubbed 'heavy'. [23] Note that the explanation above is just a (mis-)interpretation of the events by the researcher. It was further explained that small denominations of the Gulden (Stuivers and Penningen) could be converted to Guldens via a simple calculation.[24]

The core concepts of the BGB dataset can be summarized in a couple of points:

- Like the voyages in DAS, voyages leave and arrive on a specific date to and from a specific port. Unlike DAS, the voyages in BGB do not have a stopover at the Cape of Good Hope (SA);
- These voyages transported several goods with a specific value, unit of measurement, and specification;
- Voyages partook on ships that have different names over time. Note that the information captured about ships is lacking in comparison to DAS.

These assumptions are verified in line with domain experts.

Places

The final dataset can be discussed briefly. The Places dataset is a single table containing all the relevant geographical places. The table consists of a naming

[24] 1 Gulden is worth 20 Stuivers and 1 Stuiver is worth 16 Penningen

schema that firsts list the place and then the country code. Moreover, the geographical position of the place is also present in the dataset. This dataset is highly relevant in this research project due to its prevalence in other datasets. In the DAS and BGB datasets, any reference to a place is recognized and disambiguated (discussed in section 4.1) and is further linked to the Places table.

4.2 Data and ontology modeling

In the second phase of the first iteration, the gathered knowledge about the domain and the datasets is used in the data and ontology modeling phase. This phase aims to map the identified columns and concepts to the existing model and add new attributes to that model if one of these concepts does not fit the model. One of the domain experts recommended first creating a conceptual model of the data without explicitly referring to CIDOC CRM and its extension. This idea makes it more natural for the ontology to follow the data instead of making the data wrongfully fit the ontology. The conceptual model made is illustrated in figure 5.

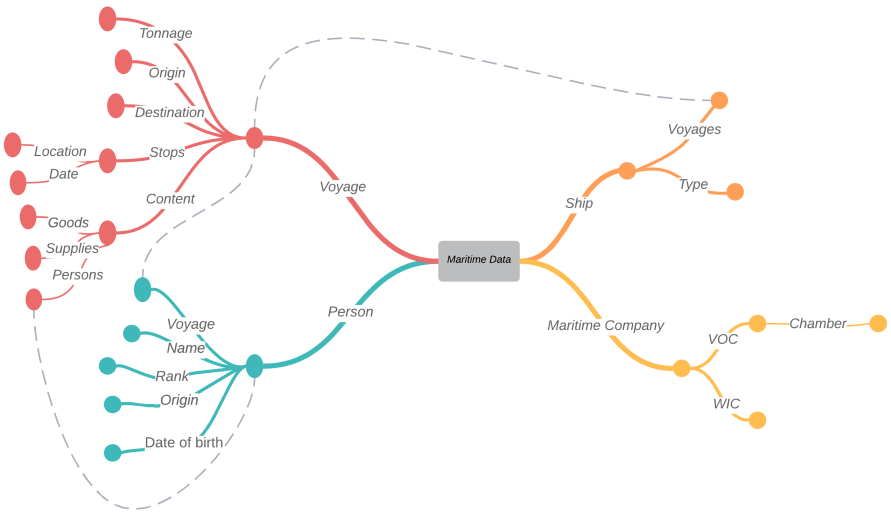

Fig. 4. Mind map of the conceptual model

Initially, in the mindmap, four main components have been identified. Note that the creation of the mindmap was before any conversions of datasets. Following the mindmap, the components have to be mapped to some existing or new ontological concept. Furthermore, the mindmap only illustrates the components and their relations but not the interrelation between components. These interrelations include, but are not limited to, a voyage taking place on a ship, a sailor

participating on a voyage, and the VOC chamber outfitting the ship before the voyage. With these high-level concepts defined, the lower-level concepts can be specified.

The starting point of the lower-level, detailed concepts is the voyages. A voyage is the journey a ship undertakes, moving from one place to another. In this journey, sailors, soldiers, and other personnel are employed while ensuring that the goods transported on the ship safely reach their destination. The goal is first to reuse CIDOC CRM classes and properties in the modeling phase, if possible. Then, if that is not possible, reuse classes and properties used by the OntoMe implementation[16]. Finally, new classes and properties are created to accommodate the envisioned data model. These newly created properties and classes are attempted to integrate into the CIDOC CRM as a subclass or subproperty of existing classes. Therefore, allowing interoperability with other CIDOC CRM extensions and models.

Displaying the complete data- and ontology model, including the design decisions, will not benefit the legibility. Therefore, a branch, starting from the voyage, is illustrated in figure 6 below. The complete mapping figures are included in the Appendices (A, B, C).

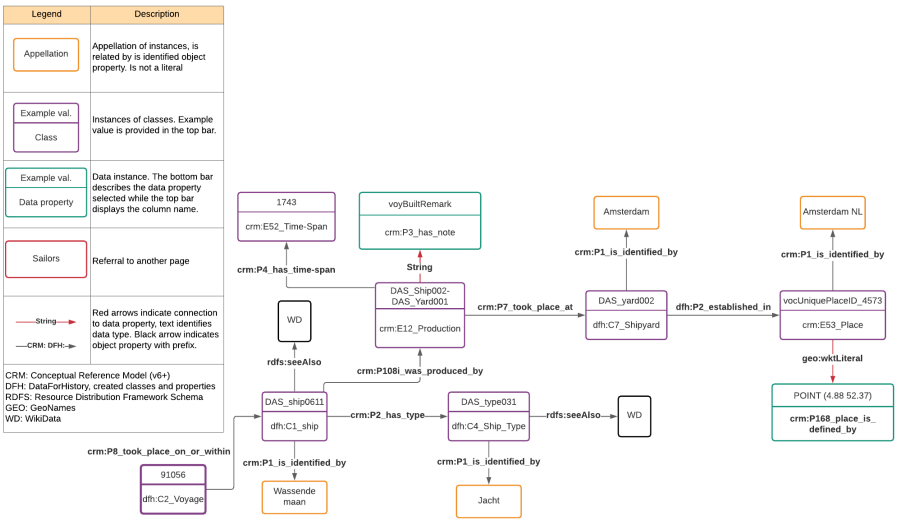

Fig. 5. Voyage to ship branch of mapping

The **voyage** instance is adopted from the OntoMe project. However, in the OntoMe project, the voyage is defined as a subclass of CRM: E7 Activity. This definition was changed later in the design iteration to a subclass of CRM: E9 Move to accommodate the linking of goods (physical objects) to the voyage via the property CRM: P25 moved. **ships** are defined as a subclass of CRM: E22

man-made object and are originating as well from the OntoMe implementation. The CIDOC CRM: P8 took place on or within is used as property between the **voyages** and the **ships**. In the property description of CRM: P8 took place on or within, the relation is even used as an example: "It describes a period that can be located with respect to the space defined by an E19 Physical Object such as a ship or a building.", validating the use of this property. The **name of the ship** is defined using the property CRM: P1 is identified by, which links the ship instance to a CRM: E41 Appellation instance. There are several benefits of having the name of something as a URI instead of a literal value. For once, it allows to find and connect things with the same name. Furthermore, the URI name can also link to other entities, such as the origin of a name.

Ship types are defined as a subclass of CRM: E55 Type, and the linking between ships and the ship types occurs with the property CRM: P2 has type. The production of ships is modeled as a CRM: E12 Production instance with outgoing links to a CRM: E52 Time-Span for the date and the created class of **shipyard** for the production place. In the OntoMe project, the shipyard was modeled as a subclass of CRM: E40 Legal Body. However, linking together a Production and a Legal Body requires a new property. It does not exist in CIDOC CRM. Thus, in this research project, the shipyard is modeled as a subclass of CRM: E53 Place; a place where they make ships. The connection between a place and a production does exist in CIDOC CRM, namely the property CRM: P7 took place at. However, that design decisions lead to an interesting issue. The **shipyard** is located in a **place**. There are properties in CIDOC CRM that can relate one CRM: E53 Place with another CRM: E53 Place. Such as CRM: P121 overlaps with or CRM: P10 falls within. While they both allow one place to fit in another place, the scope notes of these properties do not align completely with the model. Therefore, the property DFH: P2 established in was created to denote the relationship between a place and another place but with a temporal aspect. One place might not always be in that place.

Interesting design issues, decisions, and solutions are spread out throughout the first design iteration. Going over them one by one, just like above, does not fit the thesis. Therefore, the most exciting and impactful issues are listed below. A complete overview of the model can be found in the appendices (A, B, and C)

- In the first design iteration, two new classes are created for modeling the departure and arrival of ships at a port. In the OntoMe project, these activities do not have a class. They are connected via the created property P1 had departure place. This solution does seem more elegant, as it directly connects the voyage to a place. However, it is more difficult to state something about the departure or arrival of the ship in this manner. Properties of properties do not exist (at least when avoiding blank nodes) in RDF. Therefore, the classes of DFH: C10 Departing and DFH: C11 Arriving are created and modeled as subclasses of a CRM: E7 Activity. The property CRM: P9 consists of is used to connect these activities. This decision allows for easily linking dates, notes, and other events to the departure and arrival of a ship.

- In one of the data cleaning and reconciling projects of the Huygens, a match was made between masters of ships in the DAS file and the personnel logs of VOC Opvarenden (VOCOP). Not all persons could be identified, but the identified ones are linked with their VOCOP ID. This linking between datasets is captured with the CRM: P48 has preferred identifier.
- Another interesting modeling decision stems from modeling economic goods, such as copper, spices, and others, transported on a ship. These goods have a certain value, expressed in Guldens Zwaar and Guldens Licht. However, to express the value of a Thing in CIDOC CRM, one has to create a Purchase activity. In our datasets, it is unclear who or when these goods are purchased. We only know the value of these goods. Therefore, the property DFH: P9 has monetary amount was created. This property allows for linking Things (economic goods) to a monetary amount without the need for a Purchase activity.
- A final proposition made in the modeling is the utilization of stopovers during voyages. These stopovers are adopted from the OntoMe project and integrated into the first design iteration. Arriving and Departing activities are linked in the same manner as they are linked to a voyage. However, the departure and arrival place are the same during a stopover. Hence the place is linked directly to the stopover.

4.3 Transformation into linked data

In the previous section, the conceptual mindmap is converted step-by-step into a detailed, thought-out model. The datasets are mapped to the model in the next phase, thus creating the knowledge graph. In the first design iteration, a pre-processing, time-saving step was completed before moving on to the mapping and conversion. The datasets were delivered as a relational schema. Meaning, the datasets were spread out over different tables while being connected via a key - foreign key relation. In relational databases, this structure is very sensible. It saves enormous overheads in data storage. For instance, a ship can move multiple goods, so saving a single key instead of the whole ship entry makes the database leaner and easier to maintain. This database process is called normalization.[25]

Nonetheless, we are creating a different structure than a normalized database. In RDF, there is no such thing as duplicate data. Remember that RDF is just statements in the form of triples. When making a statement: "The Amsterdam is a ship" twice, the graph engine will only register one. The reason is that "The Amsterdam is a ship" is registered as URIs: unique web identifiers. The graph engine records instances with an identical URI as the same instance. If the complete triple is already entered, that information already exists as far as the graph engine is concerned. Utilizing this feature of RDF, the several normalized tables are denormalized and combined into a single table per dataset. This pre-processing of the datasets will save time in the mapping; only one table per dataset has to be converted. This process is illustrated in figure 6.

[25] `https://en.wikipedia.org/wiki/Database_normalization`

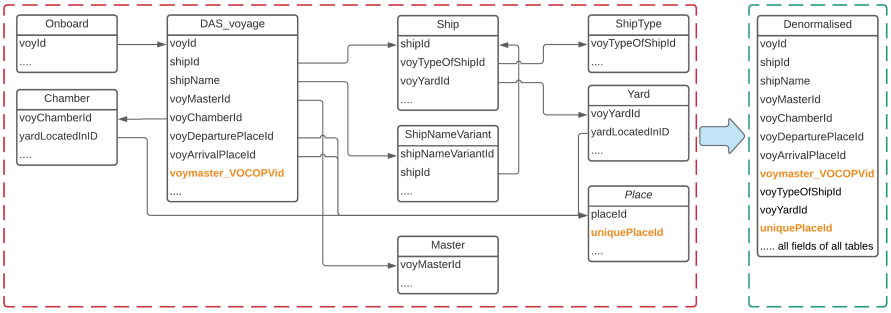

Fig. 6. Denormalizing example of the DAS tables

In principle, this pre-processing step can be completed with any relational database application. It requires the user to import the files into the database and create links from and to the different tables. Then, it is simply a matter of creating a SQL query that outputs every table and its links in a single view. In The wind in our sails project, MS Access was used due to its availability (pre-installed on most PCs) and ease of use.

In the mapping process, some columns are adjusted or newly created. Similar to the previous section, a small sample of the process is illustrated. In table 2, the places mapping is displayed.

Data Set	Source	Name	Mapped To or property used	Note
Places	Existing	uniqueStandardizedToponymID	CRM:E53_Place	
Places	Existing	uniqueStandardizedToponymCountryCode	CRM:E41_Appellation	
Places	Existing	URI	rdfs:seeAlso	
Places	Created	GeoWKT (LNG + LAT)	geo:wktLiteral	Combined two values to create WKT

Table 2. Places mapping table

In the mapping of the Places table, the *PlaceID* is mapped to the class of CRM: E53 Place. The PlaceID is used in the creation of the URI, consisting of /place/PlaceID. The *name of the place* is mapped to the CRM: E41 Appellation class. This URI starts with an /appellation/ identifier and is followed by the name and country code of the place. Note that underscores replace spaces to avoid unintuitive URI encoding. The spacebar character is encoded as a %20; an underscore is better readable. The existing URI pointing towards a GeoNames instance is transferred one on one in the knowledge graph. Finally, the created column *GeoWKT* is a composition of the existing latitude and longitude values. The reason being that this GeoWKT format can be utilized in the visualization part of the knowledge graph, more on that in the next section.

The most interesting and impactful mapping decisions are highlighted below. The complete mapping tables, including a general URI approach, can be found in the appendices (D, E, and F).

- **The denotation of time** plays a central role in the maritime model. It relates to many concepts. Such as the arrival or departure of ships. Furthermore, time can be used in calculations. For example, to derive the total length of a voyage. In the datasets, the most precise level of time is on a date level. In some entries, this precision varies. It can happen due to unreadable records such that the listed date can only be guessed. Moreover, it can happen that a departure activity happened around midnight, effectively spanning two dates. In the initial phases of the conversion, the dates were sanitized and formatted according to ISO standards. The reasoning behind this decision is as follows: an involved related researcher knows that some dates might be ambiguous. Thus they can account for that in calculations. In contrast, another researcher might not know this and assumes that all the dates are in the same format. This assumption can lead to problems in their calculations and overall lower usability of the artifact. However, in consultation with the domain expert, the original dates could enrich the dataset. It was decided that the original dates were added as an extra attribute for researchers to consult while retaining data usability.
- Converting datasets into a knowledge graph is essentially the creation of triples in RDF format. Part of this process is deciding which entity is related to which. Another essential part of this process is the creation of the entities. Entities are formatted as URIs. Whenever two entities have the same URI, then these entities must be the same. Therefore, it is critical to determine and **create unique URIs for unique things** and use URIs multiple times for the things that are not unique. An example is provided by the conversion of goods shipped on the voyages. The good copper can be shipped on different voyages and in different quantities for different prices. It will make it impossible to link this entry-specific information if a single entity is used for all these goods. Therefore unique URIs are created for every good transported. However, repeated information is stored in a type classification, eliminating data pollution. The goods URI is built out of the following components: 1386 (Product Type) - 99405 (Voyage) - 19 (Order). The Order component is added as voyages could ship the same good in different entries because of accounting norms. All the created URIs are included as an appendix (D and E) for transparency's sake.
- Creating new and unique URIs is essential for unique entities, as demonstrated in the previous point. **Nevertheless, for entities that are the same, the same URI should be used** to avoid data pollution. Identifying entities across different datasets is rather tricky[24] and it is not captured in this research project. Fortunately, other researchers have performed data recognition and linking on these datasets. [25, 26] For example, the BGB dataset is linked at some entries to DAS voyages. In these cases, the DAS

voyage entity is reused, effectively linking the two datasets. The implications of entity recognition and linking is illustrated in the appendices (X)

4.4 Data interaction and visualization

In previous steps, the different datasets are converted and intertwined. The second part of the puzzle is making the knowledge graph accessible. Researchers could query the created knowledge graph and wrangle the retrieved data to achieve their research goal. However, the usability of the knowledge graph would be significantly improved if the graph would be accessible via a straightforward interface. In The wind in our sails project, the Metaphacts platform[26] is selected as the interface. The reason is two-fold. First, the integration with GraphDB is seamless. The application comes in a pre-configured Docker container, allowing integration between different systems as well. Second, the Metaphacts platform hosts very usable graph exploration tools. These tools can help in answering the defined competency questions. In the following section, some examples are illustrated alongside their purpose related to this research project. Note that the interface can be hosted on the web, thus allowing excellent findability.

The starting page of the application is a simple home page with two search functions and some pre-configured pages. The first search function can be used to search for names—for instance, the user types in Amsterdam. The semantic search component then returns multiple results, as Amsterdam can point to the place, chamber, and ships. The second search function is similar, but it is focused on date search. Utilizing this function already solves one of the competency questions: "Search for specific information in large datasets, such as names." The home page, including the search functions, is illustrated in figure 7 below.

The pages and tools can be created and configured using HTML and CSS. These options allow for great configurability and maintainability, as these are widespread (markup) languages. The configuration of a search function using pre-installed components is relatively straightforward, as shown in the listing below.

Listing 1.1. Code example of the semantic search component

```
<div id="first">
    <semantic-simple-search
    query='
      SELECT ?resource ?label ?labelDisplay ?typeLabel WHERE {
        FILTER REGEX(str(?label), ?__token__)
        ?resource a ?type.
        ?resource crm:P1_is_identified_by ?label.
        ?type rdfs:label ?typeLabel.
        BIND ( REPLACE( str(?label), "http://example.com/appellation/","") as ?labelDisplay)
        FILTER (langmatches(lang(?typeLabel), "en"))
      } LIMIT 200'
    placeholder='Search for an appellation.. (use _ instead of spaces)'
    template='<span style="color:blue">{{labelDisplay.value}}</span> ( {{typeLabel.value}} )'
    >
    </semantic-simple-search>
</div>
```

[26] `https://metaphacts.com/product`

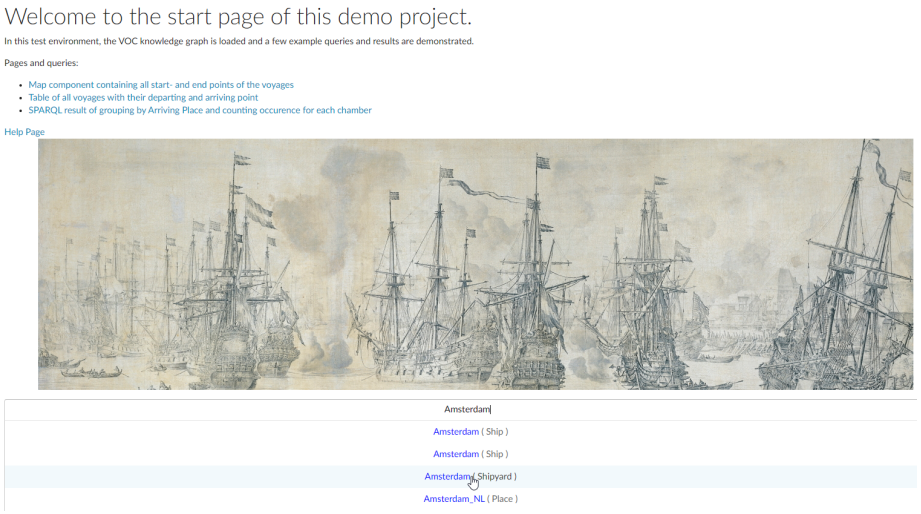

Fig. 7. Starting page of the Metaphacts platform

Another compelling feature is the ability to connect the created knowledge graph with the web of data. Entities that are reconciled at some places can be used to create a service SPARQL query. This query can include results outside of the knowledge graph, e.g., the web of data. An example is created for the ship entities in the knowledge graph. Every time a user enters the entity webpage of a ship, the application will send out a live request to Wikidata. Wikidata then returns a picture (if available) and all the facts it has about the ship. Updates on Wikidata would be immediately reflected on the platform as well. Creating this interface answers one more competency question: "Can external factors, such as war, be linked to the intensity of shipping?". External factors, as demonstrated, can easily be linked to the knowledge graph. The interface is demonstrated in figure 8 below.

There are many more components and pages created in the Metaphacts platform. These include graph exploration, table components, map components, and date searches. Screen captures of these components are included in the appendix (G).

4.5 Review of initial design

Modeling datasets into an existing ontology is a delicate process, even with high-level ontologies, such as CIDOC CRM. There is a constant push and pull between modeling from a data perspective and modeling from an ontology perspective. In a perfect world, the ontology and the data are a match. In this case, there exists a class and property for every envisioned concept. Nevertheless, this is not the case when using a general ontology, as it defeats its purpose. Therefore, the envisioned concepts should be fitted within the scope of the ontology. An

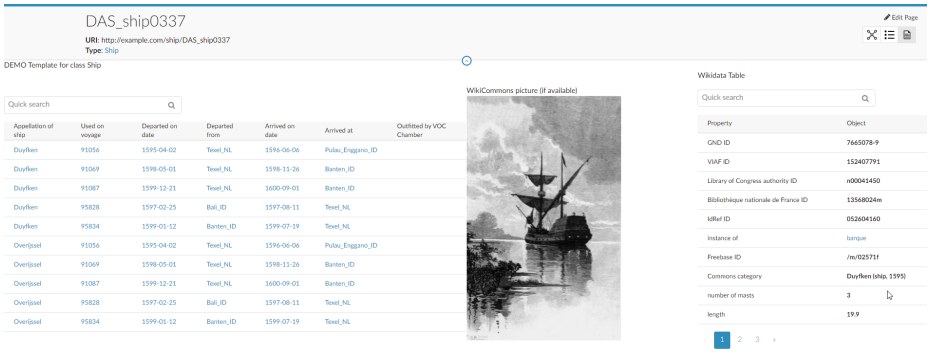

Fig. 8. Linked web implementation of the knowledge graph

economic good can not be modeled as a CRM:E21 Person, as it does not fit the scope definition of the class person. The CRM is an extensive ontology with almost 100 classes and over 200 properties. Discovering and understanding these scope notes takes time and experience. This experience is borrowed from two domain experts. The domain experts have an impressive track record with modeling projects into the CRM ontology. Hence, their knowledge and expertise during the first review period are greatly appreciated.

One of these misplacements in the first design iteration is the use of voyage. The voyage, as a class, was created as a subclass of the CRM:E9 Move. This choice stems from a modeling perspective; it links together the voyage with a physical object via the property CRM:P25 moved. In the CRM, the Move class is further defined as a subclass of the Activity class. The Activity class is defined as such:

> "This class comprises actions intentionally carried out by instances of E39 Actor that result in changes of state in the cultural, social, or physical systems documented. This notion includes complex, composite and long-lasting actions such as the building of a settlement or a war, as well as simple, short-lived actions such as the opening of a door."

Reading the scope note, the choice of modeling a voyage as a subclass of Move does not seem like a wild choice. After all, the voyage is carried out by multiple actors, moving things from one place to another. However, for the advanced modeler, such as the two domain experts, the class Activity has a slightly different meaning. CIDOC CRM was initially created as an ontology for registering museum artifacts. Typically, a move indicated that someone moved an artifact from one place to another, in a single continuous activity. The voyage seems out of place, knowing this. The sustainability of the artifact drops with these misplacements. Connecting the graph to other CRM graphs would create a world where an instance of a voyage is the same as moving a painting between musea.

This difference in semantics between classes is not unique to this project. The domain experts foresaw this and started developing an extension for the CRM ontology. This extension, focusing on social, economic, and legal life, allows for modeling concepts outside of the museum artifact realm.[27] Within extension, the class Phase exists. The use of a phase was explained as follows:

> "A teacher is still a teacher, even when they are not teaching. When that person is changing jobs, they are not a teacher anymore, thus ending that phase. Teaching, explaining something to students, is an activity."

Consequently, the voyage can be defined as a phase. During a voyage, lots of activities can happen, such as raising the sails. However, during the night, the activities dwindle. There is no continuity; thus, while the sailors are still participating on a voyage, no direct activity is involved. Other extension classes and properties are used throughout the second iteration to close the gap between the data and the ontology.

We can take a step back to a more meta-level by checking the research questions' progress. Any forthcoming discrepancies can be fixed in the second design iteration.

- **Usable:** The solution is approaching usable. In section 4.4, some of the competency questions could be answered with the interface. However, not all competency questions can be answered at this moment. The first design iteration did not include the very extensive VOC Opvarenden (VOCOP) dataset. This dataset includes rich records of the sailors who ventured during these voyages. These records will be included during the second design iteration. Thus, fulfilling the usable requirement.
- **Sustainable:** is not as strictly defined as the usability requirement. We can only review the approach and the decisions made during the first design iteration and determine where the sustainability can be improved. The approach, thus far, is *transparent* due to the extensive documentation. The Metaphacts integration allows for an *accessible* environment where the knowledge graph can be accessed interactively. By reviewing different approaches and methods, the current approach seems reasonably *reusable* as well. The reusability will only increase during the second iteration due to the utilization of the CRM extension. *Maintainability* is a quality attribute that could be improved during the second iteration. The knowledge graph could be maintained on GraphDB, as that information is not heavenly reliant on other sources. This is not the case for the ontology, as The wind in our sails projects uses multiple external ontologies. Thus, whenever one of these ontologies changes, the administrator has to adjust the graph manually. Finally, the research of Waagmeester et al.[11] shows that sustainably growing the knowledge graph is primarily because of community involvement. In the current design iteration, neither concern is addressed. These shortcomings, including the current architecture, are illustrated in figure 9

[27] `http://ontome.net/project/64`

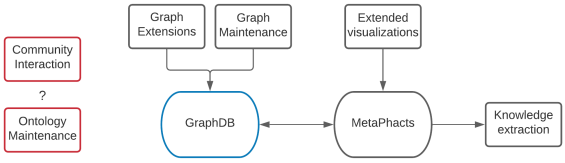

Fig. 9. Architecture of the first design iteration

5 Second iteration of the design

In the second design iteration, the results of the first review period are processed, and any shortcomings regarding the research questions are hopefully solved. This iteration will be noticeably compacter due to an improved understanding of the source data, improvements rather than additions, and fewer datasets converted.

5.1 Domain and data knowledge

The design thus far consists of voyages (DAS), cargo moved on voyages(BGB), and the places visited (Places). However, several competency questions are related to the people involved in these activities. In the second design iteration, attention is spent on adding persons to the design to solve these competency questions.

VOC Opvarenden (VOCOP)

The VOC and its chambers kept extensive records of its contracted crew members (Opvarenden in Dutch). Researchers over the years have digitized these records. As a result, over 700.000 records are stored in the Dutch Archives.[28] These records include personal data, ranks, wages, and references to voyages. The voyages overlap with the voyages of the DAS dataset.

Whenever a sailor signed up on one of the voyages, their name and origin were registered. Keen and lucky sailors could sign up again after their return. Personal identification numbers did not exist in these times. Hence, their name and origin provided enough identification, leading to more records than people. Identifying a person and understanding their career, for instance, would require entity recognition within these records. There is data stored in these records that helped researchers identify these entities. One of these data points is the reason a contract ended. If the sailor would be unfortunate enough to perish during the voyage, that person could not rejoin a new voyage. Work has been completed by Petram et al. [26] in which entries belonging to the same person are clustered with some level of confidence. This process links together multiple entries to the same person, leading to better utilization and results. This process of entity

[28] `https://www.nationaalarchief.nl/onderzoeken/zoekhulpen/voc-opvarenden`

recognition has also been completed for the places listed within the records. Just like names, places can be written differently. Due to normalization efforts, various appellations can be reduced to the same place.

Another exciting aspect of the VOCOP data set is the debt letters. These letters are linked, where possible, to the contract entries. If the sailor would not make it back safely, someone would still be entitled to their wages; a Golden Age life insurance. The debtors mainly were familial relations or spousal. In other cases, an orphanage was listed as the debtor. At first sight, this might seem like a benevolent decision. However, in reality, teenagers were forced to enlist at the VOC while the orphanage raked in their wages.

The core concepts of the VOCOP dataset are summarized in a couple of points:

- There are many records of listings that include rich details. Due to entity recognition efforts, some of the listings can be related. This is also the case for some of the places used.
- The sailors provided rights to their income for the ones who remained in the form of debt letters.
- The records include references to the voyages from the DAS dataset.

5.2 Data, ontology modeling, and transformation into linked data

The high-over inception of the model, displayed in figure 4, does not change in the second iteration of the design. The changes in the second iteration are in the details. One of the more critical changes is related to the structure of the voyages. In summary of the previous iteration: a **voyage** is linked to a starting point via a departing activity. In some cases, a **stopover** occurred during the voyage. Finally, the voyage ends with the arrival of the voyage at its destination. Persons and goods were directly linked to the voyage; it was assumed that these were involved during the whole duration of the voyage. However, in the VOCOP dataset, this is not the case. Persons could change ships during their stopover, effectively participating in two voyages. The first iteration could not adequately convey this concept.

In an attempt to correctly convey this concept, a new class is introduced. The **leg** class is, similar to the voyage, a **phase**. It indicates a continuous part of the voyage from and to a harbor. A voyage can consist of multiple legs, thus eliminating the need for a stopover entity. The time between the end of the first leg and the beginning of the second leg is the stopover. Finally, the sailors are linked to the departing and arriving properties to indicate (dis)-embarkment activities. In the figure below, this construct is illustrated, along with the properties used.

This construct might seem excessive, there exist many links between the sailors and voyage-related entities. Nevertheless, this construct allows researchers to analyze the participation on different abstraction levels. A simple search can be performed that returns all sailors who participated on a voyage, regardless if they changed ships. Another search can be performed on a leg level to determine

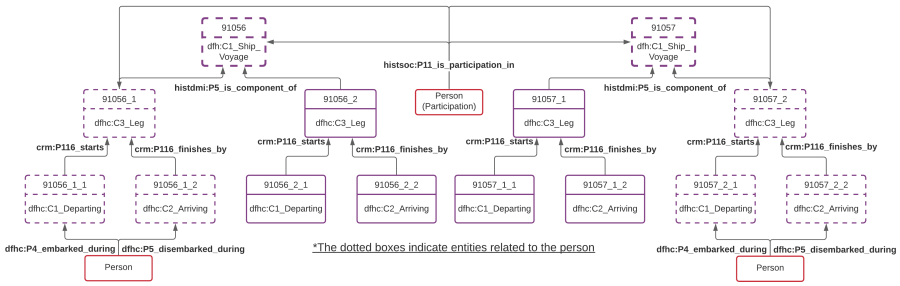

Fig. 10. Overview of the voyage construct

who was on board during a specific part of the voyage. Lastly, a query can be constructed that returns who embarked on the ship and when. This construct is also prepared and repeated for goods transported on the ship. An important assumption is that sailors disembark the ship at the end of the first leg and embark on the ship again when it leaves. This assumption is also expressed in the graph. In contrast, it is assumed that the goods are not unloaded during a stopover unless stated otherwise.

Other concepts are revisited as well. They are included in the appendices (H,I, and J). For instance, the onboard categories are updated. At first, the onboard categories were mapped via a custom data property to the voyage. However, this lean relation is a bit too short-sighted. Instead, we can model this onboard concept in a more semantic approach. These onboard components are the headcounts during a specific part of the voyage. This observation can be modeled as a CRM: E16 Measurement; it measures quantitative properties determined by observation. Furthermore, the measurement can be expressed in a CRM: E54 Dimension, e.g., a number. Expressing the onboard relation in this way creates more, maybe unnecessary, relations. However, it allows for other entities to relate better to this concept. Such as, who counted the number of people, or when the count occurred.

The VOCOP dataset has been modeled, mapped, and converted to RDF in the second design iteration. The CIDOC CRM extension (SDHSS) prefix) for economic, social, and legal life has been utilized for the VOCOP dataset. (Re-)Using this extension lowers the number of classes and properties created, as it hosts some very useful concepts. The complete mapping can be found in the appendix (K and L). In addition, the updated mapping tables of the other datasets are also included (M and N). An interesting selection of modeling and mapping decisions is summarized below:

– The persons are related to the voyage via an SDHSS: **C15 participation** entity. This participation indicates the continuous participation of a person in an activity. Persons did not participate passively; they had responsibilities and work to do. These responsibilities, in the form of rank descriptions,

were strictly defined within the VOC. The property SDHSS: **P12 is participation with social quality** is used to relate the practiced rank and thus occupation of that person.
- In the VOCOP dataset, only the median wages of the ranks are stored. Back then, the wages and the rank descriptions (aside from a reorganization in 1784) were relatively stable.[26] The **wage** is related to the **rank** via the property DFHC: **P11 monetary compensation.**
- Every **rank** has a list of responsibilities attached. For instance, a sailor is responsible for cleaning, loading and unloading, and more. There exist qualitative attribute definitions in the SDHSS. These include C15 **Skill** for physically demanding skills or C29 **Know-how** for mentally demanding jobs. However, we can not be confident of the skill or know-how of a person. They might be a lousy employee, failing their described tasks. Thus a new entity is introduced: DFHC: C5 **Occupational Responsibility**. This class mixes mentally demanding tasks, such as leading a crew, and physically demanding skills, such as hoisting the sails. The proven capabilities of a person can be converted to either C15 Skill or C29 Know-how.
- Personal relations can also efficiently be modeled within the SDHSS extension. The entity SDHSS: **C3 Social Relationship** links together two persons, a target and source. The class of SDHSS: **C4 Social Relationship Type** is then used to define the relationship. For the debt letters, a relationship type of beneficiary and recipient is initially chosen. However, the debt letters can also indicate the relationship between the beneficiary and the recipient, adding another relationship type to the social relationship.
- The normalized **places** are linked to the **Places** mapping of the first iteration. For transparency and data completion sake, the original appellation of the place is included. The **place** mentioned at the **end of the contract** is not normalized yet. Meaning the names of these places vary wildly. Drawing meaningful conclusions of these entities can be challenging, as it is unknown which entities are identical. Therefore, this appellation is included in the graph but as a data property and not as an entity. In future iterations, these place appellations can be converted to entities after recognition and linking processes.

OntoME

The changes made during the second design iteration aim to improve the *reusability* of the artifact by utilizing a complete ontology. Creating mapping figures and tables improves *transparency* concerns. Converting the VOCOP dataset ensures that the *usability* aspect is met due to completing the competency questions. However, there were some discovered concerns regarding the *maintainability* of the solution. In the first iteration, the ontology was designed using the widespread Protegé[29] application. This application has some very user-friendly

[29] `https://protegewiki.stanford.edu/wiki/Main_Page`

options to start creating an ontology. Nevertheless, it lacks automatic alignment and reusing options with other CRM-based ontologies. The OntoMe[30] application was created for projects like these. It natively supports CIDOC CRM and its common extensions. Users can create extensions themselves and connect them easily with others. The power of OntoMe is in the reusing of ontologies. The application has similarities with Github[31], allowing cooperation and discussion between users on the creation and utilization of classes and properties. Hosting the envisioned ontology, created during the cycles, in OntoMe would solve the *maintainability* issue.

5.3 Data interaction and visualization

In this chapter: short paragraph that all queries and code is changed to accomodate new design, maybe one new page/code/example of Metaphacts, the usecase of Geovisitory for community involvement. **TODO: add in the appendix; part about entity recognition**

5.4 Review of the second iteration design

Complete review of the design + check if problems in first iteration are solved. Continuation of the review: discuss workshop and data story.

6 Results in numbers

Table of triples + classes and properties added to CIDOC CRM +

7 Discussion & future work

Discussion and future work section - refer to wikidata plus (for social science) geovisitory etc. and hosting of triple somewhere plus the front-end

8 Conclusion

Evaluate the research questions

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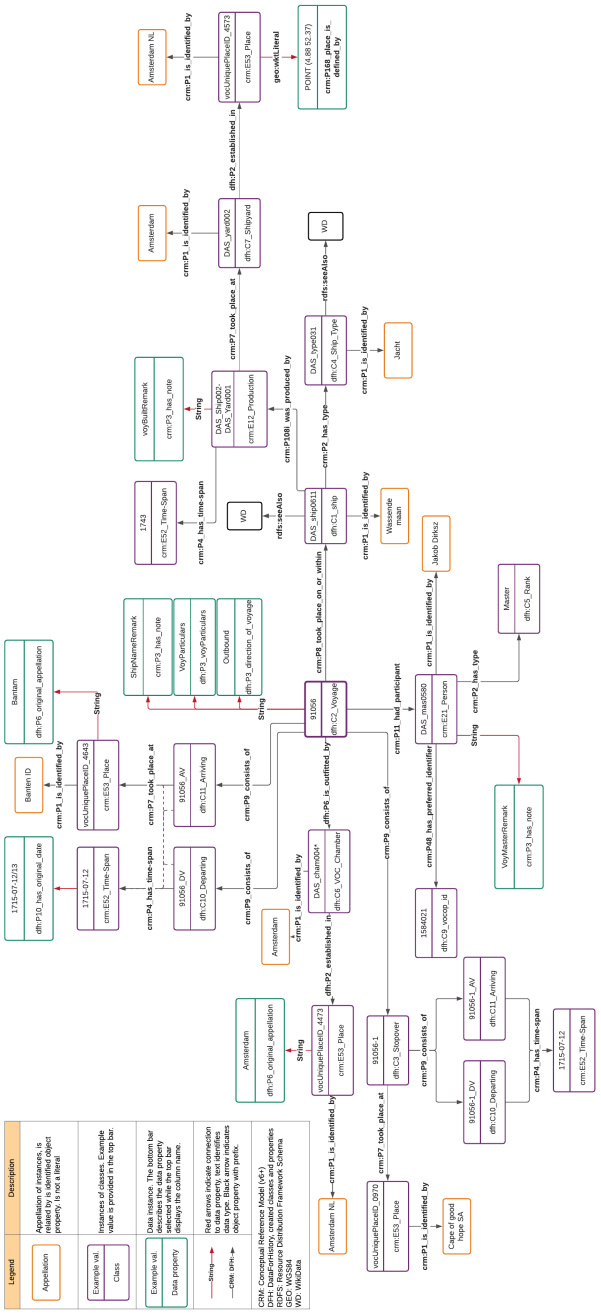
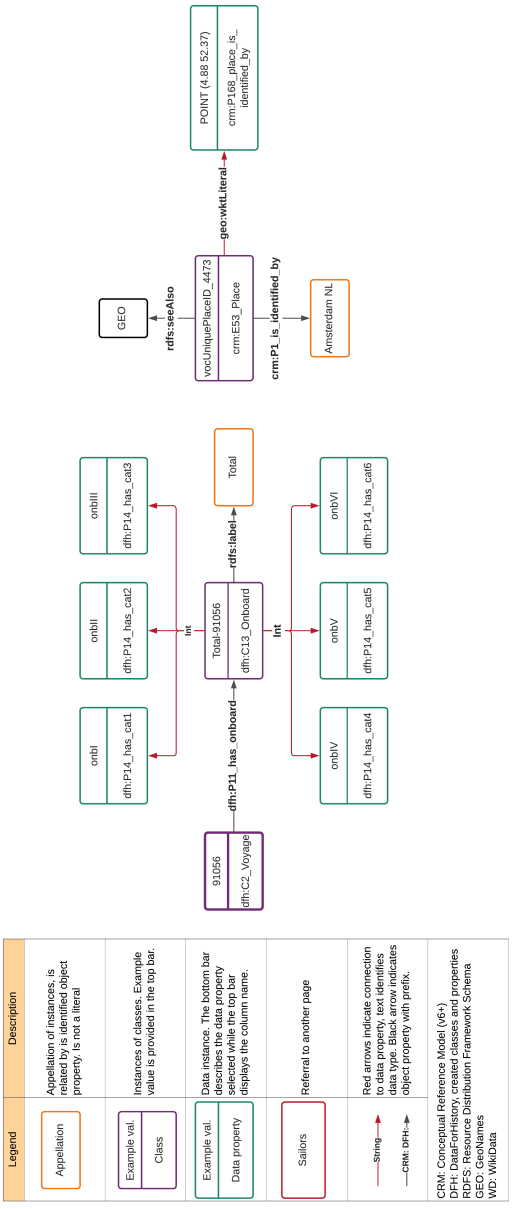
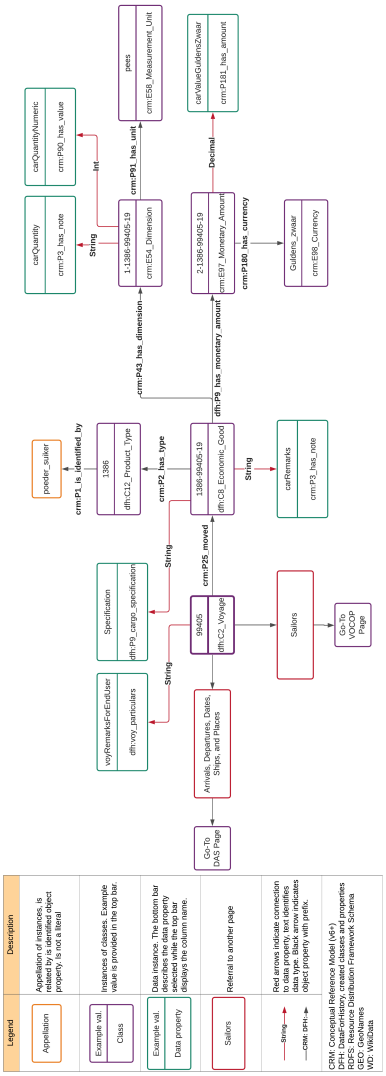
A First design iteration: DAS graph



B First design iteration: DAS onboard & places graph



C First design iteration: BGB graph



D First design iteration: DAS conversion table

Data Set	Source	Name	Mapped To or property used	Note
DAS (das_Voyage)	Existing	voyId	DFH:C2_Voyage	
DAS	Created	Direction	DFH:P3_direction_of_voyage	Combined 'heenreis' and 'terugreis'
DAS (das_Voyage)	Existing	shipID	DFH:C1_Ship	
DAS (das_Voyage)	Existing	voyMasterID	CRM:E21_Person	
DAS (das_Voyage)	Existing	voyMasterRemark	CRM:P3_has_note	
DAS (das_Voyage)	Existing	voyChamberID	DFH:C6_VOC_Chamber	
DAS (das_Voyage)	Existing	voyDepartureEDTF	CRM:E52_Time-Span	
DAS (das_Voyage)	Existing	voyCapeArrivalEDTF	CRM:E52_Time-Span	
DAS (das_Voyage)	Existing	voyCapeArrivalEDTF_Remark	CRM:P3_has_note	
DAS (das_Voyage)	Existing	voyCapeDepartureEDTF	CRM:E52_Time-Span	
DAS (das_Voyage)	Existing	voyCapeDepartureEDTF_remark	CRM:P3_has_note	
DAS (das_Voyage)	Existing	voyArrivalDateEDTF	CRM:E52_Time-Span	
DAS (das_Voyage)	Existing	voyArrivalDateEDTF_remark	CRM:P3_has_note	
DAS (das_Voyage)	Existing	voyChamber2ID	DFH:C6_VOC_Chamber	
DAS (das_Voyage)	Existing	voyParticulars	DFH:P4_voy_particulars	
DAS (das_Voyage)	Existing	voymaster_VOCOPVid	CRM:E21_Person (preferred ID)	
DAS	Created	StopoverC	DFH:C3_Stopover	To indicate a stopover at the Cape
DAS	Created	CapeUniquePlaceId	CRM:E53_Place	To set the place of the stopover
DAS	Created	DepartingValue (voyId + _DV)	DFH:C10_Departing	To create the entity for departing
DAS	Created	ArrivingValue (voyId + _AV)	DFH:C11_Arriving	To create the entity for arriving
DAS	Created	DepartingValueCape (StopOverC + _DV)	DFH:C10_Departing	To create the entity for departing at Cape
DAS	Created	ArrivingValueCape (StopOverC + _AV)	DFH:C11_Arriving	To create the entity for arriving at Cape
DAS (ship)	Existing	voyTonnageMin	DFH:P7_minimum_tonnage	
DAS (ship)	Existing	voyTonnageMax	DFH:P8_maximum_tonnage	
DAS (ship)	Existing	voyTypeOfShipID	DFH:C4_Ship_Type	
DAS	Created	Yard_Joined (ShipId + YardId)	CRM:E12_Production	To create the entity of ship building
DAS (ship)	Existing	voyBuiltRemark	CRM:P3_has_note	
DAS (ship)	Existing	voyBuiltY	CRM:E52_Time-Span	
DAS (ship)	Existing	voyYardYardID	DFH:C7_Shipyard	
DAS (shipName)	Existing	shipNameVariant	CRM:E41_Appellation	
DAS (shipName)	Existing	shipNameVariantRemark	CRM:P3_has_note	
DAS	Created	externalShipName	rdfs:seeAlso	Reconcillement on shipname with WikiData
DAS (shipType)	Existing	voyTypeOfShip	CRM:E41_Appellation	
DAS (shipType)	Existing	voyTypeOfShipExternalID	rdfs:seeAlso	
DAS	Created	voyMasterFullName	CRM:E41_Appellation	Combination of all the seperate nameparts
DAS	Created	voyMasterRank	DFH:C5_Rank	To indicate the rank of the person (Master)
DAS	Created	onbCategoryVoyage (voyageId + Category)	DFH:C13_Onboard	To create a unique identity of category and voyage
DAS (onboard)	Existing	onbI	DFH:P14_has_cat1	
DAS (onboard)	Existing	onbII	DFH:P15_has_cat2	
DAS (onboard)	Existing	onbIII	DFH:P16_has_cat3	
DAS (onboard)	Existing	onbIV	DFH:P17_has_cat4	
DAS (onboard)	Existing	onbV	DFH:P18_has_cat5	
DAS (onboard)	Existing	onbVI	DFH:P19_has_cat6	
DAS (yard)	Existing	yardLocatedIn_UniekeToponiemenVOCPOPV	CRM:E41_Appellation	
DAS (yard)	Existing	yardLocatedIn_UniekeToponiemenVOCPOPVid	CRM:E53_Place	

Table 3. DAS mapping table

E First design iteration: BGB conversion table

Data Set	Source	Name	Mapped To or property used	Note
BGB (cargo)	Existing	carVoyageId	DFH:C2_Voyage	
BGB (cargo)	Existing	carProductId	DFH:C12_Product_Type	
BGB (specification)	Existing	carSpecificationName	DFH:P9_cargo_specification	
BGB (cargo)	Existing	carUnit	CRM:E58_Measurement_Unit	
BGB (cargo)	Existing	carQuantity	CRM:P3_has_note	
BGB (cargo)	Existing	carQuantityNumeric	CRM:P90_has_value	
BGB (cargo)	Adjusted	carValueGuldens *	CRM:P181_has_amount	Converted/added stuivers and penningen to guldens
BGB (cargo)	Adjusted	carValueLichtGuldens *	CRM:P181_has_amount	Converted/added stuivers and penningen to guldens
BGB (cargo)	Adjusted	carRemarks	CRM:P3_has_note	
BGB	Created	carProductVoyageId (Product + voy + cargo)	DFH:C8_Economic_Good	To create a unique identifier for goods transported
BGB	Created	..Dimension (1-carProductVoyageId)	CRM:E54_Dimension	The leading number indicates different dimensions
BGB	Created	..MonetaryAmount (2-carProductVoyageId)	CRM:E97_Monetary_Amount	The leading number indicates different MA's
BGB (place)	Existing	vocPlaceID	CRM:E53_Place	
BGB (product)	Existing	ProductNaam	CRM:E41_Appellation	
BGB (voyageship)	Existing	shipId	DFH:C1_Ship	
BGB (voyageship)	Existing	DAS_voyage *	DFH:C2_Voyage	Used if available
BGB (voyageship)	Existing	DAS_shipID *	DFH:C1_Ship	Used if available
BGB (ship)	Existing	shipNaam	CRM:E41_Appellation	
BGB (unit)	Existing	unitNaam	CRM:E41_Appellation	
BGB (voyage)	Existing	voyDeparturePlaceId *	CRM:E53_Place	Used vocop places id
BGB (voyage)	Created	voyDepartureDate (Year + Month + Day)	CRM:E52_Time-Span	Combined date values to create ISO date format
BGB (voyage)	Existing	voyArrivalPlaceId	CRM:E53_Place	Used vocop places id
BGB (voyage)	Created	voyArrivalDate (Year + Month + Day)	CRM:E52_Time-Span	Combined date values to create ISO date format
BGB (voyage)	Existing	voyRemarksForEndUser	DFH:P4_voy_particulars	

Table 4. BGB mapping table

F URI mapping table

Fig. 11. Label

G Screen captures of Metaphacts platform: first iteration

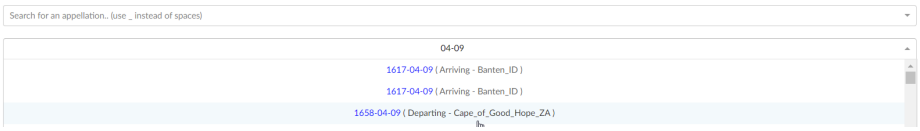


Fig. 12. Search function of dates including the activity happening on that date

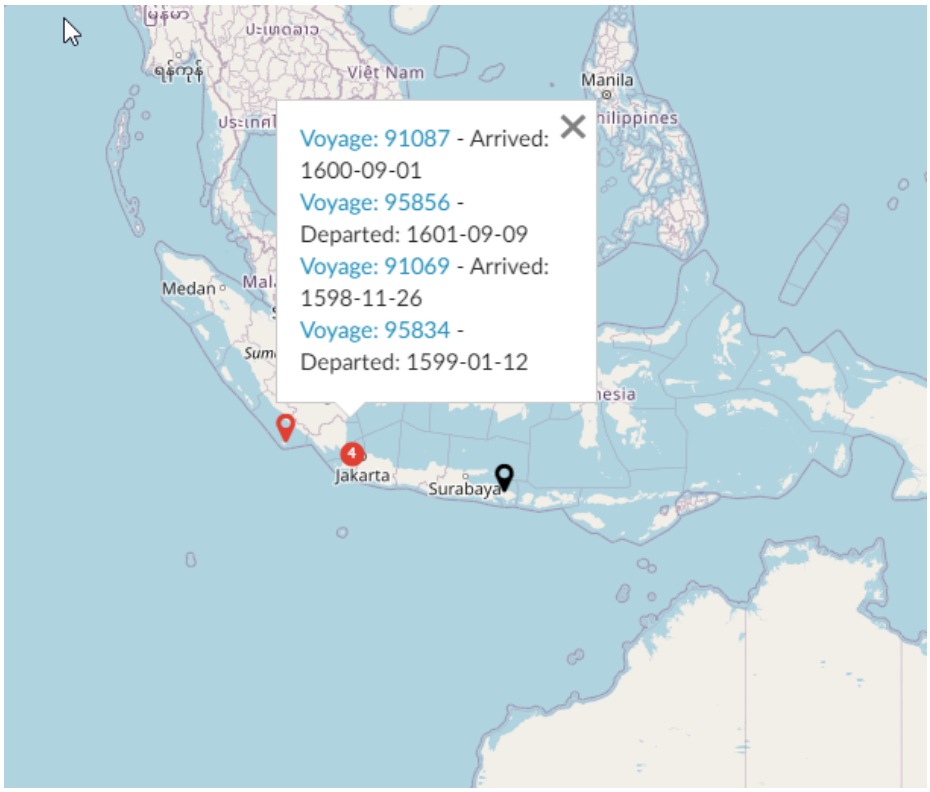


Fig. 13. Activity map of a certain ship

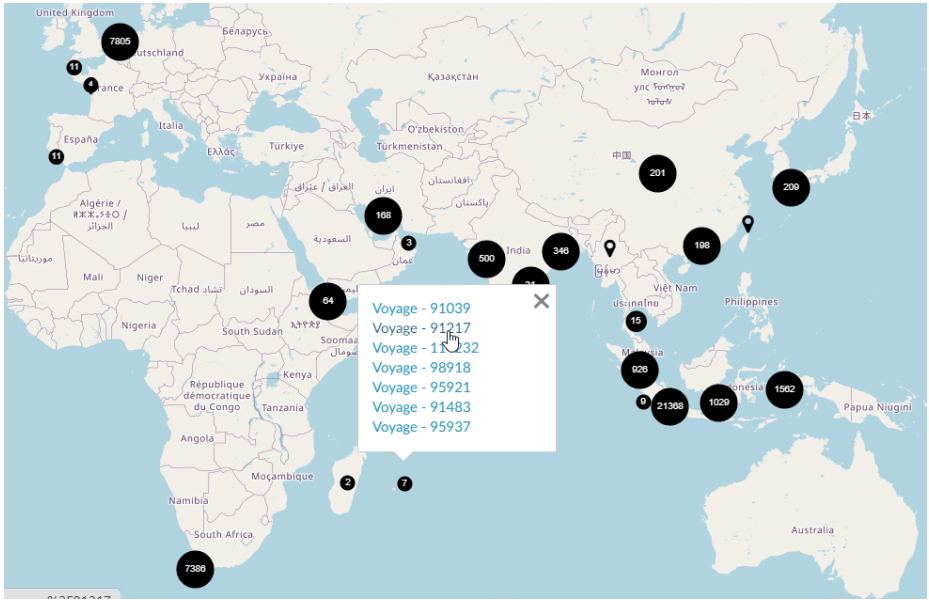


Fig. 14. Activity map of all the voyages registered

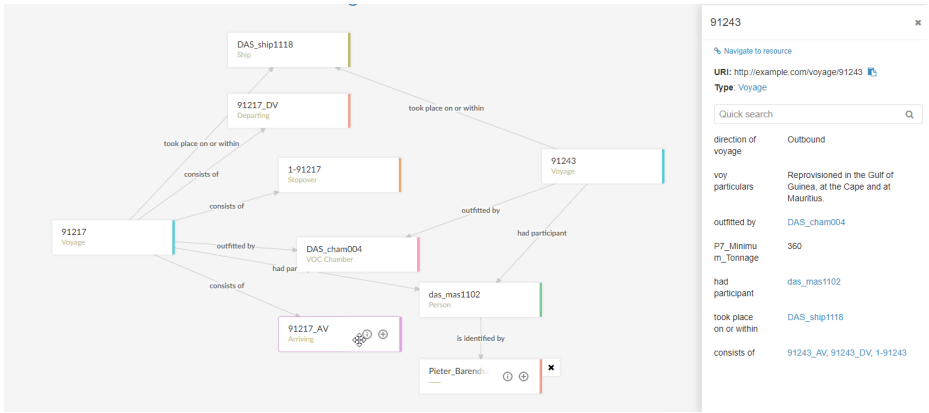


Fig. 15. Graph exploration interface

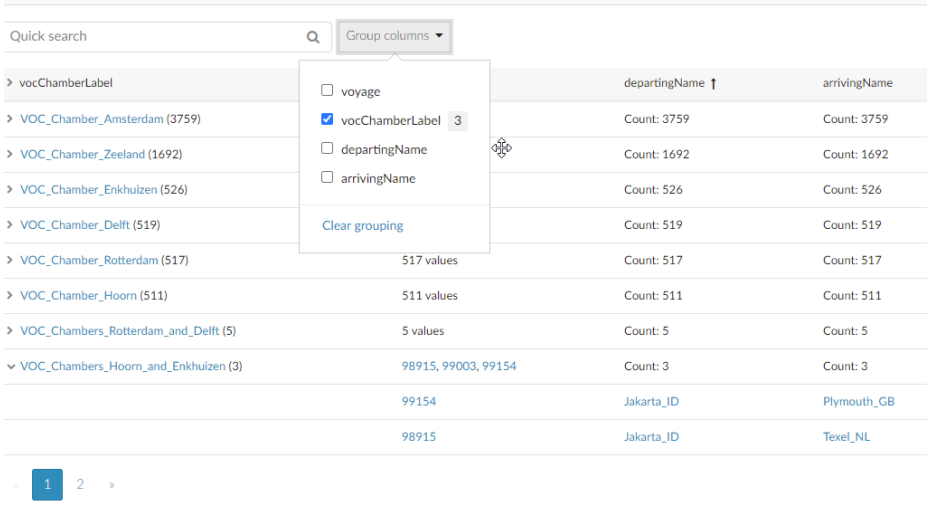


Fig. 16. Smart filterable table

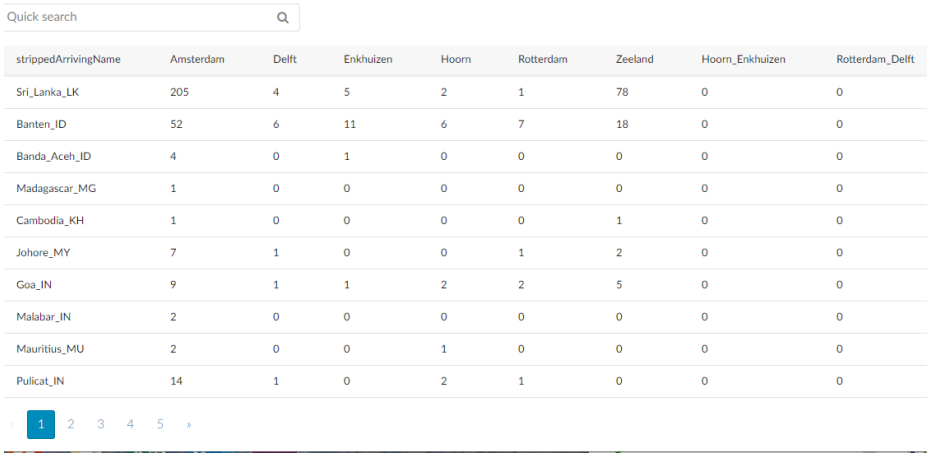
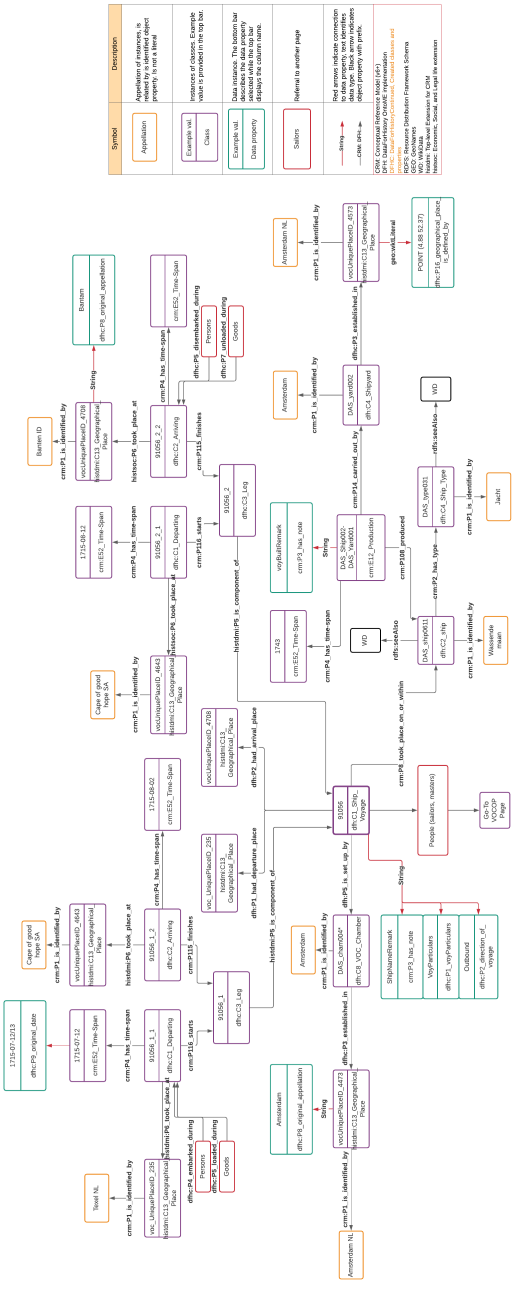
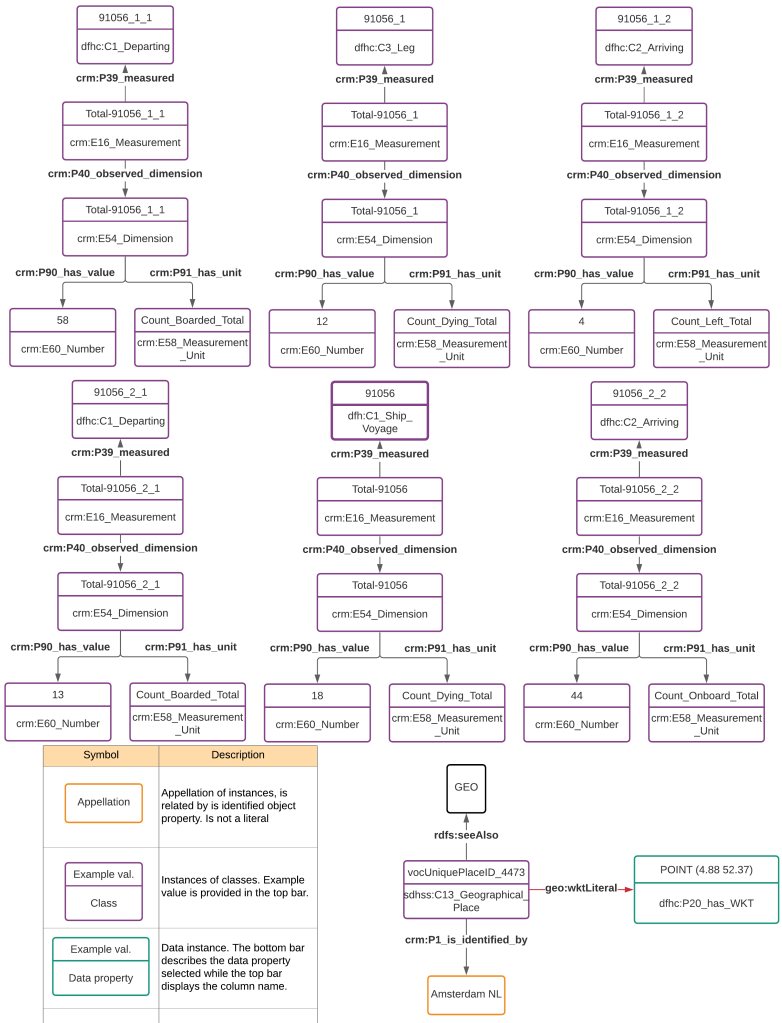


Fig. 17. Table illustrating routes between chambers, answers a competency question

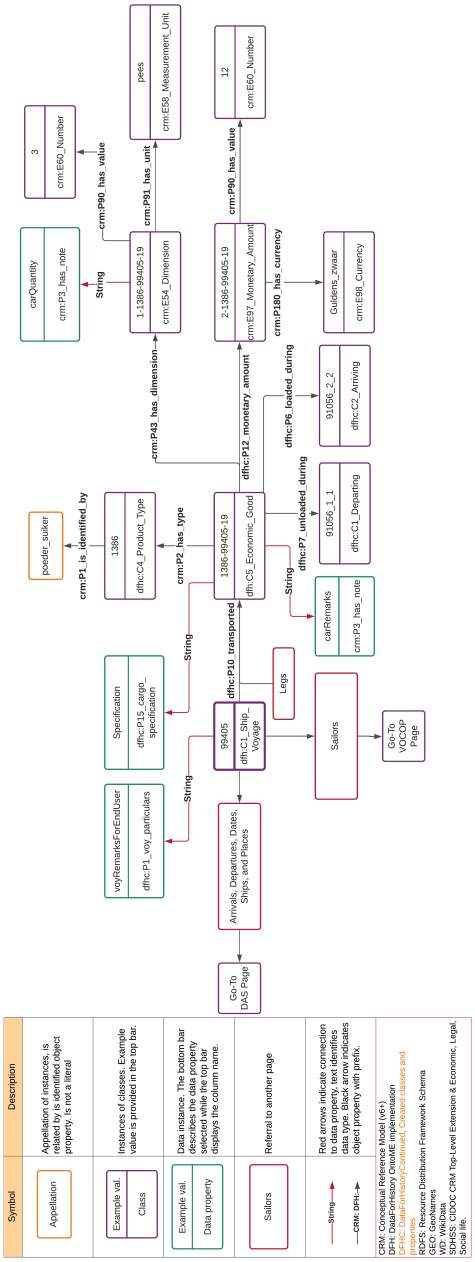
H Second design iteration: DAS graph



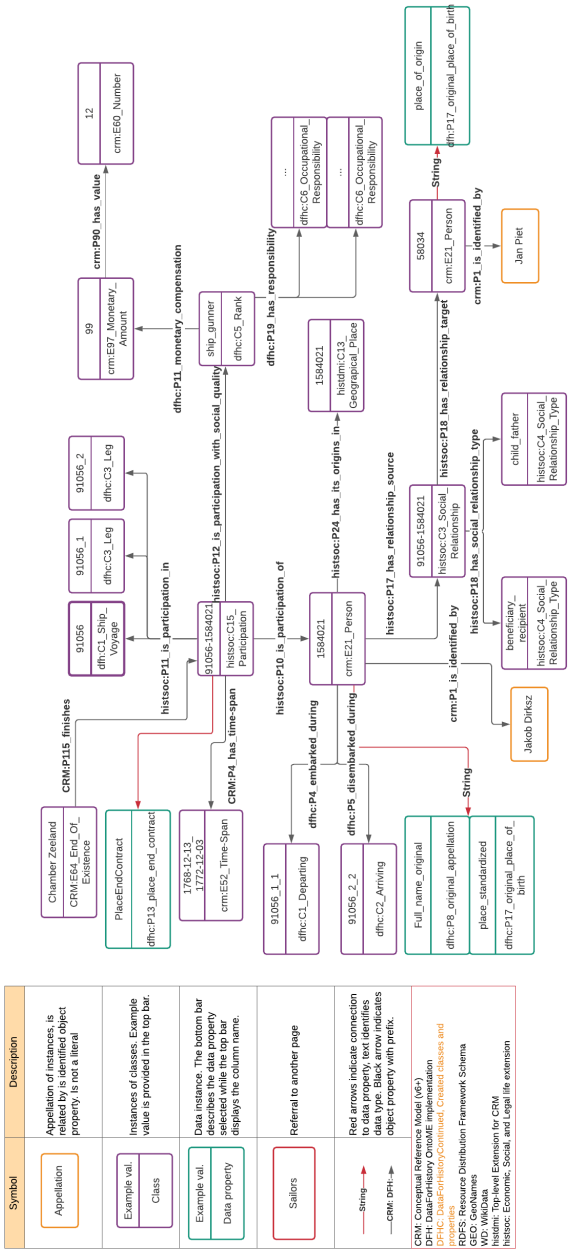
I Second design iteration: DAS onboard & places graph



J Second design iteration: BGB graph



K Second design iteration: VOCOP graph



L Second design iteration: VOCOP conversion table

Data Set	Source	Name	Mapped To or property used	Note
VOCOP (contracts)	Existing	vocop_id	dfhc:P14_original_vocop	Clusters are used, link to original id
VOCOP	Created	VID	crm:E21_Person	Used first entry of each clustered person
VOCOP (contracts)	Existing	full_name_normalized	crm:E41_Appellation	
VOCOP (contracts)	Existing	full_name_original	dfhc:P8_original_appellation	
VOCOP (places)	Existing	StandardizedId	histdmi:C13_Geographical_Place	
VOCOP (contracts)	Existing	place_normalized	dfhc:P17_original_place_of_birth	
VOCOP	Created	participation	histsoc:C15_Participation	Combined person + first voyage id (chronological)
VOCOP (contracts)	Existing	outward_voyage	dfh:C1_Ship_Voyage	Existing in DAS
VOCOP (contracts)	Existing	changed_ship_at_cape_voyage_id	dfh:C1_Ship_Voyage	Existing in DAS
VOCOP (contracts)	Existing	return_voyage	dfh:C1_Ship_Voyage	Existing in DAS
VOCOP	Created	embarked	dfhc:C1_Departing	Created arrival en departing entities
VOCOP	Created	disembarked	dfhc:C2_Arriving	for mapping embarking and
VOCOP	Created	embarked_second	dfhc:C1_Departing	disembarking activities to the persons
VOCOP	Created	disembarked	dfhc:C2_Arriving	
VOCOP	Created	embarked_cape	dfhc:C1_Departing	
VOCOP	Created	disembarked_cape	dfhc:C2_Arriving	
VOCOP (ranks)	Existing	rank	dfhc:C5_Rank	as subclass of Occupation
VOCOP (ranks)	Adjusted	rank_description(eng)	dfhc:C6_Occupational_Responsibility	Splitted the multi-valued column
VOCOP	Created	comp_rank	crm:E97_Monetary_Amount	wage entity
VOCOP (ranks)	Existing	median_wage	crm:E60_Number	
VOCOP (contracts)	Existing	reason_end_contract	crm:E64_End_Of_Existence	links to the participation
VOCOP (contracts)	Existing	place_end_contract	dfhc:P13_place_end_contract	non-normalized placenames
VOCOP	Created	time-span	crm:C4_Time-Span	Combined starting and end date
VOCOP	Created	relationship	histsoc:C3_Social_Relationship	to indicate beneficiary relation
VOCOP	Created	defaultrelation	histsoc:C4_Social_Relationship_Type	standard beneficiary - recipient
VOCOP	Adjusted	relation	histsoc:C4_Social_Relationship_Type	translated the relations to en
VOCOP (beneficiary)	Existing	beneficiary_id	crm:E21_Person	recipient
VOCOP (beneficiary)	Existing	full_name	crm:E41_Appellation	
VOCOP (beneficiary)	Existing	place_of_birth	dfhc:P17_original_place_of_birth	non-standardized

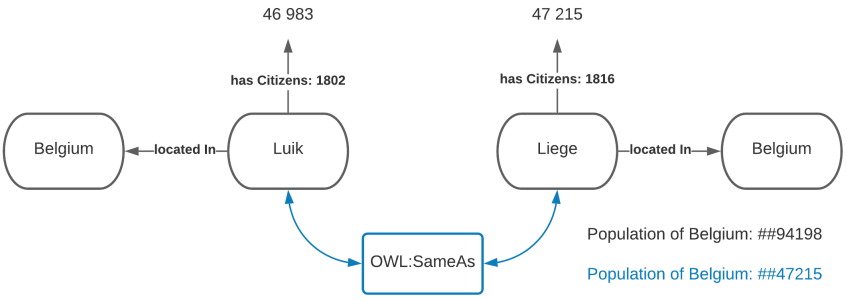
M Second design iteration: DAS & Places conversion table

N Second design iteration: BGB conversion table

O Entity recognition and linking and its implications

Entity recognition and linking processes consist of identifying and matching entities within the same or even multiple datasets. [24] For instance, the place "Luik" and "Liege" can exist both in the same dataset as a place of origin variable. If RDF conversion took these as face-value, it would create two different "City" instances when actually "Luik" and "Liege" are two names for the same city. This 'double naming' will be problematic if a researcher tries to determine the population of Belgium by taking all its cities and summing the population. The sum will count the city of "Liege/Luik" double if it both has a citizen property attached to it.

These duplicate entity issues would not be a big issue in a few instances, as they can be adjusted manually. However, in larger numbers, this would be taking considerable time and, in some cases, outright impossible. Fortunately, several natural language processing algorithms exist which can be trained to perform this exercise automatically. [27] If an entity matches, with some level of accuracy, with another entity, they could be connected via the property sameAs. This sameAs property is of a special type within RDF, and it allows connected instances to inherit all properties and class relations of each other. Meaning, the "Liege/Luik" issue described earlier would be solved by querying at most one population statistic (for instance, the most recent). Even with automated algorithms, this process is still complex due to the many variances of names and a wide range of variables to take into account. This issue and its solution are illustrated in the figure below.



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