Anticipate risk with the value and trade flows knowledge graph

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Abstract
A key to resilient supply chains is the prediction of risk. There are extensive and openly licensed data sources that can be used to predict risk. We are analyzing some of these data sources as part of the "Cognitive Economy Intelligence Platform for the Resilience of Economic Ecosystems" project. In this article, we present a solution in the context of the challenges we faced. Thereby, we put a focus on data integration and enrichment to support risk management tools for risk anticipation. To address these challenges, this paper introduces work on an ontology and a corresponding knowledge graph. The ontology contains, among other things, mappings between commonly used classification schemes for industry codes. This is one of the key pieces of information in the resulting knowledge graph. For the implementation and analysis, the knowledge graph combines information from the Organization for Economic Cooperation and Development Trade in Value Added and the International Trade at Product Level databases. These databases have been prepared in the form of knowledge graphs by various project partners from their respective sources.

Keywords
ontology, trade in value added indicators, international trade at product level, knowledge graph, resilient

1. Introduction

Global production processes are highly dependent on the resilience of global supply chains [1]. In order to measure the resilience of international trade flows various indicators from available information sources must be brought together as comprehensively as possible. A formal semantic description of international trade flows, taking into account existing standards, is suitable for such an integration of different data sources.

There are many global databases that provide insight into global supply chains [2]. For example, the World Input-Output Database (WIOD) [3], the Eora Global Supply Chain Database [4], the Global Trade Analysis Project (GTAP) [5] which use analytical models to study global supply chains, the database International Trade at Product Level (BACI), and Trade in Value Added (TiVA) databases [6].

To the best of our knowledge, these databases lack advanced analytical capabilities that use knowledge graph for semantic data integration and sharing across the various computational tools employed in resilience analytics.

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From the above list of available data sources, we have decided to use in the TiVA and the BACI in this research. This is because they have a large overlap in trade flows. The BACI publishes data on bilateral trade flows at the product level [7]. The BACI database contains information on product names and the corresponding Harmonized System (HS) nomenclature for trade, export and import country codes, trade volume, trade value, unit of measure, value and annual data. With their intersection and divergent information, the TiVA and BACI databases, when integrated, complement each other to form an information-rich basis for analyzing the resilience of many different supply chains.

However, both the TiVA and BACI databases have non-binary relationships between entities. For example, the *domestic value added content of gross export* (code name exgr_dva) indicator *has trade*, which consists of *trade amount*, *trade value* and *product name*. This means that the *exgr_dva* has values for different aspects of the existing trade relation. Its trade and amount values are decimal numbers, and product names are strings. Such non-binary relations are problematic when developing models that integrate different data sources using only binary relations. We propose the use of the Web Ontology Language (OWL) [8] to model the four and three dimensional indicators, and thus provide a framework for semantic data representation and querying. In this work, we address the following research questions (RQ):

RQ1: Can we apply n-ary relations [9] to overcome the challenge of developing a model that integrates existing data sources related to supply chains?

RQ2: How can federated querying be leveraged to efficiently retrieve information from the integrated ontology model concerning global supply chains?

RQ3: How do we ensure interoperability between different industry classification standards used in these data sources?

To address the outlined research question, the contributions of this paper are:

- To document the value and trade flows (VTF) ontology (RQ1), the implementation of mappings between the TiVA and the International Standard Industrial Classification of all Economic Activities (ISIC) Rev. 4 industry code classification schemes (RQ3), and the VTF Knowledge Graph (VTF KG) (RQ1).
- To outline the implementation details of REST API for querying the TiVA Knowledge Graph (TiVA KG) (RQ2).
- To describe the implementation of federated query against the TiVA KG and BACI Knowledge Graph (BACI KG) to enrich value and trade flows data with data about products (RQ2).

The paper is structured as follows. An overview of the TiVA indicators with four and three dimensions is provided in section 2. Related work on monitoring supply chain resilience is discussed in Section 3 following by Section 4, which describes the VTF KG. Within this section, the sub section 4.1 describes the VTF ontology. Section 5 describes the implementation of the REST API for querying the TiVA KG, and the federated query against the TiVA KG and the BACI KG to enrich value and trade flows results with information about products. The Section 6 presents conclusion and future work. The Appendix section lists all the concept and role inclusion axioms of the VTF knowledge base (KB) and federated SPARQL query.

2. Trade in value-added origin indicators in a nutshell

This section provides a brief description of four and three dimensional TiVA indicators [10]. The Economic Cooperation and Development (OECD) published a guide to TiVA [10, 11] that outlines how to measure trends in global value chains. Table 1 provides a summary of selected indicators with four and three dimensions used in this paper. The indicator code name is given at the top of each column. Each TIVA dimension consists of a country code (C) or an industry code (I). The tuples (C, I), (I), and (C) denote the country code or the industry code or both that belong to one of the TIVA perspectives. For each indicator, the number of country and industry codes should be equal to the number of dimensions. For example, the four dimensional indicator fdva_bsci (see Table 1) has two country code values and two industry code values. In this paper, all indicators have their value expressed in the USD currency and the year is set to 2018.

Table 1
Selected TiVA indicators with four and three dimensions (C=country code, I=industry code).

indicator code name	fdva_bsci	exgr_bsci	imgr_bsci	fd_exgr_va	exgr_dva
number of dimensions	4	4	4	4	3
value added origin	(C,I)	(C,I)	(C)	(C)	
exports		(C,I)	(C,I)	(C,I)	(C,I)
imports			(C)		(I)
final demand	(C,I)			(C)	
value	USD	USD	USD	USD	USD
year	2018	2018	2018	2018	2018

The code name *fdva_bsci* refers to the origin of value added in final demand, which is a four-dimensional indicator. It shows how the value of final demand and services consumed within a country is derived from the accumulation of values produced by several industries in different countries [10]. The value added origin and the final demand are determined by the country and industry codes.

The origin of value added in the gross exports dataset, identified by the code name *exgr_bsci*, provides estimates of the total gross exports grouped by each exporting industry in a country. The estimates are broken down by the value added generated by the originating industry and country [10]. Both value added origin and gross exports are determined by the respective country and industry codes.

The origin of the value added in gross imports with the code name *imgr_bsci* links the country's imports with the country of origin of the exports of goods and services of the exporting country [10]. In this indicator, the value added origin and imports are determined by country code, but exports are determined by the country and industry codes.

The gross exports by origin of the value added and final destination, denoted by the code name *fd_exgr_va*, shows the value added from the source country that is embodied in the exports of an exporting country that ends up in the final destination country [10]. In this indicator, the value added origin and final demand are described by the source country code, and exports are identified by the country and industry codes.

The domestic value added content of gross exports is a three dimensional indicator with the

code *exgr_dva* (see page 19 in [10]). This indicator is described by country and industry codes in the export dimension and the country code in the import dimension. It means that the industry of an exporting country to the partner country in the import dimension represents the exported value added generated in the economy of the exporting country. This indicator excludes intra regional trade and intra regional value added flows [10].
All indicators of global flows of goods and services can be linked in more than two hundred billion combinations as described on page 15 of the TiVA guide [10]. For example, the *origin of value added* is the Chilean copper industry. German *exports* of auto parts embodied Chilean copper. The Chinese automotive industry *imports* German auto parts. Finally, the European Union has a *final demand* for cars assembled in China.

3. Related work

Several studies have used knowledge graphs and visualization approaches to monitor supply chain resilience. A recently published market convergence prediction framework [12] uses the chain knowledge graph to improve supply chain management through network resilience experiments. The knowledge graph facilitates cross-domain information connectivity for better decision making. The framework visualizes the interconnections and collaborative relationships between companies in each industry [12].
A knowledge graph-based risk management framework (SCRM) [13] for supply chain resilience is developed. The framework includes a knowledge graph for monitoring risks and long-term disruptions. The constructed knowledge graph contains 2.5 million entities. The framework applies knowledge retrieval, data visualization analysis, risk monitoring, and early warning to supply chain risk management.
Many knowledge graphs suffer from incompleteness, which affects link prediction. To predict missing information and identify critical entities in the supply network, the knowledge graph completion methods are applied to link prediction[14].

4. Value and trade flows knowledge graph

The main purpose of this section is to describe the VTF KG and to address research questions RQ1 and RQ3. The VTF KG is federation of TiVA KG and the BACI KG. The VTF KG comprises of:

- The VTF ontology that is available at https://schema.coypu.org/vtf/1.4.
- The TiVA and the ISIC Rev. 4 industry code thesauruses, and the mappings between them.
- Individual assertions of VTF ontology derived from TiVA CSV files. The TiVA KG SPARQL endpoint is available at https://tiva.coypu.org/tiva.
- The BACI KG created by CoyPu partners.

4.1. The VTF ontology

This section describes how to encode the TiVA [10] indicators shown in Table 1 into a VTF KB and to address research question RQ1. All four dimensional indicators presented in Table 1 have a tree structure, which graphical representation is available in the CoyPu GitLab repository [1]. To elegantly express the TiVA indicators with four and three dimensions in the VTF KB, we use a Description Logic (DL) syntax [15]. The Appendix section specifies the Concept Inclusion (CI) and Role Inclusion (RI) axioms, including domain and range restrictions on role names in the VTF KB.

The term *trade in value added* refers to a set of indicators used to understand global production networks and supply chains [10]. These indicators are divided into several groups according to the number of dimensions. The VTF KB implements *GrossExports*, *OriginOfValueAddedFinalDemand*, *OriginOfValueAddedGrossExports*, *OriginOfValueAddedGrossImports*, *DomesticValueAddedContentOfGrossExports* as concept names. These concept names are subsumed by the *TradeInValueAdded* concept name, as expressed in the CI from 8 to 13 in the Appendix section. These concept names are expressed as the range side of the corresponding role names, as expressed in the CI 23 through 25, and 31 in the Appendix section.

The term *industry sector classification scheme* refers to a systematic approach to assigning classifiers to organizations based on their industry sector codes. To express this term in the VTF KB, we use the concept name *IndustrySectorClassificationScheme* from the Financial Industry Business Ontology (FIBO) [16]. The term *ISIC Rev.4* is expressed in the VTF KB as the ISIC4 concept name and is subsumed by the *IndustrySectorClassificationSchema* concept name (see CI 21 and 22 in the Appendix section).

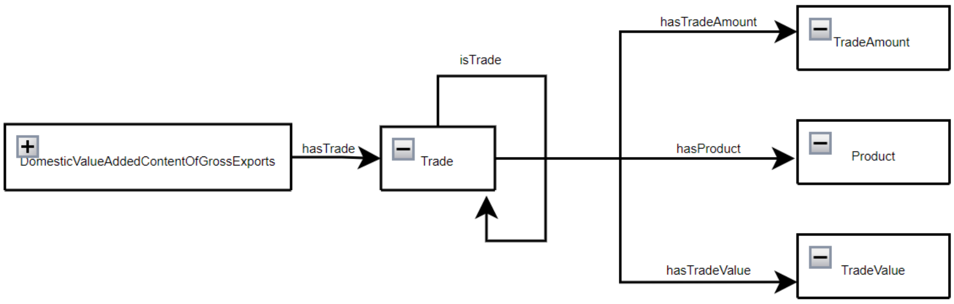

Figure 1: N-ary relation ontology design pattern to model domestic value added content of gross exports (*exgr_dva* code name).

The VTF ontology is derived from the VTF KB and it is implemented using the OWL2 language [17] to support integration and semantic querying of different data sources. Concept names from the VTF KB are implemented as classes in the VTF ontology and role names are implemented as object properties. The VTF ontology currently contains 16 classes, 15 object properties, and 23 logical axioms. However, datatype properties have not yet been implemented. The ontology is being reused to implement the *domestic value added content of gross exports* indicator (see *exgr_dva* code in Table 1), within the COY ontology [18]. There is a n-ary relation between *trade* and *domestic value added content of gross exports* terms that is problematic to represent in ontology using binary relations because there are quantitative values describing this relation that are type of decimal number or string [9]. To overcome this challenge, the n-ary relation ontology

[1]https://gitlab.com/coypu-project/coy-ontology/-/tree/main/ontology/indicators

design pattern is used [9, 19] by creating the concept name *Trade* and the role name *hasTrade* (see CI 3, 19, 20 and 28, RI 36 and 37 in the Appendix section). The concept names *TradeAmount* (CI 7 in the Appendix section), *Product* (CI 2 in the Appendix section), *TradeValue* (CI 5 in the Appendix section) and the role names *hasTradeAmount*, *hasTradeProduct*, *hasTradeValue*, including range restrictions for these role names are created to express quantitative values of *Trade* (see CI 15, 16, 17, 18, 30, 33, 34 in Appendix section). The *Trade* concept name is specified using reflexivity restriction on *isTrade* role name (see CIs 19 and 20 in the Appendix section). To link *DomesticValueAddedContentOfGrossExport*, *TradeAmount*, *Product* and *TradeValue* concept names, the RI 36, 37, 38, 39, and 40 in the Appendix section are created by using *isTrade* , *hasTradeAmount*, *hasTradeProduct*, *hasTradeValue* role names.
The evaluation of the VTF ontology includes tests for accuracy, completeness, computational efficiency, consistency, and coherence [20]. The accuracy test has been passed, and there are no illegal re-declarations of entities within the VTF ontology. However, the completeness test has not been passed, because the full list of value added origin indicators [10] has not been implemented. The VTF ontology implements four indicators with four dimensions among more than 40 of the indicators listed in Table 3.1 in [10]. The computational efficiency test shows that the DL expressivity of the VTF ontology is equivalent to *ALRI* DLs, which is between DL-Lite [21] and *SROIQ* DLs [22]. This means that the HermiT [8] reasoner is able to classify the VTF ontology. The reasoner detects that the ontology is consistent and coherent.

4.2. TiVA and ISIC Rev. 4 industry code thesauruses

This section describes the implementation of thesauruses for the TiVA and the ISIC Rev. 4 industry sector codes using an ontology-based approach, including the implementation of mappings between them. This subsection addresses research question RQ3. The Simple Knowledge Organization System (SKOS) [23] is used to serialize mapping between the thesauruses. The result of this implementation is:

- The TiVA industry sector codes thesaurus.
- The ISIC Rev. 4 industry sector codes thesaurus.
- Automatically produced mapping between these two thesauruses.

The CoyPu GitLab repository [2] provides the complete implementation and an explanation of how to reproduce the listed thesauruses and mappings. We start by using Table A.3, which was published in [10], and the ISIC Rev. 4 document, which is available in [24]. Table A.3 provides a comprehensive list of all TiVA industry sector codes and their correspondence to ISIC Rev. 4 industry sector codes. The rationale for the approach used in this section is twofold. It can be used to produce and validate mappings between any other industry codes that are not explicitly given, as shown in Table A.3. The other reason is that the ISIC Rev. 4 industry sector codes may change over time and this generic solution can be used to produce and validate mappings between the TiVA industry sector codes and the ISIC Rev. 4 industry sector code based on these changes.

[2]https://gitlab.com/coypu-project/coy-ontology/-/tree/main/ontology/mapping

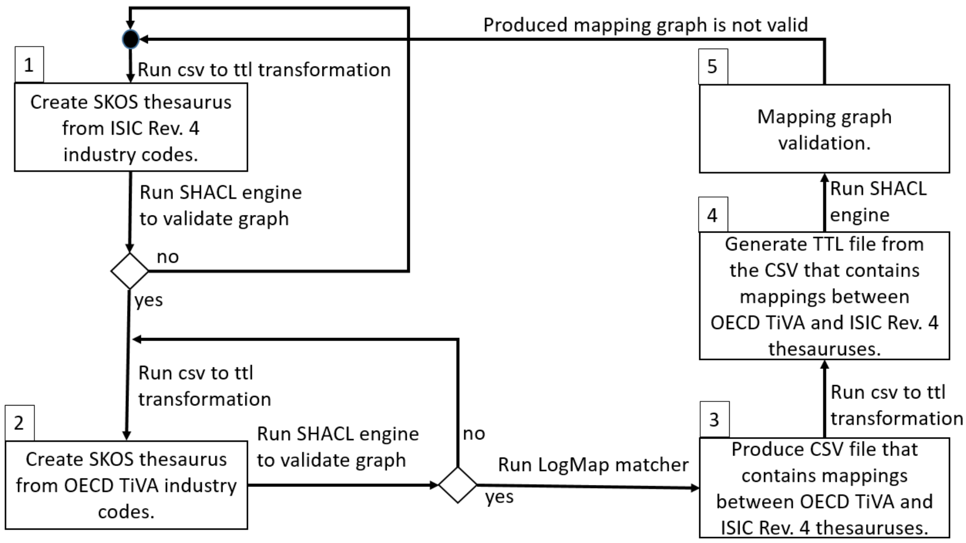

Figure 2: The ontology development workflow for the ISIC Rev. 4 and the TiVA industry sector codes.

Figure 2 shows the implementation workflow. The first task is to automatically generate SKOS-based thesaurus from ISIC Rev. 4 industry sector codes [2]. This is achieved by mapping from the ISTC Rev. 4 CSV file to the corresponding TTL file using RDFizer [25]. The resulting SKOS-based thesaurus is validated against SKOS shapes by using the TopBraid SHACL [26] engine. In the next step, marked with number 2 in Figure 2, the TiVA SKOS-based thesaurus is automatically created and validated against the SKOS shapes. Table A.3 published in [10] shows the correspondence between the TiVA industry sector codes and the ISIC Rev. 4 industry sector codes, but does not show the semantic relations between these two sets of industry codes. In this work, these semantic relations are automatically generated by the LogMap [27] matching tool. The tool accepts the ISIC Rev. 4 and TiVA as source and target thesauruses respectively. As a result, the tool generates 38 mappings between the source and target thesauruses. The LogMap tool did not produce conflictive mappings between these two thesauruses. Each mapping contains a SKOS concept from the ISIC Rev. 4 thesaurus, a SKOS concept from the TiVA thesaurus, the type of mapping between these two SKOS concepts, the mapping direction, and the mapping confidence. This information is stored in a CSV file available in the CoyPu Gitlab repository [2]. In the 4th and 5th steps shown in Figure 2, the RDFizer tool converts the CSV file containing information about mappings into a TTL file. The resulting TTL file is validated against the SKOS shapes using the TopBraid SHACL engine.

4.3. Implementation TiVA KG

The TiVA KG is implemented by processing the raw data, which are available as CSV files [6] and representing four dimensional indicators listed in Table 1. The raw data consists of industry and country code names, which are string types, and value and year, which are numbers. The Python code transforms raw data into TTL files consisting of individual assertions, which are instances of the VTF ontology schema.

Table 2
Size of ontologies generated for each indicator shown in Table 1

Indicator code name	ontology size
fdva_bsci	60GB
exgr_bsci	54GB
imgr_bsci	67GB
fd_exgr_va	76GB

Table 2 summarizes the size of the ontology files generated for each TiVA indicator raw file. The final step is to load generated TTL files, VTF ontology schema, TiVA and ISIC Rev. 4 industry sector code thesauruses, and the produced and validated mappings between these two thesauruses [28] into a remote triple store. The size of the VTF KG is 257GB and it contains 1128749054 triples.

4.4. Implementation of the BACI KG

Data on the domestic value added content of gross exports (*exgr_dva* code name) three dimensional indicator are stored in the BACI KG[3]. The BACI KG is populated from the international trade at product level database [7]. It contains information on exporting and importing country codes, product names, product codes, trade amount value, trade amount, year of trade. The BACI KG contains 185251116 triples and was created by CoyPu project partners.

5. Implementation of the REST API to query VTF KG

In this section, we discuss the design and implementation of the REST API to query VTF KG. It addresses research question RQ2. The pipeline consists of two main building blocks, namely *Backend*, *Data Storage* , which are shown in Figure 3.

5.1. Backend

The output of the Backend module is a JSON file as a result of querying VTF KG by executing parameterized SPARQL queries against a remote TiVA or BACI SPARQL endpoints [28]. The Swagger interface[4] allows users to interact with the API implemented in the Backend module by passing parameters for each operation. Users can also implement their own client-side solutions using this RESTful API.

Figure 4 shows an example of a parameterized SPARQL query. The parameter in this query is a trade location, highlighted in red, of the value added origin in the origin of value added in gross imports indicator. The result of this query is a JSON file consisting of *exports trade location*, *exports industry code*, *imports trade location*, value and year for *origin of value added* in *gross imports*.

[3]https://skynet.coypu.org/#/dataset/coypu-internal/query
[4]https://service.tib.eu/sandbox/tiva/swagger-ui/index.html

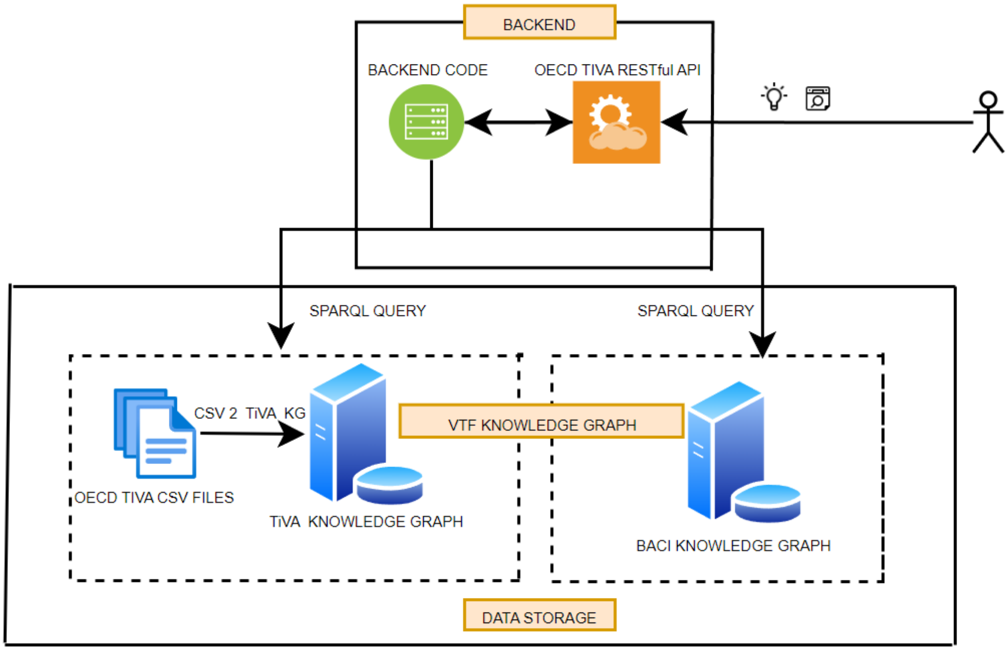

Figure 3: Querying VTF KG via REST API.

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
SELECT DISTINCT ?exTradeLocation ?exIndustryCode ?importTradeLocation ?vao_import_value ?vao_import_year
WHERE {
?vao_import rdf:type <https://schema.coypu.org/vtf#ImgrBsci> .
?vao_import <https://schema.coypu.org/global#hasValue> ?vao_import_value .
?vao_import <https://schema.coypu.org/global#hasYear> ?vao_import_year .
?vao_import <https://schema.coypu.org/vtf#hasValueAddedOrigin> ?vao .
?vao rdf:type <https://schema.coypu.org/vtf#Vao> .
?vao  <https://schema.coypu.org/vtf#hasTradeLocation> "+ locationIri + " .
?vao_import <https://schema.coypu.org/vtf#hasExport> ?ex .
?ex rdf:type <https://schema.coypu.org/vtf#Export> .
?ex <https://schema.coypu.org/vtf#hasIndustryCode> ?exIndustryCode .
?ex <https://schema.coypu.org/vtf#hasTradeLocation> ?exTradeLocation .
?vao_import <https://schema.coypu.org/vtf#hasImport> ?import .
?import rdf:type <https://schema.coypu.org/vtf#Import> .
?import <https://schema.coypu.org/vtf#hasTradeLocation> ?importTradeLocation .
} LIMIT 5000000
```

Figure 4: A SPARQL query to fetch exports trade location, exports industry code, imports trade location, value and year for origin of value added in gross imports indicator.

5.2. Federated query against TiVA KG and BACI KG

The aim of the previous sections was to present our work with regard to the integration of data sources. This section addresses research question RQ2, essentially how we can utilise integrated data sources. As a proof of example, we have created a federated SPARQL query, available in Appendix section, to get information about product trade information, about location of exporting and importing country, product code and name and value (in the USD currency).

The implementation of the federated query involves a SPARQL query executed programmatically against the two SPARQL endpoints of TIVA KG and BACI KG (see *Data Storage* component shown in Figure 3). A JSON object as a result of the execution of this federated query contains the value, year, exporting and importing trade location of the imgr_bsci indicator available in TiVA KG (see 27 and 28 rows in the federated SPARQL query). These exporting and importing trade locations must match the importing and exporting trade locations of the exgr_dva indicator available in BACI KG (see rows 41 and 42 in the federated SPARQL query). Based on this match, the resulting JSON object also contains the product name, product code, quantity value and year of trade available in BACI KG.

6. Conclusions and future work

In this work all research questions are addressed. This paper shows valuable results that are the basis for deeper analysis of international trade flows via building more federated SPARQL queries and implementation of a dashboard that should dynamically generate charts using implemented REST API. The OECD forum [5] recently discussed four key issues [6] for resilient supply chains. To address one of these issues, this paper presents VTF KG and a RESTful API. The OECD discusses the need to implement policies that strengthen the resilience of supply chains. One of the key policy actions is to *determine government role*, which includes the international exchange of information [7]. This paper addresses this issue by enabling services and tools to share information about trade flows using a RESTful API and to perform federated queries against TiVA and BACI knowledge graphs. We observe gaps in this work that should be addressed in further development such as to infer missing information in the VTF KG and to solve the incompleteness of the VTF ontology.

Appendix

Value and trade flows (VTF) knowledge base (KB) expressed in Description Logic (DL) syntax:

Concept inclusion (CI) axioms

1. Exports $\sqsubseteq \top$
2. Product $\sqsubseteq \top$
3. Trade $\sqsubseteq \top$
4. Imports $\sqsubseteq \top$
5. TradeValue $\sqsubseteq \top$
6. FinalDemand $\sqsubseteq \top$
7. TradeAmount $\sqsubseteq \top$
8. TradeInValueAdded $\sqsubseteq \top$
9. GrossExports $\sqsubseteq$ TradeInValueAdded

[5] https://www.oecd.org/trade/resilient-supply-chains/
[6] https://www.sustainablesupplychains.org/blog/four-keys-to-resilient-supply-chains/
[7] https://www.oecd.org/trade/resilient-supply-chains/determine-government-role/

10. DomesticValueAddedContentOfGrossExports $\sqsubseteq$ TradeInValueAdded
11. OriginOfValueAddedFinalDemand $\sqsubseteq$ TradeInValueAdded
12. OriginOfValueAddedGrossExports $\sqsubseteq$ TradeInValueAdded
13. OriginOfValueAddedGrossImports $\sqsubseteq$ TradeInValueAdded
14. ValueAddedOrigin $\sqsubseteq \top$
15. DomesticValueAddedContentOfGrossExports $\sqsubseteq$ ∃hasTrade.Trade
16. ∃hasTrade.Trade $\sqsubseteq$ DomesticValueAddedContentOfGrossExports
17. Trade $\sqsubseteq$ ∃hasTradeAmount.TradeAmount $\sqcap$ ∃hasTradeProduct.Product $\sqcap$ ∃hasTradeValue.TradeValue $\sqcap$ ∃hasTradeValueAdded.TradeInValueAdded
18. ∃hasTradeAmount.TradeAmount $\sqcap$ ∃hasTradeProduct.Product $\sqcap$ ∃hasTradeValue.TradeValue $\sqcap$ ∃hasTradeValueAdded.TradeInValueAdded $\sqsubseteq$ Trade
19. Trade $\sqsubseteq$ ∃isTrade.Trade
20. ∃isTrade.Trade $\sqsubseteq$ Trade
21. IndustrySectorClassificationScheme $\sqsubseteq \top$
22. ISIC4 $\sqsubseteq$ IndustrySectorClassificationScheme

Domain and range restrictions on role names

23. $\top \sqsubseteq$ ∀hasExport.Exports
24. $\top \sqsubseteq$ ∀hasFinalDemand.FinalDemand
25. $\top \sqsubseteq$ ∀hasTradeValueAdded.TradeInValueAdded
26. $\top \sqsubseteq$ ∀hasImport.Imports
27. $\top \sqsubseteq$ ∀hasIndustryCode.IndustrySectorClassificationScheme
28. $\top \sqsubseteq$ ∀hasTrade.Trade
29. ∃hasTrade.$\top \sqsubseteq$ TradeInValueAdded
30. $\top \sqsubseteq$ ∀hasTradeAmount.TradeAmount
31. ∃hasTradeLocation.$\top \sqsubseteq$ TradeInValueAdded
32. $\top \sqsubseteq$ ∀hasTradeLocation.$\top$
33. $\top \sqsubseteq$ ∀hasTradeProduct.Trade
34. $\top \sqsubseteq$ ∀hasTradeValue.TradeValue
35. $\top \sqsubseteq$ ∀hasValueAddedOrigin.ValueAddedOrigin

Role inclusion axioms

36. hasTrade $\sqsubseteq$ hasTradeValueAdded^{-1}
37. hasTradeValueAdded $\sqsubseteq$ hasTrade^{-1}
38. hasTradeValueAdded$^{-1} \circ$ isTrade $\circ$ hasTradeProduct $\sqsubseteq$ hasTradeInValueAddedProduct
39. hasTradeValueAdded$^{-1} \circ$isTrade$\circ$hasTradeAmount $\sqsubseteq$ hasTradeInValueAddedTradeAmount
40. hasTradeValueAdded$^{-1} \circ$ isTrade $\circ$ hasTradeValue $\sqsubseteq$ hasTradeInValueAddedTradeValue

Federated SPARQL query

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX vtf: <https://schema.coypu.org/vtf#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX skos: <http://www.w3.org/2004/02/skos/core#>
PREFIX coy: <https://schema.coypu.org/global#>
SELECT DISTINCT ?vaoImportValue ?vaoImportYear ?exTradeLocation
?importLocation ?import ?export ?productMatch ?productLabel
?amountYear ?amountValue ?value
WHERE {
GRAPH <https://data.coypu.org/trade/baci/> {
?exgrdva rdf:type vtf:ExgrDva .
?exgrdva vtf:hasImport ?import .
?exgrdva vtf:hasExport ?export .
?exgrdva vtf:hasTrade ?trade .
?trade vtf:hasTradeProduct ?product .
?product rdfs:label ?productLabel .
?product skos:exactMatch ?productMatch .
?trade vtf:hasTradeAmount ?tradeAmount .
?tradeAmount coy:hasYear ?amountYear .
?tradeAmount coy:hasValue ?amountValue .
?trade coy:hasTradeValue ?tradeValue .
?tradevalue coy:hasValue ?value .
FILTER(str(?amountYear)='2018') .
}
SERVICE <https://tiva.coypu.org/tiva> {
{
SELECT ?vaoImportValue ?vaoImportYear ?exTradeLocation
?importLocation
WHERE {
?imgrbsci a vtf:ImgrBsci .
?imgrbsci coy:hasValue ?vaoImportValue .
?imgrbsci coy:hasYear ?vaoImportYear .
?imgrbsci vtf:hasExport ?ex .
?imgrbsci vtf:hasImport ?imgrImport .
?imgrImport vtf:hasTradeLocation ?importLocation .
?ex rdf:type vtf:Export .
?ex vtf:hasTradeLocation> ?exTradeLocation .
}
}
}
FILTER(str(?import)=str(?importLocation) &&
```

```
str(?export)=str(?exTradeLocation)) .
}LIMIT 10;
```


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References

[1] R. C. Johnson, G. Noguera, A portrait of trade in value-added over four decades, The Review of Economics and Statistics 99 (2017) 896–911. doi:10.1162/REST_a_00665.

[2] X. Gong, E. Keeble, D. Boko, A. Deveza, Building afciot and tiva indicators in africa in support of afcfta (2023). URL: https://iioa.org/conferences/29th/papers/files/4853_PaperonAfCIOT_2023-05-15.pdf.

[3] World input-output database project, 2024. URL: www.wiod.org, accessed February 28th, 2024.

[4] The eora global supply chain database, 2024. URL: https://worldmrio.com/, accessed February 28th, 2024.

[5] Global trade analysis project (gtap), 2024. URL: https://www.gtap.agecon.purdue.edu/, accessed February 28th, 2024.

[6] Trade in value added origin principal indicators raw data, 2024. URL: https://stats.oecd.org/DownloadFiles.aspx?HideTopMenu=yes&DatasetCode=TIVA_2021_C1, accessed February 21st, 2024.

[7] G. Gaulier, S. Zignago, BACI: International Trade Database at the Product-Level. The 1994-2007 Version, Working Papers 2010-23, CEPII, 2010. URL: http://www.cepii.fr/CEPII/en/publications/wp/abstract.asp?NoDoc=2726.

[8] B. Motik, P. F. Patel-Schneider, B. Parsia, C. Bock, A. Fokoue, P. Haase, R. Hoekstra, I. Horrocks, A. Ruttenberg, U. Sattler, et al., Owl 2 web ontology language: Structural specification and functional-style syntax, W3C recommendation 27 (2009) 159.

[9] P. Hayes, C. Welty, Defining n-ary relations on the semantic web. w3c working group note, 12 april 2006, World Wide Web Consortium. http://www. w3. org/TR/swbp-n-aryRelations/(last visited December 27, 2012) (2006).

[10] OECD, Guide to oecd's trade in value added (tiva) indicators, 2018 edition, 2019. URL: https://stats.oecd.org/fileview2.aspx?IDFile=88076c6d-d86a-4f18-8cd9-923c26fb4c98.

[11] J. M. Guilhoto, C. Webb, N. Yamano, Guide to oecd tiva indicators, 2021 edition (2022). URL: https://www.oecd-ilibrary.org/science-and-technology/guide-to-oecd-tiva-indicators-2021-edition_58aa22b1-en.

[12] S. Zhou, Y. Liu, Y. Liu, A market convergence prediction framework based on a supply chain knowledge graph, Sustainability 16 (2024). URL: https://www.mdpi.com/2071-1050/16/4/1696.

[13] Y. Yang, C. Peng, E.-Z. Cao, W. Zou, Building resilience in supply chains: A knowledge graph-based risk management framework, IEEE Transactions on Computational Social Systems (2023) 1–9. doi:10.1109/TCSS.2023.3334768.

[14] Y. Liu, B. He, M. Hildebrandt, M. Buchner, D. Inzko, R. Wernert, E. Weigel, D. Beyer, M. Berbalk, V. Tresp, A knowledge graph perspective on supply chain resilience, arXiv preprint arXiv:2305.08506 (2023).

[15] F. Baader, I. Horrocks, C. Lutz, U. Sattler, An Introduction to Description Logic, Cambridge University Press, 2017. doi:10.1017/9781139025355.

[16] M. Bennett, The financial industry business ontology: Best practice for big data, Journal of Banking Regulation 14 (2013) 255–268.

[17] M. Smith, I. Horrocks, M. Krotzsch, B. Glimm (eds.), OWL 2 Web Ontology Language conformance (second edition), 2012. URL: https://www.w3.org/TR/owl2-overview/, accessed February 21st, 2024.

[18] A. Schaefer, E. Hoerster, F. Engel, J. Reineke, J. Rathschlag, L. Michaelis, L. Bühmann, M. Weber, N. Weissmann, N. Arndt, N. Krdzavac, P. Ulrich, R. Usbeck, S. Gründer-Fahrer, S. Bin, T. Grabo, Coypu ontology, 2023. URL: https://schema.coypu.org/global/2.3, accessed February 26st, 2024.

[19] M. Giunti, G. Sergioli, G. Vivanet, S. Pinna, Representing n-ary relations in the semantic web, Logic Journal of the IGPL 29 (2021) 697–717.

[20] H. Hlomani, D. Stacey, Approaches, methods, metrics, measures, and subjectivity in ontology evaluation: A survey, Semantic Web Journal 1 (2014) 1–11.

[21] D. Calvanese, G. De Giacomo, D. Lembo, M. Lenzerini, R. Rosati, Tractable reasoning and efficient query answering in description logics: The dl-lite family, Journal of Automated reasoning 39 (2007) 385–429.

[22] I. Horrocks, O. Kutz, U. Sattler, The even more irresistible sroiq., Kr 6 (2006) 57–67.

[23] A. Miles, J. R. Pérez-Agüera, Skos: Simple knowledge organisation for the web, Cataloging & Classification Quarterly 43 (2007) 69–83. doi:10.1300/J104v43n03_04.

[24] U. N. D. of Economic, S. A. S. Division, International standard industrial classification of all economic activities (isic) rev.4, 2008. URL: https://unstats.un.org/unsd/publication/seriesm/seriesm_4rev4e.pdf, accessed February 21st, 2024.

[25] E. Iglesias, S. Jozashoori, D. Chaves-Fraga, D. Collarana, M.-E. Vidal, Sdm-rdfizer: An rml interpreter for the efficient creation of rdf knowledge graphs, in: Proceedings of the 29th ACM international conference on Information & Knowledge Management, 2020, pp. 3039–3046.

[26] H. Knublauch, An open source implementation of the w3c shapes constraint language (shacl) based on apache jena., 2023. URL: https://github.com/TopQuadrant/shacl, accessed February 27th, 2024.

[27] E. Jiménez-Ruiz, B. Cuenca Grau, Logmap: Logic-based and scalable ontology matching, in: The Semantic Web–ISWC 2011: 10th International Semantic Web Conference, Bonn, Germany, October 23-27, 2011, Proceedings, Part I 10, Springer, 2011, pp. 273–288.

[28] L. Buehmann, Oecd tiva knowledge graph sparql endpoint, 2024. URL: https://tiva.coypu.org/tiva, accessed February 26st, 2024.