Computation and Knowledge Mapping for Data Entities

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***Abstract*—This paper presents the research and results from developing resources and knowledge based methods for the creation of new context for objects and entities, based on the methodology of knowledge mapping. The results are an architecture allowing advanced knowledge mapping including flexible deployment of computational sequences and an implementation of resources and application components. The knowledge mapping enables to put knowledge objects in new context, which can be used in arbitrary scenarios, e.g., with knowledge mining and decision making. The paper shows the importance of facilities for different implementations and presents a resulting architecture and case studies of two different implementations for a task. The implementation cases are based on a computational case of spatial visualisation. For demonstration, a publicly available central data object was used for data entity analysis. The paper presents practical examples and discusses the high level views of implementations and case study. The main goal of this research is to create a functional architecture based on sustainable long-term multi-disciplinary knowledge resources, which can provide a wide range of flexibility for knowledge mapping and different computational solutions.**

***Keywords*–Knowledge Mining and Mapping; Computational Procedures; Context Creation; Universal Decimal Classification; Advanced Data-centric Computing.**

I. INTRODUCTION

Resources of knowledge are steadily increasing and so is the complexity and heterogeneity of the associated knowledge. In most cases, it is not possible to find satisfying results even though the basis of data is rapidly growing. New approaches are needed in order to find answers to challenging knowledge mining requests.

Concepts used in the past mostly provided non consistent and insufficient approaches when dealing with the complexity of knowledge. In most cases, those concepts basically consider dealing with ‘data’ and claim to result in ‘knowledge’ or even ‘wisdom’ of some kind [1]. For example, the Data-Information-Knowledge-Wisdom (DIKW) approach widely used in Data Mining (DM) lacks an understanding of data being only one aspect of knowledge [2].

Implementations are mostly neglecting the knowledge associated with originary resources and referred knowledge and therefore deal with the applications and isolated technical features, which are neither able to be integrated for improving results nor do they provide reasonable freedom of solutions.

Concepts like DIKW are lacking a profound relation of data and information [3]. Terms like “knowledge hierarchy” and “information hierarchy” are more misleading than constructive, especially when we have to deal with complex and long-term resources. Approaches used with data warehousing [4] on that basis, e.g., Extract, Transform, Load (ETL) and Extract, Load, Transform (ELT) for integrating data newly also resulted in requiring hybrid approaches but have not been based on a profound understanding of knowledge.

The described deficits are a major motivation for this long-term research. The fundaments of terminology and of understanding knowledge are layed out by Aristotle [5][6], being an essential part of ‘Ethics’ [7]. Information sciences can very much benefit from Aristotle’s fundaments and a knowledge-centric approach [8] but for building holistic and sustainable solutions they need to go beyond the available technology-based approaches and hypothesis [9] as analysed in Platons’ Phaidon. Making a distinction and creating interfaces between methods and applications [10], the principles are based on the methodology of knowledge mapping [11], which fundaments are not outlayed here again. The implementation can make use of objects and conceptual knowledge [12] and shows being able to build a base for applications scenarios like associative processing [13] and advanced knowledge discovery [14].

Considering this state-of-the-art, the methodology deployed in this research and the accompanying implementation of methods consequently focusses on the complex knowledge basis, which allows to integrate the different aspects of knowledge and the complexity of knowledge context. In result, the methodology allows to create methods focussing on alternative contexts based on a wide range of criteria and solutions provided by knowledge context. Implementations are considered knowledge-centric, with data being one complementary facet of knowledge. Therefore, the methodology and, in consequence, the method implementations based on this methodology, are vastly scalable. Scalability support ranges from fixed associations to arbitrarily fuzzy understanding.

This paper is organised as follows. Section II introduces to the state-of-the-art, architecture, and frame of universal knowledge. Section III presents an exemplary case study with different implementations. Section IV discusses the results of the case study, evaluates them based on the sequences and architecture and delivers a computational footprint in context with referred knowledge. Section V summarises the results and lessons learned, conclusions, and future work.

II. ARCHITECTURE AND UNIVERSAL KNOWLEDGE

An understanding of the essence and complexity of universal, multi-disciplinary knowledge can be achieved by taking a closer look on classification. The state-of-the-art of classifying ‘universal knowledge’ is the Universal Decimal Classification (UDC) and its solid background and long history. The LX knowledge resources’ structure and the classification references [15] based on UDC [16] are essential means for the processing workflows and evaluation of the knowledge objects and containers. Both provide strong multi-disciplinary and multi-lingual support. For the research, all small unsorted excerpts of the knowledge resources objects only refer to main UDC-based classes, which for this publication are taken from the Multilingual Universal Decimal Classification Summary (UDCC Publication No. 088) [17] released by the UDC Consortium under the Creative Commons Attribution Share Alike 3.0 license [18] (first release 2009, subsequent update 2012). Nevertheless, the research conducted here in deploying knowledge provides a new solution not precedented by comparable approaches, from the view of methodology and implemented methods.

A. *Architecture*

The implementation architecture is shown in Figure 1.

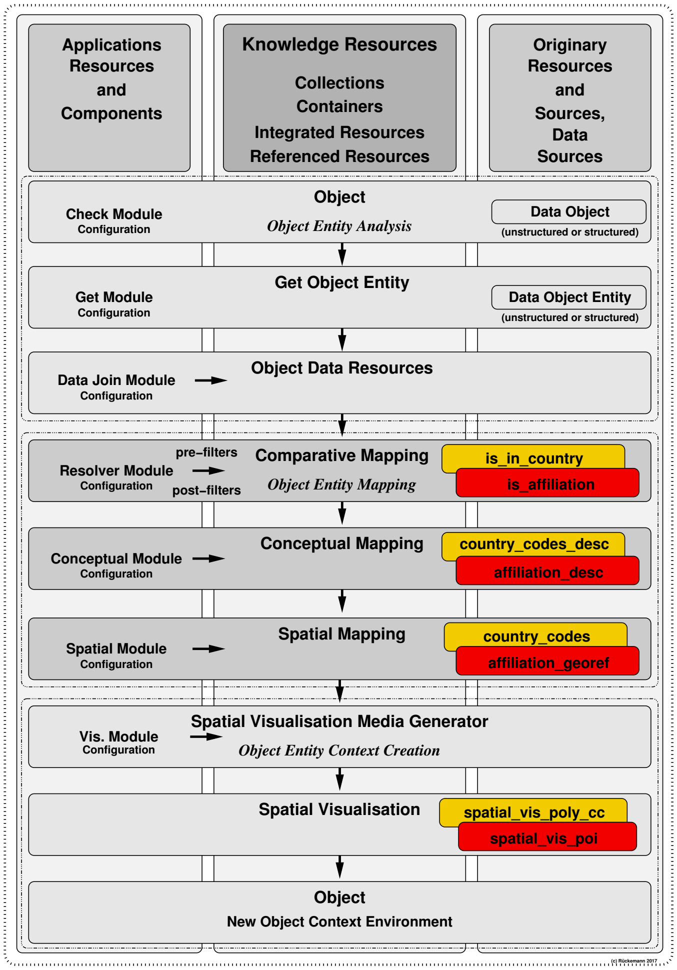

Figure 1. Architecture for mapping arbitrary objects / entities to new context environments, allowing different methods (yellow/red) for implementations.

The illustration of the architecture for knowledge mapping of arbitrary objects and entities to new object context environments also takes into account that the context of objects and their entities can contain many different facets and references from different origin. The target for the case studies is a knowledge mapping providing two different mapping views. The spatial visualisation is an illustrative step, providing insights on new context. Data and modules are provided by Knowledge Resources, originary resources, and application resources and components. The architecture is also aware of allowing different methods (e.g., highlighted in yellow/red) for implementations regarding the same resources and target.

The core of the knowledge mapping in this case consists of comparative mapping, conceptual mapping, and spatial mapping. All the examples in the case studies are based on the methodology of knowledge mapping [11]. The integration of originary sources provides a generic view for terms like ‘knowledge integration’ and ‘knowledge representation’ as such might be used in less generic approaches.

Here, in the mapping and the consecutive steps (here, a visualisation for illustration purposes), we do have the major differences of different methods for implementing alternative ways for the same resources and target.

The following case study demonstrates the different characteristics of implementations based on the same universal knowledge. From a multitude of applications scenarios, a term to location association providing ways of knowledge mapping of textual context to space and place were choosen for case studies.

B. *Data and Universal Knowledge*

The next passages show some major steps for creating spatially linked context from plain text, which were used in the workflows required for the cases. The single data object in this case study implementation (Figure 2) contains mostly unstructured text [19] markup, and formatting instructions.

```
<!DOCTYPE html PUBLIC "-//W3C//DTD␣XHTML␣1.0␣Transitional//EN" ... <title>
 GEOProcessing 2018 ...</title>
..., Leibniz Universit&auml;t Hannover / Westf&auml;lische
 Wilhelms-Universit&auml;t M&uuml;nster / North-German Supercomputing Alliance
       (HLRN), Germany ...
..., Technion - Israel Institute of Technology, Haifa,      Israel<br />
..., Consiglio Nazionale delle Ricerche - Genova,      Italy <br />
..., Centre for Research in Geomatics - Laval University,      Quebec, Canada <
 br />
..., Curtin University, Australia <br />
..., Lomonosov Moscow State University, Russia&nbsp; <br />
..., FH Aachen, Germany</p> ...
         <p>..., Universiti Tun Hussein Onm Malaysia, Malaysia<br />
           ..., Cardiff University, Wales, UK<br />
           ..., Universidade  Federal do Rio Grande, Brazil<br />
           ..., GIS unit Kuwait Oil  Company, Kuwait<br />
           ..., Middle East Technical  University, Turkey<br />
           ..., University of  Sharjah, UAE<br />
           ..., Georgia State University, USA<br />
           ..., Centre for Research  in Geomatics - Laval University, Quebec,
            Canada<br />
           ..., Environmental Systems  Research Institute (ESRI), USA<br />
           ..., ORT University -  Montevideo, Uruguay<br /> ...
```

Figure 2. Mapping target: Single object, unstructured text (excerpt).

The sample object is the committees’ page of the GEOProcessing 2018 conference in Rome [19]. Passages not relevant for demonstration were reduced to ellipses. The spatial visualisation can result from identifying and mapping entities in the text of an object to various knowledge context. The identification of entities is resulting from automated analysis.

Figure 3 shows the object content after automatically integrated with the Knowledge Resources via a join module. The Object Entity Mapping facilitates to associate relevant objects, e.g., via conceptual knowledge and comparative methods. The objects and their entities can contain any knowledge, e.g., factual and conceptual knowledge.

```
GEOProcessing 2018 [...]: ...
  ..., Leibniz Universität Hannover / Westfälische Wilhelms-Universität Münster
   / North-German Supercomputing Alliance (HLRN), Germany ...
  ..., Technion - Israel Institute of Technology, Haifa, Israel
  ..., Consiglio Nazionale delle Ricerche - Genova, Italy
  ..., Centre for Research in Geomatics - Laval University, Quebec, Canada
  ..., Curtin University, Australia
  ..., Lomonosov Moscow State University, Russia
  ..., FH Aachen, Germany ...
  ..., Universiti Tun Hussein Onm Malaysia, Malaysia
  ..., Cardiff University, Wales, UK
  ..., Universidade  Federal do Rio Grande, Brazil
  ..., GIS unit Kuwait Oil  Company, Kuwait
  ..., Middle East Technical  University, Turkey
  ..., University of  Sharjah, UAE
  ..., Georgia State University, USA
  ..., Centre for Research  in Geomatics - Laval University, Quebec, Canada
  ..., Environmental Systems  Research Institute (ESRI), USA
  ..., ORT University -  Montevideo, Uruguay ...
```

Figure 3. Object instance representation after integration (excerpt).

In this case, dealing with space and place data, the references, e.g., referred conceptual knowledge, carried in objects are most relevant. The complement knowledge used with the mapping contains multi-disciplinary and multi-lingual knowledge, it can contain names and synonyms in different languages, dynamically usable geocoordinates, geoclassification, and so on.

Example excerpts of possibly relevant main classification codes of the UDC references are shown in Table I.

TABLE I. UDC CODES OF SPATIAL FEATURES AND PLACE: MAIN CLASSIFICATION CODES USED FOR CONCEPTUAL MAPPING (EXCERPT).

UDC Code	*Description*
UDC:(1)	Place and space in general. Localization. Orientation
UDC:(2)	Physiographic designation
UDC:(3)	Places of the ancient and mediaeval world
UDC:(4/9)	Countries and places of the modern world

The references, e.g., classification, facets, concordances, and textual description, are usable in all the procedures and steps and allow to consider and implement arbitrary flexibility of fuzziness. During the research, two computational sequences were implemented for illustration. These sequences show different characteristics in content and context, as well as different characteristics in architecture and computational requirements.

III. IMPLEMENTATION: MULTIPLE WAYS TO SPACE

The following case study presents two different methods for implementing object/entity knowledge mapping to space and place targets and discusses major insights. Computational knowledge mapping procedures are presented for both methods, as well as the visualisation of the results. The computational application components are part of the available resources. The Generic Mapping Tools (GMT) [20] suite application components were used for handling the spatial data, applying related criteria, and for the visualisation. All provided spatial presentations are using the same Mercator projection (region: -180/180/-60/84) in order to provide a common base for the comparison.

A. Space and place: Affiliation based knowledge mapping

This method implements the knowledge mapping based on affiliations. Table II gives the computational sequence of the core computational procedures.

TABLE II. AFFILIATION BASED MAPPING: COMPUTATIONAL SEQUENCE OF CORE COMPUTATIONAL PROCEDURES AND REFERRED MODULES.

Procedure	*Module*
Comparative Mapping Configuration	`is_affiliation`
Conceptual Mapping Configuration	`affiliation_desc`
Spatial Mapping Configuration	`affiliation_georef`

The means, regarding space and place: Affiliation mapping, affiliation association via conceptual knowledge and textual description, and affiliation georeferencing.

Figure 4 shows an excerpt of affiliation references from the Knowledge Resources as associated with the comparison.

```
...
9.7196989 52.3829641 Leibniz Universitaet Hannover, Germany
...
7.6131826 51.9635705 Westfaelische Wilhelms-Universitaet Muenster
...
-61.5289325 16.2242724 Universite des Antilles - LAMIA, France, Guadeloupe
...
```

Figure 4. Knowledge Resources: Affiliation references used in comparative mapping (excerpt).

In practice, the number of such place references can be very large. In case of this study, the numbers are in the range of millions of places. The visualisation of the results (red bullets) from the affiliation based procedures was done on a spatial map (Figure 5).

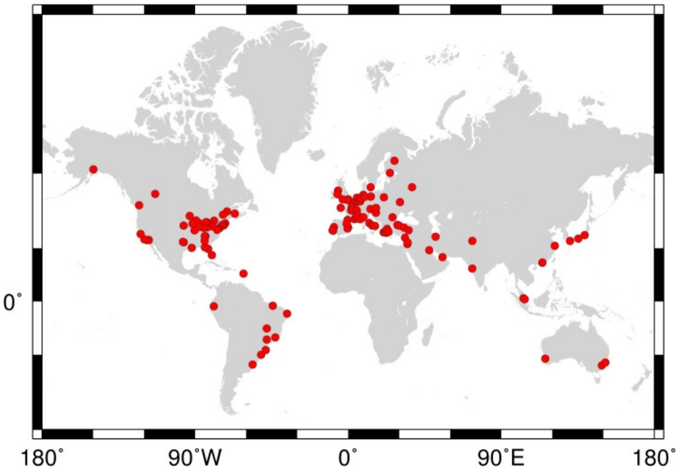

Figure 5. Visualisation of the result of affiliation based knowledge mapping: Geo-referenced place association.

The computing task can be parallelised for objects and entities. For demanding application scenarios, e.g., dynamical implementations, this implementation benefits to a small extend from parallelisation.

B. *Space and place: Country code based knowledge mapping*

This method implements the knowledge mapping based on country codes. Table III gives the computational sequence of the core computational procedures.

TABLE III. COUNTRY CODE BASED MAPPING: COMPUTATIONAL SEQUENCE OF CORE COMPUTATIONAL PROCEDURES AND REF. MODULES.

Procedure	*Module*
Comparative Mapping	`is_in_country`
Configuration	
Conceptual Mapping	`country_codes_desc`
Configuration	
Spatial Mapping	`country_codes`
Configuration	

That means, regarding space and place: Country mapping, association of country codes via codes description, and evaluation of country codes and visualisation.

Figure 6 shows an excerpt of country code references from the Knowledge Resources as associated with the comparison.

```
...
"Germany|Deutschland" lxcoco-DE
"Ghana"  lxcoco-GH
"Gibraltar" lxcoco-GI
"Greece" lxcoco-GR
"Greenland|Grønland" lxcoco-GL
"Grenada" lxcoco-GD
"Guadeloupe" lxcoco-GP
...
```

Figure 6. Knowledge Resources: Country Codes used for comparative mapping (excerpt).

In practice, the number of such country code references have several hundred pattern-code entities for a certain year or era. In case of this study, the numbers are in the range of about 300 pattern rules per language. Resolving can be done automatically via geo-referencing and visualisation application components.

The visualisation of the results (yellow country colourisation) from the country code based procedures was done on a spatial map (Figure 7). The country codes are based on the standard of the International Standards Organisation (ISO).

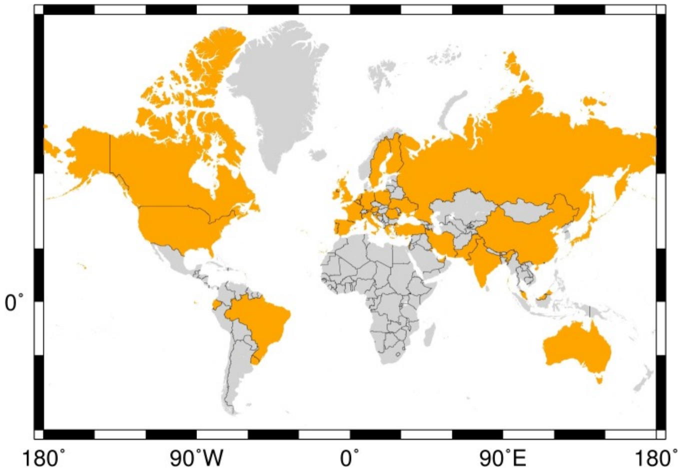

Figure 7. Visualisation of the result of country code based knowledge mapping: ISO referenced state association.

The computing task can be parallelised for objects and entities. For demanding application scenarios, e.g., dynamical implementations, this implementation widely benefits from parallelisation.

IV. DISCUSSION

Implementations can range from generic to specialised, as granted by the methodology, all the components and the illustrated architecture. A reason for illustrating the methodology with a well defined implementation is that from many experiences made from working with methodologies, specialised implementations tend to be better comprehensible by the majority of researchers in various disciplines.

The methodology of knowledge mapping, as illustrated via implementation of two methods discussed here, allows a versatile number of methods to be created for a purpose, based the same knowledge and data.

A. *Comparison and discussion of results*

The two sequences show different characteristics

- in content and context, as well as
- in architecture and computational requirements.

Country code based and affiliation based solutions result in visualisation of different distribution patterns. While an affiliation based solution can have a higher granularity it can be more precise in detail. In that context, a country code based solution is associated with more dependencies in the results – border lines, different country context, especially for handling and visualising long-term intervals. For example, considering the same data, on the one hand geo-references of a place do not really change much over time, on the other hand border lines of states change much faster on a global scale.

For a visual comparison, the results from both the affiliation based and country code based sequences were placed on the same spatial map (Figure 8).

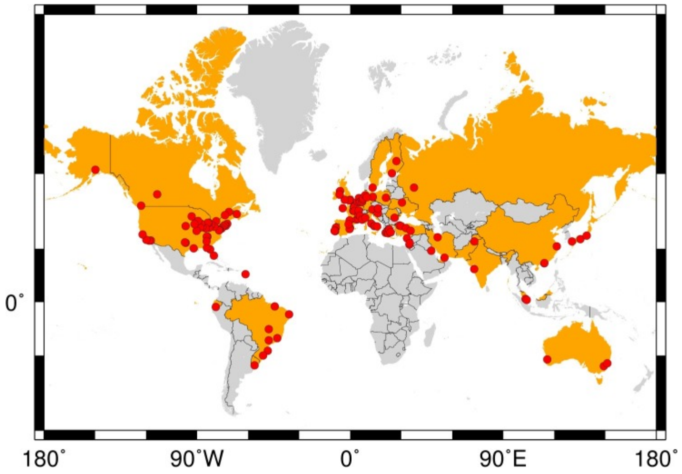

Figure 8. Comparison of both affiliation and country code based knowledge mapping: Geo-referenced place and ISO referenced state results.

There are more differences in detail, which can influence decisions on applicability and implementation. In general, there are arbitrary ways of implementing a knowledge mapping target based on the same Knowledge Resources. An implementation will in most cases be triggered by a combination of items, e.g., purpose, implementation efficiency, and computational performance. The characteristics and resolvability achieved via different knowledge mapping may be different. The number of countries is much more limited and the identification can be much more standardised than for geo-references places. The distribution of affiliation associated places can create a different impression than a visualisation based on country data. The sizes of mapped country areas can create a different impression than a visualisation based on country data. Associations based on both results can be significantly different, leading to further different knowledge context.

A further significant difference of the two case study implementations is the fact that the computational requirements are much more complex for affiliation mapping than for country code mapping. Depending on the objects and entities and the selected knowledge resources the factor of complexity can go up by millions. This is foremost relevant for the computation of comparative modules and analysis and visualisation of results.

B. *Knowledge and its computational footprint*

Based on the case studies, the characteristics of both solutions result in different computational requirements. Table IV compares the solutions regarding the numbers of computational checks required, done for the same object and entities.

TABLE IV. CORE PROCEDURES AND OBJECTS: COMPARISON OF COUNTRY CODE AND AFFILIATION BASED MAPPING.

Procedure	*Country Code*	*Affiliation*
Comparative Mapping		
pre-filter Checks	5,500	72,000
Knowledge Mapping Checks	40,000	570,000
post-filter Checks	7,000	75,000
Conceptual Mapping		
Checks UDC	300	5,000,000
Checks, other references	300	500,000
Spatial Mapping		
Results	> 50 Polygons	>50 Points
Context, object level	> 120 Polygons	0 Polygons
Context, basic	1 Basemap	1 Basemap

Different implementations involve different knowledge. As can be reasoned from the comparison, the case of affiliation based knowledge mapping might be a challenge for certain architectures, e.g., a distributed service implementation.

On the opposite, country code mapping can mean higher requirements for supportive data and higher load on spatial mapping application components, e.g., polygons provided by additional data, requests, application bound features, and visualisation. The supportive data can easily get into the range of millions of entities and Giga Bytes of data size per single request. If considering that country shapes will differ for a certain year or era, then multiple supportive data set might be needed. Therefore, load distribution is very much different for the implementations due to the nature of the different methodologies. The core sequences required for the knowledge mapping result in significant computational loads, especially at two steps: Comparisons and visualisation. These result in both comparative mapping load and supportive application load. Configuration of resources and modules can help to scale the computational load, nevertheless, any different configurations will have additional impact on the associated knowledge involved, which can be a significant reason for decision: For most component implementations and investments it does make a difference if a computational step takes two seconds or two days and if the required knowledge and data are involved or not. In addition to different knowledge being associated during the sequences, there is another difference: Most of the procedures are not bidirectional. If the affiliation based knowledge mapping is used in order to compute a consecutive country code based knowledge mapping and even if the result would be identical to the plain country code mapping this does not indicate that the country code mapping could also provide a consecutive affiliation mapping in the same manner.

V. CONCLUSION

The paper presented the research and results based on the developments of resources and advanced knowledge based methods. The methodology of knowledge mapping is deployed for the creation of new context for objects and entities as successfully demonstrated via two different methods.

The result of this research is a functional architecture, which proved to provide most flexible facilities for creating knowledge mapping and different and very scalable computational solutions. In consequence, the further development of resources and methods allows to consider different constraints when implementing solutions for a certain task. It was shown that the architecture allows to efficiently create implementations with significantly different characteristics.

The knowledge resources and the knowledge based solutions provide comprise universal knowledge and are not limited to a certain discipline or task. Nevertheless, examples limited to a defined task had to be taken for demonstration. The presented case studies illustrated how the knowledge mapping is applied for different solutions, namely country code based knowledge mapping and affiliation based knowledge mapping. The knowledge objects involved for these solutions however were not limited to a single discipline and task and are truly multi-disciplinary and multi-lingual as are all the components and referenced knowledge involved in the scenarios. Both solutions are very much visualisations of object entities. Regardless of that fact, both workflows are significantly different in steps, methods, algorithms, details of involved knowledge, and computational characteristics.

The facts, which become visible when the case study examples are discussed as an example of general abstraction, while still accessing the same resources: The large range of flexibility from knowledge, algorithmic, and computational perspectives. The complements of possibly required solutions share the complementary knowledge. Here, results comparable to the country code solution can be created with geo-referenced place data. In contrast, from the data involved with the country code solution it is not possible to create a geo-referenced view based on the associated data. Therefore, besides the individual context and results delivered by different implementations, it holds “The journey is the reward”. The methodology of knowledge mapping as described can be used for any knowledge and context. The conducted case study is using terms in arbitrary text on the one hand, which can be associated with geo-referencing on the other hand. A different application scenario can be regional floras and faunas being mapped to an biological context, in which case even no geo-referencing or cartographic visualisation needs to be involved. Instead, the results can show the level of complexity for certain cases.

In conclusion, one can choose solutions under different constraints of application scenarios, e.g., knowledge involved, flexibility of sequences, and computational requirements. That way, it is possible to create scalable solutions considering the implementation of required procedures and methodologies, as well as the implementation of required infrastructures. Future research will be spent on extending the dimensional extent of knowledge resources and on the creation of advanced methodologies for deploying the complements of knowledge, further improving knowledge mapping, integration, and handling.

ACKNOWLEDGEMENTS

We are grateful to the “Knowledge in Motion” (KiM) long-term project, Unabhängiges Deutsches Institut für Multidisziplinäre Forschung (DIMF), for partially funding this implementation, case study, and publication under grants D2016F1P04683, D2017F1P04708, D2017F1P04812 and to its senior scientific members, especially to Dr. Friedrich Hülsmann, Gottfried Wilhelm Leibniz Bibliothek (GWLB) Hannover, to Dipl.-Biol. Birgit Gersbeck-Schierholz, Leibniz Universität Hannover, to Dipl.-Ing. Martin Hofmeister, Hannover, and to Olaf Lau, Hannover, Germany, for fruitful discussion, inspiration, practical multi-disciplinary case studies, and the analysis of advanced concepts. We are grateful to Dipl.-Ing. Hans-Günther Müller, Cray, Germany, for his work and support providing practical private cloud and storage solutions and excellent technical support. We are grateful to all national and international partners in the Geo Exploration and Information cooperations for their constructive and trans-disciplinary support. We thank the Science and High Performance Supercomputing Centre (SHPSC) for long-term support of collaborative research since 1997, including the GEXI developments and case studies and The International ARS Science and History Network for providing multi-disciplinary reference data.

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