Components and Computational Modules for Knowledge Mapping: A Case of Spatial Knowledge

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***Abstract*—This paper presents the research results from an extended case study and implementation for the identification and spatial mapping of arbitrary non-georeferenced input data entities. The implemented components and methods are based on the methodology of knowledge mapping. The methodology enables to implement and realise methods for the creation of new context for objects and entities, e.g., creating support for the tasks of knowledge mining and decision making. The focus of the methodology is the mapping of knowledge and its facilities of creating substantially different practical method implementations for identical input objects while aiming on comparable tasks. The main goal of these case studies and implementations is to demonstrate how to create two different automatable methods for knowledge mapping to be applied on each input object, based on a functional architecture of sustainable long-term multi-disciplinary knowledge resources and components, which provide support for a wide range of flexibility for knowledge mapping and different computational solutions. The implementation cases are based on automated computational cases of spatial visualisation. In addition, the results from any of these realisations are used to further valorise new knowledge and continuously improve the contributing long-term knowledge resources.**

***Keywords*–Knowledge Mapping; Spatial Knowledge; Context Creation Algorithms; Universal Decimal Classification; Advanced Data-centric Computing.**

I. Introduction

Knowledge Mining and decision making are facilities, which are required for a large number of application scenarios but which are, nevertheless, in practice widely based on plain methods of data mining only.

This extended research is based on the results from the collaborations on computation and Knowledge Mapping for data entities, which was presented at the INFOCOMP 2018 conference in Barcelona, Spain [1]. The methodology goes beyond creation of plain methods and the practically very limited view of 'data', which is commonly used. The paper illuminates the view of the Principles of Superordinate Knowledge [2], which is not restricted to a plain data view but focusses on advanced knowledge based context creation for arbitrary knowledge. The principles are general, compared to simpler approaches. Therefore, the principles should not be intermixed with 'data' based mining approaches.

There are no other, comparable realisations known so far, which use standardised, universal conceptual knowledge frameworks for creating context, e.g., spatial context.

This paper presents context-methods for multi-dimensional context creation based on the new methodology of Knowledge Mapping. The methodology allows to create knowledge mapping and new context for arbitrary objects, based on knowledge, e.g., conceptual knowledge. The results are methods based on an architecture allowing advanced knowledge mapping, including flexible deployment of computational sequences and an implementation of resources and application components.

This paper is organised as follows. Section II introduces to the motivation, state-of-the-art, and the base of the new approach. Section III presents the architecture, frame of universal knowledge, target input and associated universal knowledge. Section IV presents an exemplary approach, with the details of two well comparable but different case study implementations and all essential components. Section V discusses the results of the case studies, evaluates them based on the conceptual knowledge, computational sequences, and architectures and delivers a computational footprint in context with referred knowledge. Section VI summarises the results and lessons learned, conclusions, and future work.

II. Motivation and approach

Resources of knowledge are steadily increasing in number and size 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 [3]. 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 [4].

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 and resources nor can they provide reasonable freedom of solutions.

Concepts like DIKW are lacking a profound relation of data and information [5]. 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 [6] 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.

It should be explicitly stated, as commonly not sufficiently understood: The knowledge based concept is superior to a plain, data based concept. Mining and management based on the data concept is by far insufficient due to its most limited analysis approaches where accuracy is restricted to attributed data, e.g., simple data mining procedures and character string comparisons.

The described deficits are a major motivation for the long-term research presented in this paper. The fundaments of terminology and of understanding knowledge are layed out by Aristotle [7][8], being an essential part of ‘Ethics’ [9]. Information sciences can very much benefit from Aristotle’s fundaments and a knowledge-centric approach [10] but for building holistic and sustainable solutions they need to go beyond the available technology-based approaches and hypothesis [11] as analysed in Platons’ Phaidon.

Making a distinction and creating interfaces between methods and applications [12], the principles are based on the methodology of knowledge mapping [13], which fundaments are not outlined here again. The implementation can make use of objects and conceptual knowledge [14] and shows being able to build a base for applications scenarios like associative processing [15] and advanced knowledge discovery [16].

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.

III. 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 [17] based on UDC [18] are essential means for the processing workflows and evaluation of the knowledge objects and containers. Both components provide strong multi-disciplinary and multi-lingual support.

For this part of 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) [19] released by the UDC Consortium under the Creative Commons Attribution Share Alike 3.0 license [20] (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.

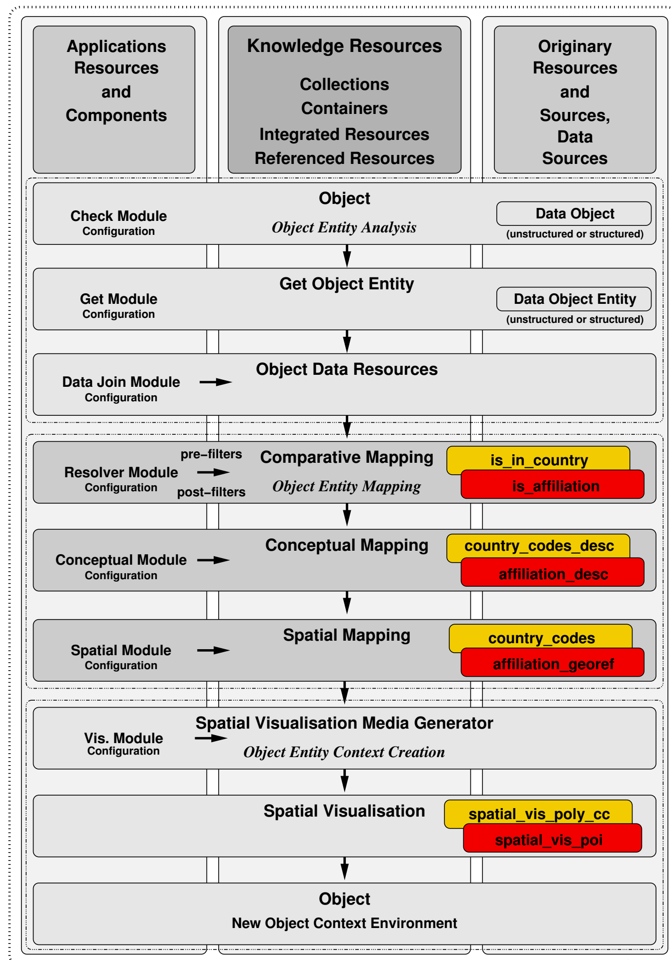

Figure 1. Architecture for mapping arbitrary objects / entities to new context environments, allowing different methods (yellow/red) for implementations.

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 [13]. 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 studies, all from real productive implementations, demonstrate the different characteristics of implementations based on the same universal knowledge. From a multitude of application scenarios, a term to location association providing ways of knowledge mapping of textual context to space and place were choosen for case studies.

B. Target 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.

For demonstration, a publicly available central target object was used for input to both implemented methods realised in this paper and for data entity analysis.

1) Target data: Natural language target: The single data object in this case study implementation (Figure 2) contains mostly unstructured text [21] 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  <br />
..., FH Aachen, Germany</p>
...
..., Erciyes University, Turkey <br />
..., Synodon Inc., Canada<br />
..., Royal Observatory of Belgium (ROB), Belgium<br />
..., Oracle America Inc., USA  <br />
..., Environmental Systems Research Institute (ESRI), USA<br />
..., OSCARS, France<br />
..., Geospatial technologies/Oracle Server Technologies      - Sophia Antipolis,
  France<br />
..., University of Coimbra/INESC Coimbra, Portugal</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 containing various natural language references to locations (excerpt).

The sample object is the publicly available committees' page of the Tenth International Conference on Advanced Geographic Information Systems, Applications, and Services (GEOProcessing 2018), in Rome [21].

Large passages of text not relevant for demonstration of the principles 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.

2) Knowledge Resources: Location, integrated: Figure 3 shows the object content after automatically integrated with the Knowledge Resources via a join module.

```
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
  ...
  ..., Erciyes University, Turkey
  ..., Synodon Inc., Canada
  ..., Royal Observatory of Belgium (ROB), Belgium
  ..., Oracle America Inc., USA
  ..., Environmental Systems Research Institute (ESRI), USA
  ..., OSCARS, France
  ..., Geospatial technologies/Oracle Server Technologies, Sophia Antipolis,
  France
  ..., University of Coimbra/INESC Coimbra, Portugal
  ...
  ..., 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 into knowledge resources, containing source references and locations (excerpt).

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. 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, places, and synonyms in different languages as well as extensive context references, dynamically usable geo-coordinates, geo-classification, and so on. The complement knowledge is continuously improved and extended by manual means, integration of resources as well as by training procedures.

3) UDC: Place and Space: Tables I, II, and III show example excerpts of relevant main classification codes and details of the UDC references used for conceptual mapping. For conceptual knowledge of place and spatial context the implementations requires to provide references to classification codes. The UDC provides references based on the common auxiliaries of place of the UDC [22] as excerpted here for facets of place and space, physiographic designation, and places from ancient to modern world.

TABLE I. CONCEPTUAL MAPPING REFERENCES WITH UDC CODES OF SPATIAL FEATURES / PLACE: AUXILIARIES OF PLACE (EXCERPT).

UDC Code	*Description*
UDC:(1/9)	**Common auxiliaries of place.**
UDC:(1)	Place and space in general. Localization. Orientation
UDC:(100)	Universal as to place. International. All countries in general
UDC:(1-0/-9)	Special auxiliary subdivision for boundaries and spatial forms of various kinds
UDC:(1-0)	Zones
UDC:(1-1)	Orientation. Points of the compass. Relative position
UDC:(1-2)	Lowest administrative units. Localities
UDC:(1-5)	Dependent or semi-dependent territories
UDC:(1-6)	States or groupings of states from various points of view
UDC:(1-7)	Places and areas according to privacy, publicness and other special features
UDC:(1-8)	Location. Source. Transit. Destination
UDC:(1-9)	Regionalization according to specialized points of view

TABLE II. CONCEPTUAL MAPPING REFERENCES WITH UDC CODES OF SPATIAL FEATURES / PLACE: PHYSIOGRAPHIC DESIGNATION (EXCERPT).

UDC Code	*Description*
UDC:(2)	**Physiographic designation**
UDC:(20)	Ecosphere
UDC:(21)	Surface of the Earth in general. Land areas in particular. Natural zones and regions
UDC:(23)	Above sea level. Surface relief. Above ground generally. Mountains
UDC:(24)	Below sea level. Underground. Subterranean
UDC:(25)	Natural flat ground (at, above or below sea level). The ground in its natural condition, cultivated or inhabited
UDC:(26)	Oceans, seas and interconnections
UDC:(28)	Inland waters
UDC:(29)	The world according to physiographic features
UDC:(3/9)	Individual places of the ancient and modern world

TABLE III. CONCEPTUAL MAPPING REFERENCES WITH UDC CODES OF SPATIAL FEATURES / PLACE: PLACES (EXCERPT).

UDC Code	*Description*
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. Entry points to relevant and associated knowledge may be in any disciplinary context due to the consistent framework of the UDC and the multi-disciplinary and multi-lingual Knowledge Resources. During the research, two computational sequences were implemented for illustration of such procedures. These sequences show different characteristics in content and context, as well as different characteristics in architecture and computational requirements.

IV. IMPLEMENTATION: MULTIPLE WAYS TO SPACE

The following case studies present two different methods for implementing object/entity knowledge mapping to space and place targets and discuss 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) [23] suite application components were used for handling the spatial data, applying related criteria, and for the visualisation. All provided spatial presentations in the following examples 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. The implementation is done according to the implementation architecture (Figure 1).

1) Computational sequence: Table IV gives the computational sequence of the core computational procedures.

TABLE IV. 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.

The module `is_affiliation` is responsible for the comparative mapping. The module `affiliation_desc` is responsible for the conceptual mapping. The module `affiliation_georef` is responsible for the spatial mapping.

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

```
...
-3.1788641 51.4866271 Cardiff University, Wales, UK
...
-71.2747424 46.7817463 Centre for Research in Geomatics, Laval University,
 Quebec, Canada
...
8.9011038 44.4086615 Consiglio Nazionale delle Ricerche (CNR), Genova, Italy
...
-117.195686 34.056077 Environmental Systems Research Institute (ESRI), USA
...
-84.3852819 33.753068 Georgia State University, USA
...
47.6598413 28.922652 Kuwait Oil Company, Kuwait
...
9.7196989 52.3829641 Leibniz Universitaet Hannover, Germany
...
32.7778538 39.8956446 Middle East Technical University, Turkey
...
-56.1905803 -34.9038526 ORT University, Montevideo, Uruguay
...
37.5286696 55.7039349 Moscow State University, Russia
...
7.6131826 51.9635705 Westfaelische Wilhelms-Universitaet Muenster
...
35.0231271 32.7767783 Technion, Israel Institute of Technology, Haifa, Israel
...
-51.2185702 -30.0338411 Universidade Federal do Rio Grande, Brazil
...
-61.5289325 16.2242724 Universite des Antilles - LAMIA, France, Guadeloupe
...
103.0855782 1.858626 Universiti Tun Hussein Onm Malaysia, Malaysia
...
55.4783714 25.2867708 University of Sharjah, United Arab Emirates
...
```

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. Therefore, it is important to understand what the tasks of the modules are.

2) Module tasks:

- The first module creates possible entities, including a recoder for alternative re-coding of codepages, a corrector generating attempts for corrections of writing, and a comparator computing comparisons with known and available affiliation space and place in the resources and references, here on base of affiliations and distinctive locations.
- The second module identifies the resulting entities based on the fit, according to the conceptual knowledge relevant for the targeted knowledge mapping, here geospatial association and referencing.
- The third module creates the spatial mapping and visualisation, depending on the choosen base.

With all modules, functional code is generated for the respective steps. The generation ensures that appropriate implementations can be achieved depending on the computing resources and infrastructures, which are used for the computational tasks. This is important, especially for large numbers of target data sets because many millions of comparisons may be required for each step and, e.g., the computation be parallelised appropriately.

3) Output representation: The visualisation of the results (red bullets) from the affiliation based procedures was done on a spatial map (Figure 5).

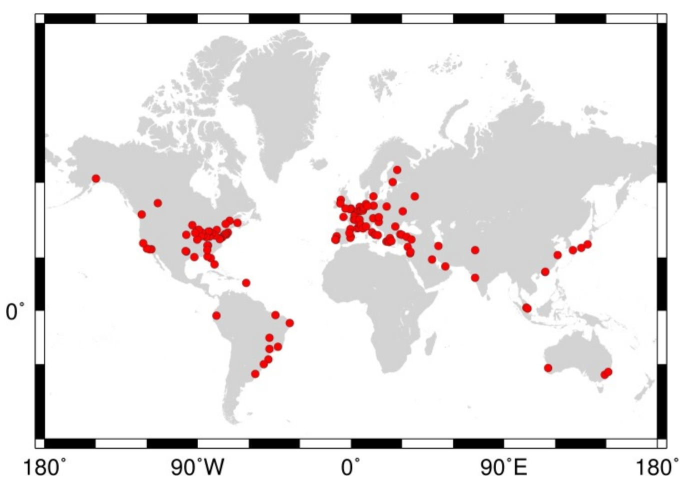

Figure 5. Visualisation of the result of affiliation based knowledge mapping: Geo-referenced place association (Mercator projection).

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. The implementation is done according to the implementation architecture (Figure 1).

1) Computational sequence: Table V gives the computational sequence of the core computational procedures.

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

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

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

The module `is_in_country` is responsible for the comparative mapping. The module `country_codes_desc` is responsible for the conceptual mapping. The module `country_codes` is responsible for the spatial mapping.

2) Module tasks:

- The first module creates possible entities, including a recoder for alternative re-coding of codepages, a corrector generating attempts for corrections of writing, and a comparator computing comparisons with known and available country and country code space and place in the resources and references, here on base of countries and larger areas.
- The second module identifies the resulting entities based on the fit, according to the conceptual knowledge relevant for the targeted knowledge mapping, here geospatial association and referencing.
- The third module creates the spatial mapping and visualisation, depending on the choosen base.

Here, too, with all modules, functional code is generated for the respective steps. The generation ensures that appropriate implementations can be achieved depending on the computing resources and infrastructures, which are used for the computational tasks. This is important, especially for large numbers of target data sets because many millions of comparisons may be required for each step and, e.g., the computation be parallelised appropriately.

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

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.

```
...
"Australia" lxcoco-AU
"Brazil|␣Brasil" lxcoco-BR
"Canada" lxcoco-CA
...
"Germany|Deutschland" lxcoco-DE
"Ghana"  lxcoco-GH
"Gibraltar" lxcoco-GI
...
"Great␣Britain" lxcoco-GB3
...
"Greece" lxcoco-GR
"Greenland|Grønland" lxcoco-GL
"Grenada" lxcoco-GD
"Guadeloupe" lxcoco-GP
...
"Israel" lxcoco-IL
"Italy" lxcoco-IT
"Kuwait" lxcoco-KW
"Malaysia" lxcoco-MY
"Russian␣Federation" lxcoco-RU1
"Russia" lxcoco-RU2
"Turkey" lxcoco-TR
"United␣Arab␣Emirates" lxcoco-AE1
"UAE|U\.A\.E\." lxcoco-AE2
"United␣Kingdom" lxcoco-GB1
",␣UK" lxcoco-GB2
"United␣States␣of␣America|USA|U\.S\.A\.|U\.S\." lxcoco-US
"Uruguay" lxcoco-UY
...
```

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

Due to the nature of arbitrary and heterogeneous input objects the corrector algorithms benefit from continuous training. An excerpt of the corrector algorithm is shown in a correcting code listing (Figure 7).

```
...
s+George Mason University.*?Romanian Academy, USA.*?Romania+George Mason
 University, USA\nRomanian Academy, Romania+g
s+UAP and SEU, Bangladesh.*Islamic University in Madinah, KSA+UAP and SEU,
 Bangladesh\nIslamic University in Madinah, KSA+g
s+Swiss National Science Foundation.*Oregon Health.*Science University, USA+
 Swiss National Science Foundation, Switzerland\nOregon Health \& Science
 University, USA+g
s+World Precision Instruments, Inc. USA; University of South Florida, USA+World
 Precision Instruments, Inc. USA\nUniversity of South Florida, USA+g
s+Bowie State University; University of Maryland, College Park, USA+Bowie State
 University, USA\nUniversity of Maryland, College Park, USA+g
s+Cardiff University School of Medicine,.*\|.*Welsh e-Science Centre+Cardiff
 University School of Medicine\nWelsh e-Science Centre+g
s+California NanoSystems Institute (CNSI), Brain Research Institute (BRI).*\|.*
 University of California at Los Angeles (UCLA), USA+California NanoSystems
 Institute (CNSI), Brain Research Institute (BRI)\nUniversity of California at
 Los Angeles (UCLA), USA+g
s+CEA-Leti\/DACLE\/LIALP Lab, Verimag Lab.*?Grenoble University, France+CEA-Leti
 \/DACLE\/LIALP Lab, Verimag Lab, France\nGrenoble University, France+g
s+CISTER, INESC/TEC.*\|.*Polytechnic Institute of Porto, Portugal+CISTER, INESC/
 TEC, Portugal\nPolytechnic Institute of Porto, Portugal+g
s+Instituto de Telecomunica<UTFSeq>es, Aveiro, Portugal.*University of Bradford,
  UK+Instituto de Telecomunica<UTFSeq>es, Aveiro, Portugal\nUniversity of
 Bradford, UK+g
s+Instituto de Telecomunica<UTFSeq>es, Aveiro, Portugal.*American University of
 Nigeria, Nigeria+Instituto de Telecomunica<UTFSeq>es, Aveiro, Portugal\
 nAmerican University of Nigeria, Nigeria+g
s+University of Pisa, Italy.*Leiden University, The Netherlands+University of
 Pisa, Italy\nLeiden University, The Netherlands+g
s+(University of Hamburg)/.*?(Regional Computer Center), Germany+<DSym>{1},
 Germany\n<DSym>{2}, Hamburg, Germany+g
s+Defence R.*?D Canada, Valcartier.*?Univ. Laval.*?Univ. de Montr.*?al, Canada+
 Defence R\&D Canada, Valcartier, Canada\nUniv. Laval, Canada\nUniv. de Montreal
 , Canada+g
s+Defence R\&D, Canada+Defence R\&D Canada, Canada+g
s+Sensemaking-PACOM Fellowship \& AIRS, Swansea University/Hawaii Pacific
 University, UK/USA+Sensemaking-PACOM Fellowship \& AIRS, Swansea University\
 nHawaii Pacific University, UK/USA+g
s+Department of Computing Science and HPC2N.*+Department of Computing Science,
 Ume<UTFSeq> University, Sweden\nHigh Performance Computing Center North (HPC2N)
 , Ume<UTFSeq> University, Sweden+
s+High Performance Computing Center North (HPC2N), Sweden+High Performance
 Computing Center North (HPC2N), Ume<UTFSeq> University, Sweden+g
s+California NanoSystems Institute (CNSI), Brain Research Institute (BRI) |
 University of California at Los Angeles (UCLA), USA+California NanoSystems
 Institute (CNSI), USA\nBrain Research Institute (BRI), USA\nUniversity of
 California at Los Angeles (UCLA), USA+g
s+Westf.*lische Wilhelms-Universit.*t M.*nster.*Leibniz Universit.*t Hannover.*
 North-German Supercomputing Alliance, Germany+Westfälische Wilhelms-Universität
  Münster, Münster, Germany\nLeibniz Universität Hannover, Hannover, Germany\
 nNorth-German Supercomputing Alliance, Germany+g
s+University Politehnica Bucharest, Romania.*?Texas A\&M University, USA+
 University Politehnica Bucharest, Romania\nTexas A\&M University, USA+g
s+Brown University, USA.*University of Saskatchewan, Canada+Brown University,
 USA\nUniversity of Saskatchewan, Canada+g
s+ICT-KTH, Sweden.*?IDI-NTNU, Norway+ICT-KTH, Sweden\nIDI-NTNU, Norway+g
s+Center for Service Research \(CfSR\)\/National Institute of Advanced
 Industrial Science and Technology \(AIST\), Japan+Center for Service Research (
 CfSR), Japan\nNational Institute of Advanced Industrial Science and Technology
 (AIST), Japan+g
s+Wirtschafts- und Sozialwissenschaftliches Institut, D.*?sseldorf, Karlsruhe
 Institute of Technology, Germany+Wirtschafts- und Sozialwissenschaftliches
 Institut, Düsseldorf, Germany\nKarlsruhe Institute of Technology, Germany+g
s+Colorado State University, USA.*Lancaster University, UK+Colorado State
 University, USA\nLancaster University, UK+g
s+University of Carthage, Tunis.*El Manar University, Tunisia+University of
 Carthage, Tunis, Tunisia\nEl Manar University, Tunisia+g
s+University of Carthage, Tunis<DSym>+University of Carthage, Tunis, Tunisia+g
s+The University of Melbourne, Australia+University of Melbourne, Australia+g
s+Ural Federal University.*Ekaterinburg, Russian Federation.*University of
 Peloponnese.*Tripolis, Greece+Ural Federal University, Ekaterinburg, Russian
 Federation\nUniversity of Peloponnese, Tripolis, Greece+g
s+University of Twente and University of Groningen.*,The Netherlands+University
 of Twente, The Netherlands\nUniversity of Groningen, The Netherlands+g
s+French National Institute of Geographic and Forest Information.*, France+IGN
 Institut National de l Information GÃ©ographique et ForestiÃ¨re, France+g
s+ForestiÃ¨re+Forestiere+g
...
```

Figure 7. Correcting code for the corrector algorithm (excerpt).

The examples from the Knowledge Resources are a small subset from hundreds of thousands of comparable entries. The entries are presented here in Perl Compatible Regular Expressions (PCRE) style [24] based on widely common Perl [25] conventions. For display, dollar symbols are substituted as `<DSym>`, various UTF sequences are substituted as `<UTFSeq>`.

After conceptual mapping, correcting algorithms, sorting, and removing duplicates a list of country codes can be generated using a country code container from the knowledge resources. Figure 8 shows the list of resulting country codes automatically generated for the target data.

```
AE,AT,AU,BE,BR,CA,CN,CY,DE,EC,ES,FI,FR,GB,GP,GR,HK,HR,IE,IL,IN,IR,IT,JP,KW,MY,NL
,PK,PL,PT,RO,RU,SE,SG,TR,UA,US,UY
```

Figure 8. Knowledge Resources: Country Codes automatically generated for the target data (excerpt).

3) Output representation: The visualisation of the results (yellow country colourisation) from the country code based procedures was done on a spatial map (Figure 9). The country codes are based on the standard of the International Standards Organisation (ISO).

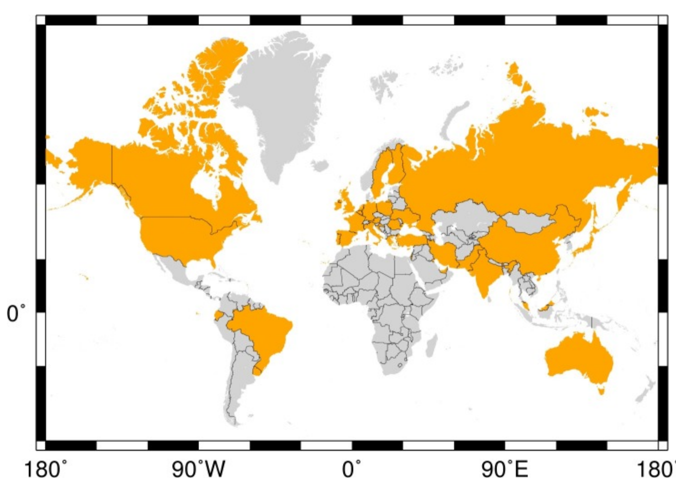

Figure 9. Visualisation of the result of country code based knowledge mapping: ISO referenced state association (Mercator projection).

The computing task can be parallelised for objects and entities. For demanding application scenarios, e.g., dynamical implementations, this implementation widely benefits from parallelisation. The parallelisation will be an individual task of implementing a parallelisation concept optimal for the resources, on precondition that the computational resources and architectures are known in detail and available.

C. Visualisation

The spatial visualisation for the presented implementations is done according to the implementation architecture (Figure 1).

Table VI lists the alternative modules implemented for visualisation of both methods implemented for affiliation based knowledge mapping and country code based knowledge mapping.

TABLE VI. SPATIAL VISUALISATION: ALTERNATIVE PROCEDURES FOR AFFILIATIONS AND COUNTRY CODES.

Alternative Procedures	*Module*
Spatial Visualisation Affiliation Configuration	`spatial_vis_pol`
Spatial Visualisation CC Configuration	`spatial_vis_poly_cc`

The module `spatial_vis_pol` is responsible for visualisation of affiliation based computational sequences. The module `spatial_vis_poly_cc` is responsible for visualisation of country code based computational computational sequences.

The functional code for the modules is generated for the respective type of visualisation. In this case, there is no principle impediment for a combined application of both codes if required.

The essential attribute characteristics for affiliation based knowledge mapping spatial visualisation are illustrated by the listing in Figure 10.

```
...
gmt pscoast -JM4.5i -R-180/180/-60/84 -F<CountryCodes>+glightgray -Glightgray
 -Baf -BWSne -P -K > <PSFile>
...
gmt psxy <DataFile> -J -O -R -Sc0.15c -G255/0/0 -W0.05p,black >> <PSFile>
...
```

Figure 10. Spatial affiliation based knowledge mapping visualisation characteristics for GMT (excerpt).

The essential attribute characteristics for country code knowledge mapping based spatial visualisation are illustrated by the listing in Figure 11.

```
...
gmt pscoast -JM4.5i -R-180/180/-60/84 -F<CountryCodes>+glightgray -Glightgray
 -Baf -BWSne -P -K > <PSFile>
...
gmt pscoast -J -R -N1/0.15p,black -F<CountryCodes>+gorange -O >> <PSFile>
...
```

Figure 11. Country code based knowledge mapping spatial visualisation characteristics for GMT (excerpt).

Individual attributes can be a matter of module configuration or visualisation attributes in a certain context can be a matter of training procedures.

V. 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 12).

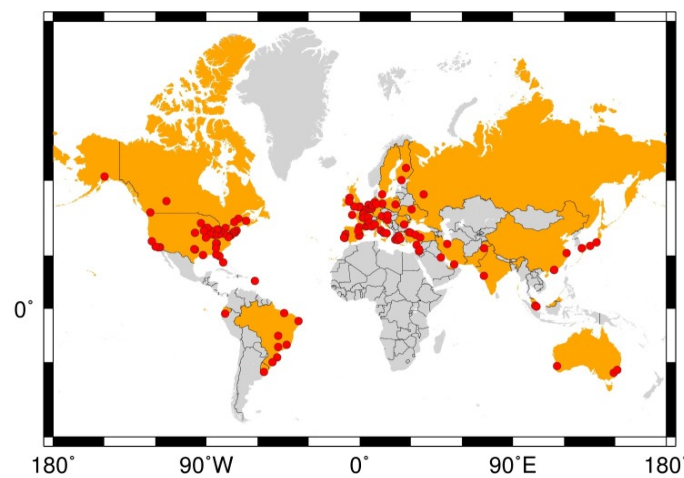

Figure 12. Comparison of both affiliation and country code based knowledge mapping: Geo-referenced place and ISO referenced state results.

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-referenced 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 VII compares the solutions regarding the numbers of computational checks required, done for the same object and entities.

TABLE VII. 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 sets 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.

C. Re-use, continuous creation, and improvement

Access and interface modules, especially for accessing structures, dealing with formatting, and handling of sorting and filtering can easily be reused or cloned with modifications. Visualisation modules can also be easily reused and adopted for different methods of knowledge mapping.

The modules characteristic for a respective knowledge mapping method make up the core for a case. Different algorithms should be implemented in modular ways, e.g., allowing standalone of algorithms as well as an integrated use of algorithms. Nevertheless, on premise of sufficient complexity of the knowledge resources, even all the knowledge required with different knowledge mapping methods can overall be delivered by the knowledge resources. The delivered knowledge can comprise the knowledge complements, e.g., including supportive knowledge for methods, references, algorithms, implementations of algorithms, and visualisation components.

With natural language target data or comparable sources a lot of processing may have to be done before getting into the knowledge mapping itself. For example, codepages have to be resolved and codepages have to be recoded, languages may have to be recognised by document, sentence, and even word and different ways of writing the same object may have to be resolved. Incomplete object references may be associated with full entries and so on. Creation and improvement of resources and knowledge content are continuous processes. The optimisation, e.g., regarding the resources and modules for improving resulting outputs is intrinsically supported by the application of the modules itself. This is based on the fact that intermediate results from any application or run can be used for training of procedures and Knowledge Resources.

VI. CONCLUSION

This paper presented the research results from an extended case study and implementation for the identification and spatial mapping of arbitrary non-georeferenced input data entities.

The methodology of knowledge mapping was used for creating methods and implementing components for different tasks, e.g., for advanced knowledge as successfully demonstrated with the case studies. The methodology allowed an efficient implementation and realisation of methods for the creation of new context for objects and entities.

It was successfully demonstrated that the goal of the studies and implementations to create different automatable methods for knowledge mapping in a spatial context can be efficiently achieved in very flexible, modular, and reusable ways.

The more, due to the high quality of the knowledge resources in addition with the long-term training, the completeness of the resulting mapping in this case proved to be ultimatively complete and sufficiently precise for the target objects without additional intervention, for both methods.

The multi-disciplinary and multi-lingual Knowledge Resources and the Knowledge Mapping based implementations can benefit from being continuously assisted by training procedures, which can contribute to the complementary knowledge content. In addition, the results from any of these realisations can be used to further valorise new knowledge and continuously improve the long-term knowledge resources, which again extends the quality and quantity of available resources.

With this research the implementations targeted on knowledge based, automatable computational cases of spatial visualisation. This goal was achieved while preserving facilities for any form of non automated or semi-automated use without principle constraints.

In addition, the Knowledge Resources could be extended and improved in quality and quantity by applying the implementations to various target objects, due to the successfully mined results achieved from the implemented cases, which become part of the knowledge resources themselves.

In consequence, 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.

From the educational view on insight it may be interesting being able to generate different views of knowledge and information in different ways and with different media based on this methodological approach. The achieved results can become part of what is known in addition of what is remembered [26] and can preserve contextual details not learned otherwise.

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. Further future research will be spent on extending the dimensional extent of knowledge resources and on the creation of advanced methodologies for creating method for advanced knowledge mining, further increasing quality and quantity of multi-disciplinary and multi-lingual content, knowledge mapping, and integration.

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