Multi-dimensional Context Creation Based on the Methodology of Knowledge Mapping

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Abstract*—The extended research presented in this paper focusses on advanced context creation as practicable in knowledge based disciplines. This extended research presents methods for multi-dimensional context creation based on the new methodology of Knowledge Mapping. The methodology of Knowledge Mapping allows the knowledge based mapping of objects and entities for purpose of context creation. The mapping to new context can improve complex knowledge mining, discovery, and decision making results. The new context increases the potential for creating new insights. The paper presents implemented methods and case studies along with an extended introduction of the new methodology used with advanced knowledge mining and provides the latest results of the present research. The different methodology based knowledge mining method implementations deploy various spatial representations for illustration. All method implementations utilise commonly available unstructured data and create new multi-disciplinary knowledge context. Resulting entities are spatially mapped. The results can be used for further analysis in integration with data and advanced tools, e.g., automated and visual analysis. The methodology can employ integrated knowledge resources and services for mapping support and can be applied to any content from arbitrary disciplines. The results of the mapping to new context can be used for knowledge mining workflows, for gaining new insight, and for creating and further improving long-term knowledge resources. The methodology also supports automated learning processes. This extended research aims on illustrating the flexibility of possible methods for new practical mining procedures and algorithms from the knowledge perspective.

Keywords–Methodology of Knowledge Mapping; Data-centric Knowledge Mining; Multi-dimensional Context Creation; Spatial Knowledge Mapping Methods; High End Computing based on Knowledge Resources.

I. Introduction

Knowledge Mining is a goal, which is required for a large number of application scenarios but which is nevertheless in practice widely based on plain methods of data mining.

This extended research is based on the new Methodology of Knowledge Mapping, which was presented at the GEOProcessing 2018 conference in Rome, Italy [1]. The paper goes beyond plain methods and the limited view of 'data'.

The research presented here illuminates the superordinate knowledge view [2] and is therefore not restricted to a simple data view and focusses on advanced context creation for arbitrary knowledge. This paper presents context-methods for multi-dimensional context creation based on the new methodology of Knowledge Mapping. The methodology of Knowledge Mapping allows the knowledge based mapping of arbitrary objects and entities for purpose of context creation. The mapping to new context can improve complex knowledge mining, discovery, and decision making results. The new, multi-dimensional context increases the potential for creating new insights. In terms of knowledge, context creation is a multi-disciplinary effort however limited and strict the discipline focus is defined.

The implemented context-methods and case studies along with of the illustrated case studies based on the new methodology are used with based on advanced knowledge mining and provide the latest results of the present research. The different methodology based knowledge mining method implementations deploy various spatial representations.

All the context-method implementations utilise commonly available unstructured data and create new multi-disciplinary knowledge context. Resulting entities are spatially mapped. The results can be used for further analysis in integration with data and advanced tools, e.g., automated and visual analysis.

The rest of this paper is organised as follows. Sections II and III introduce to the state of the art from previous work, fundaments and motivation. Section IV introduces the new methodology of knowledge mapping. Section V discusses fundaments, components, and used resources. Section VI presents the principles of multi-dimensional context creation based on knowledge mapping. Section VII illustrates implemented methods, generated for interactive dynamical context examples. Sections VIII and IX discuss the multi-dimensional features of methodology and implementation and summarise the lessons learned, conclusions, and future work.

II. State of the Art of Previous Work

It is a truth universally acknowledged, that any knowledge, e.g., based on unstructured and structured data, can contain parts, which may refer to other knowledge but which are not explicitely linked. Further, existing methods promising to deal with lexical and term mapping or ontologies showed deficient and inadequate for coping with challenges of arbitrary knowledge mapping and multi-dimensional context. Methods [3] and implementations for automated mapping [4] are not sufficient, the more as approaches do not span disciplines [5]. Term identification [6] is not suitable for mapping beyond simple context like bibliographic data, too. Available mapping approaches are very limited to non-general knowledge related tasks [7], even when dealing with context [8].

Regarding managerial aspects, modern knowledge organisation systems [9] can support the processes [10], nevertheless, they are just components — besides knowledge. If system components are not specialised on knowledge itself but more or less on functional processes, e.g., tool components for collaboration [11], collaborative knowledge [12], and 'knowledge based collaboration' [13]. An approach with historical data from many multi-disciplinary sources is the Venice Time Machine (VTM) [14] project. However, there is no general methodological approach associated with the project.

The essential fundament for knowledge mapping is the knowledge. The methodology employed here was developed in order to create methods for the identification of entities inside of or referenced with data and create new context for knowledge objects and entities. Besides the context relevant for this research, further basic terms and definitions are explained in the referenced publications, e.g., for data entities, mapping, and computing [15] as well as for entities and references [16].

The principle of this approach is superior to data and information based approaches as the methodology takes benefit of knowledge complements [17]. Knowledge is an excellent integrator as it can complement, e.g., from [18]

- factual,
- conceptual,
- procedural,
- and metacognitive knowledge.

Data and information can be associated with all the complements. In consequence, this methodology allows to deploy a knowledge based level, e.g., creating knowledge mining where information can result from information peeling processes [17].

Knowledge mapping is the process of creating mappings between two data objects. In that way knowledge mapping contributes significantly to data integration and data sciences methods [19]. The means of referring objects and sub-objects, "entities", with a new context is considered as "knowledge mapping". Objects, e.g., a document, a part of a text, or an image may be associated with other objects, by its knowledge, e.g., its factual or conceptual knowledge. For example, creating new spatial context for textual entities in knowledge objects requires to build non-fixed associations, apply a fuzzy spatial locate, and implement a text location to map-mapping. The procedure enables to automatically create a spatial mapping for possible locations in a document, e.g., Points Of Interest (POI) or other places in a data set or file.

III. Fundaments and Motivation

The fundaments of terminology and understanding knowledge are layed out by Aristotle [20], being an essential part of 'Ethics' [21], which makes Aristotle probably most the primarily relevant knowledge reference. Information science can very much benefit from Aristotle's fundaments and a knowledge-centric approach [18] but information science needs to go beyond the available technology-based approaches for building holistic and sustainable solutions, supporting a modern definition of knowledge [22]. Triggered by the results of a systems cases study, it is obvious that superordinate systematic principles are still widely missing. Making a distinction and creating interfaces between methods and the implementation applications [23], the results of this research are illustrated here along with the practical example of the Knowledge Mapping methodology [1] enabling the creation of new object and entity context environments, e.g., implementing methods for knowledge mining context. This motivating background allows to build methods for knowledge mapping on a general methodological fundament.

The Organisation for Economic Co-operation and Development (OECD) has published principles and guidelines for access to research data from public funding [24]. The principles and guidelines are meant to apply to research data that are gathered using public funds for the purposes of producing publicly accessible knowledge. Anyhow, from the knowledge management point of view they have much wider importance as they

- address the protection of intellectual property,
- deal with knowledge generated from the re-use of existing data, and
- describe important aspects when establishing evaluation criteria.

The guidelines recommend the following items should be considered in establishing evaluation criteria:

- Overall public investments in the production and management of research data.
- Management performance of data collection and archival agencies.
- Extent of re-use of existing data sets.
- Knowledge generated from the re-use of existing data.
- The use of targeted foresight exercises to determine the nature and scope of data preservation activities and the types of data most likely to be needed in the future.

The means to achieve such recommendations even for complex scenarios is to use the principles of Superordinate Knowledge, which integrate arbitrary knowledge over theory and practice. Core assembly elements of Superordinate Knowledge [2] are:

- Methodology.
- Implementation.
- Realisation.

Separation and integration of assemblies have proven beneficial for building solutions with different disciplines, different levels of expertise.

IV. Methodology of Knowledge Mapping

The methodology can be used for creating new object and entity context environments, e.g., in knowledge mining context. The following steps describe the methodology.

1) Start is an arbitrary object.
2) Object / entity analysis.
3) Object / entity mapping.
4) Context creation.
5) Result is an object and / or entity with a new context environment.

Objects can be arbitrary objects, unstructured or structured, unreferenced or referenced, e.g., containing different entities of content. The methodology is not limited to any possibly restricted implementation or platform. In case of textual objects and entities, the object can, e.g., be a text document. In case the mapping targets on geo-referencing otherwise non geo-referenced objects or entities, then the mapping can be considered a spatial mapping. With the latter target the context creation can be considered a spatial visualisation.

The methodology of knowledge mapping for arbitrary objects and entities can be schematically summarised (Figure 1).

For example (Figure 2): When the object is a plain text-object and creating spatial visual context is the target, then the steps can be implemented with object and entity analysis, spatial object / entity mapping, and spatial visualisation for creating an object / entity spatial mapping in a new context.

The targets for the case study are spatial visualisation and context. The implementation architecture of mapping arbitrary objects and entities to a new object context environment is shown in Figure 3. Data and modules are provided by Knowledge Resources. The originary resources deliver the data objects and entities, which can be unstructured or structured. The application resources and components contain appropriate modules for the required steps:

- The object is retrieved,
- possible object entities are extracted,
- object data resources are being analysed,
- objects are being compared,
- a conceptual mapping is performed on objects,
- spatial mapping is performed on objects,
- appropriate spatial media is generated,
- including media formats and colourisation, and
- a spatial visualisation is performed.
- The result is an object / entity instance in a new context environment.

The modules and filters perform the analysis and handle the objects and entities, e.g.,

- entities in different context inside an object,
- transcriptions, transliterations, translations,
- abbreviations, acronyms, . . .

In many cases, additional handling of data will be desired, even if not essential for the procedure of a method or the operation of a service. For example, in case of textual objects and entities a number of aspects exist, which contribute to the attainment of a certain quality:

- Differently organised or structured entities per object.
- Sub-entities, multiple entities in a pseudo-entity.
- Inconsistencies in data.
- Errors in data.
- Typographic differences.
- Ambiguous or plurivalent entities.
- Multi-lingual entities.
- Different diction.
- Different syntax.
- Different element ordering in entities.
- Different structures.
- Time dependencies of aspects, mapping, and meaning.

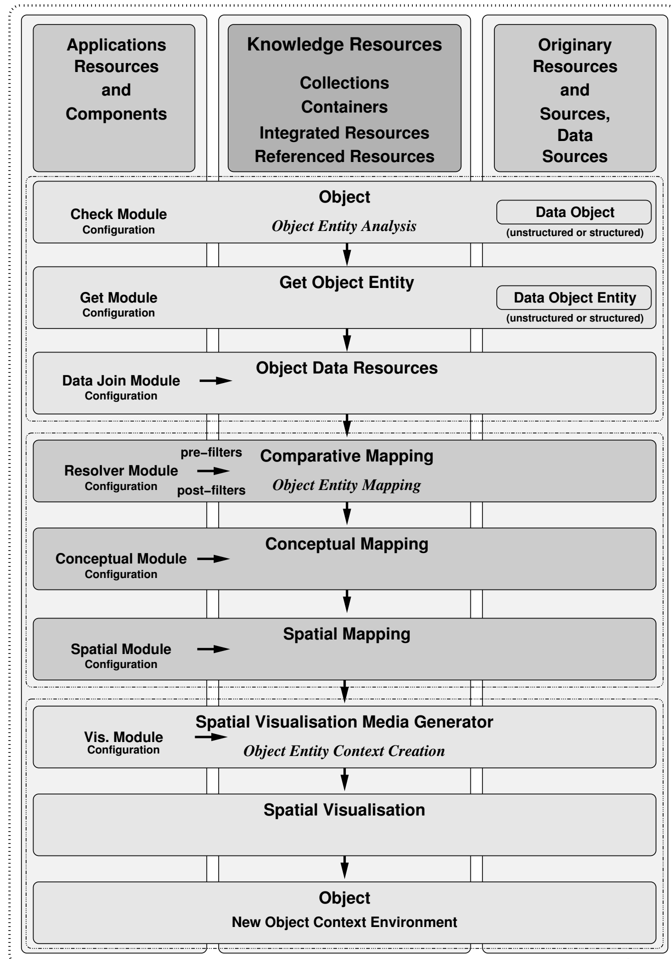

Figure 3. Architecture for implementation of mapping arbitrary objects and entities to new context environments, e.g., spatial visualisation and context. Data and modules are provided by Knowledge Resources, originary resources, and application resources and components.

- Different character sets.
- Different formatting.

Any of these and comparable aspects are handled by the modules and appropriate pre- and post-filters. With the case study, for the above aspects respective research was conducted gathering various data and developing suitable methods over several years, data which can be deployed to create filters, which were used for holding the results presented here.

It is required to abstract certain information in many application scenarios, e.g., for generalisation or privacy. Besides any kind of filter, the method also allows to implement fuzziness in a flexible and wide range of ways. For example, on the one hand a precise location can be reduced to city, region, or country. Comparable but different locations can be unified to one different location representing a larger area. On the other hand, location coordinates can be automatically or manually reduced in precision and/or equipped with an offset. With these means, workflows can deliver kind of “Fuzzy Context”, e.g., a fuzzy location, providing a precision level of a public region instead of showing a certain building in a result.

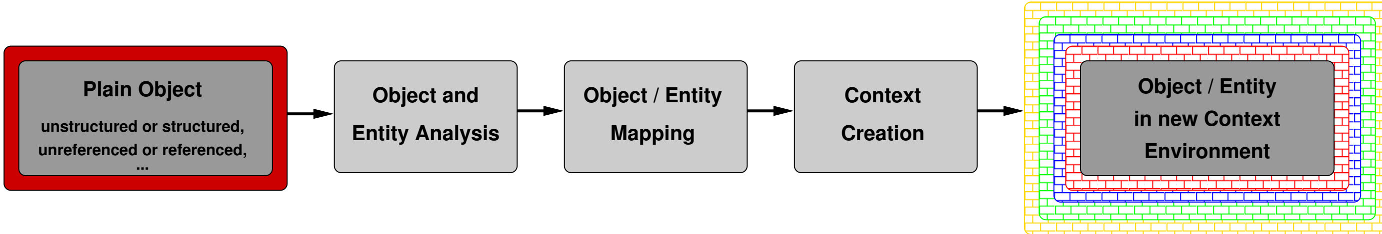

Figure 1. Methodology mapping arbitrary objects and entities for creating new context environments. The methodology requires the major complementary steps of object / entity analysis, mapping, and context creation. Depending of the object, the steps can be implemented using different tools.

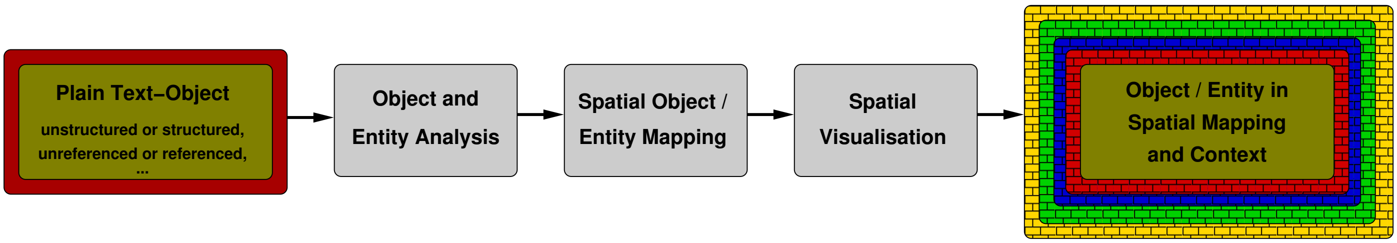

Figure 2. Plain text to spatial mapping context: Mapping arbitrary text objects and entities to new spatial mapping and context. In this case the object is plain text, analysis is conducted with knowledge-mining-in-text algorithms, mapping is spatial mapping, and context creation is spatial visualisation context.

V. Previous work, components, and resources

For the implementation of case studies, the modules are built by support of a number of major components and resources, which can be used for a wide range of applications, e.g., creation of resources and extraction of entities.

The facility for consistently describing knowledge is a valuable quality, especially conceptual knowledge, e.g., using the Universal Decimal Classification (UDC). The knowledge resources objects can refer to main UDC-based classes, which for this publication are taken from the Multilingual Universal Decimal Classification Summary (UDCC Publication No. 088) [25] released by the UDC Consortium under the Creative Commons Attribution Share Alike 3.0 license [26] (first release 2009, subsequent update 2012).

UDC provides auxiliary signs [27], shown in Table I, which represent kinds of standardised "operations".

Table I. UDC Common Auxiliary Signs used with classification references (English Version).

Sign	*Description (English)*
+	Coordination. Addition (plus sign).
/	Consecutive extension (oblique stroke sign).
:	Simple relation (colon sign).
::	Order-fixing (double colon sign).
[]	Subgrouping (square brackets).
*	Introduces non-UDC notation (asterisk).
A/Z	Direct alphabetical specification.

Using these features UDC allows the creation of facetted knowledge. UDC code references based on the main tables of the UDC [28] are shown in Table II. "UDC:" is the designated notation of references for knowledge resources used with references in ongoing projects. The UDC illustrates the width and depth of knowledge dimensions, multi-disciplinary content and context, and facets. The full details of organisation are available from UDC.

Table II. Classification code references to UDC main tables used for knowledge mapping (Excerpt, English Version).

UDC Code	*Description (English)*
UDC:0	Science and Knowledge. Organization. Computer Science. Information Science. Documentation. Librarianship. Institutions. Publications
UDC:1	Philosophy. Psychology
UDC:2	Religion. Theology
UDC:3	Social Sciences
UDC:5	Mathematics. Natural Sciences
UDC:6	Applied Sciences. Medicine, Technology
UDC:7	The Arts. Entertainment. Sport
UDC:8	Linguistics. Literature
UDC:9	Geography. Biography. History

Data and objects result from public, commonly available, and specialised Knowledge Resources. The Knowledge Resources are containing factual and conceptual knowledge as well as documentation and instances of procedural and metacognitive knowledge. These resources contain multi-disciplinary and multi-lingual data and context.

The fundament to create mining methods based on this methodology of knowledge mapping is presented with an illustrative scenario. All disciplines, e.g., in the UDC knowledge spectrum, can contribute to this application scenario. Context data for calculations and visualisation also requires cartographic thematic context data. The knowledge resources were integrated with data based on the gridded ETOPO1 1-arc-minute global relief model data [29]. Data can be composed from various sources, e.g., adding Shuttle Radar Topography Mission (SRTM) data [30] from the Consultative Group on International Agricultural Research (CGIAR) [31].

The Network Common Data Form (NetCDF) [32] developed by the University Corporation for Atmospheric Research (UCAR/Unidata), [33], National Center for Atmospheric Research (NCAR) [34] is used for spatial context data. NetCDF is an array based data structure for storing multi-dimensional data. A NetCDF file is written with an ASCII header and stores the data in a binary format, e.g., with a mapping suite.

The Generic Mapping Tools (GMT) [35] suite application components are used for handling the spatial data, applying the related criteria, and for the visualisation.

The visualisation files generated from the mapping results are using the Keyhole Markup Language (KML), an eXtended Markup Language (XML) based format for specifying spatial data and content. KML is considered an official standard of the Open Geospatial Consortium (OGC). The KML description can be used with many spatial components and purposes, e.g., with a Google Earth or Google Maps presentation [36], with a Marble representation [37], using OpenStreetMap (OSM) [38] and national data, e.g., [39].

Modules are employing Perl Compatible Regular Expressions (PCRE) for specifying common string patterns and Perl [40] for component wrapping purposes with this case study.

VI. Multi-dimensional Context Creation

The following sections provide information regarding implemented components (`lxloccoord`, module for location coordinates) and a practical case study, which was done for demonstrating the methodology of mapping objects and entities, creating new context environments. The case study shows components, which were built for mapping scenarios creating spatial context (Figure 3) and illustrates new insights and relevance for knowledge creation and advanced mining.

A. The components

All the components and modules required for the architecture (Figure 3) were implemented. The following components were created for the practical implementation of the three major central modules, object / entity analysis, mapping, and context creation, demonstrating all steps of the methodology.

- The object / entity analysis modules process objects for entities, which can be fed into a mapping mechanism.
- The pre-filters change, mark, and remove entities before the mapping modules try to create entity mappings.
- The mapping modules do have the task to deliver spatial coordinates for appropriate entities.
- The post-filters change, mark or remove entities after the resolver worked on entities for a spatial mapping.
- The context creation modules deliver the geo-referencing for a spatial application.

The modules can be centralised or distributed, e.g., implemented as a local directory of comparable and resolved entities or an online service. Appropriate directories can be provided by knowledge resources as well as by spatial mapping services.

Change processes in pre- and post-filters can include unification, improvements for resolvability, mapping and so on.

Different application components with different features can be deployed for dynamical and interactive use and visualisation, e.g., GMT, Marble, and Google Maps.

B. Case study: From plain text to spatially linked context

The following passages show some major steps for creating spatially linked context from plain text (Figure 4), which were used in the workflows required for the case studies.

```
<!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> ...
        <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 4. Mapping target: Single object, unstructured text (excerpt).

The single data object contains mostly unstructured text [41] (status of November 2017), markup, and formatting instructions. Passages not relevant for demonstration were shortened to ellipses. Figure 5 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 ...
  ..., 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 5. Object instance representation after integration (excerpt).

The Object Entity Mapping can associate relevant objects, e.g., via conceptual knowledge and comparative methods. Table III shows an excerpt of the conceptual data (UDC) used for characteristics and place classification, creating spatial context.

Table III. Classification references, object/entity analysis and mapping: Characteristics & place (LX [17]).

UDC Code	*Description (English, excerpt)*
UDC:(1)	Place and space in general. Localization. Orientation
UDC:(100)	Universal as to place. International. All countries in general
UDC:-05	Common auxiliaries of persons and personal characteristics
UDC:-057.4	Professional or academic workers
UDC:378	Higher education. Universities. Academic study

The codes especially reflect the common auxiliaries of general characteristics and place with the analysis of the object and entities, e.g., affiliation and spatial location.

Figure 6 shows an excerpt with possible entities of locations after an object entity analysis and mapping.

```
...
Centre for Research in Geomatics, Laval University, Quebec, Canada
Curtin University, Australia
Lomonosov Moscow State University, Russia ...
Universiti Tun Hussein Onm Malaysia, Malaysia ...
Environmental Systems Research Institute (ESRI), USA ...
```

Figure 6. Possible place entities after object / entity analysis (excerpt).

After object entity analysis, filters, and mapping, a resolver module can equip the entities with geo-references (Figure 7).

```
...
-71.2747424,46.7817463,Centre for Research in Geomatics, Laval University,
 Quebec, Canada
115.8944182,-32.0061951,Curtin University, Australia
37.5286696,55.7039349,Moscow State University, Russia ...
103.0855782,1.858626,Universiti Tun Hussein Onm Malaysia, Malaysia ...
-117.195686,34.056077,Environmental Systems Research Institute (ESRI), USA ...
```

Figure 7. Resolver module result: Resulting entities equipped with geo-references after object entity analysis, filters, and mapping (excerpt).

For this result, the pre- and post filters handled all issues as described. The entries are shown in a special 3 column Comma Separated Value (CSV) format. The GMT format for the geo-referenced CSV is straight forward (Figure 8).

```
...
-71.2747424 46.7817463 Centre for Research in Geomatics, Laval University,
 Quebec, Canada
115.8944182 -32.0061951 Curtin University, Australia
37.5286696 55.7039349 Moscow State University, Russia ...
103.0855782 1.858626 Universiti Tun Hussein Onm Malaysia, Malaysia ...
-117.195686 34.056077 Environmental Systems Research Institute (ESRI), USA ...
```

Figure 8. Geo-references object entity in GMT format (excerpt).

The context creation includes the media generation. Figure 9 excerpts a KML representation of the above geo-referenced entities, resulting from the original mapping.

```
<?xml version="1.0" encoding="UTF-8"?>
<kml xmlns="http://www.opengis.net/kml/2.2">
<Document>
<name>Locations</name>
<Folder><name>Conferences</name><Style id="locationsconferences"><BalloonStyle>
<text><![CDATA[<b><font color="#0000CC" size="+2">$[name]</font></b><br/><br/><
 font face="Courier">$[description]</font><br/><br/>$[address]
$[id]
$[Snippet]
$[geDirections]
]]></text></BalloonStyle>
<IconStyle><Icon><href>http://maps.google.com/mapfiles/kml/pushpin/grn-pushpin.
 png</href></Icon></IconStyle></Style> ...
<Placemark><name>Centre for Research in Geomatics</name>
<description>Centre for Research in Geomatics, Laval University Quebec Canada</
 description>
<styleUrl>#locationsconferences</styleUrl>
<Point><coordinates>-71.2747424,46.7817463,0</coordinates></Point></Placemark>
<Placemark><name>Curtin University</name>
<description>Curtin University, Australia</description>
<styleUrl>#locationsconferences</styleUrl>
<Point><coordinates>115.8944182,-32.0061951,0</coordinates></Point></Placemark>
<Placemark><name>Moscow State University</name>
<description>Moscow State University, Russia</description>
<styleUrl>#locationsconferences</styleUrl>
<Point><coordinates>37.5286696,55.7039349,0</coordinates></Point></Placemark>
 ...
<Placemark><name>Universiti Tun Hussein Onm Malaysia</name>
<description>Universiti Tun Hussein Onm Malaysia, Malaysia</description>
<styleUrl>#locationsconferences</styleUrl>
<Point><coordinates>103.0855782,1.858626,0</coordinates></Point></Placemark> ...
<Placemark><name>Environmental Systems Research Institute (ESRI)</name>
<description>Environmental Systems Research Institute (ESRI), USA</description>
<styleUrl>#locationsconferences</styleUrl>
<Point><coordinates>-117.195686,34.056077,0</coordinates></Point></Placemark>
 ...
</Folder>
</Document>
</kml>
```

Figure 9. Media representation (KML) of geo-referenced object entities, resulting from original mapping (excerpt).

A global view of all resulting entities automatically analysed and mapped from the single object [41] is shown in Figure 10. The single-object-view integrates the new spatial context of the object entities with a high precision topographic-oceanographic thematic view. The bullets are very much oversized for this illustration.

The respective components are provided by GMT suite applications, especially `pscoast` and `gmtselect` [17], which allow a multitude of spatial operations and criteria in context with the entities. Further, KML can be used with many spatial applications, e.g., with Marble and Google Maps. Generators can be configured to mark different types of locations with different markers. It is also possible to automatically mark locations with thumbnail photos being associated with the respective location and so on.

With a general approach, on knowledge side, the universal classification can classify any location and context, the more, it allows to integrate any multi-dimensional context with the full conceptual knowledge. On application component side, GMT provides many functional features, e.g., spatial math, map material assembly, and any map projections.

Therefore, the integration of just two but very powerful components like UDC and GMT, can provide a huge spectrum of flexibility and fuzzyness of expressing location and context. As any documents, e.g., plain texts, Hypertext Markup Language (HTML), and LaTeX documents can be handled for affiliation matching can base on fuzzy algorithms based on matching knowledge (e.g., item libraries and classification).

The knowledge resources and data sets are used for demonstration purposes only and, as far as shown here, are publicly available. The used conceptual knowledge framework is publicly available to the given extent. Further licenses can be obtained, e.g., from the authors of UDC, for further and wider use. Adopters are further free to create their own conceptual knowledge framework to be used with the methodology. The methodology and resulting method frameworks can then be used accordingly.

When interactivity in the results is a desired target, then components like Marble and Google Earth can provide dynamical features in order to create special cognostic features, e.g., with focus of special details appearing in cognostic context.

The following implementations show case studies for different context and the resulting output, especially including context of the necessary topography (longitude, latitude, elevation), data, and information used, after the result was visualised via GMT. The examples show automatic spatial mappings of potential POI locations generated for a simple single text object.

VII. IMPLEMENTED METHODS: DYNAMICAL CONTEXT

Dynamical application components are focussing on targets, which are dynamic. From this point of view, the components themselves are not a matter of change. These components and their contexts are dynamical as the targets are primarily refering to dynamics, to something variable.

A. Creating context by knowledge mapping and context data

Context data can be any data, which show a reference with the knowledge, with which the case is dealing with. This can

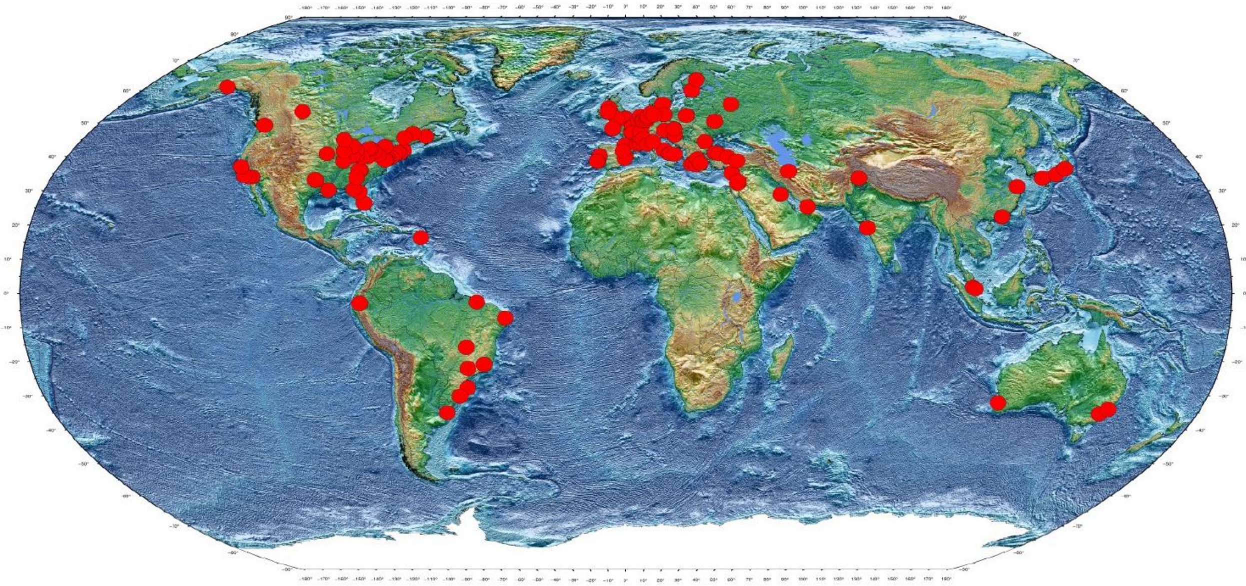

Figure 10. Spatial visualisation result for mapping entities in the text of a single object to a new spatial context and topographic-oceanographic thematic view: Entities resulting from automated analysis and affiliation mapping (red bullets). Sample object: Committee page [41], GEOProcessing 2018 conference, Rome.

be visual context, e.g., concentrations on a thematic mapping, for example with topographic, climatic or political mapping. This can also be mathematical background, e.g., mathematical algorithms being able to describe context and references, e.g., GMT math context or spatial tools context. In case of the above example, such supportive context data can, e.g., be

- climate data,
- weather data,
- political data,
- historical data,
- planetary data (eclipse, areas of visibility, ...),
- routing / navigation data.

Such context, e.g., data allows

- spatial mapping and
- spatial operations.

In consequence, sample facilities are

- location context,
- altitude,
- sea / land / island / ...,
- temperature,
- precipitation,
- satellite data context,
- location / POI context.

We can create context-methods for arbitrary knowledge mapping and context strictly based on the Methodology of Knowledge Mapping. The following implemented context-methods directly refer to the above case study and the given knowledge samples.

B. Political context

If the target is a context creation of possible political context of object/entities then the steps are:

1) Start: Unstructured object/entities (e.g., from text).
2) Analysis of object/entities. Analysis of references, e.g., classifications, concordances, and associations.
3) Knowledge Mapping for object/entities. Mapping object/entities with available knowledge.
4) Creation of politically referenced context (e.g., political mapping). Referencing with supportive context data (e.g., spatial political maps)
5) Result: Object/entities mapped on a dynamical political context map (e.g., Marble, political map).

Figure 11 is a screenshot of an dynamical, interactive view (Marble), a political map context for above created context.

Figure 11. New context for automatically created analysis and mapping of resulting entities of a single object: Political context for labeled entities.

A consecutive mapping allows to analyse the entities in completely new context. For example, parts of an unstructured document can be put into context with any type of n-dimensional information, e.g., historical and climatological context by using spatial information [42] and mapping for finding links. In this case, data entities can be spatially mapped and associated with multi-dimensional data from many disciplines, and data entities can not only be associated in space but also in time. The data allows to do detailed knowledge mining analysis as well as visual analysis.

The following method implementations create varying contexts and cognostic levels of detail in order to show a small subset of knowledge dimensions for application with spatial targets. Some of the features, e.g., interactive and dynamical features, cannot be illustrated in the figures but will be discussed afterwards.

C. Climate context

If the target is a context creation of possible climate context of object/entities then the steps are:

1) Start: Unstructured object/entities (e.g., from text).
2) Analysis of object/entities. Analysis of references, e.g., classifications, concordances, and associations.
3) Knowledge Mapping for object/entities. Mapping object/entities with available knowledge.
4) Creation of climate referenced context (e.g., climatological mapping). Referencing with supportive context data (e.g., spatial climate maps)
5) Result: Object/entities mapped on a dynamical climate context map (e.g., Marble, climate map).

For the created context, Figure 12 shows a screenshot of an interactive globe-view (Marble) with climate zone context.

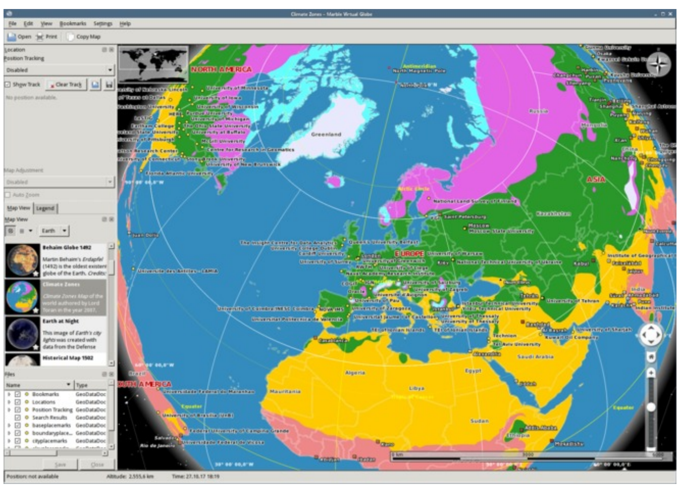

Figure 12. New context for automatically created analysis and mapping of resulting entities of a single object: Climate zones context in 3D.

D. Topographic context

If the target is a context creation of possible global topographic earth context of object/entities then the steps are:

1) Start: Unstructured object/entities (e.g., from text).
2) Analysis of object/entities. Analysis of references, e.g., classifications, concordances, and associations.
3) Knowledge Mapping for object/entities. Mapping object/entities with available knowledge.
4) Creation of topographically referenced context (e.g., global topographical mapping). Referencing with supportive context data (e.g., spatial earth topography maps)
5) Result: Object/entities mapped on a dynamical topographic context map (e.g., Google Earth, Earth view).

For the created context, Figure 13 shows a screenshot of an interactive view (Google Earth) with Earth view context.

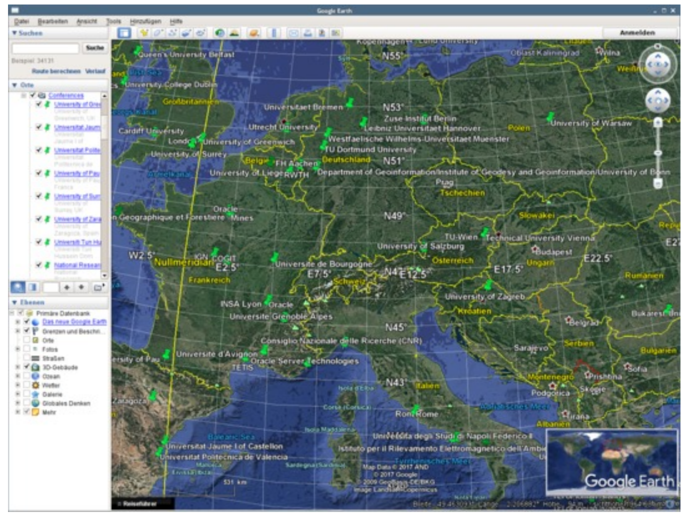

Figure 13. New context for automatically created analysis and mapping of resulting entities of a single object: Google Earth context, labeled entities.

Besides the new context of spatial distribution and according algorithms and math, the new context environments build links in order to associate entities with knowledge from arbitrary disciplines and proceed with further analysis.

Due to conceptual attributes of knowledge mapping and spatial algorithms, the implementation allows high grades of scalability and fuzziness. New context can also be kept and used in learning systems components. This, e.g., can provide conditional object / entity aggregation and time sequences.

E. Super zoom object context

If the target is a context creation of possible super zoom context of object/entities, including context POI and local objects, then the steps are:

1) Start: Unstructured object/entities (e.g., from text).
2) Analysis of object/entities. Analysis of references, e.g., classifications, concordances, and associations.
3) Knowledge Mapping for object/entities. Mapping object/entities with available knowledge.
4) Creation of referenced context (e.g., topographical mapping, integration of POI). Referencing with supportive context data (e.g., topic maps)
5) Result: Object/entities mapped on a dynamical, zoomable POI context map (e.g., Google Earth).

For the created context, Figure 14 shows a screenshot of an interactive context zoom (Google Earth) of a single entity.

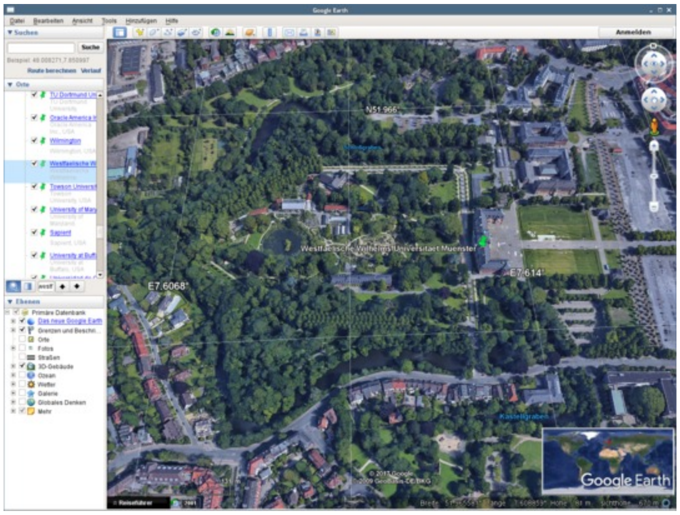

Figure 14. New context for automatically created analysis and mapping of resulting entities of a single object: Google Earth context, super zoom.

This way, any knowledge mapped entity can be made automatically available in its new context. Context can be statical and dynamical as well as it can consist of combinations. Many consecutive analysis can be performed as a plethora of algorithms is available to deal with spatial data. Examples are Points of Interest in a certain area or distances to other objects.

F. Public transport context

Figure 15 shows a screenshot of an interactive context view (Marble) of the public transport. The target leading to this application component is the context creation of possible public transport context of object/entities.

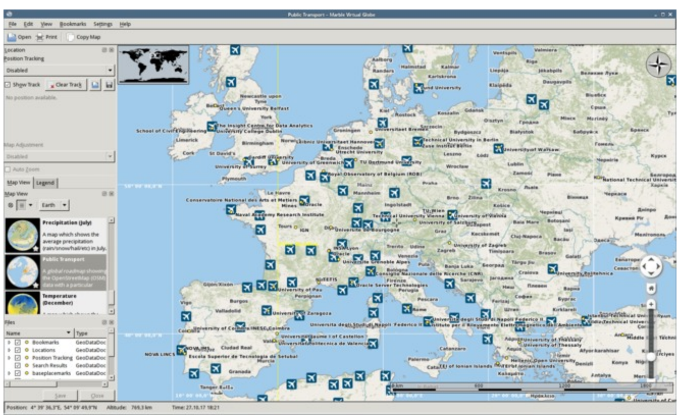

Figure 15. New context for automatically created analysis and mapping of resulting entities of a single object: Public transport.

For this target of context creation of possible public transport context of object/entities the steps are:

1) Start: Unstructured object/entities (e.g., from text).
2) Analysis of object/entities. Analysis of references, e.g., classifications, concordances, and associations.
3) Knowledge Mapping for object/entities. Mapping object/entities with available knowledge.
4) Creation of transport referenced context (e.g., public transport mapping). Referencing with supportive context data (e.g., spatial road/rail maps)
5) Result: Object/entities mapped on a dynamical transport context map (e.g., Marble).

Questions can be addressed, for example, if there is a correlation between entities referred in an object and the available public transport facilities.

G. Street map context

If the target is a context creation of possible street map context of object/entities then the steps are:

1) Start: Unstructured object/entities (e.g., from text).
2) Analysis of object/entities. Analysis of references, e.g., classifications, concordances, and associations.
3) Knowledge Mapping for object/entities. Mapping object/entities with available knowledge.
4) Creation of transport referenced context (e.g., street mapping). Referencing with supportive context data (e.g., spatial road/rail maps)
5) Result: Object/entities mapped on a dynamical street context map (e.g., Marble, OSM).

For the created context, Figure 16 shows a screenshot of an interactive context view (Marble, OSM) for Open Street Map.

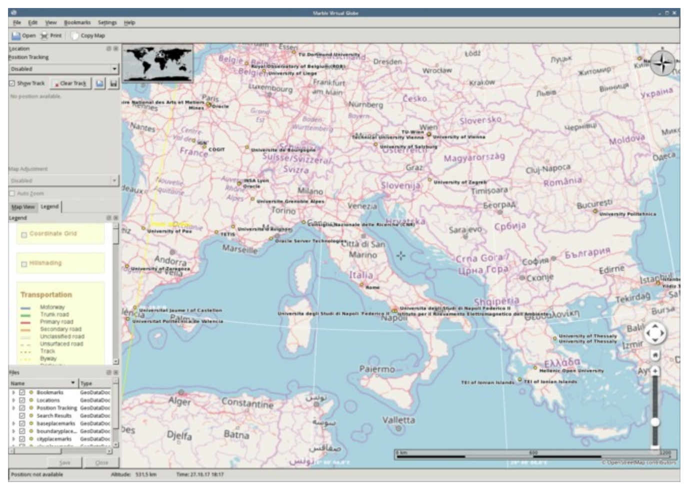

Figure 16. New context for automatically created analysis and mapping of resulting entities of a single object: Open Street Map.

Analysis addressed with navigational context can provide information on relations between entities and their infrastructure based environments.

VIII. Discussion of Multi-dimensional Context Features of Methodology and Implementations

A. Integration of Context

As the same objects/entities can be brought into different context views, an integration of contexts can deliver new knowledge and insight.

In the above cases, contexts have been created for the entities of a single object, using various dimensions, especially spatial knowledge, time, and other associated knowledge. These contexts, e.g., global distribution, climate, state affiliation, topography, traffic, and navigation in near environment and so on can reveal different insights regarding different object entities.

Even with practical implementations based on publicly available universal conceptual knowledge it is nevertheless only possible to demonstrate a very small range of scenarios of multi-dimensional knowledge context.

Using different spatial framework components, like GMT and Marble, we illustrated some features and what these features can provide for text objects and entities. The methodology allows an overlay and integration of knowledge dimensions. The methods can integrate important data, e.g., raster and vector data, basic spatial object types (esp., points, lines, polygons), and other non spatial data. The implementations allow various types of calculation, e.g., object distance relations and geo-statistics. The methods of analysis range from automated analysis to visual analysis.

A solution integrating GMT can provide practical access to spatial and non-spatial knowledge dimensions, for example:

- Categories of arbitrary land data,
- elevation data, height and depth,
- colourisation of data,
- shading of data,
- borders, political boundaries,
- coastlines,
- water bodies, lakes, permanent rivers, categories of intermittent rivers, categories of canals,
- POI (e.g., cities, sites, locations), and
- context labels.

The individual data can be composed from different sources, different time intervals. Therefore it is possible to compose context from an infinite number of possible combinations.

A solution integrating Marble/KML can provide practical access to spatial and non-spatial knowledge dimensions, for example:

- Categories of arbitrary topic data,
- dynamical changes (e.g., traffic, public transport, POI),
- interactive features,
- environmental and disaster analysis,
- fly-over perspectives,
- time zones,
- lighting (e.g., dawn/dusk areas, daylight/night).

Besides referencing in various dimensions, as illustrated, the methodology allows to create methods for generating time series and animation sequences as well as to handle scalability targets and learning system components. The following features were implemented with the above scenarios.

B. Time series and animation context

All the implementations of methods creating dynamical and statical context, which are based on knowledge mapping –like the above– include features to further create knowledge and knowledge-based implementations on top.

On the one hand, for example, the knowledge and implementations allow to aggregate knowledge, e.g., for creating time series of data. Aggregated knowledge can be used to create secondary and consecutive knowledge and to build and choose appropriate secondary data and applications, e.g., generating KML data and applying it with appropriate application components. The above examples allow animations, e.g., FlyTo views (fly to a certain point of interest) and Tour views (fly to a sequence of points on interests).

On the other hand, the context can be variable over time. This may, for example, be resulting from historical background data like historical satellite data or by integrating real time data.

To this account, aggregated knowledge is a discrete value. For many scenarios, aggregated knowledge otherwise cannot be recreated by other means or at other times. For example, in the above scenario, it is a common case that affiliations are existing for a certain interval in time. Institutions and organisations get founded, and can get renamed, relocated or terminated.

The knowledge to create references is therefore only available in certain time intervals and will change. If creating the same mapping, for example, ten years later may show that references are then missing or having been changed. Aggregating and persistently keeping the knowledge at a time can therefore preserve knowledge, which cannot be created at other times later.

C. Object-entity aggregation

The above object scenario illustrates the multi-dimensional context of one object. The methods can handle arbitrary knowledge objects in any context, e.g., refer to multiple objects and entities in one view, e.g., object instances over an interval of years or different objects within one year, as well as different object instances over an interval of years.

Any precomputed or intermediate result that might be interesting for reuse, either from knowledge or from implementation point of view. There is no general implementation for arbitrary long-term knowledge objects, which means the organisation and management may have to include database components as well as distributed access and interfaces.

Holistic views should also take into consideration that it can be reasonable to also gather and aggregate supportive context data, like old map data, historical POI descriptions and so on.

D. Learning system components

Creating learning system components is just one possible subset within the range of the methodology.

Implementation components and realisations can make use of learning system components for arbitrary scenarios. Learning system components can provide modules in scenarios like the above and reuse knowledge as well as contribute to new knowledge and insight, which allow to collect knowledge developing in terms of time, application, and context.

As an example, learning system components can be built to use aggregated knowledge over long periods of time in order to extend dimensions in knowledge, e.g., in space and time.

Entities in objects may require older context, which cannot created from present objects, independent of the date of the object. For example, the context of entities in online data does not need to correspond with the date of the hosting file. Lost or missed context may not be possible to be recreated from present data. Long-term application and archiving learning components' results can therefore contribute to a significant quality improvement in many application cases.

E. Checkpointing and knowledge gathering

The methodology allows to create methods, which save checkpointing information for the mapping process.

It can also be reasonable to save resolved references and geolocations persistently because of changes over time, which may not be resolvable later.

When implementing and realising methods, these considerations should be considered with the creation of the modules.

Checkpointing can make use of the mechanisms of knowledge gathering from knowledge as well as from implementation point of view, e.g., collecting time dependent data, data aggregation, and inter module checkpointing data during workflows.

F. Compute resources outline

Depending on the details of resources and scenarios, the computational characteristics can vary. For the case studies some typical numbers are shown in Table IV.

TABLE IV. CASE STUDY COMPUTE AND MAPPING OUTLINE (LX).

Count	*Number of*
≈10,000,000	Objects addressed in Knowledge Resources
≈100	Corrective patterns for a single entity
≈100	Entities per object
≈100	Entity mappings
≈10,000,000	Comparisons
— 100×100×....	Calculations

As with the implemented methods in the demonstrated case studies it is not uncommon to have millions of comparisons per object and consecutive large numbers of calculations and operations. Multi-dimensional contexts can be much more complex than simple computational frameworks without a knowledge-centric focus. Therefore, a certain computational framework or solution, e.g., parallelisation and linear behaviour related characteristics, can only fit a context to a certain extent.

G. Scalability

The scalability of solutions is most important for any assemblies, the more as the implementations of any methods, which are handling complex context very much correlate with the complexity involved. Due die the complex conditions nd dependencies of knowledge, knowledge mapping methods rely very much on the data delivered by knowledge resources. In many cases this is increasingly significant for realisations after an implementation. Realisations mean, for example, building services based on implementations. In the above case study implementations can handle locations in many ways. Common targets for realisations may be

- precise locations,
- fuzzy locations,
- location precision restricted by criteria, ...

The precision is depending on the associated knowledge and supportive knowledge but also on the intended realisation. The differences of knowledge involved and the consequences on algorithmic and computational efforts may be remarkable.

Within each method, it is possible to take advantage of modifying the contributing factors of scalability when methods are implemented and realised.

IX. CONCLUSION

This paper introduces to multi-dimensional context creation based on the new methodology of Knowledge Mapping and presents the results of the present research. The methodology provides knowledge based mapping of arbitrary objects and entities and creating new multi-dimensional context. The research presented a number of successfully implemented methods, the fundaments of the theoretical background of the methodology, and the results of the implementation case studies. Analysis and case studies implemented advanced context generation, e.g., with spatial visualisation, 2D, 3D, route mapping, public transport, the prerequisites of context related animation and fly-over tours as well as analysing computational requirements, which are widely scalable, depending on implementation of components and computing architectures.

The methodology fulfills the goals of successfully creating new multi-dimensional context. The Knowledge Mapping methodology can improve complex knowledge mining and associated tasks as well as it can be beneficial for the development of knowledge resources. Practical case studies, evaluated by groups of independent researchers, showed that applying the methodology can create relevant new context for entities in commonly available unstructured data. Regarding the case studies, mapping to spatial context is just one of an arbitrary number of possible mappings, which can be created with the methodology.

The quality of results can significantly benefit from a training and learning phase, depending on context. Here, with resolving nearly all possible place entities with the used new resources, the creation and learning phase of the modules accumulates to several years. The methodology allowed to implement a data-centric checkpointing with the methods. The checkpointing corresponds to associated learning processes.

As shown, in most cases it may be advisable for flexibility to create modular architectures of components instead of monolithic applications. It can further be convenient to consider robustness and reliability of service modules, depending on the architecture of an overall implementation. One means of dealing with infrastructure can be a failure correction, e.g., multiple task runs and check modules.

Future work will concentrate on further developing and improving the mapping modules and features for closer integration with and fostering an even wider range of application of multi-disciplinary knowledge resources.

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