Advanced Knowledge Discovery and Computing based on Knowledge Resources, Concordances, and Classification

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***Abstract*—This article presents an extended research of the main results from creating objects equipped with classifications and concordances as base for advanced discovery, processing, and computing based on knowledge resources. Today big data collections and resources sadly combine one or more deficits of being unclassified, unstructured, isolated, and weakly developed on the one hand and in consequence only accessible with insufficient simplistic means on the other hand. New classification features, structures, and components have been developed, which can be flexibly used with multi-disciplinary, multi-lingual long-term knowledge resources. The extended facilities can be used for universal long-term knowledge resources beyond the simple and isolated use of knowledge and data. The goal of this research is to create advanced resources and methods based on classifications and concordances. The focus is to provide facilities for advanced discovery processes based on universal knowledge resources and showing that content, classification, and concordances are valuable long-term assets.**

***Keywords*–Knowledge Resources; Concordances; Classified Classification; Advanced Computing; Knowledge Discovery.**

I. Introduction

This extended research is based on the results from multi-disciplinary project for the creation of objects and concordances, which are intended to be used for long-term knowledge creation knowledge processing, and advanced computing. The basic fundaments of the results were presented at the INFOCOMP 2015 conference in Brussels, Belgium [1].

Advanced knowledge discovery and computing can be based on appropriate knowledge resources, concordances, and classification. The knowledge resources require spanning a reasonable width and depth of knowledge and universal and long-term features.

The fundaments of these required features are the results from the development of advanced object features for long-term knowledge resources, which can be used for universal documentation and consequent purposes. For the consequent purposes like advanced knowledge discovery, further creation and development of knowledge resources, visualisation, and education suitable, data-centred structures have been created being usable for advanced knowledge discovery and processing and for advanced and dynamical computing.

Up to now the world of increasingly big data is limited to data and data collections, which are rapidly growing in quantity, mostly even growing in storage requirements instead of knowledge only. Besides the data being unstructured, isolated, and often inconsistent in content and form it is also missing quality and essential features for conceptional knowledge like classification. One consequence is that in the last decades the means for accessing and handling data have not changed a lot regarding the content, context, and a next generation of features and quality.

The facilities provide advanced features for processing of knowledge as well as for flexible computing. Therefore, the creation and long-term care for suitable knowledge objects is a central issue. The knowledge resources have to be able to document any knowledge and data, e.g., factual and procedural knowledge, which require vertical as well as horizontal scalability for individual and subsequent use. In order to cope with the deficits this architecture can integrate structured and unstructured data, support universal classification and concordances and it can enable advanced knowledge processing, like parallel processing and dynamical visualisation.

The goal of this research is to create advanced resources and methods based on classifications and concordances. The focus of this research is to provide sustainable facilities for advanced discovery processes based on universal knowledge resources and showing that content, classification, and concordances are valuable long-term assets for integrating documentation and applicability. This paper presents the up-to-date research results from the creation of classifications and concordances for long-term knowledge resources' components, structures, and workflows for advanced processing and computing – and in the end most important on the long run, fostering the investments in the development of the data itself. Therefore, the major contributions of this research are the content and context, especially the integration of classification and concordances, on the one hand and on the other hand the new practical insights on improving the state-of-the-art of long-term documentation and application of universal knowledge.

This paper is organised as follows. Section II introduces state-of-the-art and motivation for creating an overall system. Section III discusses the research fundaments. Sections IV and V present the data-centric implementation, the implementation of resources, including concordances and classification with the creation of objects. Section VI shows the definition and organisation of implemented knowledge resources. Section VII provides selected content facets. Section VIII summarises the implemented features for processing and computing. and Sections IX and X provide an evaluation and summarise the main results, lessons learned, conclusions and future work.

II. State-of-the-art and motivation

Conceptual knowledge is an important issue with many aspects of knowledge discovery. Content and context can be provided by structured and unstructured data. Both can be assembled and collected, e.g., in collections and containers. Regarding the value of data it can be seen as a drawback that most public developments are focussing on technical implementations and not on the content [2]. In public presentation and marketing common understanding of containers is reduced to certain aspects, e.g., security features [3], [4]. Other container concepts for handling Big Data, especially scientific data, e.g., the NERSC 'Shifter' at the National Energy Research Scientific Computing Center [5] are focussing on technology-centric and implementation purposes.

These approaches are insufficient from the content and knowledge related point of view of containers. For example, on the one hand, there is nothing general for a container when postulating that it should contain "everything". At the same level, security features have to be considered very special with specific cases of application. In addition, in most cases the advanced application scenarios trigger those secondary conditions. On the other hand, containers must not only provide computational features. The result is that up to now we neither have a commonly discussed container concept nor a set of universal features.

A container is a term for a data or file format bundling the data for certain purpose and application. The features for anything more interesting will include data, documentation, references and so on. Doing so includes how the information is transferred or accessed, which includes to define the modalities for a certain scenario. When discussing containers from the content and knowledge view, many scenarios suggest a target beyond universal application [6], which induces a much more general understanding of containers.

For the required purposes the knowledge resources require a set of features, especially facilities for multi-disciplinary and multi-lingual knowledge and content. Content should be kept consistent and easily accessible, e.g., in collections and containers. One of the most desirable properties are long-term facilities and long-term availability. Especially, the organisational units and objects need to carry conceptual knowledge, e.g., in form of classifications.

III. Fundaments and previous work

Many developments have contributed to the state-of-the-art on knowledge processing and discovery. Also, many developments have provided new technical means to cope with the new developments in computing architectures and services. In the context of knowledge processing, discovery, and search we are often faced with "prominent" examples like Internet search engines, library search engines, specialised expert systems, and maybe social media systems. If at all then there are some interfaces, e.g., for automated requests or web-service creation.

The algorithms applicable to this kind of 'art' are very limited and often not sufficient in delivering a reasonable quality for requested results or for following advanced goals. Therefore, various concepts, developments, and approaches have been created, addressing different aspects and special purposes. Nevertheless, these tools, classifications, and algorithms only try to handle the symptoms of the state of the data.

The approaches cover in-depth classifications and handling, e.g., library classification specialised on geological publications [7], handling historical geographic resources, especially in library context [8], and international patent classification [9]. The algorithms touch processing and automation, e.g., statistical models for online text classification [10] and automation with a classification [11].

The discussions and analyses range from research aspects to reliability and non-disciplinary approaches, e.g., classification as a research tool [12], reliability of diagnostic classification [13], and the Universal Decimal Classification (UDC) [14] as a non-disciplinary [15] universal [16] classification system, and legal and general aspects within Information Science, Security, and Computing [17].

In depth, aspects of mapping, organisation and multi-lingual data have been discussed, e.g., simple mapping between a classification and an "index" [18], simple conceptual methods for using classification in libraries [19], knowledge organisation [20], multi-lingual lexical linked data cloud [21]. In principle, any multi-disciplinary data resources may be used, e.g., projects like Europeana [22], European Cultural Heritage Online (ECHO) [23] or World Digital Library (WDL) [24]. Although these examples are focussed on providing special information they lack in sufficient content, organisation, and structure.

The main motivation for this extended research was the lack of multi-disciplinary data-centric approaches, which can be used for long-term creation of knowledge and scalable implementations. A major reason for the lack of data-centric approaches for these purposes is the missing understanding of value of data, which does not only manifest with data breaches. Considering a possible data breach the analysis has shown an even increased value of data within the last years [25].

With data-centric implementations this is also significant for quality steering [26], evaluation, and acceptance of information systems [27]. In many cases the long-term data value of the results is much higher than the funding value for creating the data [2].

The data used here is based on the content and context from the knowledge resources, provided by the LX Foundation Scientific Resources [28]. The LX knowledge resources' structure and the classification references [29] based on UDC [30] are essential means for the processing workflows and evaluation of the knowledge objects and containers. Both provide strong multi-disciplinary and multi-lingual support.

For this part of the research all small unsorted excerpts of the knowledge resources objects only refer to main UDC-based classes, which for this part of the publication are taken from the Multilingual Universal Decimal Classification Summary (UDCC Publication No. 088) [14] released by the UDC Consortium under the Creative Commons Attribution Share Alike 3.0 license [31] (first release 2009, subsequent update 2012).

The analysis of different classifications, development of concepts for intermediate classifications, and experiences from case studies from the research conducted in the Knowledge in Motion (KiM) long-term project [32] have contributed to the application of UDC and different classifications and concordance schemes in the context of knowledge resources.

The following term definitions for object, container, and matrix can be helpful in this context.

- An object is an entity of knowledge data being part of knowledge resources. An object can contain any documentation, references, and other data. Objects can have an arbitrary number of sub-objects.
- A container is a collection of knowledge objects in a conjoint format.
- A matrix is a subset of the entirety, the "universe", of knowledge. A workflow can consist of many sub-workflows each of which can be based on an arbitrary number of knowledge matrices. The output of any sub-workflow or workflow can be seen as an intermediate or final result matrix.

The flexible creation of objects carrying references, especially classification and concordances is the fundament for advanced. knowledge processing and computing.

IV. Data-centric implementation

In order to concentrate on the challenges of the data itself so-called data-centric, data-defined, document-oriented or document-centric approaches have been developed. This went along with extending features like Structured Query Language (SQL) and "Not only SQL" (NoSQL) [33], e.g., via MySQL [34] and respective SQL [35] and MongoDB [36] and in consequence [37] also in bridging relational and data- or document-centric approaches [38]. Anyhow, implementations like MongoDB, Docker, and CoreOS are technology-centric components, e.g., they are mostly used for Web and application development [39], [40], [41]. The very minimalistic "map" and "reduce" functions approach of MapReduce [42], which attracted many quick and simple solutions is a nice example for building simple workflow elements.

As the knowledge resources' approach [28] is even much more general [29] it allows for arbitrary measures and also for processing implementing map and reduce functions, which can be based on the creation of objects and concordances.

Regarding a distributed computer system theoretical computer science can state the CAP (Consistency, Availability, Partition tolerance) theorem. In condensed form this means: *Consistency*: All nodes see the same data at the same time, *Availability*: A guarantee that every request receives a response about whether it succeeded or failed, *Partition tolerance*: The system continues to operate despite arbitrary message loss or failure of part of the system. Accordingly, learning from decades of case-studies, regarding the long-term knowledge and information sciences we can state a "CLU" theorem:

- *Consistency*: All knowledge in context used is neither in contradiction to other knowledge in context nor disaccording within its content,
- *Long-term sustainability*: Data-centric architectures, the core knowledge resources can be used for an arbitrary number of different implementations,
- *Universal documentation*: Documentation is supported for any knowledge and data, e.g., factual, conceptual, procedural, and metacognitive knowledge.

There is no direct reasonable equivalent for the P and A aspects. Besides the consistency, the items much more important are the long-term sustainability and universal documentation aspects. This includes the requirements for any type of knowledge as well as its multi-lingual documentation and features.

V. Implementation and resources

The implementation for dynamical visualisation and computation is based on the framework for the architecture for documentation and development of advanced scientific computing and multi-disciplinary knowledge [43].

The architecture implemented for an economical long-term strategy is based on different development blocks. Figure 1 shows the three main columns: Application resources, knowledge resources, and originary resources.

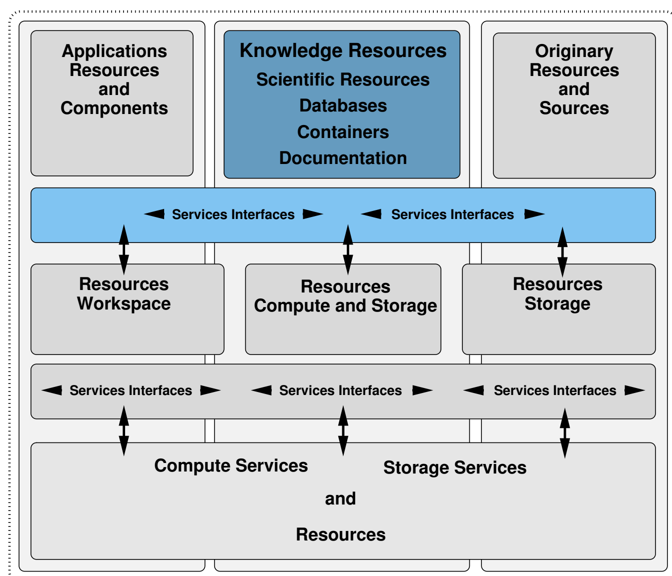

Figure 1. Architecture: Columns of practical dimensions. The knowledge resources are the central component within the long-term architecture.

The central block in the "Collaboration house" framework architecture [29], covers the knowledge resources, scientific resources, databases, containers, and documentation (e.g., LX [28], databases, containers, list resources). These can be based on and refer to the originary resources and sources (photos, scientific data, literature).

The knowledge resources are used as a universal component for compute and storage workflows. Application resources and components (Active Source, Active Map, local applications) are implementations for analysing, utilising, and processing data and making the information and knowledge accessible.

The related information, all data, and algorithm objects presented are copyright the author of this paper, LX Foundation Scientific Resources [28], all rights reserved. The structure and the classification references based on the LX resources and UDC, [44], especially mentioning the well structured editions [14] and the multi-lingual features [45], are essential means for the processing workflows and evaluation of the knowledge objects and containers. Both provide strong multi-disciplinary and multi-lingual support.

The three blocks are supported by services' interfaces. The interfaces interact with the physical resources, in the local workspace, in the compute and storage resources the knowledge resources are situated, and in the storage resources for the originary resources.

All of these components do allow for advanced scientific computing and data processing, as well as the access of compute and storage resources via services interfaces. The resources' needs depend on the application scenarios to be implemented for user groups.

A. Data-centricity

The architecture allows data-centric and computing-centric implementations. In this case, the plan is the integration of long-term creation of knowledge and scalable implementations, which motivates a data-centric approach.

The knowledge resources play the central role. With a data-centric approach the properties of objects may influence workflow decisions and code paths and logics may be defined through references, e.g., relations and constraints, optimising the access of dynamical states of the data and minimising code. Results and object stages can be stored with the data objects and the computing can be done by reading and writing object instances.

Therefore, the focus to provide facilities for advanced discovery processes based on universal knowledge resources is closely linked with data-centric classification and concordances.

B. Context for concordances and classification

Knowledge resources, concordances, and classification are based on an organisation of knowledge. The underlying organisation of knowledge is important for working with knowledge dimensions and for creating computational views, which can be used for advanced knowledge discovery and computing.

The available dimensions depend mostly on features and complexity of the available data. Therefore, a number of essential aspects have been considered when creating content with the knowledge resources. Regarding the views many new arrangements and visualisations are possible. Nevertheless, it can be quite challenging for application developers to create representations, which can be visualised, and to implement suitable components. In many cases so called "Section Views" can be computed, which use n-dimensional sections from 'n+m'-dimensional knowledge context.

Views are supported by knowledge dimensions, meaning the implementation of the types of knowledge, all of which can be integrated in the workflows.

C. Implementation of knowledge dimensions

The implemented knowledge resources integrate factual, conceptual, procedural, and metacognitive knowledge. Table I shows the major types of knowledge as complementary parts of the knowledge resources [46]. The table shows some practical examples, which illustrate the benefits of the integration.

The data itself is represented in knowledge objects containing any kind of information and collections, including content, classifications, and references.

TABLE I. COMPLEMENTARY KNOWLEDGE IN THE KNOWLEDGE RESOURCES, TYPES AND EXAMPLES.

Knowledge	*Examples*
Factual knowledge	Terminologies
	Factual details
Conceptual knowledge	Classifications, categorisations
	Principles, generalisations
	Theories, models, structures
Procedural knowledge	Algorithms, workflows, skills
	Methods, techniques
	Determination on procedures, decision making
Metacognitive knowledge	Strategies
	Self-knowledge
	Cognitive tasks, contexts, conditions

With the content and context documentation the knowledge objects describe the integrated knowledge space, for which any dimensions can be interconnected. Conceptual knowledge can be expressed with classifications.

It is useful to support classifications in general, as there are more than one classification available and in practice. Therefore, also concordances have a strong base in the conceptual knowledge.

D. Section views

The implemented structure and content enable to create section views based on the knowledge dimensions, which can, e.g., be physical or contextual dimensions. Table II shows some section views, which can be based on the combination of contextual and factual knowledge.

Generators can access the knowledge resources and their workflows can apply any appropriate components with their references and algorithms, e.g., classifications, concordances, phonetics [47], associations, references, keywords, and statistics. There will always be different objects, e.g., for different purposes and from different sources.

TABLE II. SECTION VIEWS BASED ON THE KNOWLEDGE DIMENSIONS. SECTION VIEWS AND EXAMPLES IN PRACTICE.

Section Views	*Examples*
Attributes	colour, size, ... extremes ...
Space and location	spatial distributions geo-references depth distribution
Time	timelines time index
Cultures	context history time location society inventions art
Disciplines	physics geophysics archaeology
Multi-disciplines	geosciences natural sciences – humanities
Multi-lingual	English German Romanic language
Combinations	depth distribution - timelines location-fixed: Objects over time time-fixed: Objects over space/locations culture-fixed: Objects over space and time

There is no need that such properties are available in all available objects but it can vastly enrich the quality of content and context if they are available. Therefore, the creation and ‘development’ of knowledge resources and objects is mostly a dynamical process.

E. Creation of objects and conceptual knowledge

Practical creation of objects has shown to be most efficient when three different categories of creation are considered:

- Manually created objects,
- Hybrid (semi-automatically) created objects, and
- Automatically created objects.

In any case creating objects is supported by universal classification, e.g., references to UDC. Therefore, that can also be applied for the creating concordances with objects.

The listing in Figure 2 shows an instance of a simple object excerpt from an object collection. The excerpt shows keywords, content, e.g., including references, documentation, factual knowledge, and conceptual knowledge.

```
Vesuvius [Vulcanology, Geology, Archaeology]:
 (lat.) Mons Vesuvius.
 (ital.) Vesuvio.
 (deutsch.) Vesuv.
 Volcano, Gulf of Naples, Italy.
 Complex volcano (compound volcano).
 Stratovolcano, large cone (Gran Cono).
 Volcano Type: Somma volcano,
 VNUM: 0101-02=,
 Summit Elevation: 1281 m.
 The volcanic activity in the region is observed by the
 Oservatorio Vesuviano. The Vesuvius area has been
 declared a national park on 1995-06-05.
 The most known antique settlements at the Vesuvius are
 Pompeji and Herculaneum.
 Syn.: Vesaevus, Vesevus, Vesbius, Vesvius
 s. volcano, super volcano, compound volcano
 s. also Pompeji, Herculaneum, seismology
 compare La Soufrière, Mt. Scenery, Soufriere
 ...
 UDC:[911.2+55]:[930.85]:[902]"63"(4+37+23+24)=12
 ...
 UCC:UDC2012:551.21
 UCC:UDC2012:551
 UCC:UDC2012:902/908
 UCC:MSC2010:86,86A17,86A60
 UCC:LCC:QE521-545
 UCC:LCC:QE1-996.5
 UCC:LCC:QC801-809
 UCC:LCC:CC1-960,CB3-482
 UCC:PACS2010:91.40.-k
 UCC:PACS2010:91.65.-n,91.
```

Figure 2. Processed instance of a simple object (excerpt) from an object collection.

Both classification and concordances, the Universal Classified Classification (UCC), were collected and created semi-automatically over a period of time. The rest of the object was created manually.

The listing in Figure 3 shows an instance of a simple container entry excerpt from a volcanological features container.

```
CONTAINER_CONCEPTUAL_KNOWLEDGE: UCC:UDC2012:551.21
CONTAINER_CONCEPTUAL_KNOWLEDGE: UCC:UDC2012:551
CONTAINER_CONCEPTUAL_KNOWLEDGE: UCC:UDC2012:551
 .2,551.23,551.24,551.26
CONTAINER_CONCEPTUAL_KNOWLEDGE: UCC:UDC2012:902/908
CONTAINER_CONCEPTUAL_KNOWLEDGE: UCC:MSC2010:86,86A17,86
 A60
CONTAINER_CONCEPTUAL_KNOWLEDGE: UCC:LCC:QE521-545
CONTAINER_CONCEPTUAL_KNOWLEDGE: UCC:LCC:QE1-996.5
CONTAINER_CONCEPTUAL_KNOWLEDGE: UCC:LCC:QC801-809
CONTAINER_CONCEPTUAL_KNOWLEDGE: UCC:LCC:CC1-960,CB3-482
CONTAINER_CONCEPTUAL_KNOWLEDGE: UCC:PACS2010:91.40.-k
CONTAINER_CONCEPTUAL_KNOWLEDGE: UCC:PACS2010:91.65.-n,91.
CONTAINER_CONCEPTUAL_KNOWLEDGE: UCC:PACS2010:91.40.Ge
 ,91.40.St,91.40.Rs,*91.45.C-,*91.45.D-,90
...
CONTAINER_OBJECT_EN_ITEM: Vesuvius
CONTAINER_OBJECT_DE_ITEM: Vesuv
CONTAINER_OBJECT_EN_PRINT: Vesuvius
CONTAINER_OBJECT_DE_PRINT: Vesuv
CONTAINER_OBJECT_EN_COUNTRY: Italy
CONTAINER_OBJECT_DE_COUNTRY: Italien
CONTAINER_OBJECT_EN_CONTINENT: Europe
CONTAINER_OBJECT_DE_CONTINENT: Europa
CONTAINER_OBJECT_XX_LATITUDE: 40.821N
CONTAINER_OBJECT_XX_LONGITUDE: 14.426E
CONTAINER_OBJECT_XX_HEIGHT_M: 1281
CONTAINER_OBJECT_EN_TYPE: Complexvolcano
CONTAINER_OBJECT_DE_TYPE: Komplex-Vulkan
CONTAINER_OBJECT_XX_VNUM: 0101-02=
```

Figure 3. Processed instance of a simple container entry (excerpt).

The excerpt shows a representation of conceptual knowledge for the container and various factual knowledge. The data was collected and created semi-automatically over a period of time. The conceptual knowledge is a matter of more detailed discussion in the next subsections and sections.

The excerpts have been processed with the appropriate `lx_object_volcanology` and `lx_container_volcanology` interfaces, selecting a number of items and for the container also items in English and German including a unique formatting.

The resources' access and processing can be done in any programming language, assuming that the interfaces are implemented. For example, combining scripting, filtering, and parallel programming can provide flexible approaches.

F. *Creation of concordances*

Many disciplines and large fields of application have developed and used individual adapted frameworks of conceptual knowledge for their purposes. The reasons have been multifold, in that cases either developing a universal approach was too demanding or a distinction for certain reasons might have been considered adequate. In many cases, various classifications required to be "compared" and to be used together.

However, when developing content with conceptual knowledge and classifications sooner or later also the individual classifications get in the focus of development and may require to be "mapped".

In most cases, this can be done with the means of concordances, for example, concordances with classification in medicine and health [48] or the creation concordances between two classifications systems [49], in concordance projects like coli-conc [50] or for benefits in industry classification systems [51], [52]. Therefore, the organisation of the resources and objects is significant for the long-term aspects and the vitality of the data.

Taking advantage of the modular architecture of the overall resources (Figure 1) the main objectives are the knowledge resources, services, and interfaces, which are deployed for creating workflows. Figure 4 illustrates an excerpt of selected knowledge resources' objects. The selected objects are associated to collections and containers and contain references to concordances and classifications. The excerpt in this case shows a distinct handling of manually, hybrid, and automatically created data.

The collection objects carry mostly only their individual conceptual knowledge, as there are concordances and classification, for example. The container objects are commonly similiar types of objects and structures where the container can carry a respective commonly valid conceptual knowledge for the container (symbolised in the figure by brick-structures for the objects). The respective knowledge resource, on the level integrating collections and resources, can also contain a respective commonly valid conceptual knowledge for the resource.

There are different ways of handling the processes for semi-automatically and automatically created concordances. With the main focus on processing and advanced computing we concentrate of the object and references side of the resources. This concept has shown vital benefits, which enables implementations with comparably high flexibility. Disciplines, services, and resources can be integrated in a very scalable way. Practical creation of concordances has shown to be most efficient when three different categories of creation are considered:

- Manually created concordances,
- Hybrid (semi-automatically) created concordances, and
- Automatically created concordances.

Manually-created-concordances is a type of concordances, which has resulted from manually inserting references from objects into a concordance instance. Hybrid-created-concordances is a type of concordances, which has resulted from a combination of manual and automated (semi-automatically) processes.

The processes may work on primary concordances or on any level of secondary data in order to support the creation of concordances. Automatically-created-concordances is a type of concordances, which have been generated, e.g., by an automated workflow process. This is mostly done for big data, which are used as quantity data and not due to their quality. In any way, an integration with the knowledge resources' references and structures is the target.

The workflows can contain several functions comparable to the map and reduce concept. A map function finds the data according to the criteria and creates a map result matrix. A reduce function does the appropriate operation on the map result matrix output.

The listing in Figure 5 shows a simple object instance classification and concordances excerpt (Figure 2) from a volcanological object in a collection.

```
...
UCC:UDC2012:551.21
UCC:UDC2012:551
UCC:UDC2012:902/908
UCC:MSC2010:86,86A17,86A60
UCC:LCC:QE521-545
UCC:LCC:QE1-996.5
UCC:LCC:QC801-809
UCC:LCC:CC1-960,CB3-482
UCC:PACS2010:91.40.-k
UCC:PACS2010:91.65.-n,91.
```

Figure 5. Classification and concordances excerpt of a simple object instance (knowledge resources collection).

The excerpt shows classification concordances in several different classifications as used in different disciplines. Possibly multiple views from different disciplines or author groups on a certain object are not shown in this reduced view but they can also hold the full spectrum of classifications and concordances. The following listing (Figure 6) excerpts classification and concordances of a (volcanological features) container (Figure 3).

The differences in classification and concordances are resulting from the different level of detail in the collections and containers as well as in different potential of the various classification schemes to describe certain knowledge as can be seen from the different depth of classification.

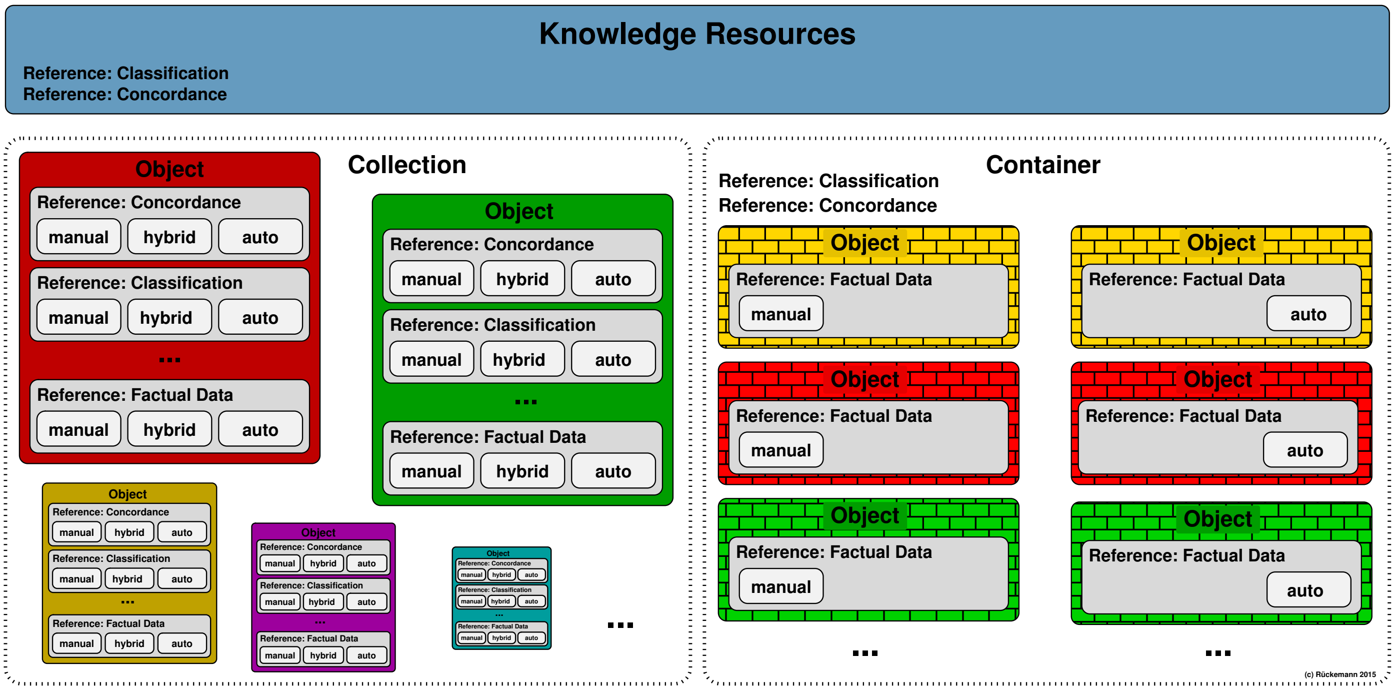

Figure 4. Resources and objects: Selected knowledge resources' objects containing references for concordances and classifications in collections and containers. In this case, the excerpt shows a distinct handling of manually, hybrid, and automatically created data, especially regarding classifications and concordances.

```
UCC:UDC2012:551.21
UCC:UDC2012:551
UCC:UDC2012:551.2,551.23,551.24,551.26
UCC:UDC2012:902/908
UCC:MSC2010:86,86A17,86A60
UCC:LCC:QE521-545
UCC:LCC:QE1-996.5
UCC:LCC:QC801-809
UCC:LCC:CC1-960,CB3-482
UCC:PACS2010:91.40.-k
UCC:PACS2010:91.65.-n,91.
UCC:PACS2010:91.40.Ge,91.40.St,91.40.Rs,*91.45.C-,*91.45.
 D-,90
...
```

Figure 6. Classification and concordances excerpt of a simple container instance (knowledge resources container).

In integration, together the concordances can create valuable references in depth and width to complementary classification schemes and knowledge classified with different classification.

The term concordance is not only used in the simple traditional meaning. Instead, the organisation is that of a meta-concordances concept. That results from the use of universal meta-classification, which in turn is used to classify and integrate classifications [53].

The samples include simple classifications from UDC, Mathematics Subject Classification (MSC) [54], Library of Congress Classification (LCC) [55], and Physics and Astronomy Classification Scheme (PACS) [56]. For PACS the asterisk ($*$) indicates entries from the "Acoustics Appendix / Geophysics Appendix".

The UCC entries contain several classifications. The UCC blocks provide concordances across the classification schemes. The object classification is associated with the items associated with the object whereas the container classification is associated with the container, which means it refers to all objects in the containers.

VI. Definition and Organisation of Knowledge: Classifications and Concordances

Most content / context documentation and knowledge discovery efforts are based on data and knowledge entities.

Knowledge is created from a subjective combination of different attainments, which are selected, compared and balanced against each other, which are transformed, interpreted, and used in reasoning, also to infer further knowledge. Therefore, not all the knowledge can be explicitly formalised. Knowledge and content are multi- and inter-disciplinary long-term targets and values [57]. In practice, powerful and secure information technology can support knowledge-based works and values.

Computing goes along with methodologies, technological means, and devices applicable for universal automatic manipulation and processing of data and information. Computing is a practical tool and has well defined purposes and goals.

A. *Organisation of knowledge*

Knowledge requires a universal organisation in order to establish a practical long-term implementation for knowledge objects, which can be flexibly used for varying computing requirements. The sketch of a two-dimensional representation for the organisation of knowledge resources (Figure 7) shows the structure of attributes and references as used for illustration with this research.

The figure illustrates an excerpt of depth and width of resources. These two-dimensional representation is based on n-dimensional resources, which have no general limitations regarding attributes and references.

The knowledge resources contain collections, containers, and other forms of providing information and data.

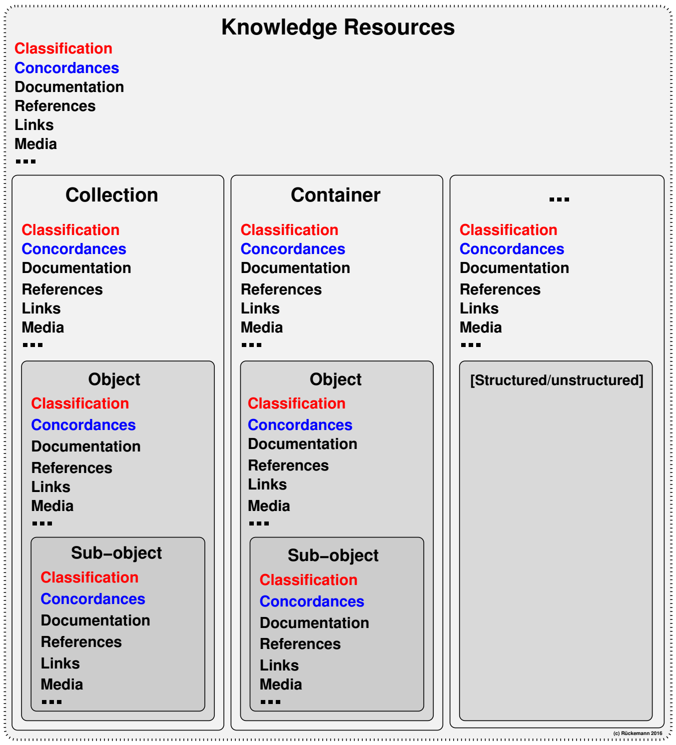

Figure 7. Sketch of a two-dimensional representation for the organisation of knowledge resources, showing an attributes/references structure.

A collection contains objects, which can widely differ, e.g., regarding internal structure, content, and references. For example, different references may be available, classification for objects being available or not. A container contains objects, which can have a common structure and comparable content and data, e.g., a mineral collection container or a volcanic features database. From the conceptual knowledge point of view, classification for the objects in a container will be very much the same.

From this point of view all knowledge objects will have a number classifications, for the resources, for the collection or container, for the object itself, for sub-objects, and probably references to object with classifications in the available dimensions.

Therefore, in this example, in a two-dimensional representation a sub-object in an object, in a container, in knowledge resources can have at least four classifications from the structural hierarchy.

B. Conceptual knowledge: Classification and concordances

The object as described with the creation of concordances is classified by use of one or more classifications. In this case, the UCC concordance holds entries from UDC, MSC, LCC, and PACS.

- UDC is fully integrating the object in a multi-disciplinary and multi-lingual context.
- LCC is providing a comparable but much less multi-lingual integration.
- MSC is a mathematical and natural sciences classification but not providing much depth and details and in this case neither covering volcanology nor archaeology.
- PACS is a traditional classification, which has been used with physics and astronomy and natural sciences context. In this case, it is significant that archaeology is not covered by PACS.

Table III shows the referred conceptual knowledge for an object resulting from more than one classifications.

TABLE III. INSIDE CONCORDANCES: CONCEPTUAL KNOWLEDGE FROM MANY CLASSIFICATIONS (KNOWLEDGE RESOURCES, ENGLISH VERSION).

UDC Code	*Description*
UDC2012:551.21	Vulcanicity. Vulcanism. Volcanoes. Eruptive phenomena. Eruptions
UDC2012:551	General geology. Meteorology.
UDC2012:551.2	Internal geodynamics (endogenous processes)
UDC2012:551.23	Fumaroles. Solfataras. Geysers. Hot springs. Mofettes. Carbon dioxide vents. Soffioni
UDC2012:551.24	Geotectonics
UDC2012:551.26	Structural-formative zones and geological formations
UDC2012:902/908	Archaeology. Prehistory. Cultural remains. Area studies
MSC2010:86	Geophysics
LCC:QE521-545	Volcanoes and earthquakes
LCC:QE1-996.5	Geology
LCC:QC801-809	Geophysics. Cosmic physics
LCC:CC1-960	Archaeology
LCC:CB3-482	History of Civilization
LCC:QC1-999	Physics
LCC:Subclass Q	Science (General)
PACS2010:91.40.-k	Volcanology
PACS2010:91.65.-n	Geology
PACS2010:91.	Solid Earth physics
PACS2010:91.40.Ge	Hydrothermal systems, volcanology of
PACS2010:91.40.St	Mid-ocean ridges, in volcanology
PACS2010:91.40.Rs	Subduction zones, in volcanology
PACS2010:*91.45.C-,91.45.Cg	Continental tectonics
PACS2010:*91.45.D-,91.45.Dh	Plate tectonics
PACS2010:90	Geophysics, Astronomy, and Astrophysics
PACS2010:—	Archaeology

Not only that supporting multiple classifications can be used to integrate resources from multiple sources, which include different classifications. The spectra and focus of many classifications are representing various views and disciplines. Therefore, the use of “complementary” classifications leads to a broader conceptual knowledge with the available content. This is most interesting for multi-disciplinary and multi-lingual knowledge.

VII. Content facets of knowledge

A. References and features

For most cases, practically usable knowledge is available at the object level and deeper, e.g., in object elements. That means, within any process available conceptual knowledge can be considered appropriately, according to the respective depths and views. Practically available collection and container reference types from the above examples are, for example:

- Categorisation,
- Multi-lingual elements,
  - Including multi-lingual objects,
  - Including multi-lingual elements in elements of other languages,
- Sorting support,
- Keywords,
- Classification,
- Concordances,
- Content Factor,
- Check sums,
- Signatures,
- Comments,
- Sources, ...
- Formatting elements,
- Links,
- Media,
- Documentation,
  - Including equations and other items,
- Algorithms,
- See,
- Comparison, ...
- Special entries,
- Indexing, general, n-level,
- Indexing, special,
- Glossar, ...

Collections are mostly used for gathering individual objects of any size and content. Containers can be used for keeping objects of comparable thematical content and context. Examples are containers implemented for volcanic features, volcanic eruptions, earthquakes, tsunamis, and minerals.

B. Spanning multi-lingual content

Knowledge resources provide features to document any part of knowledge, e.g., a knowledge resources collection, container, object, or element of an object in any kind and language.

This sounds much simpler than it is for complex knowledge resources. A Latin entry can, e.g., contain documentation for multiple audiences, e.g., English and German. The English references can direct to German objects and vice versa. The German documentation and the German objects can again contain English terms or references. Any of these snippets of language can, e.g., require to provide different views, classification, and formatting. With classification the conceptual knowledge can also provide classification descriptions.

As can be seen from the descriptions, which are available in many languages: It can be reasonable to have support tables, e.g., synonym, variation, and transliteration lists for multilingual descriptions.

C. Spanning classifications

Complementary to the fact that the objects are spanning multi-lingual content is the feature that their conceptual knowledge is also spanning different classification and concordance spaces.

Therefore, they are spanning different conceptual knowledge views, which refer to their trees of knowledge. The complementary views also help improving the quality and robustness of discovery processes based on data, especially long-term and heterogeneous data [58]. Very flexible and extendable trees are, e.g., provided by the decimal architecture of UDC.

Although classification can be used and created dynamically, for many reasons most classifications are long-term conceptual knowledge applied manually and explicitely, persistent to the respective object. This may be met with applying editions for the respective classifications. The result is the benefit of consistent and trackable classification.

D. Application case: Components and cycles

The following example illustrates the components and workflow cycles, especially related to collections and containers including conceptual knowledge.

Table IV shows the specifications with the selected environment, major workflow steps with types of involved information, and the result matrix. The start point for the discovery was Vesuvius. The target was to discover 10 associated ancient locations

The ranking relates to the respective resources, specifications, and workflow. The first matrix elements are more related than the following. The resources and workflow components also allow context associations. However, less related from a primary discovery process can mean more related from a secondary discovery process.

VIII. Knowledge processing and computing

The advanced processing of knowledge resources benefits from a significant number of unique attributes in its elements. These attributes can be references, classification, keywords, textual content, links, and many more. The elements can consist of objects or collections of objects, the containers, integrating factual data with object information and structure.

Workflows for creating arbitrary result matrices (Figure 8) have been based on the organisation and object features (Figure 4) in the knowledge resources.

TABLE IV. COMPONENTS AND WORKFLOWS SUPPORTED BY CONCEPTUAL KNOWLEDGE: VESUVIUS-ASSOCIATED ANCIENT LOCATIONS.

Specification	*Selected Environment*
• Knowledge resources,	
Collection,	geosciences, archaeology, ...
Container,	volcanic features, stones, ...
Media,	[no explicit limit]
References,	[no explicit limit]
Links,	[no explicit limit]
Classification,	[no explicit limit]
Concordances, ...	[no explicit limit]
• Internet associations	[no explicit limit]
Workflow and Information	
• Knowledge resources (concordances-manual + structured data)	
• Associated data (concordances-auto + unstructured data)	
• Intermediate result matrix elements (concordance-manual, concordances-auto + structured + unstructured data)	
• Final result matrix elements (English, 10)	
Result Matrix	*Ranking*
Campi Flegrei	[01]
Naples	[02]
Pompeji	[03]
Oplontis	[04]
Stabiae	[05]
Herculaneum	[06]
Nuceria	[07]
Salernum	[08]
Surrentum	[09]
Misenum	[10]

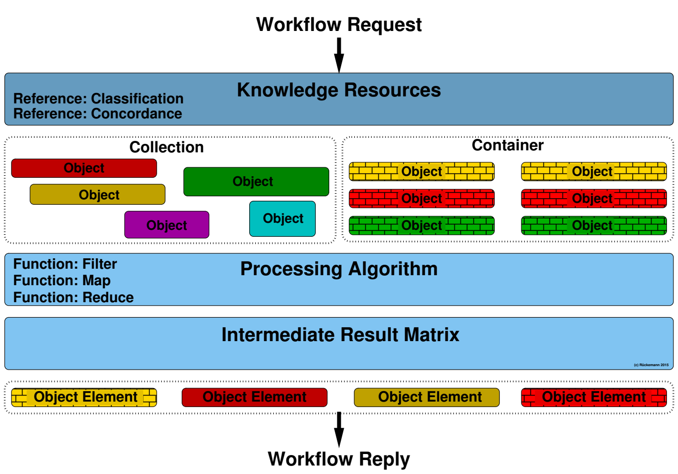

Figure 8. Creation of intermediate result matrices from resources and references (collections and containers) in reply to workflow requests.

The illustration shows that object information is gathered from the objects and references in collections and containers. Configurable algorithms like filters and mapping are then used in order to compute a result matrix. Here, the result matrix is considered "intermediate" because any of such workflows can be used in combination with other workflows, workflow chains or further processing.

For example, there is no "archaeology" in PACS, the concordances refer to resources including "archaeology" via some of the other schemes. MSC also does not contain a classification neither for volcanology or geology nor for associated features. Instead, even the geophysics section classifying geological problems refers to computational methods. The above examples (Figures 5 and 6) also illustrate this. The concordances' blocks allow to bridge between classifications and data resources, which can efficiently increase the available data pool size. Common options are in-depth computation with the container, or in-width with the general object collections. The concordances' blocks allow to follow in-depth or in-width references within data resources, which efficiently supports to improve the quality of result matrices and the quantity of elements, which also impacts on scalability and efficiency of workflows. Table V shows the shares of items regarding processing and computing with the main steps at knowledge resources, processing algorithms, and intermediate result matrices for the Vesuvius / volcanology case (Figures 2–6).

TABLE V. PROCESSING AND COMPUTING WITHOUT (/w) AND WITH (w/) CLASSIFICATION & CONCORDANCES (VESUVIUS/VOLCANOLOGY CASE).

Items of Processing and Computing	*Values* /w	w/
Knowledge resources		
Collection	10,000	200
Container	300	5
Processing algorithm		
Mean	750	230
String comparison	90,000	8,000
Associations	344	127
Phonetics	34	22
Weighting	296	84
Intermediate result matrix		
4 result matrix elements	120	20

The number of operations is based on subset of 100,000 collection and container objects from the knowledge resources, which have been accessed for the study. The number of items to be handled by the processing and computing for creating a comparable or higher quality result matrix have been much smaller in the major number of practical workflows when classification and concordances are included in the workflows. Especially, the primary number of requests on the collections and containers can be reduced. Consequently, the number of algorithm calls is reduced. The number of string comparisons and associated algorithms is most prominent here as the majority of objects in the resources contain text.

Figure 9 shows an elementary sample workflow batch implementation of a generated caller script used for the processing parallelisation for the computing tasks, e.g., calling from Integrated System components like actmap [59].

```
#!/bin/bash
#PBS -A ruckema
#PBS -N PARA_Discover
#PBS -j oe
#PBS -l feature=mpp1
#PBS -l nodes=16:ppn=6
#PBS -l walltime=00:60:00
cd $PBS_O_WORKDIR
msub para_discover.sh
```

Figure 9. Generated workflow parallelisation with `PARA_Discover`.

Every instance of this sample Portable Batch System (PBS) script uses 16 compute nodes and 6 processors per node in order to execute a `para_discover` call for maximum 60 minutes walltime. A regular run with the above values requires about 5 minutes walltime per instance without and about 25 seconds with classification and concordances. With four times the nodes and cores we can handle about four times the subset data.

However, it is important to choose a right knowledge representation for universal long-term data. The Resource Description Framework (RDF) [60] is a simple example for representing Web data. In many cases, simple directed labeled graphs are not sufficient to represent knowledge. References to directed labeled or other kinds of representations should be possible.

The structure should provide an intuitive and flexible access to the data. There should be features for integrating any kind of external data, e.g., objects, references, links, from structured to unstructured data with the available data. The elementary means of accessing the data should be independent from a certain implementation or certain purpose. The integration, interfaces, and interchange of data should be provided in most sustainable ways. This means any kind of structure and references and conceptual knowledge representation can be integrated. For example, in case of Web data even RDF can be deployed for Uniform Resource Identifiers (URI) naming relationships between data at the "ends" of a link, which in simple context enables to use graph analytics even on powerful High End Computing resources.

IX. Evaluation

The section views were created over longer periods of time while developing the knowledge resources, especially the objects. The implementation of knowledge dimensions is a fundamental means, which is based on complementary knowledge, especially factual, conceptual, procedural, and metacognitive knowledge.

Supporting more than one classification allows to integrate different sources and disciplinary views. This support can be beneficial for the discovery processes and the quality and value of data. Concordances are based on the same classification methods. The integrated use of multiple classifications allows to support a wider and deeper representation of conceptual knowledge.

On the one hand, the wide range of references, which have been implemented and can be extended arbitrarily, enables to support any data and sources. On the other hand, spanning multi-lingual content and spanning classifications allows to document with many languages and even specialised conceptual knowledge and integrate multi-lingual content as well as bridging areas of knowledge, which would be considered 'dark' in a single language or single classification.

As shown, objects and containers can carry complementary information and knowledge. The classifications and concordances feature a fuzzy bridging between resources, which allows modular in-depth as well as in-width workflows. In addition to that, workflows can require strongly adaptive code and algorithms. This may result in significant variations of runtime behaviour and resources' requirements. The workflows can integrate any objects for the processing, e.g., from collections and containers. These objects and their content may result from manual to automated origin. For example, the spectrum of creation includes use of classification, keywords, text analysis, and context analysis for the purpose of integration.

All the elements like classification, concordances, and factual data can result from manual, hybrid, and automatic processes. For example, Big Data [61] resources can be automatically outfitted with classifications and concordances following the container components. The level of details in content, context, and structure is arbitrary and can be scaled defined by the focus of the creator of the respective data. Therefore, associated conditions can be used in workflows for weighting the types of processes and qualities involved.

In practice, during the processing and computing, the numbers of algorithm calls for requests on the collections and containers can be significantly reduced with considering classification and concordances in workflows even when creating result matrices of comparable or higher quality. There will always be non-automated resources, which might be the knowledge intensive ones. The knowledge review can also be supported by distributed authorities as well as by means of automation.

Overall, classifications and concordances can easily be integrated with application components and workflows and allow an improved documentation for object along with additional information for supporting discovery processes, which can, e.g., be used for decision making and relevance considerations within discovery processes.

X. Conclusion and Future Work

With this extended research knowledge resources were created, which integrate flexible facilities for classifications and concordances. The organisation of the knowledge resources allows efficient long-term references structures. Therefore, the resources and objects can include any classification and concordances. Section views and knowledge dimensions have proven to be of long-term benefit for creating and developing knowledge resources.

The support of multiple classifications and concordances is a surplus value in many ways. The support advances the integration of knowledge and the facilities for discovery processes.

The types of objects and concordances shown in this paper have been successfully created and further developed within the knowledge resources. These results have also been integrated into the knowledge resources. The workflows for creating the structures and the features for the advanced processing and computing based on these resources have been successfully implemented with in the last years. From this research, we have learned some major results.

Experiences with the creation and development of objects within the knowledge resources have resulted in the fact that the data-centric approach neither conflicts with the long-term aspects nor with the deployment of advanced processing and computing features. This way, it should be possible to keep knowledge persistent even under changes of technology and paradigms.

The integration of objects, classification, and concordances has provided new means of documenting and accessing knowledge as well as for the efficient application of computational means. The structure of the long-term multi-disciplinary and multi-lingual knowledge resources' components enables to easily integrate objects from collections and containers. In more depth the conceptual knowledge, e.g., the classification can improve the quality of the result matrices. It enables to integrate more objects via strong means of knowledge instead of statistics or pattern matching algorithms only.

The implementation of the concordances and workflows has shown that the integrability of objects regarding multi-disciplinary and multi-lingual aspects has improved. The introduction of a universal classification and concordances is an excellent means of breaking up the isolated state of knowledge resources' content and associated data. In this context, creating concordances mainly contribute in two ways. On the one hand, concordances enable to considers different views of different and even special disciplines with the knowledge processing. On the other hand, concordances can be used to build bridges between isolated data resources.

The flexibility of the knowledge processing benefits from the advanced organisation of the data, which enables various scalable computational means for implementing directed graphs to fuzzy links, for which High End Computing resources can be deployed.

In summary, the wide range of implemented and arbitrarily extendable references and spanning languages and classifications enabled to improve documentation, integrability, and discovery with any data and sources. Creation and development of knowledge resources and knowledge discovery have benefited from classifications and concordances.

Future work will concentrate on advanced methodologies for data description and analysis, which can be applied with structured and unstructured knowledge objects and integrated with classifications, concordances, and references.

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