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Approaches to Coherent Conceptual Knowledge Integration for Prehistory, Archaeology, Natural Sciences, and Humanities:

Information Science Based Computation of Structural Knowledge and Spatial Context Information

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Abstract—**This extended paper delivers new results from the long-term information science research on creation and deployment of structure and cognostic addressing of structural knowledge ('nucleal cognstructure') for problem solving. The paper presents approaches towards the new methodological base and methodology focussing on structure-based fusion solutions and implementations for computational scenarios, especially advanced knowledge-centric mining. The paper presents two major cases of advanced multi-disciplinary coherent conceptual knowledge contextualisation and integration for prehistory, namely structure-based fusion realisation and integrated spatial context computation. Both cases include results on practical implementation components, and associated advances on computation and processing of multi-disciplinary and multi-lingual knowledge object entities and resources. The goal of this fundamental research is to create structure-based methods for efficient problem solving. Case studies implement the methods to consistently integrate knowledge context from prehistory and archaeology disciplines with knowledge in natural sciences and humanities. Previously unpublished insights on prehistoric cists tombs, contexts, and methods are available with this publication.**

Keywords*–*Prehistory; Speleology; Multi-disciplinary Knowledge Integration; Structure-based Information Science Methods; Computation and Processing.

I. INTRODUCTION

In information science, context is becoming increasingly relevant for many kinds of knowledge integration. This paper is an extended presentation of the research based on the publication and presentation at the INFOCOMP 2020 conference in Lisbon, Portugal [1]. The long-term project addresses two major challenges of coherent conceptual knowledge integration for prehistory, archaeology, natural sciences, and humanities: The integration of respective conceptual knowledge with structural knowledge and spatial information. The major goal is to create a framework of suitable long-term components for multi-disciplinary knowledge complements. It has become common practice during the last decades to tackle challenges regarding knowledge and related content solely with procedural approaches, besides the fact that creation processes, handling, and management may allow more effective and efficient measures in context of computation, processing, analysis, and long-term development or resources. Common ways, implementing procedural [2] approaches as plain technical solutions are often neither effective nor efficient. In addition, such approaches often lack long-term adaptability and scalability.

Procedure-based approaches are largely not addressing the knowledge and information content. Structure-based approaches can fill the gap. This motivation is supported by the experience that inefficiencies of procedural approaches regarding their creation, development, and execution can often be avoided by focussing on structure. Compared to procedure-based approaches, structure-based approaches are in general substantially different. Structure and formatting contain valuable information and closely correspond with logic, which should not be lost in many cases, e.g., this is especially the case for any sustainable long-term knowledge. That means, it is not intended to convert structures or to change formatting of resources. For information science and a universal knowledge context, meaning knowledge complements including conceptual knowledge, we also require a consistent, advanced definition of structure. It is important to understand what structure and form mean in theory and practice. The fundaments will be delivered before practical implementations are discussed.

The presented methodology addresses the shortcomings of common procedure-based approaches. The new structure-based fusion methodology and method implementations presented here are created as general purpose implementations, which can be realised in any Turing complete machine programming language, supporting creation and development of resources as well as computation, processing, and analysis. For the illustrative case studies, these approaches are used for dealing with various aspects of knowledge management and knowledge mining in information science context.

Knowledge resources' structures are commonly set and have proven long-term flexibility and sustainability. They cover content, context, consistency, and sustainability features for millions of information content, references, and object entities for long periods of time. Therefore, solutions for procedural components have to be found, which do provide comparably defiant long-term flexibility and sustainability. In addition, the procedural components require a very high level of knowledge-centricity and may need to exploit resource features, which are commonly not paid attention. When working with long-term resources, structural knowledge on resources and entities and their organisation has shown to provide a high potential. Inherent structural information also promises to achieve a high level of integration. Therefore, it might seem obvious to consider structure-based approaches for advanced and challenging tasks.

The rest of this paper is organised as follows. Section II gives an overview of previous work and resources development. Section III introduces to structure and addressing. Section IV presents an implementation case for structure-based methodology and method realisation. Section V discusses an implementation case of spatial context computation. Section VI summarises conclusions and future work.

II. PREVIOUS WORK, COMPONENTS, AND RESOURCES

A. Fundaments

The fundaments of terminology and understanding knowledge are layed out by Aristotle [3], being an essential part of 'Ethics' [4] and can lead to an understanding of the knowledge complements employed in the following approaches. Information sciences can very much benefit from Aristotle's fundaments and a knowledge-centric approach [2] but for building holistic and sustainable solutions, supporting a modern definition of knowledge [5], they need to go beyond the available technology-based approaches and hypothesis [6] as analysed in Platon's Phaidon. 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. Here, it is essential to regard the most important fundaments of structural knowledge and information of language and respective content.

The concept of meaning differs from the concept of signification. Semantic and syntactic structures do not suffice to determine the discursive meaning of an expression [7]. Discourse means a way of speaking. On the one hand, grammatically correct phrases may lack discursive meaning. On the other hand, grammatically incorrect sentences may be discursively meaningful. Knowledge and meaning are closely tied with intrinsic and extrinsic properties. Therefore, understanding of intrinsic and extrinsic properties of entities is significant for any context. This is nevertheless true for any case of natural language, especially considering langage, langue, and parole [8], especially when interpretation [9] and meaning [10] should be considered, especially regarding cognition and insight [11].

B. Components, conceptual knowledge and structures

The Universal Decimal Classification (UDC) [12] is the world's foremost document indexing language in the form of a multi-lingual classification scheme covering all fields of knowledge and constitutes a sophisticated indexing and retrieval tool. The UDC is designed for subject description and indexing of content of information resources irrespective of the carrier, form, format, and language. UDC is an analytico-synthetic and facetted classification. UDC schedules are organised as a coherent system of knowledge with associative relationships and references between concepts and related fields. UDC-based references in this publication are taken from the multi-lingual UDC summary (UDCC Publication No. 088) [12] released by the UDC Consortium under a Creative Commons license [13]. Facets can be created with any auxiliary tables.

A means of choice to achieve overall efficient realisations even for complex scenarios is to use the principles of Superordinate Knowledge, integrating arbitrary knowledge. The core assembly elements of Superordinate Knowledge [14], e.g., for practical mathematical-computational scenarios [15], are:

- Methodology.
- Implementation.
- Realisation.

Comprehensive focussed subsets of conceptual knowledge can also provide excellent modular and standardised complements for information systems component implementations, e.g., for environmental information management and computation [16]. The presented implementations strictly follow the fundamental methodological algorithm base of the the Conceptual Knowledge Pattern Matching (CKPM) methodology [17] providing and accessing knowledge object patterns based on the Superordinate Knowledge Methodology, which allows systematical use and thorough processing. Core eager beaver procedure- and structure-based implementation components, grep and join, are written in C, as commonly known. Module examples are employing Perl Compatible Regular Expressions (PCRE) [18] syntax for specifying common string patterns. This is independent from the procedural realisation using Shell and Perl [19] for component wrapping purposes with case studies.

C. Prehistory long-term resources development

Several major Knowledge Resources (KR) and reference implementations are used with this multi-disciplinary research in prehistory, archaeology, natural sciences, and humanities and in long-term development. In order to overcome shortcomings of public 'data collections' the objects, entities, and respective conceptual knowledge references' excerpts and examples are taken from The Prehistory and Archaeology Knowledge Archive (PAKA). PAKA has been in continuous development for more than three decades [20] and is further developed and released by DIMF [21]. A main reference implementation in development, used in practice with ongoing long-term research, applied for KR is the prehistory-protohistory and archaeology Conceptual Knowledge Reference Implementation (CKRI) edition, including multi-disciplinary context references of natural sciences and humanities (E.0.4.2) [22], [23].

III. STRUCTURE AND INFORMATION

Structure is an organisation of interrelated entities in a material or non-material object or system. Structure is essential in logic as it carries unique information. The more, we have to recognise the differences of structure and form. The case of text is a good example. The structure of a text consists of the particular text units and their context, in order to make the text coherent. The form of a text is the arrangement of the text units, which commonly has to follow predefined rules.

A. Structure systematics, meaning, levels

As meaning can be understood in context of langage, langue, and parole, the available rules of structure and form should be used. If whatever non linguistic, artistic expression is primary target then different structure and form could be used. Anyway any linguistic parole context should be aware of the specific conditions: Academic use should be aware of the specific academic context. Commercial use should be aware of the specific commercial context. Marketing use should be aware of the specific marketing context. There are rarely reasonable compromises fitting diametrical approaches to form equally well. Consequences of these fundaments are, especially: Structure is not dependent on physical, non physical, analogous, digital or comparable being and properties. Structure is not dependent on same/uniform ways of structuring. Structure is not intrinsic to a certain scale of information. Structure should not imagined to be dependent of a location or dependent of management. Instead, it is more likely to yield consistent results when we follow a methodology regarding the systematics of structure. In information science and context of knowledge resources we can consider three major levels:

- Object entity structure (entities as part of an object).
- Object structure.
- Supra-object structure (e.g., complexity or inconsistency introduced by application or service scenario).

The methodological approach is beneficial when expressing disciplinary views and targeting purposes as it can

- help to create a consistent understanding of structure,
- address responsibility,
- help to assure logical and consistent development and management of structure, etc.

B. Structure and means of addressing

There are merely higher and lower facility levels of how structures can be addressed, which result from structure levels. For example, structure can be addressed by:

- Logic.
- Names.
- References.
- Address labels.
- Pointers.
- Fuzzy methods.
- Phonetic methods. . . .

For example, 'non-structures' can be addressed by:

- Locality.
- Source.
- Context.
- Logic.
- Attributes.
- Size.
- Quantity. . . .

Substantial differences of properties and facilities of different levels of structure and non-structure do have multi-fold origin and reason, especially:

- Structure is associated with different formalisation levels and respective consequences.
- Less complementary knowledge realisation, less potential, e.g., for logic.
- Less structure, less potential for approaches.
- Intrinsic and extrinsic properties are not interchangeable.
- Higher levels of structure mostly include tools usable for lower levels.
- Low level structures are limited to low level tools and soft criteria, e.g.,
    - Statistics.
    - Heuristics.
    - . . .
- Potential from quality is different than from quantity.

With that background we should be aware that lower structure levels can only be addressed on higher formalisation levels, independent of the fact that structure may either be not available or not recognised. Substantial deficits of lower level structured data cannot be compensated by tools. In consequence, structure is and especially reflects:

- Knowledge (complements of factual, conceptual, procedural, metacognitive, structural, . . .).
- Context.
- Experience.
- Persistence.
- Reusability.
- Sustainability.
- Value.
- Formalisation (including abstraction and reduction). . . .

In result, it is structure that means features and facilities.

IV. CASE: STRUCTURE-BASED REALISATION

The implementation strictly follows the fundamental methodological algorithm base, summarised in the following passages.

A. Methodological algorithm base and resulting method

The structure-based fusion methodology targets on supporting efficient problem solving, providing and accessing knowledge and knowledge object patterns. The methodology for creating structure-based fusion methods can be summarised on high level by:

- Pre-processing of structures.
- Option routines, for optional steps preparing fusion.
- Structure-based fusion of knowledge complements.
- Post-processing of structures.

This methodology is contrasting to plain procedure-based approaches. Here, structures are adapted for solving problems mostly allowing minimising procedure-based efforts and gaining higher efficiency and performance regarding creation and realisation of solutions. A method based on the structure-based fusion, implemented for knowledge mining context does consist of the basic steps:

- Pre-processing of knowledge mining structures.
- Options' routine, e.g., used for prioritisation and sorting. May contain procedures outside the range of balanced pre- and post-processing.
- Structure-based fusion of object structures, objects represented by knowledge complements.
- Post-processing of fusion result structures.

Besides the strictly structure-based fundament for the steps, realisations can use the whole gamut working for knowledge complements, e.g., comparisons, generic and standard component implementations, and knowledge complements and identification. Table I shows the method implementation and realisation of a structure-based fusion.

TABLE I. METHOD IMPLEMENTATION AND REALISATION: STEPS OF STRUCTURE-BASED FUSION.

Method Implementation Steps	*Realisation Example*
Outer pre-processing	individual, out of scope here
Input	**standard input, echo**
Inner pre-processing of structures	**perl**
Options' routines, prioritisation & sorting	**perl & sort**
Structure-based fusion	**join**
Inner post-processing of structures	**perl**
Output	**standard output**
Outer post-processing	individual, out of scope here

Any input and output can be intermediate, part of a complex mining process. Pre- and post-processing are handling the input and output for the options' routines and consecutive fusion, the central steps. For this implementation and demonstration processing is done via Perl, options' routines via Perl and sort, and the fusion via join.

The following structure based fusion code illustrations of realisations use inline GNU Bourne-Again SHell syntax, I/O and naming features for ease of demonstration and reproducibility.

B. Structure-based realisation: Simple case result

An instructive, simple case example implementation is a comparison and filter process of groups of arbitrary numbers of objects and object entities, which each can be of arbitrary volume and length. A procedural approach would create a procedure handling the structure and form of the entries as they appear and create and call a grep function for each of all the target entries or patterns. In advanced knowledge mining and processing, we often have to deal with sequences of steps creating intermediate results from previous results, all of which may need to be compared, sorted, filtered and so on. In that context the following scenario works as a basic example.

1) At a certain stage in a mining process we may have two groups of different knowledge object line entities.
2) We have to find only those various different string entries contained in one group and list those of the entries, which are also contained in the other group and produce combined object entities containing the content of respective entries from both groups.
3) We have to create an appropriate method and realisation, which, ideally, works for arbitrary numbers of objects with different sizes and content and which is flexible and knowledge-centric.

So, how can such ‘search, comparison, filter, and sort’ be realised for large numbers of objects, avoiding to call a routine or thread thousands or hundreds of thousand times per intermediate step and deploying ‘structural information’ instead? Figure 1 shows a structure-based solution. Its realisation is a self-contained regular shell script containing object groups and solution for ease of reconstructing the train of thought.

```
#
# Structure-based fusion sample -- (c) CPR, 2019, 2020
#
cnta="Natural Sciences collection entry 10:05:34 Volcano
Natural Sciences collection entry entities 10:05:35
 Soufriere
Media attachment entry 10:06:34 Soufriere Photo
Addendum entry 10:05:30 References
Object entry compendium 10:06:37 comments"
cntb="Object entry 10:05:35 delivered
Excavation slide 10:05:34 updated
Object documentation update 10:06:34 request
System service no date
Object entity mining request 10:06:37 researcher id
 DF98_007
Object collection status 10:05:28 no resources reference
Object entity documentation request 10:05:30 user id
 database"
export cnta
export cntb
join -1 1 -2 1 <(echo "$cnta"|perl -pe ’s/^(.*?)
 ([0-9][0-9]:[0-9][0-9]:[0-9][0-9])(.*?)$/$2 1_BEFORE{$1}
  1_AFTER{$3}/’|sort) <(echo "$cntb"|perl -pe ’s/^(.*?)
 ([0-9][0-9]:[0-9][0-9]:[0-9][0-9])(.*?)$/$2 2_BEFORE{$1}
  2_AFTER{$3}/’|sort)
exit
```

Figure 1. Structure-based fusion solution, working with arbitrary one-lined object entities (excerpt), overcoming thousands of grep calls.

Here, two content groups of single line object instances are used for demonstration, content “a” and content “b”. As can be seen, the content groups are asymmetric regarding object instances, content, and context aspects. For convenience of demonstration an excerpt of the contents is embedded in the code and represented by the exported variables named `cnta` and `cntb`. This excerpt is doing a selection of objects by fusion of arbitrary length and arbitrary number of objects by criteria (time stamps), which are reflected by structure.

The solution for that purpose achieves that result explicitly without the use of ‘grep’ (Global Regular Expression Parser), ‘search’, or comparable procedural routine instances. In order to create a straightforward solution and to easily follow the strategy, the steps are implemented using 5 external calls. Figure 2 shows the result of the realisation (Figure 1).

```
10:05:30 1_BEFORE{Addendum entry} 1_AFTER{ References} 2_BEFORE{Object entity
 documentation request} 2_AFTER{ user id database}
10:05:34 1_BEFORE{Natural Sciences collection entry} 1_AFTER{ Volcano} 2_BEFORE{
 Excavation slide} 2_AFTER{ updated}
10:05:35 1_BEFORE{Natural Sciences collection entry entities} 1_AFTER{ Soufriere
 } 2_BEFORE{Object entry} 2_AFTER{ delivered}
10:06:34 1_BEFORE{Media attachment entry} 1_AFTER{ Soufriere Photo} 2_BEFORE{
 Object documentation update} 2_AFTER{ request}
10:06:37 1_BEFORE{Object entry compendium} 1_AFTER{ comments} 2_BEFORE{Object
 entity mining request} 2_AFTER{ researcher id DF98_007}
```

Figure 2. Result of the structure-based approach, working with arbitrary one-lined object entities (excerpt).

The result reflects the target task based on structure-based fusion. The solution includes a sort of resulting object entities by respective string entries and appropriate marking of content from the groups for illustration.

C. Structure-based realisation: Multi-line case result

A different kind of complexity is what we commonly face in context of knowledge resources, same task and still with arbitrary length and arbitrary number of objects and entities with multi-line formatting (Figure 3) to be preserved.

```
Nisyros                 [Volcanology, Geology]:
                        Volcano, Type: Strato volcano, Island.
                        Status: Historical, Summit Elevation: 698\UD{m}. ...
                        VNUM: 0102-05=, ...,
                        Craters: ..., ...
                        %%IML: UDC:[550.3],[930.85],[911.2]
                        %%IML: media:...{UDC:[550.3+551.21],[911.2](4+38+23)}...jpg
                        Stefanos Crater, Nisyros, Greece.
                        LATLON: 36.578345,27.1680696
                        %%IML: GoogleMapsLocation: https://www.google.com/...@36
                         .578345,27.1680696,337m/...
                        Little Polyvotis Crater, Nisyros, Greece.
                        LATLON: 36.5834105,27.1660736 ...
```

Figure 3. Knowledge resources’ object (‘Nisyros’): Multi-line formatting, conceptual knowledge, media object entities, and georeferences (excerpt).

Focus task is to find only those arbitrary object instances, which appear in one content context and also in another content context and to combine the data of those instances in a result object instance. It is preferable if the realisation allows a multi-object fusion, meaning more than one object in a process. A common procedure realisation would, e.g., have to call a ‘grep’ function (especially a Global Regular Expression Parser) for every of the thousands of object instances in one context for searches in another context

Figure 4 shows a more efficient, structure-based realisation for such objects. As with the previous example realisation above, its realisation is presented as a self-contained regular shell script for ease of demonstration. The excerpt fully confirms with a standard shell and Perl syntax and features and is compact. In order to create a straightforward solution and to easily follow the strategy, the steps are implemented using 10 external calls, which could still be further reduced. As can be seen, these calls already include formatting cleanup with pre- and post-processing, too. The solution targets contexts for larger numbers of multi-line, multi-entity object instances (thousands or hundreds of thousands). As common, results should be considered intermediate for complex knowledge mining procedures.

```
#
# Structure-based fusion mining -- (c) CPR, 2019, 2020
#
cnta="Nirgal                  [Etymology]:
                     ...
Nisyros              [Archaeology, Geology, Volcanology]:
                     Island, Volcano, Greece, Dodecanese Islands. ...
                     The island provides unique archaeological remains, esp. ...
                     History and mythology of the island and volcano are ...
                     %%IML: UDC:[902],[930.85],[911.2]"63"(4+38+23+24)=14
Nisyros_archive      [Archaeology]:
                     Media, Archaeology Digital Object Archive (ADOA). ...
NMR                  [Archaeology]:
                     ..."
cntb="Niggli                  [Petrography, Mineralogy]:
                     ...
Nisyros              [Volcanology, Geology]:
                     Volcano, Type: Strato volcano, Island, Greece.
                     Status: Historical, Summit Elevation: 698\UD{m}. ...
                     VNUM: 0102-05=, ..., Craters: ..., ...
                     %%IML: UDC:[550.3],[930.85],[911.2]
                     %%IML: media:...{UDC:[550.3+551.21],[911.2](4+38+23)}...jpg
                     Stefanos Crater, Nisyros, Greece.
                     LATLON: 36.578345,27.1680696
                     %%IML: GoogleMapsLocation: https://www.google.com/...@36
 .578345,27.1680696,337m/...
                     Little Polyvotis Crater, Nisyros, Greece.
                     LATLON: 36.5834105,27.1660736 ...
Nisyros_archive      [Volcanology]:
                     Media, Geosciences Digital Object Archive (GDOA). ...
NLBR                 [Platetectonics, Volcanology]:
                     ...
N-MORB               [Platetectonics, Volcanology]:
                     ..."
export cnta
export cntb
join -1 1 -2 1 -t" " \
  <(echo "$cnta"|\
    perl -pe 's/^(\S)/TMPBOL$1/;s/$/TMPEOL/;s/\n//;'|perl -pe 's/TMPBOL//;s/
 TMPBOL/\n/g'|\
    perl -pe 's/^(.*?)(\[.*?\]:)(.*)$/$1$2$3/'|sort -k 1b,1)\
  <(echo "$cntb"| \
    perl -pe 's/^(\S)/TMPBOL$1/;s/$/TMPEOL/;s/\n//;'|perl -pe 's/TMPBOL//;s/
 TMPBOL/\n/g'|\
    perl -pe 's/^(.*?)(\[.*?\]:)(.*)$/$1$2$3/'|sort -k 1b,1)|\
  perl -pe 's/TMPEOL$//g;s/TMPEOL/\n/g;'
exit
```

Figure 4. Structure-based fusion solution, working with arbitrary multi-line knowledge resources' object entities (excerpt), overcoming grep.

With the above scenario the realisation should be fully logical and self explanatory. The easiest way to comprehend the implementation principle is to follow the sequence of instructions and reproduce step by step, directly to the result. The realised solution should be reasonably flexible and robust. Figure 5 shows the result of the realisation (Figure 4).

```
Nisyros              [Archaeology, Geology, Volcanology]:
                     Island, Volcano, Greece, Dodecanese Islands. ...
                     The island provides unique archaeological remains, esp. ...
                     History and mythology of the island and volcano are ...
                     %%IML: UDC:[902],[930.85],[911.2]63(4+38+23+24)=14
              [Volcanology, Geology]:
                     Volcano, Type: Strato volcano, Island, Greece.
                     Status: Historical, Summit Elevation: 698\UD{m}. ...
                     VNUM: 0102-05=, ..., Craters: ..., ...
                     %%IML: UDC:[550.3],[930.85],[911.2]
                     %%IML: media:...{UDC:[550.3+551.21],[911.2](4+38+23)}...jpg
                     Stefanos Crater, Nisyros, Greece.
                     LATLON: 36.578345,27.1680696
                     %%IML: GoogleMapsLocation: https://www.google.com/...@36
                      .578345,27.1680696,337m/...
                     Little Polyvotis Crater, Nisyros, Greece.
                     LATLON: 36.5834105,27.1660736 ...
Nisyros_archive      [Archaeology]:
                     Media, Archaeology Digital Object Archive (ADOA). ...
      [Volcanology]:
                     Media, Geosciences Digital Object Archive (GDOA). ...
```

Figure 5. Result of the structure-based approach, working with arbitrary multi-line object entities, result shows the multi-object fusion (excerpt).

Objects (`Nisyros` and `Nisyros_archive`) have correctly been identified (criteria name string) and unified. Entities have been preserved and conceptual knowledge of instances have been combined in a unique object instance each.

Even the indentation of the resulting content reflects the operations and is exactly preserved. Besides valuable knowledge content, conceptual knowledge integration is considered a marker regarding the range of knowledge and efficiency of a solution when working with knowledge resources. In this case the knowledge resources use UDC references with millions of object instances and entities. Universally consistent conceptual knowledge, e.g., used for CKPM, is based on UDC references for demonstration, spanning the main tables [24] shown in Table II.

TABLE II. CKRI: IMPLEMENTED UDC CODE REFERENCES, MAIN TABLE (E.0.4.2).

Code / Sign Ref.	*Verbal Description (EN)*
UDC:0	Science and Knowledge. Organization. Computer Science. Information. 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

Natural sciences related conceptual knowledge pattern entities are created based on UDC references [25] of mathematics and natural sciences. An excerpt of the implementation is shown in Table III.

TABLE III. CKRI: IMPLEMENTED UDC CODE REFERENCES OF MATHEMATICS AND NATURAL SCIENCES (EXCERPT, E.0.4.2).

Code / Sign Ref.	*Verbal Description (EN)*
UDC:51	Mathematics
UDC:53	Physics
UDC:535	Optics
UDC:535.6	Colours and their properties. Colour theory
UDC:539	Physical nature of matter
UDC:54	Chemistry. Crystallography. Mineralogy
UDC:55	Earth Sciences. Geological sciences
UDC:550.3	Geophysics
UDC:551	General geology. Meteorology. Climatology.
UDC:551.21	Vulcanicity. Vulcanism. Volcanoes. Eruptive phenomena. Eruptions
UDC:551.24	Geotectonics
UDC:551.4	Geomorphology. Study of the Earth's physical forms
UDC:551.44	Speleology. Caves. Fissures. Underground waters
UDC:551.46	Physical oceanography. Submarine topography. Ocean floor
UDC:551.7	Historical geology. Stratigraphy. Palaeogeography
UDC:551.8	Palaeogeography
UDC:56	Palaeontology
UDC:57	Biological sciences in general
UDC:58	Botany
UDC:59	Zoology

Conceptual knowledge pattern entities of archaeology and history are created based on UDC references [26] of geography, biography, history (Table IV).

TABLE IV. CKRI: IMPLEMENTED UDC CODE REFERENCES OF GEOGRAPHY, BIOGRAPHY, HISTORY (EXCERPT, E.0.4.2).

Code / Sign Ref.	*Verbal Description (EN)*
UDC:902	Archaeology
UDC:903	Prehistory. Prehistoric remains, artefacts, antiquities
UDC:904	Cultural remains of historical times
UDC:908	Area studies. Study of a locality
UDC:91	Geography. Exploration of the Earth and of individual countries. Travel. Regional geography
UDC:912	Nonliterary, nontextual representations of a region
UDC:92	Biographical studies. Genealogy. Heraldry. Flags
UDC:93/94	History
UDC:94	General history

The geoscientific / prehistory / archaeology integration from the case studies and implementations for geoscientific information systems and application components is used for illustration in the next sections. The example will show a tiny subset of the comprehensive, universal conceptual knowledge used, integrating UDC:902/908 (Archaeology. Prehistory. Cultural remains. Area studies) and UDC:55 (Earth Sciences. Geological sciences) and humanities (UDC main table trees).

D. Multi-line knowledge ranges and computation

As commonly we have to handle many objects, we can illustrate how efficiency and performance scale with numbers of objects. The examples use the above multi-line knowledge case, as knowledge resources' objects regulary have a high variety of content, with different object volumes and lengths. Therefore, this is more for practical experience than a benchmark. The overall number of object instances in the respective primary knowledge ranges for the resources' excerpt is shown in the UDC references' test environment (Table V).

TABLE V. PRIMARY KNOWLEDGE RANGES OF CONCEPTUAL KNOWLEDGE ENTITY REFERENCES IN THE TEST ENVIRONMENT (EXCERPT).

Knowledge Range	*Entities' Count*
UDC:9 (incl. UDC:902/904)	930,000
UDC:5 (incl. UDC:55/56)	1,700,000

The ranges can be comprehended in all details by following the publicly available online conceptual knowledge framework already discussed above. Table VI shows an implementation excerpt and computational footprint for the different approaches. The different case results were achieved on Intel® Xeon® CPU X5570 (2.933 GHz) systems under Linux.

TABLE VI. COMPUTATIONAL FOOTPRINT OF PROCEDURE-/STRUCTURE-BASED SOLUTIONS, CONCEPTUAL KNOWLEDGE REF. CASES (EXCERPT).

Knowledge Range	*Entities' Count*	*Context Calls' Count and Wall Time*			
		Procedure-based		*Structure-based*	
UDC:902	48,000	≫48,000	2,440 s	10	32 s
UDC:55	54,000	≫54,000	3,938 s	10	45 s
UDC:902/904	107,000	≫107,000	24,775 s	10	198 s
UDC:55/56	295,000	≫295,000	189,100 s	10	945 s

The values allow to rate the discussed conventional approach (max. 1,000 loosely parallel pattern matching calls 'practical') using a procedure-based solution and the structure-based approach. The two examples of the approaches to challenging mining cases are using the same range of knowledge/data content each, specified by ranges of referenced conceptual knowledge. Requirements for the consideration of wider knowledge ranges do show a major impact on the procedure-based solution, resulting in relatively larger increase of context calls and wall times. Even if more loosely parallel calls would be logically possible with a mining algorithm it is not practical to increase their number on the same machine with procedure-based solutions. The counts of object entries in the two content resources are of major impact for the efficiency differences. The context calls' count (10) for structure-based fusion is based on the above presented multi-line object solution and can be kept stable. The result of the comparison of the computational footprint is clearly in favor of the structure-based solution. This tendency even improves with increasing numbers of objects involved.

V. CASE: SPATIAL CONTEXT COMPUTATION

Contextualisation, besides prehistoric knowledge computation itself, often requires multi-disciplinary component integration, especially advanced spatial context computation, e.g., integration of Digital Elevation Models (DEM), processing, and analysis. The case of structure-based realisation demonstrated the efficiency of structure-based approaches. The structure-based scenario of KR, e.g., employing PAKA, can further be natively integrated with the realisations of cognostic addressing of structure and structural knowledge ('nucleal cognstructure') [27], for contextualisation supported by standardised components, especially efficient and effective spatial context computation and processing, as practically implemented and realised for the methodological structure-based approach and illustrated in exactly the above examples (Figures 3 and 5).

Efficient computation and processing are relevant for many contextualisation tasks, e.g., with chorological contexts in prehistory and archaeology regarding

- height reference computation,
- resampling,
- illumination,
- spatial parametrisation,
- spatial computation, and
- symbolic representation.

The following components in the workflow enable a per instance and per core parallelisation, e.g., chronological and/or chorological slices and other conceptual knowledge. This allows to create the required number of time slices, especially series of images and other symbolic representation.

Each context may require different parametrisation with respect to the state of the art of research, e.g., prehistorical knowledge resources and chronological and chorological object discretisation and quantification on the one hand, and geoscientific parametrisation for a relevant time interval on the other hand.

A. Prehistory context relevant CKRI entity groups

The following passages excerpt relevant entity groups of the prehistory-protohistory and archaeology Conceptual Knowledge Reference Implementation (CKRI), including multi-disciplinary contexts of natural sciences and humanities (E.0.4.2) [28] [23]. Geodesy related conceptual knowledge pattern entities are created based on UDC references [25], part of the astronomy, astrophysics, space research, and geodesy sections. An excerpt of the implementation is shown in Table VII.

TABLE VII. CKRI: IMPLEMENTED UDC CODE REFERENCES OF GEODESY (EXCERPT, E.0.4.2).

Code / Sign Ref.	*Verbal Description (EN)*
UDC:52	Astronomy. Astrophysics. Space research. Geodesy
UDC:528	Geodesy. Surveying. Photogrammetry. Remote sensing. Cartography
UDC:528.2	Figure of the Earth. Earth measurement. Mathematical geodesy. Physical geodesy. Astronomical geodesy
UDC:528.3	Geodetic surveying
UDC:528.4	Field surveying. Land surveying. Cadastral survey. Topography. Engineering survey. Special fields of surveying
UDC:528.5	Geodetic instruments and equipment
UDC:528.7	Photogrammetry: aerial, terrestrial
UDC:528.8	Remote sensing
UDC:528.9	Cartography. Mapping (textual documents)

An excerpt of major references from the auxiliaries of time [29] is shown in Table VIII.

TABLE VIII. CKRI: IMPLEMENTED UDC CODE REFERENCES, AUXILIARIES OF TIME (EXCERPT, E.0.4.2).

Code / Sign Ref.	*Verbal Description (EN)*
UDC:“0”	First millennium CE
UDC:“1”	Second millennium CE
UDC:“2”	Third millennium CE
UDC:“3/7”	Time divisions other than dates in Christian (Gregorian) reckoning
UDC:“3”	Conventional time divisions and subdivisions: numbered, named, etc.
UDC:“32”	The year. Seasons and other divisions of the year
UDC:“321/324”	Seasons
UDC:“321”	Spring
UDC:“322”	Summer
UDC:“323”	Autumn (fall)
UDC:“324”	Winter
UDC:“325”	Quarters (quarter years, trimesters)
UDC:“327”	Months
UDC:“328”	Weeks
UDC:“329”	Days
UDC:“34”	Day and night phenomena. Hours or times of day
UDC:“344”	Daytime. Daylight hours
UDC:“345”	Night-time. Hours of darkness or semi-darkness
UDC:“36”	Times of peace, war, danger, emergency, difficulties
UDC:“362”	Peacetime. Time of no danger
UDC:“363”	Time of danger, threat
UDC:“364”	Wartime
UDC:“367”	Times according to volume of use, load, demand
UDC:“37”	Time of work activity, occupation, production, daily routine
UDC:“372”	Working hours. Service hours. Time of occupation
UDC:“377”	Rest and recreation time. Spare time. Free time. Time outside working hours
UDC:“38”	Holidays. Festive and commemorative occasions
UDC:“382”	Religious holidays, festive and commemorative occasions
UDC:“383”	Public, national or regional holidays (other than religious)
UDC:“385”	Personal private holidays, vacation or leave time
UDC:“4”	Duration. Time-span. Period. Term. Ages and age-groups
UDC:“5”	Periodicity. Frequency. Recurrence at specified intervals.
UDC:“6”	Geological, archaeological and cultural time divisions
UDC:“61/62”	Geological (lithological / biological / palaeoecological) time division
UDC:“61”	Precambrian to Mesozoic (from more than 600 to 70 MYBP)
UDC:“62”	Cenozoic (Cainozoic). Neozoic (70 MYBP - present)
UDC:“63”	Archaeological, prehistoric, protohistoric periods and ages
UDC:“67/69”	Time reckonings: universal, secular, non-Christian religious
UDC:“67”	Universal time reckoning. Before Present
UDC:“68”	Secular time reckonings other than universal and the Christian (Gregorian) calendar
UDC:“69”	Dates and time units in non-Christian (non-Gregorian) religious time reckonings
UDC:“7”	Phenomena in time. Phenomenology of time

The auxiliaries of time can be used for creating arbitrary facets, including arbitrary time concepts. Facets can be used to integrate addressing different concepts, e.g., absolute and relative time concepts used in prehistoric, archaeological, and natural sciences contexts.

Table IX shows an excerpt of the implementation. Auxiliaries of spatial features/place (UDC (1/9) [30] Place and space in general. Localization. Orientation

TABLE IX. CKRI: IMPLEMENTED UDC CODE REFERENCES OF SPATIAL FEATURES / PLACE: AUXILIARIES OF PLACE, BOUNDARIES AND SPATIAL FORMS (EXCERPT, E.0.4.2).

Code / Sign Ref.	*Verbal Description (EN)*
UDC:(1)	Place and space in general. Localization. Orientation
UDC:(100)	Universal as to place. International. All countries in general
UDC:(2)	Physiographic designation
UDC:(20)	Ecosphere
UDC:(21)	Surface of the Earth in general. Land areas in particular. Natural zones and regions
UDC:(23)	Above sea level. Surface relief. Above ground generally. Mountains
UDC:(24)	Below sea level. Underground. Subterranean
UDC:(25)	Natural flat ground (at, above or below sea level). The ground in its natural condition, cultivated or inhabited
UDC:(26)	Oceans, seas and interconnections
UDC:(28)	Inland waters
UDC:(3/9)	Individual places of the ancient and modern world
UDC:(3)	Places of the ancient and mediaeval world
UDC:(31)	Ancient China and Japan
UDC:(32)	Ancient Egypt
UDC:(33)	Ancient Roman Province of Judaea. The Holy Land. Region of the Israelites
UDC:(34)	Ancient India
UDC:(35)	Medo-Persia
UDC:(36)	Regions of the so-called barbarians
UDC:(37)	Italia. Ancient Rome and Italy
UDC:(38)	Ancient Greece
UDC:(399)	Other regions. Ancient geographical divisions other than those of classical antiquity
UDC:(4/9)	Countries and places of the modern world
UDC:(4)	Europe
UDC:(5)	Asia
UDC:(6)	Africa
UDC:(7/8)	America, North and South. The Americas
UDC:(7)	North and Central America
UDC:(8)	South America
UDC:(9)	States and regions of the South Pacific and Australia. Arctic. Antarctic

These entities can be used for arbitrary facets, including orientation and relative position.

B. *Prehistory context multi-disciplinary views*

Table X shows an excerpt of UDC:903. . . :2 ritual/burial object and subgroup examples, and conceptual view groups [12] for prehistory and protohistory (PAKA, [20] [21]).

TABLE X. PREHISTORY AND PROTOHISTORY RITUAL/BURIAL OBJECT AND SUBGROUP EXAMPLES, AND CONCEPTUAL VIEW GROUPS [12] (EXCERPT).

Major Object Group	*Selected Objects*	*Conceptual View Group*
Ritual places, burials	yes	UDC:903. . . :2
Cemetery	–	UDC:903. . . :2
Barrow	–	UDC:903. . . :2
round	–	UDC:903. . . :2
long	–	UDC:903. . . :2
Cist	–	UDC:903. . . :2
Dolmen	–	UDC:903. . . :2
Tomb	–	UDC:903. . . :2
chamber	–	UDC:903. . . :2
court	–	UDC:903. . . :2
portal	–	UDC:903. . . :2
rock cut	–	UDC:903. . . :2
wedge	–	UDC:903. . . :2
Pithos burial	–	UDC:903. . . :2
Cave	–	UDC:903. . . :2
Body finding	–	UDC:903. . . :2
Urn	–	UDC:903. . . :2
. . .	–	UDC:903. . . :2

For this illustrative object scenario, the excerpt does not show individual micro-groups. Besides different distributions and different origins, object context can be referred, e.g., artificial origin and natural origins as well as relevant object properties, materials, and soil contexts can be considered. The components can be integrated via coherent conceptual knowledge.

For illustration of this case, we want to discover the contexts of a possible range of comparable tombs in a target area with those for the suggested type and/or time of the Odyssey in the respective region. Here, the target is the distribution of groups of cist tombs in North-Rhine Westphalia and Lower Saxony, Germany and The Netherlands in context with the distribution of groups of cist tombs in the time of king Odysseus in the Homeric Ithaca, Kefalonia (Cephalonia), Paliki region. The result configuration should provide homogeneous context topography and context soil references and contain the respective groups in the regions and the distribution of caves in the respective countries.

C. Resulting coherent knowledge context integration

Enabled by coherent conceptual knowledge contexts, cist tombs can be selected from PAKA (Table X) and prehistoric caves in borders of today's North-Rhine Westphalia and Lower Saxony, Germany, The Netherlands, Greece.

Respective conceptual and symbolic representation criteria, e.g., spatial criteria can be deployed the integrating knowledge complements from available KR.

The available multi-disciplinary context components are shown. The geodesic distance calculations based on the ellipsoidal parameters of Earth's sphere select cist tombs in association of the Kefalonia acropolis and sites like Tzanata. In this case, considered cists are "Early Geometric cist tombs".

Each conceptual space-time slice requires a number of contributions, especially:

- Resampling,
- spatial computation (DEM),
- intensity computation,
- parametrisation,
- colourisation palette creation,
- spatial selection,
- spatial computation (vector),
- Point on Interest (POI), line, and polygon criteria selection.
- soil context computation,
- KR computation,
- projection, and
- computation of symbolic representation.

Figure 1 shows a generated, resulting coherent conceptual knowledge integration sketch for the realisation based on the KR. Selection criteria can be complex, a decent illustrative example employing a workflows of spatial criteria, e.g.,

- polygon criteria, e.g., in North-Rhine Westphalia and Lower Saxony, Germany and The Netherlands,
- spherical distance criteria, e.g., 100 km. For such criteria, the calculation of distances on planetary bodies like Earth depends on the ellipsoidal parameters of the body and the respective method of computation. Here, required geodesic distance calculations are based on the ellipsoidal parameters of Earth's sphere [31].

Context components, workflows, and procedures can be standardised. Nevertheless, for considering any scientific task and associated questions, a solid understanding of all the algorithms and the consequences of integration should be mandatory, especially regarding resulting analysis and interpretation.

The sketch considers the major conceptual references for illustration. Detailed research can further detail on prehistoric object groups, characteristics, and properties, topographic properties, soil properties, and many more. Therefore, the conceptual sketch view can result in levels of arbitrary numbers of different integrations of complements and associated properties as resulting from the KR, which are discussed in the following. The result integrates required KR components based on coherent conceptual knowledge and systematical chorological knowledge for multi-disciplinary contexts, e.g., arbitrary group representations, classification based representations, and geospatial representations.

Knowledge objects and contexts are provided by The Prehistory and Archaeology Knowledge Archive (PAKA) [20] [21]. The multi-disciplinary coherent contextualisation employs the base of a new soil system reference development with soil types (UDC:631.4...) of the World Reference Base (WRB) standard, reference contexts, especially for UDC:903... .:2,551.7+"628".. . ., prehistorical, protohistorical time spans and respective objects and artefacts for this case, related to religion and rituals, geology, especially stratigraphy and paleogeography, quaternary, especially late glacial and Holocene.

The integrated natural sciences KR further provide information on caves in the respective region. Contextualisation is enabled by the Conceptual Knowledge Reference Implementation (CKRI), including multi-disciplinary contexts of natural sciences and humanities (E.0.4.2) [23]. The conceptual knowledge base is The Universal Decimal Classification (UDC) [12].

Associated information, e.g., on soil specifications and properties, can be found as reference in the WRB for soil resources [32], [33] from the Food and Agriculture Organisation (FAO), United Nations.

In this illustration plain Digital Chart of the World (DCW) data are used [34]. The coastline database is the Global Self-consistent Hierarchical High-resolution Geography (GSHHG) [35] [36], which was mainly compiled from the World Vector Shorelines (WVS) [37], the CIA World Data Bank II (WDBII) [38], and the Atlas of the Cryosphere (AC).

An equal area projection (Eckert IV) is advised due to the type of discipline knowledge representation. The compilation uses the World Geodetic System (WGS). The symbolic representation of the contextualisation is done via LX Professional Scientific Content-Context-Suite (LX PSCC Suite) deploying the Generic Mapping Tools (GMT) [39] for visualisation.

D. Prehistory context multi-disciplinary integration facets

Table XI shows the reference facets of a respective multi-disciplinary target contextualisation.

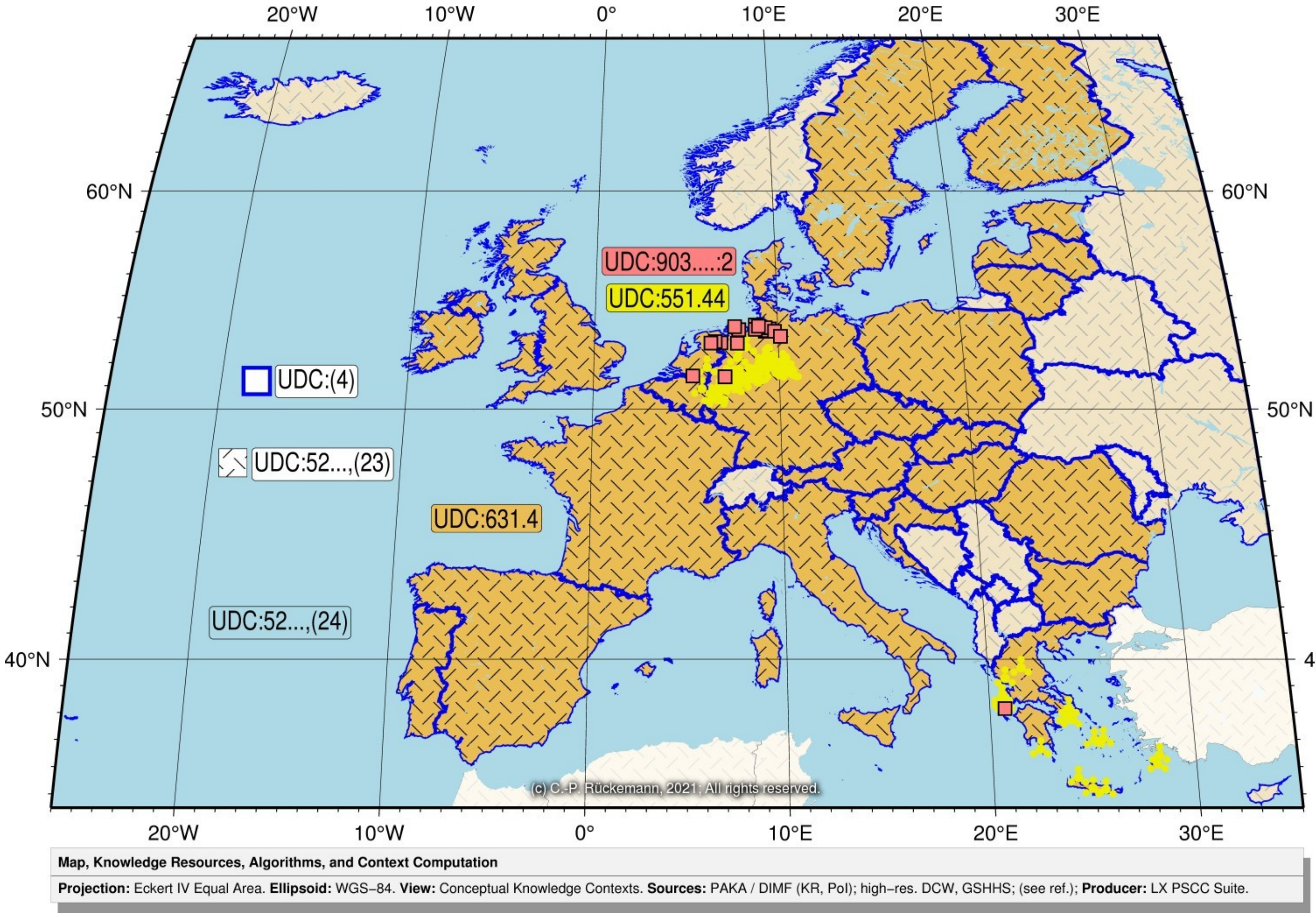

Figure 1. Resulting coherent conceptual knowledge integration sketch diagram showing knowledge resources for a prehistoric, natural sciences, and spatial contextualisation for excerpts of prehistoric cist tomb distributions, remote sensing data, and soil properties with respective knowledge references.

TABLE XI. REFERENCE FACETS OF A MULTI-DISCIPLINARY TARGET CONTEXTUALISATION OF PREHISTORY CONTEXT, BASED ON CKRI (E.0.4.2), IMPLEMENTED USING UDC CODE REFERENCES (EXCERPT).

Code / Sign Ref.	*Verbal Description (EN)*
	Geography. Biography. History
UDC:903.. . .	Prehistory, prehistoric remains, artefacts, antiquities
. . .:2. . .CIST	referring to religion and rituals . . . cist tomb
. . .,“62. . .”	from Holocene
. . .,(4. . .DENW)	. . . in North-Rhine Westphalia, Germany
. . .,(4. . .DENI)	. . . in Lower Saxony, Germany
. . .,(4. . .NL)	. . . in The Netherlands
. . .,(38):	Ancient Greece
. . .,(495)	Greece. Hellenic Republic. Elliniki Dimokratia
	Earth sciences, geological sciences
UDC:551.44	Speleology, caves, fissures, underground waters
	Applied sciences, agriculture in general
UDC:631.4	Soil research data
	Geodesy. Photogrammetry
UDC:52. . .,(23)	Remote sensing data, above sea level
UDC:52. . .,(24)	Remote sensing data, below sea level
	Contextualisation Place
UDC:(4)	Europe

The contextualisation uses coherent conceptual knowledge and refers to the chorological references for consequent knowledge integration and symbolic representation. Respecting the principles of formalisation, methodology, research focus, and the integrated context components, this implementation result allows numerous individual solution facilities for further investigation.

E. Components’ spatial contexts and computation

This case can employ the structure-based fusion for the respective KR computation and processing. The integrated spatial components’ computation and processing can deploy parallelisation, e.g., for creation of slices.

Table XII shows an implementation excerpt and computational footprint for the components in the given case. For comparison to the above values, the results are given for an Intel® Xeon® CPU X5570 (2.933 GHz) systems under Linux.

TABLE XII. COMPUTATIONAL FOOTPRINT OF PROCESSING AND COMPUTATION FOR COMPONENTS WITH PARALLEL SUPPORT (EXCERPT).

Contributing Components	*Description / Resources*	*Wall Time*
Preprocessing	DEM, KR, PAKA	280 s
Slice (parallelised instance)		52 s
UDC:52.. . .	DEM, raster, vector, KR	38 s
UDC:903.. . .:. . .	Entities, KR, PAKA	5 s
UDC:551.44	Entities, KR	3 s
UDC:631.4	Entities, soil context, KR	6 s
Postprocessing	[Symbolic representation]	350 s

The number of slices can range from one to n, commonly many thousands for standard applications. The respective overall wall clock times are about n-times of parallelised instances for slices and benefit from the parallelisation, e.g., via OpenMP [40], [41], [42]. In this case the wall times for even small numbers of slices, e.g., 360 slices result in $360 \cdot 52\,\mathrm{s} = 18{,}720\,\mathrm{s}$ versus 52 s for parallel instances. Therefore, pre- and postprocessing do not contribute significantly in demanding cases.

The contributing components allow for prehistory and archaeology to consider the knowledge processing, parametrisation, and the required chorological contexts, e.g., height reference computation, resampling, illumination, spatial parametrisation, spatial computation, and symbolic representation during preprocessing, spatial context integration, and postprocessing in an efficient and scalable way.

VI. CONCLUSION

It is generally preferable to integrate multi-disciplinary knowledge with the expertise of the respective participated disciplines. This research has shown to allow a coherent integration of multi-disciplinary knowledge with the respective backgrounds.

This paper presented two successful cases of prehistory-protohistory contextualisation, structure-based fusion realisation (prehistory-archaeology knowledge resources and volcanology contexts) and integrated spatial context computation (cist tombs, speleology, spatial, and soil contexts).

This research achieved the goal to create performant methods for efficient problem solving deploying the new structure-based fusion methodology and spatial context computation. Structure-based fusion can provide a valuable, scalable option alternative to procedure-based approaches. The presented case realisation successfully considered conceptual knowledge, especially the core component of UDC references, which is most important in context of handling advanced structures for universal, multi-disciplinary, and multi-lingual knowledge for many objects. The case implementations illustrated that even complex scenarios with computational challenges and large numbers of involved objects can be efficiently created and realised. Structure-based methods increase the means to address structure and to beneficially use structural knowledge and information, which are otherwise not easily deployable by procedure-based approaches. The solutions showed the flexibility of knowledge- and data-centricity. The implementations of the methods proved being able to minimise the number of calls and threads. The methodology and efficiency in creating and adapting implementations that way can have significant impact on sustainability and consistency of long-term solutions.

The structure-based fusion solutions not just provide facilities for fast, resource efficient operation, even if not optimised as the shown realisations. They are modular, long-term sustainable, and widely programming / language implementation independent. Realisations can be easily adapted to different environments (programming languages / shells and operating systems). For the research group and partners the solutions proved adaptability and efficiency in many practical realisation, for years, new and rewritten, in context of resources development and knowledge mining and many solutions beyond.

The coherent conceptual knowledge integration of components also showed the vast potential for understanding multi-disciplinary contexts and processes – not only for prehistory, archaeology, natural sciences, and humanities.

Future research will continue creating structure-based fusion solutions for knowledge mining and day-to-day challenges. Further research will be done on multi-disciplinary and spatial context computation for enabling an ongoing analysis refinement with the continuous development of integrated components contributed by many disciplines, especially taking new findings and context integration in prehistory and archaeology into account.

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