The Coherent Multi-disciplinary Knowledge Case of Prehistorical Insight: Information Science at the Edge of Structured Data Comprehension

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Abstract: *Up to these days, we are experiencing an omnipresent lack of a general approach for cognitive addressing of knowledge structures. This article presents new results and component reference implementations based on frameworks of coherent conceptual knowledge. Coherent conceptual knowledge provides valuable instruments for multi-disciplinary contextualisation, e.g., for contexts in prehistory and protohistory. This research addresses scientific methodologies, valorisation and intelligent re-valorisation of any scientific insight, cognostic addressing of structures, also known as nucleal cognstructures. The resulting component reference implementations enable productive, fertile environments, and learning-improvement-cycles. Central goal of this research is a consistent coherent conceptual integration of knowledge. Prehistory and prehistoric archaeology and their contexts and contextualisation provide a plethora of instructive multi-disciplinary scientific scenarios of high complexity. Thus, component reference implementations for these scenarios are implementation blueprints for informational modeling, industrial learning, and improvement cycles. The results of this long-term research provide solutions based on practical information science, beneficial for prehistory, prehistoric archaeology, and their multi-disciplinary contexts as well as for providing approaches to general solutions.*

Keywords: *Prehistory; Archaeology; Information Science; Information Theory; Structural Knowledge; Conceptual Knowledge; Epistemological Fundaments; Logic; Methodologies; Methods; Informatics; Integration Strategies.*

MSC: *03A10; 03A05; 68Pxx; 62R07; 94A15; 94A17.*

ITHEA Keywords: *Data; Computing Methodologies; Systems and Information Theory; Analysis of Algorithms and Problem Complexity; Mathematical Logic and Formal Languages; Logics and Meanings of Programs.*

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Introduction

This paper presents new results and component reference implementations based on frameworks of coherent conceptual knowledge. Motivation is an omnipresent lack of a general approach for cognitive addressing of knowledge structures. Coherent conceptual knowledge provides valuable instruments for multi-disciplinary contextualisation, e.g., for contexts in prehistory and protohistory. This research continues previous research [Rückemann 2021b; Rückemann et al. 2021; Rückemann 2021a, 2020f] and addresses scientific methodologies, valorisation and intelligent re-valorisation of any scientific insight, cognostic addressing of structures, also known as nucleal cognstructures [Rückemann 2021a; Rückemann et al. 2021]. Nucleal cognstructures [Rückemann et al. 2021] workflows can be used for creating productive, fertile environments and foster the improvement of industrial learning and development cycles, solution integrates with industrial learning processes, e.g., Machine 'Learning' (ML) and Deep 'Learning' (DL), enables knowledge complements, beyond procedural approaches and taxonomies.

The resulting component reference implementations employ multi-disciplinary, multi-lingual coherent conceptual knowledge based contextualisation [Rückemann 2021d,c]. The component reference implementations enable productive, fertile environments, and learning-improvement-cycles. Central goal of this research is a consistent coherent conceptual integration of knowledge. Prehistory and prehistoric archaeology and their contexts and contextualisation provide a plethora of instructive multi-disciplinary scientific scenarios of high complexity. Thus, they are an implementation blueprint for informational modeling, industrial learning, and improvement cycles. The results of this long-term research provide solutions based on practical information science.

Background and Fundaments – Information, Sciences, Knowledge

The fundaments of terminology and of understanding knowledge are layed out by Aristotle [Aristotle 2008] [Aristotle 2009], being an essential part of 'Ethics' [Aristotle 2005]. Information science can very much benefit from Aristotle's fundaments and a knowledge-centric approach (Anderson and Krathwohl) [Anderson and Krathwohl 2001] but for building holistic and sustainable solutions they need to go beyond the available technology-based approaches and hypothesis [Plato 2008] as analysed in Platon's Phaidon. In consequence, an updated view on the knowledge complements including the creation of interfaces between methods and applications (e.g., based on the methodology of Superordinate Knowledge [Rückemann 2019b, 2020d] and the methodology of Knowledge Mapping [Rückemann 2018a]) is addressed in the following excerpts.

Essential factors for application are cognition and contextualisation. The implemented methods and integration modules for result context creation and georeferencing have delivered viable, efficient, and flexible solutions for many case scenarios. Implementations are far from trivial but any discipline being able to ask questions as demonstrated should also be able to deploy the methodology and presented components for creating solid fundaments and own practical solutions for challenging, complex scenarios, e.g., classification and dating of objects [Gleser 2004], geoscientific prospection, surveying [Gleser et al. 2015], and knowledge [Gleser 2015], chorological and chronological context [Gleser 2016], can contribute to the fundaments of cognition in prehistoric and protohistoric archaeology [Gleser 2020] and insight [Gleser 2018] regarding realia and abstract objects, knowledge, and contexts.

The presented knowledge-based method and conceptual knowledge framework allow to address context very flexibly, e.g., in order to enable the metacognitive documentation of metacognitive and procedural knowledge of Geoscientific Information Systems or Geographic Information System analysis [Filloramo et al. 2020], filtering contextualised artistic representations [Becker 2018] and managing object collections [Becker 2012]. Knowledge-based approaches can also be beneficial without advanced knowledge resources, e.g., in cases of realia collections, information management and service oriented institutions and research data collection, e.g., The Digital Archaeological Record [tDAR 2020] and Digital Antiquity [DigitalAntiquity 2020]. For example, in focus cases of pre- and protohistory, archaeology, and history context and georeferencing can further be supported by facet creation into more dimensions and also allows the application of a consistent conceptual base for description and fuzziness, beyond common auxiliaries and georeferencing.

Prehistory, Archaeology, Natural Sciences, Humanities and Coherent Conceptual Integration

Contexts in prehistory are peculiar in a way that there are no direct historical sources and respectively no literary reference and documentation. Contextualisation is therefore a main intrinsic task in prehistory and protohistory. 'Witness contexts' and 'memory features' are key assets.

Prehistoric context, *even for chorologically, chronologically, and thematically restricted object groups* [Häßler 2002] [Kröber 2001] [Wiechers-Weidner 1985] comprises of a *wide and highly multi-faceted spectrum of knowledge*, *applied approaches*, and *formalisation*, including *abstraction* [Cochrane and Jones 2012] and *documentation* [Skoglund et al. 2015].

Further, the application practices of not well satisfying approaches and methodological deficits, especially in multi-disciplinary context, are often *fragmented, heterogeneous, and lacking required coherence and precision* [Fritsch et al. 2010] or require *unnecessary estimations and approximations* [Nimura 2016].

Approaches have to conform with *information science fundaments and universal knowledge* and *enable an integration of required components from methodologies to realisations* for knowledge representations of realia and abstract contexts (fundamental methodological algorithm base of the *Conceptual Knowledge Pattern Matching (CKPM) methodology*) [Rückemann 2020a] while many *facets of knowledge*, epistemological contexts, including prehistory, need to be *continuously acquired and reviewed* [Gleser 2021] [Gleser 2018] [Becker 2018].

Systematical View on Knowledge: FCPM and Structure Complements

The complements of knowledge (FCPM, factual, conceptual, procedural, metacognitive, structural knowledge) and corresponding example implementations [Rückemann et al. 2021; Rückemann 2021a, 2020f] are shown in Table 1.

Table 1: Complements of knowledge and example implementations.

Knowledge Complement		*Example Implementation*
Factual Knowledge	⇔	Numerical data, data . . .
Conceptual Knowledge	⇔	Classification . . .
Procedural Knowledge	⇔	Computing . . .
Metacognitive Knowledge	⇔	Experience . . .
Structural Knowledge	⇔	Standard hybrid formats . . .
. . .	⇔	. . .

The 'Best Practice and Definitions Series' introduced with the annual international Symposium on Advanced Computation and Information in Natural and Applied Sciences (SACINAS) so far focussed on the major topics of "Knowledge and Computing" [Rückemann et al. 2015], "Data-centric and Big Data – Science, Society, Law, Industry, and Engineering" [Rückemann et al. 2016], "Data Sciences – Beyond Statistics" [Rückemann et al. 2017], "Data Value" [Rückemann et al. 2018], "Formalisation and Formalism" [Rückemann et al. 2019], and "Concepts of Cognostic Addressing Structured and Non-structured Data" [Rückemann et al. 2021].

Obstacles, which should be addressed, otherwise possibly reducing success and efficiency with the processes are, e.g., time consumption (e.g., staff, project timelines), documentation (e.g., low percentage of reusability), classification (e.g., limited views), tools (e.g., changing repeatedly), “standards” (e.g., changing repeatedly), up to different perception of goals, strategies, and completeness.

Examples are methodologies addressing full text and keywords, with various methods available for object groups, regular expressions, search functions, or phonetics, e.g., Soundex. Soundex, for example, provides algorithms for calculating codes from text strings, representing phonetic properties. Originally, Soundex was only used for names, in Englisch. The original algorithm mainly encodes consonants. The goal is to encode homophones with the same representation. Minor spelling differences do result in the same representation. There are various modifications for any language, topics, any kind of words, with support for many programming environments [Russel and Odell 1918; Knuth 1973; Rempel 1998; Rückemann 2013a]. Implemented instruments targetting factual, conceptual, procedural, and metacognitive complements include Knowledge Resources, Universal Decimal Classification (UDC), Unified Modeling Language (UML), Documentation, Decision making (in means of information science), Structures (in means of information science), High End Computing (HEC), Open Archives Initiative (OAI), and OAI-Protocol for Metadata Harvesting (OAI-PMH). Acolytes are always complementary to instruments. Helpers, staff and resources, are needed when dealing with knowledge. The quantity of staff and resources depends. However, the ‘quality’, targetting Quality of Data (QoD) can help to ‘optimise’ requirements for staff and resources.

Structures are relevant for mostly all instruments. We should learn to understand what structures mean in information science and take care that structures are capable to contain and refer to any content and context.

Information Science: Structure and Form

> ***Definition:*** Structure is an organisation of interrelated entities in a material or non-material object or system, on homogeneous intrinsic levels. A structured object or system is sometimes called a structure.

Besides structure and its background [Rückemann 2020f; Rückemann et al. 2021], information science does require an understanding of structure categories. Examples of basic categories are:

Material structures are *natural objects* such as biological organisms, minerals, and chemicals and *man-made* objects such as architectural buildings and machinery.

Abstract structures are any (knowledge / information / data) structures in information science, used in theory and practice.

In both cases, ***structure types*** are hierarchies or lattices, for example.

From discipline’s views only, information Science and structure may show up heterogeneous. In logic and philosophy, structure is essential, e.g., a structure of arguments. An argument consists of one or more premises from which a conclusion is inferred. Basic inferences are deduction and induction. In problem solving, a data structure is generally an integral part of the respective algorithm. In mathematics, a structure is a set endowed with additional features on the set.

Examples of features are topology, operation, relation, metric, especially, algebraic structures (e.g., groups, fields), metric structures (geometries), orders, events, equivalence relations, differential structures, and categories.

In chemistry, the term chemical structure refers to both molecular geometry and electronic structure. Structure can be represented by various diagrams, e.g., structural formulas. In informatics, implementations of structures are a) array and index or b) a linked list and pointers. In software architecture, the structure of software system is the way in which interrelated components are partitioned. Associated features and terms are dependencies, modules, robustness, tolerance, and redundancy.

Axiom: Structure can mean features and facilities.
Axiom: Regarding the specification structured / unstructured it is not relevant how much data is compatible with / uniform / part of any of your records, system, accounting, inventory management, order systems etc.

Regarding structure and form, let us take a look on dealing with written text.

> 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.

Axiom: There are neither standard structures nor standard forms of data.
Axiom: Information is inherent with form.
Axiom: Form follows function (in best practice).

Especially, if meaning should be expressed by langage, langue, and parole [de Saussure 1916] then the available rules of structure and form should be used. If whatever non linguistic, artistic expression is primary target then different structure an form could be used. 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.

Information science fundaments in this context can deal with arbitrary fields of concern and can be applied in any fields and tasks in theory and practice, e.g., knowledge resources (millions of objects, entities, and references), knowledge mining, prehistory, protohistory / archaeology, natural sciences, humanities, creating insight, knowledge-valorisation context, research data reuse, calculation, processing, and computation (simulation, modelling), integration, long-term documentation, algorithms, automation, and autonomous instruments, numerical applications, information and processing systems, and management and governance.

Trail Landscapes Towards Comprehension

When dealing with knowledge complements, policies should foster diligent and careful creation and deployment of implicit-explicit formalisations. There should be precautions not to mix knowledge complements, e.g., factual, conceptual, procedural, metacognitive, and structural.

The determination of which properties of a material object, of knowledge, of data are implicit and explicit is relevant for consideration, implementation, and sustainability. The determination of implicit and explicit properties of structures deployed is further relevant at comparable level. Digitisation is comprised from two conceptually distinct aspects, namely discretisation and quantisation. Further, no material structure is analog or digital.

When addressing structures, principal conceptual concepts are logic and associative. Care has to be taken when implementations are provisioned and used as, e.g., there are very limited numbers of different logic implementations and realisations available. Associative approaches result in 2nd, 3rd, . . . order levels.

Different levels of structure are linked with substantial differences, e.g.:

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

Substantial differences result in consequences, e.g., substantial deficits of lower level structured data cannot be compensated by tools. Structures may need to be addressed accordingly.

Structure coexists with methods. With realisations we have to be aware that different implementations and realisations may be required for different tasks.

Structure and valorisation and continuous development are very distinct. In principle, we have to consider factual valorisation / development and formal valorisation / development.

It should always be remembered that meaning itself is neither ‘in the data’ nor ‘in the structure’. Also, semantic shifts and further effects should be considered.

However, it should be clear that neither dealing with knowledge complements nor dealing with structure is without efforts. In any comprehension targeting case scenario, we have to analyse the referred and associated details and properties, before a knowledge-based, conceptual solution is implemented and further continuously developed on a multi-disciplinary background. We can only illustrate by naming some excerpt examples.

Coherent observant comprehension: Commonly observant objects are referred when considering material and abstract structures. For example, substances fading are observants for faints of colours. Fossils are observants for faints of structures. Excavations are observants for faints of in-situ contexts.

Coherent chorology comprehension: In spatial context essential structures are implemented from elementary spatial data, e.g., Points of Interest (POI), lines, and polygons. In this context further knowledge may be required to decide on benefits sub-structure context, what a point does stand for, if there are benefits of orientation and sort order of points in lines or polygons. Even such elementary structures do require expert knowledge, e.g., on different formalisation aspects, different intrinsic/extrinsic properties, different methods, different algorithms, different mathematical operations, workflow integration, and different contexts, consequences for integration, and consequences for contextualisation.

Coherent knowledge and workflow dependent comprehension: When taking series of photos, it maybe required to have further knowledge, e.g., on if it will be beneficial to follow a certain sort order for a photo-creation series, if the context of time and sun may have an effect, and how close the stored geo-position is to the position of the object on a photo. Examples of knowledge-dependent issues are algorithms, workflows, logic, parallelisation (not just multiples "job parallel"), and case scenarios, e.g., with different views being significant.

Coherent chronology comprehension: A prominent prehistoric valorisation example is the swimming reindeer [Cook 2015] included in detail in [Rückemann 2020f].

Coherent indicators and references comprehension: In cases of prehistoric contextualisation and geo-structures, e.g., meteorite craters, there maybe secondary, tertiary, . . . indicators. Indicators may exist in form of ruderal plants and indicator plants, e.g., with the Kaali crater field, Saaremaa, Estonia [Rückemann 2017b,a; Gersbeck-Schierholz 2016]. Specimen crater pond material contains quartz, melane particles, lacustrine deposits, and biogenic material. The references included in the knowledge mining workflow provided the complementary information that fine particles from the Kaali crater include *impactor remains* (esp. significant *Ni-Wüstite, Ni-Maghemite, Ni-Goethite, Hematite, Magnetite, Taenite, Kamacite*), spherules and splash-forms. The vegetation includes an extensive appearance of *Lilium martagon* at the top of the crater rim [Rückemann 2017b,a; Gersbeck-Schierholz 2016,?; GEXI 2016]. The resulting Kaali knowledge object is referring to bibliographic references for meteorite craters on the island of Saaremaa [Tiirmaa 2005] as well as to meteorite craters in Estonia. Other references point to information for *meteorite-material-usage*, e.g., in context with archaeological and historical or mythical context like *King Arthur's sword Excalibur* ('Ex-Kali-bur') [Faure and Mensing 2012] directly associated with Kaali (*mother goddess Kali*) and its metal material and via association of sword synonyms and metal object classification to *Tutankhamun's dagger* [Comelli et al. 2016], made with meteorite iron from the desert in the West of Egypt.

Coherent view-dependent comprehension: For example, think of an itself non-material but also physical phenomenon, which is tied with physical objects, e.g., every human being, while associated properties can vary. The shadow. What type of properties are those of shadows? How can properties be described, e.g., hybrid, analog, or extrinsic?

Structured Comprehension Grows on Coherent Conceptual Knowledge

The next sections give a compact overview of major component implementations and development integrated with this research on knowledge complements and frameworks for coherent knowledge integration in prehistory, natural sciences, and humanities. A more detailed, comprehensive discussion and examples regarding the fundaments are available with the research on methodology, contextualisation, and conceptual knowledge. Relevant pre-existing and ongoing component developments addressing knowledge with multi-disciplinary Knowledge Resources (KR) have been summarised [Rückemann 2021d].

The following component reference implementations provide the resulting, comprehensive set of complements and components required for an advanced practical long-term case scenario, integrating knowledge on prehistory and prehistorical archaeology, natural sciences, remote sensing, and soil science.

The presented practical component reference implementations are based on a number of component groups, which are in continuous long-term development. The methodology, methods, case scenarios and the fundaments of the component reference implementations and components were lately publicly presented and discussed at the Informational Modeling - Theory and Practice - International Conference, Sofia, Bulgaria [Rückemann 2020f], at the International Conference on Mathematics of Informational Modeling, Varna, Bulgaria [Rückemann 2021b], both Bulgarian Academy of Sciences, at the Delegates' Summit, Symposium on Advanced Computation and Information in Natural and Applied Sciences, Rhodes, Greece [Rückemann et al. 2021], and at the Machine Learning for Industry Forum hosted by the High-Performance Computing Innovation Center and Data Science Institute at the Lawrence Livermore National Laboratory, USA [Rückemann 2021a].

1) COMPONENT REFERENCE IMPLEMENTATION: Conceptual Knowledge Frameworks

Conceptual knowledge frameworks were created and are further continuously developed and used in practice with ongoing long-term research and applied for *KR* [Rückemann 2021d], e.g.:

- ***Prehistory-protohistory and archaeology Conceptual Knowledge Reference Implementation (CKRI)***, including multi-disciplinary contexts of *natural sciences and humanities* and any facets [Rückemann 2020f] [Rückemann 2020c].
- ***Mathematical and computational conceptual knowledge framework*** [Rückemann 2020d].
- ***Environmental information systems conceptual knowledge framework*** [Rückemann 2018b].

2) COMPONENT REFERENCE IMPLEMENTATION: Conceptual Knowledge Base

Conceptual knowledge base is The ***Universal Decimal Classification (UDC)*** [UDCS 2012], a general plan for knowledge classification, providing an analytico-synthetic and *faceted* classification, designed for subject description and indexing of content of information resources *irrespective of the carrier, form, format, and language*. UDC-based references for demonstration are taken from the multi-lingual UDC summary [UDCS 2012] released by the UDC Consortium, Creative Commons license [Creative Commons 2012].

3) COMPONENT REFERENCE IMPLEMENTATION: Integration of Scientific Reference Frameworks

Relevant scientific practices, frameworks, and standards from disciplines and contexts. *Natural sciences*, *geosciences*, and *soil science* are continuously delivering updated state of the art research and insight, including geodiversity and standardisation [Das 2019] [LPDAAC 2021]. Associated information, e.g., on *soil drainage, wetness, pH status, base saturation, chloride, subsoil organic material, and stiffness* can be found as reference in the ***World Reference Base (WRB) for soil resources*** [FAO 1998, 2006] from the *Food and Agriculture Organisation (FAO)*, United Nations.

4) COMPONENT REFERENCE IMPLEMENTATION: Formalisation

All integration components, for all disciplines, require an *explicit and continuous formalisation* [Rückemann et al. 2019] *process* in order to conform with the information science principles according to the practices in the disciplines [Rückemann 2020b]. This includes *knowledge objects and entities* as well as *procedural components* (e.g., ***C*** [GNU GCC 2021], ***Fortran*** [GNU Fortran 2021], ***Perl***

[Perl 2021], ***Shell wrapper***, ***Julia*** [Balbaert 2018] [Sherrington 2015] [Joshi 2016]), computation model support, e.g., ***parallelisation standards, OpenMP*** [Dagum and Menon 1998] [OpenMP Architecture Review Board 2020], Reg Exp patterns, e.g., ***Perl Compatible Regular Expressions (PCRE)*** [Perl Compatible Regular Expressions 2021], further standard tools, e.g., ***Structured Query Language (SQL)***, ***Tool Command Language (TCL)*** [Tcl 2021], Extract Transform Load (ETL), Extract Load Transform (ELT), and hybrid solutions. Addressing aspects of *discipline related parole* [de Saussure 1916].

5) COMPONENT REFERENCE IMPLEMENTATION: Methodologies and Workflows Integration

Methodologies for creating and utilising methods include model processing, remote sensing, spatial mapping, high information densities, and visualisation. Respective contextualisation of (prehistoric) scenarios should each be done under specific (prehistoric) conditions, especially supported by *standard algorithms* [Press et al. 1996], *multi-dimensional criteria, spatial operations*, *interpolation geodesic computation* [Vincenty 1975], *triangulation* [Renka 1997], *gradient computation* [Horn 1981], and *projection* [Kent and Vujakovic 2018]. Workflow integration includes problem solving, e.g., *mathematical algorithms, mathematical processes, filter processes*, *phonetic and linguistic context support* [Rückemann 2013b]. *Visualisation*, ***Generic Mapping Tools (GMT)*** [Wessel et al. 2020].

6) COMPONENT REFERENCE IMPLEMENTATION: Prehistory Knowledge Resources

Common sources of information in many disciplines are often not yet aware of universal knowledge concepts and multi-lingual approaches. Common sources are in many cases not sufficiently coherent, consistent, and structured and more often they show to be fragmented and heterogeneous. In order to overcome basic 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)***, in continuous development for more than three decades [Rückemann 2019a] and is released by DIMF [PAKA 2021].

7) COMPONENT REFERENCE IMPLEMENTATION: Natural Sciences Knowledge Resources

Several coherent systems of major natural sciences' context object groups from ***KR realisations*** have been implemented [Rückemann 2021d] [UDCS 2012] [Rückemann 2020e].

8) COMPONENT REFERENCE IMPLEMENTATION: Inherent Representation Groups

The methodology can consider a wide range of *representation groups* for major disciplines and context object groups regarding their inherent representation and common utilisation, e.g., ***points***, ***polygons***, ***lines***, ***Digital Elevation Model (DEM) representations*** sources, e.g., from ***satellites***, ***drones*** (*raster data*, *RAdio Detection And Ranging (RADAR)*, *Synthetic Aperture Radar (SAR)*, *Light Detection And Ranging (LiDAR)*, . . .), ***positioning/navigation*** *(common satellite systems / satellite navigation systems, e.g., Galileo, Europe; Global Positioning System (GPS), USA; GLObalnaja NAwigazionnaja Sputnikowaja Sistema (GLONASS), Russia; Quasi-Zenith Satellite System (QZSS), Japan; Indian Regional Navigation Satellite System (IRNSS) / Navigation Indian Constella-*

tion (NAVIC), India), ***z-value representations***, ***distance representations***, ***area representations***, ***raster***, ***vector***, ***binary***, and ***non-binary data***.

Essential base context sources should provide ***worldwide homogeneous and consistent data*** [LPDAAC 2021] allowing extrapolation and interpolation in various dimensions, e.g., from the School of Ocean and Earth Science and Technology (SOEST), National Aeronautics and Space Administration (NASA), Goddard National Space Science Data Center (NSSDC), National Oceanographic and Atmospheric Administration (NOAA), Central Intelligence Agency (CIA) resources, European Community (EC) resources, and national and federal organisations and initiatives for further integration and future solutions.

9) COMPONENT REFERENCE IMPLEMENTATION: Scientific Context Parametrisation

Scientific ***context parametrisation of prehistoric targets*** can use the overall insights, e.g., from *geoscientific disciplines* [Brinkmann 1986] [Woldstedt and Duphorn 1974].

A relevant example is contextualisation with *palaeolandscapes* [Bailey et al. 2017]. In case of prehistory, parametrisation depends on the prehistorical context, e.g., the geoscientific parametrisation and geoscientific contextualisation depend of the respective selected prehistorical object groups and associated properties. The highly inter-dependent complexity can make the *scientific parametrisation* an extremely *advanced long-term challenge*.

10) COMPONENT REFERENCE IMPLEMENTATION: Structures and Symbolic Representation

The deployment of long-term universal structure and data standards is essential. Relevant examples of sustainable implementations are ***NetCDF*** [NetCDF 2021] based standards, including advanced features, hybrid structure integration, and parallel computing support (***PnetCDF***) and generic multi-dimensional table data, universal source and text based structure and code representations.

INTEGRATION CASE: Example Excerpts of Resulting Implementations and Realisations

A means of choice in order to achieve overall efficient realisations even for complex scenarios, integrating arbitrary knowledge, is to use the principles of Superordinate Knowledge. The core assembly elements of Superordinate Knowledge are methodology, implementation, and realisation [Rückemann 2019b]. In the following solution [Rückemann 2021d,c], scenario targets are

- *contexts of prehistoric cemeteries and burials*
- *at the North Sea coast, in North-Rhine Westphalia, Lower Saxony, and The Netherlands.*
- *Integration targets are natural sciences and*
- *speleological contexts, caves and cave systems*
- *in North-Rhine Westphalia, Lower Saxony, and The Netherlands,*
- *soil diversity, and overall integration with*
- *chorological, symbolical, spatial context representations, e.g., place, spatial planning,*
- *auxiliary subdivisions for boundaries and*
- *spatial forms and*

- *administrative units,*

for all of which knowledge needs to be created, continuously developed, and re-used [Rückemann 2021d,c]
Therefore, this integration case, considers the *major conceptual references*. Specific research can address further detail on any contexts and properties, e.g.,

- *prehistoric object groups*,
- *object characteristics*, and
- *object properties*,
- *topographic properties*,
- *soil properties*, and many more.

Therefore, a conceptual sketch view can result in levels of arbitrary numbers of different integrations of complements and associated properties as resulting from the KR.

INTEGRATION CASE: Coherent Conceptual Knowledge Implementation

Relevant knowledge can be referenced, e.g., from the implemented *prehistory-protohistory and archaeology CKRI* [Rückemann 2020f]. The methodology allows to address any other references on a coherent information science knowledge base, e.g., geoscientific knowledge from natural sciences KR components. Further, the reference implementation enables to address chorology on the coherent knowledge base. Table 2 shows a general overview containing an excerpt of major references of coherent conceptual knowledge, relevant for the case scenario. In this case example, universally consistent conceptual knowledge is based on UDC references [UDC Consortium 2020].

Table 2: Coherent conceptual knowledge deployed for contextualisation, selected UDC code references (excerpt).

Code / Sign Ref.	*Verbal Description (EN)*
UDC:0	Science and Knowledge. Organization. Computer Science. Information. Documentation. Librarianship. Institutions. Publications
UDC:004	*Computer science and technology. Computing.*
UDC:1	Philosophy. Psychology
UDC:2	*Religion. Theology*
UDC:3	Social Sciences
UDC:5	Mathematics. Natural Sciences
UDC:52	*Astronomy. Astrophysics. Space research. Geodesy*
UDC:53	Physics
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. Historical geology. Stratigraphy. Palaeogeography
UDC:551.44	*Speleology. Caves. Fissures. Underground waters*
UDC:551.46	Physical oceanography. Submarine topography. Ocean floor
UDC:551.7	Historical geology. Stratigraphy
UDC:551.8	Palaeogeography
UDC:56	Palaeontology
UDC:6	Applied Sciences. Medicine, Technology
UDC:63	Agriculture and related sciences and techniques. Forestry. Farming. Wildlife exploitation
UDC:631.4	*Soil science. Pedology. Soil research*
UDC:7	The Arts. Entertainment. Sport
UDC:8	Linguistics. Literature
UDC:9	Geography. Biography. History
UDC:902	Archaeology
UDC:903	*Prehistory. Prehistoric remains, artefacts, antiquities*
UDC:904	Cultural remains of historical times
UDC (1/9)	Common auxiliaries of place
UDC:(1)	Place and space in general. Localization. Orientation
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:(4/9)	Countries and places of the modern world
UDC:(4)	*Europe*
UDC:"..."	Common auxiliaries of time.
UDC:"6"	Geological, archaeological and cultural time divisions
UDC:"62"	*Cenozoic (Cainozoic). Neozoic (70 MYBP - present)*

INTEGRATION CASE: Multi-disciplinary Prehistory and Archaeology Contexts

Table 3 shows examples of prehistory and protohistory ritual/burial objects and subgroups, and conceptual view groups, an excerpt of UDC:903.. . .:2 *groups* [UDCS 2012] *for prehistory and protohistory* as referenced from PAKA [Rückemann 2019a; PAKA 2021]. Objects are selected from a major object group, including subgroups.

Table 3: Prehistory and protohistory ritual/burial object and subgroup examples, and conceptual view groups [UDCS 2012] (excerpt).

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

INTEGRATION CASE: Soil Diversity Reference System

Table 4 shows a compilation of the implemented and realised *soil type conceptual reference system for prehistory and archaeology* (UDC:631.4. . . base).

The soil type reference system is based on soil diversity standards and universal conceptual knowledge. The reference system deploys implemented and realised WRB standard soil type reference groups and soil type specifications.

Associated information, e.g., on soil drainage, wetness, pH status, base saturation, chloride, subsoil organic material, and stiffness can be found as reference in the *World Reference Base (WRB) for soil resources* [FAO 1998, 2006] from the *Food and Agriculture Organisation (FAO)*, United Nations.

For this research, the created reference system is based on *standard soil references and UDC*, both enabling a systematic and coherent approach. In this context, the conceptual references are referring to the respective categories, e.g., UDC:631.4. . .:903+"4. . .".

Soil diversity groups are relevant for prehistorical and archaeological objects and contexts. Contextualised soil diversity groups are *referenced in a consistent, standardised way*.

From this base compilation, a properties based reference system can be created for further contextualisation, parametrisation, and processing with the *ongoing research on soil diversity for prehistory and archaeology*.

Table 4: Compilation of conceptual reference system (UDC:631.4. . .), implemented and realised WRB standard soil type reference groups and soil type specifications.

Soil Type Reference Group	*Soil Type Specification Name in WRB 2006 / WRB 1998*
Acrisol	Haplic / Ferric, Gleyic, Haplic, Humic, Plinthic
Alisol	Plinthic
Albeluvisol	Haplic / Endoeutric, Gleyic, Haplic, Histic, Stagnic, Umbric
Andosol	Aluandic / Dystric, Humic, Umbric, Mollic, Vitric
Anthrosol	Anthrosol, Plaggic
Arenosol	Albic, Haplic, Protic
Calcisol	Aridic
Chernozem	Calcic, Haplic, Gleyic, Haplic, Luvic
Cambisol	Haplic / Calcaric, Haplic / Chromic, Haplic / Dystric, Haplic / Eutric, Gleyic, Haplic, Mollic, Vertic
Fluvisol	Haplic / Calcaric, Haplic / Dystric, Haplic / Eutric, Gleyic, Haplic, Histic, Mollic, Salic, Thionic
Gleysol	Haplic / Calcaric, Haplic / Dystric, Haplic / Eutric, Haplic / Haplic, Histic, Humic, Mollic, Thionic
Gypsisol	Haplic / Aridic
Histosol	Histosol, Hemic / Dystric, Hemic / Eutric, – / Fibric, – / Gelic, – / Sapric
Kastanozem	Calcic, Haplic, Luvic
Leptosol	Haplic / Calcaric, Haplic / Dystric, Haplic / Eutric, Haplic / Haplic, Haplic / Humic, Rendzic, Lithic
Luvisol	Albic, Haplic / Arenic, Calcic, Haplic / Chromic, Haplic / Dystric, Haplic / Ferric, Gleyic, Haplic, Vertic
Phaeozem	– / Albic, Haplic / Calcaric, Gleyic, Haplic, Luvic, Haplic / Sodic
Planosol	Haplic / Dystric, Haplic / Eutric, Haplic
Podzol	Haplic / Carbic, Haplic / Entic, Gleyic, Haplic, Leptic, Placic, Haplic / Rustic, Umbric
Regosol	Haplic / Calcaric, Haplic / Dystric, Haplic / Eutric, Haplic
Solonchak	Gleyic, Haplic, Haplic / Takyric, Mollic
Solonetz	Gleyic, Haplic, Mollic
Umbrisol	Arenic, Gleyic
Vertisol	Haplic / Chromic, Haplic, Haplic / Pellic

INTEGRATION CASE: Multi-disciplinary Integration Facets

An excerpt of reference facets of coherent knowledge of the case scenario is shown in Table 5.

Table 5: Reference facets of a multi-disciplinary target contextualisation, based on CKRI, implemented and realised using UDC code references (excerpt).

Code / Sign Ref.	*Verbal Description (EN)*
	Geography. Biography. History
UDC:903.. . .	Prehistory, prehistoric remains, artefacts, antiquities
. . .:2	referring to religion and rituals
. . .,"62. . ."	from Holocene
. . .,(4. . .DENW)	. . . in North-Rhine Westphalia, Germany
. . .,(4. . .DENI)	. . . in Lower Saxony, Germany
. . .,(4. . .NL)	. . . in The Netherlands
	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

INTEGRATION CASE: Resulting Coherent Multi-disciplinary Knowledge Integration

The knowledge integration is achieved by following the described component reference implementations. Figure 1 shows a generated sketch map illustrating the knowledge integration.

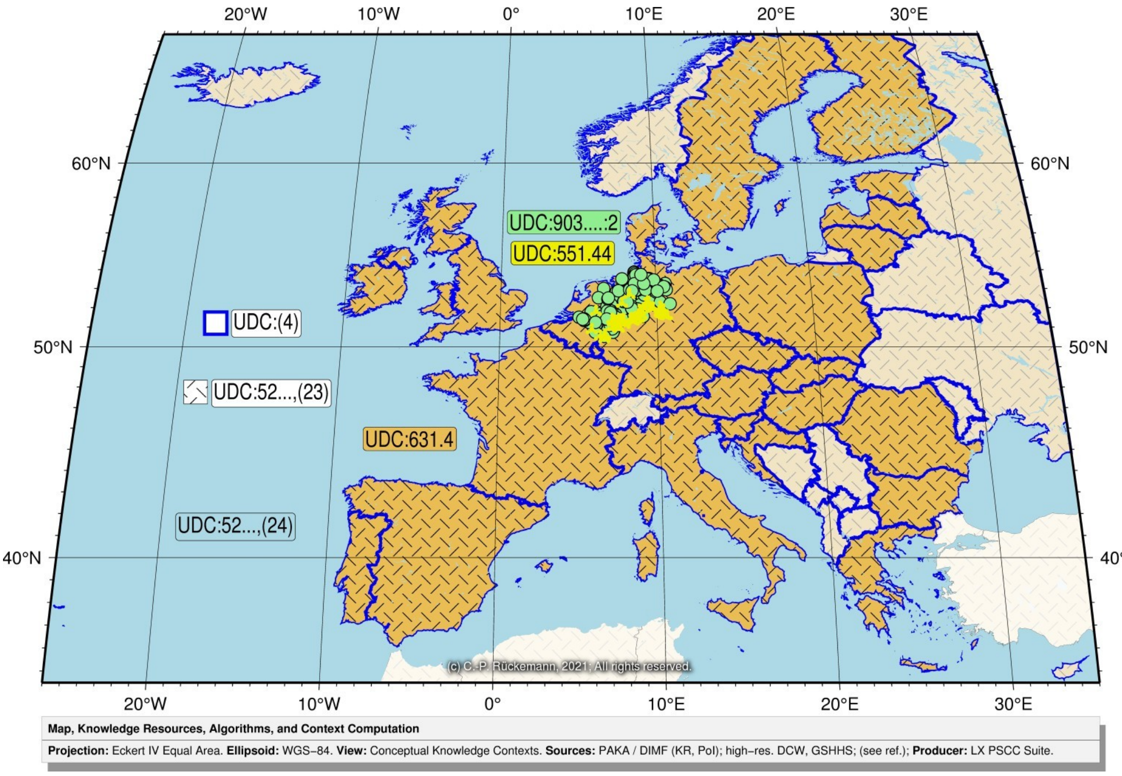

Figure 1: Resulting coherent conceptual knowledge integration sketch diagram showing knowledge resources for a prehistoric, natural sciences, and spatial contextualisation for excerpts of prehistoric cemeteries' and caves' distributions, remote sensing data, and soil properties with respective knowledge references [Rückemann 2021d,c].

The figure shows the *resulting coherent conceptual knowledge integration sketch diagram*, integrating *knowledge resources for a prehistoric, natural sciences, and spatial contextualisation for excerpts of prehistoric cemeteries' and caves' distributions, remote sensing data, and soil properties with respective knowledge references*. The sketch considers the *major conceptual references* for illustration and overview of example context contributions.

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 resulting solution 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*.

The knowledge integration enables universal conceptual knowledge for all components, a wide range of knowledge contextualisation and high flexibility for implementation and realisation. Especially, the sketch map shows flexible component realisations for integration of contexts, enabling management of KR, symbolic representation, and projection. In this integration case, the *coherent multi-disciplinary contextualisation* employs a base of the following contexts:

- Knowledge objects and contexts are provided by
  The Prehistory and Archaeology Knowledge Archive (PAKA) [Rückemann 2019a] [PAKA 2021].
- *New soil system reference development* / (UDC:631.4. . .), WRB standard,
- reference contexts, especially for UDC:903.. . .:2,551.7+“628”.. . .,
- *prehistorical, protohistorical time* & *artefacts related to religion and rituals*,
- *geology*, especially *stratigraphy* and
- *palaeogeography*, *quaternary, especially late glacial and Holocene*.
- The integrated natural sciences KR further provide information on *caves in the respective region*.
- The component reference implementations allow for flexible multi-disciplinary scientific, chorological contextualisation, e.g., Digital Elevation Model (DEM) data from satellites and drones.

In this illustration plain *Digital Chart of the World (DCW)* data are used [Wessel 2018]. The coastline database is the *Global Self-consistent Hierarchical High-resolution Geography (GSHHG)* [Wessel 2016] [Wessel and Smith 1996], which was mainly compiled from the *World Vector Shorelines (WVS)* [Soluri and Woodson 1990], the *CIA World Data Bank II (WDBII)* [Gorny 1977], 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)* [Wessel et al. 2020] for visualisation and considering integration aspects and development of relevant future components and resources [PAKA 2021; Wessel et al. 2021].

Conclusion

Coherent conceptual knowledge approaches provide valuable general tools for contextualisation and can enable sustainable long-term coherent knowledge development and integration, especially for prehistory, archaeology, natural sciences, and humanities. Complex multi-disciplinary case solutions can be based on creating component reference implementations for respective multi-disciplinary integration.

Nevertheless, long-term sustainable multi-disciplinary solutions require an information science level of understanding structure. This includes that knowledge and 'intelligence' are not 'in' and do not come 'with' the technology. Instead, it is beneficial to learn strengths and limitations of knowledge complements, application components, and methods employed.

It was successfully demonstrated that coherent multi-disciplinary conceptual knowledge can be efficiently and effectively employed for complex solutions, providing long-term fundaments for comprehension and gaining new and future insight. The component reference implementations were demonstrated to be beneficial in complex scenarios, e.g., contextualisation of prehistory, archaeology, natural sciences, and humanities. Structure and information science' knowledge fundaments are relevant assets for comprehension and long-term strategies. Especially, structure is essential for complementary knowledge integration benefits. Structure carries relevant information. Structured data creation and development and the consequent creation and employment of long-term Knowledge Resources and suitable reference systems based on long-term standards are strategic assets. Further, consideration of multi-disciplinary contexts needs to be planned. Achievements in information deduction (including extraction) should be documented. The knowledge-based integration targetting structured data comprehension allows decisive selection criteria for multi-disciplinary scenarios and knowledge transfer for new insight.

Future research on theory and practice will concentrate on further developing the component reference implementations and creating knowledge reference based solutions for scenarios and disciplines.

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