The Information Science Paragon: Allow Knowledge to Prevail, from Prehistory to Future – Approaches to Universality, Consistency, and Long-term Sustainability

Claus-Peter Rückemann

Abstract: *Nowerdays we face widely spreaded shisms between disciplines, neologisms, and smattering. Terms are used increasingly loose, for a wide range of reasons. In consequence, we see deficits when solid fundaments dealing with any kind of information are required. In contrary, advanced and inter-disciplinary research, integration, and collaboration tasks, require knowledge and practice of information science fundaments, with a small subset being informatics and technology. Information Science –if understood on a more than 'technical-only' level– can provide a wide and in-depth plethora of methodologies and methods, which essentially contribute to solutions and enable insight, universality, consistency, and long-term sustainability in theory and practice. Information science comprises the fields of collection, documentation, classification, analysis, manipulation, storage, retrieval, movement, dissemination, and protection of information. The key to information science is a solid understanding of knowledge and its context for day-to-day application. The topics provide essential information science fundaments from the base to advanced insight. Presented outcomes result from the last decades of research in information science theory, practice, and scholarly education, spanning advanced application scenarios in management, information and knowledge mining, data processing, information systems, natural sciences, philosophy, prehistory, archaeology, computer science, high end computing, supercomputing, simulation, modeling, and research data reuse.*

Keywords: *Information Science; Information Theory; Epistemology; Logic; Methodologies; Methods; Prehistory; Protohistory; Archaeology; Natural Sciences; Humanities; Informatics; Conceptual Knowledge; 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.*

Introduction

This article presents the results on knowledge-based approaches to universality, consistency, and long-term sustainability for challenges from multi-disciplinary research and advanced, complex context. The information science methodology and method based implementation solutions address a wide range of knowledge and application scenarios and were triggered to provide solid fundaments contrary to omnipresent deficits seen in many fields dealing with respective challenges.

For quite a time now, public and research have to face smattering and buzz in generalised statements and practice, e.g., "Data, information, knowledge . . . are basically the same . . .", "*Structure* and format are very much alike . . .", "There are *structure* standards . . .", "*Structure* can be created by digitisation . . .", "*Intelligent applications* can deliver solutions . . .". Common views try to imagine that artificial 'intelligence' could deal with structured and unstructured data, that intelligent systems would be based on technical implementations, that solutions would be a matter of informatics realisations, that using ('buzz') technologies could create knowledge from data, that objectives can be seen when looking at present instruments, and that education should focus on training for developing technical apps. Such environments rarely allow to deal with knowledge and contexts in appropriate ways, nevertheless, inspiring the need for more holistic solutions.

With this research, we create methodological approaches and extensive multi-disciplinary, multi-lingual knowledge resources and application scenarios spanning pre- and protohistory and archaeology to natural sciences, computation, and humanities. The knowledge resources are in continuous development for decades and contain millions of knowledge objects and entities, and arbitrary references to distributed resources. The resources can comprise all facets of knowledge, including state-of-the-art conceptual knowledge frameworks. The presented results from information science theory, practice, and scholarly education achieved during the last decades span advanced application scenarios in management, information and knowledge mining, data processing, information systems, natural sciences, philosophy, pre- and protohistoric archaeology, classical archaeology, computer science, high end computing, supercomputing, simulation, modeling, and research data reuse [Rückemann 2017]. This article presents excerpts of the results of a Conceptual Knowledge Reference Implementation (CKRI) created, developed, and used with non-disciplinary context, especially with prehistory, archaeology, natural science, and humanities [Rückemann 2019a]. The goal of this long-term research is to further create knowledge resources, knowledge-based methodologies and methods enabling to handle even challenging scenarios with universality, consistency, and long-term sustainability.

Information Science

Information science fundaments and backgrounds are often neither understood and taught nor practically respected. Society, academy, education are commonly reacting with simplification and training. Our vision, approach, and practice target the insights that we have to start far before getting into technical aspects or implementations of application software, that knowledge is not the output or result of a tool, that the fundament of any Turing machine / computer is formalisation, going along with abstraction and reduction, and that 'information processing' should be addressed via context of knowledge complements. This is also true whenever addressing information, e.g., with gathering, filtering, compression of information but also whenever discussing criteria of hermeticism like quality and optimisation. In consequence, we require education for solid information science fundaments, knowledge complements' integration, information science based methods. A starting point is the fact that data is neither information nor knowledge.

> ***Notion:*** Data are "things given". (Latin) data :: (Latin, singular) "datum", given.
>
> ***Axiom:*** 'Data' cannot be 'turned' into 'information'.
> Trying, consequently leads to arbitrary results and arbitrary organisational states.
>
> Practice: Information can result from information peeling processes, e.g.,
> creating knowledge mining implementations.
>
> ***Notion:*** Information science is the science of information in theory and practice.
>
> The essential fundaments of information science are information and philosophy.
>
> ***Notion:*** Information comprises of aspects of knowledge, e.g., facts or details, supplied to or learned by someone. (Latin) formatio :: formation, construction, arrangement, "creation".

We should always be aware of commonly less holistically consistent descriptions, e.g., in public statements but also in widely known dictionaries. Therefore, we need a more consistent understanding.

Information science investigates the being of information, information related properties, and information processes. Information science focuses on theory and methodologies and their application in practice, understanding information related problems, preserving, developing, and making use of information. Information science primarily tackles systemic problems rather than individual pieces of technology within systems. Information science comprises the fields of collection, documentation, classification, analysis, manipulation, storage, retrieval, movement, dissemination, and protection of information. Information science is associated with psychology, computer science, and technology. Information science is interlinked with cognitive science, archival science, linguistics, museology, management, mathematics, philosophy, commerce, law, public policy, and social sciences. Information science deals with any information and communication, e.g., knowledge in organisations, interaction between people, information systems, understanding information systems, and creating, replacing, improving information systems.

Prehistory to Future: Information, History, and Information Management

There are manifold case scenarios, with content and context from natural sciences, geology, and prehistory to classic, medieval, and modern constellations. Table 1 shows a small range of examples.

Table 1: Example cases of lost knowledge over time.

Prehistory (. . . to protohistory / archaeology)	$\Rightarrow$	“art” to “technology”, how to contextualise?
Heron of Alexandria (Greek antique, “Steam Ball”)	$\Rightarrow$	“entertainment” but not used as technology.
Isidore of Seville (encyclopaedic, broad documentation)	$\Rightarrow$	end of medieval phase, not further used.
Polyhistor (Martin Fogel)	$\Rightarrow$	broad base, not further used.
Last decades / Internet	$\Rightarrow$	huge amounts of ‘knowledge’ potential lost.

Summarising, we have to realise that in percentage we nearly know nothing about the past. A reason is that we are widely not practicing universal preservation, documentation, and valorisation. It is necessary, in most cases, to contextualise by consequent multi-disciplinary and sustainable means including appropriate documentation. That means, for pre- and protohistorical, ancient, historical, and near past that realia, their contexts, meaning, and possible documentation are mostly lost and technologies are not fully understood. Therefore, contextualisations of prehistoric to future scenarios require more holistic and basically different approaches than commonly considered when reusing ‘known’ experiences or written sources. Starting with the experiences on information and management we can consider the following frame of preconditions. Information science can provide fundaments and answers. Prehistory and natural sciences as well as many associated information sources do have and do require special context. Knowledge should be addressable by ‘holistic’ approaches. Cognition based on prehistoric information is special. Content and context of said research targets require special methodologies. Methodologies need to enable a plethora of implementations, and decision making needs to address knowledge, special content and context.

Information science is based on a fundament of intrinsically tied complements: Episteme (Greek: $\acute{\varepsilon}\pi\iota\sigma\tau\acute{\eta}\mu\eta$) refers to “knowledge”, “understanding”, and “science”. Techne (Greek: $\tau\acute{\varepsilon}\chi\nu\eta$) refers to “craft” and “art”. Doxa (Greek: $\delta\acute{o}\xi\alpha$) originates from “to appear”, “to seem”, “to accept”, and “to think”.

Knowledge transfer is essential, over generations of objects and subjects. The transfer requires knowledge recognition (expertise), knowledge documentation for any aspect of nature and society (sciences, literature, technical descriptions, tools, cultural heritage, mythology, songs, media, . . .), and long-term means.

The assets we are dealing with in information science are the complements of knowledge (factual, conceptual, procedural, metacognitive, . . .) and the potential of the existing plethora of knowledge and insight.

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] 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.

Expertise and Skills: Best Practice and Definitions

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", "Data-centric and Big Data – Science, Society, Law, Industry, and Engineering", "Data Sciences – Beyond Statistics", "Data Value", and "Formalisation and Formalism".

Knowledge: "Knowledge is created from a subjective combination of different attainments as there are intuition, experience, information, education, decision, power of persuasion and so on, which are selected, compared and balanced against each other, which are transformed, interpreted, and used in reasoning, also to infer further knowledge. Therefore, not all the knowledge can be explicitly formalised. Knowledge and content are multi- and inter-disciplinary long-term targets and values. In practice, powerful and secure information technology can support knowledge-based works and values." [Rückemann et al. 2015]

Computing: "Computing means methodologies, technological means, and devices applicable for universal automatic manipulation and processing of data and information. Computing is a practical tool and has well defined purposes and goals." [Rückemann et al. 2015]

Data-centric: "The term data-centric refers to a focus, in which data is most relevant in context with a purpose. Data structuring, data shaping, and long-term aspects are important concerns. Data-centricity concentrates on data-based content and is beneficial for information and knowledge and for emphasizing their value. Technical implementations need to consider distributed data, non-distributed data, and data locality and enable advanced data handling and analysis. Implementations should support separating data from technical implementations as far as possible." [Rückemann et al. 2016]

Big Data: "The term Big Data refers to data of size and / or complexity at the upper limit of what is currently feasible to be handled with storage and computing installations. Big Data can be structured and unstructured. Data use with associated application scenarios can be categorised by volume, velocity, variability, vitality, veracity, value, etc. Driving forces in context with Big Data are advanced data analysis and insight. Disciplines have to define their 'currency' when advancing from Big Data to Value Data." [Rückemann et al. 2016]

Data science: "Qualified Data, especially for an enterprise, represents frozen knowledge or in other words frozen value. The abilities to understand and manage these data is what we call data science. Data results from action, hence, data science can be defined secondary to data. The essence of Data Science is to give qualified access to relevant data to owners and users. Hardware and software and their implementation represent the tertiary level of qualified and high level data." [Rückemann et al. 2017]

Data value: "Data value is the primary ranked value in scenarios comprised of data and computing context. In general, processing of data, is the cause for computing. In consequence, data, including algorithms and other factual, procedural, and further knowledge, have to be ranked primary on the scale of values whereas machinery for processing data, including computing, are providing means of secondary ranked value. In addition, further values, including economic values, can be associated with consecutive deployment of data and machinery. (This is unaffected by varying views and attributions, including quality. Nevertheless, different views can scale values.)" [Rückemann et al. 2018]

Formalisation: "Formalisation is the process of creating a defined set of rules, allowing a formal system to infer theorems from axioms. Formal systems may represent well-defined systems of abstract thought. Description and analysis of any detail of any more or less complex system and physical background essentially require a formalisation process. The process includes abstraction and reduction of knowledge, keeping the preconditioned importance of respective context. Consequently, formalisation should be created and context observed by educated experts within the respective discipline. (All mathematical-machine based systems, e.g., computers, are formal systems. Ideologies should be kept outside of formalisation.)" [Rückemann et al. 2019]

Systematical View on Knowledge: FCPM Complements and Instruments

The complements of knowledge (FCPM, factual, conceptual, procedural, metacognitive knowledge) and corresponding example implementations are shown in Table 2.

Table 2: Complements of knowledge and example implementations.

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

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 2013].

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. A structured object or system is sometimes called a structure.

Be aware of the etymological background:
structura (Latin) :: fitting together, adjustment, building, a building, edifice, structure.
struere (Latin), structus (past participle) :: pile up, arrange, assemble, build.
Dome / domí, δομή; domes, δομές (pl.) (Greek) :: structure, construction (physical, social, political).
Domus (Latin) :: house.

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.

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.

Prehistory to Future

All of the examples, objects, entities, and respective conceptual knowledge references' excerpts are taken from The Prehistory and Archaeology Knowledge Archive (PAKA), DIMF, 2020 [Rückemann 2019a]. Table 3 is showing an illustrative overview of the major divisions and a range of excerpts, from 'prehistory to future'. Conceptual knowledge references are introduced by an 'UDC:' marker.

Table 3: Divisions and example range of consistent conceptual knowledge references, from ‘prehistory to future’.

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
UDC:001	Science and knowledge in general
UDC:113	General laws of nature. Transformation and transience of matter. *Origin of the universe. Creation. Cosmogony*
...	
UDC:903	*Prehistory. Prehistoric remains, artefacts, antiquities*
UDC:902	*Archaeology*
UDC:904	Cultural remains of historical times
UDC:93/94	*History*
...	
UDC:001.18	*Future of knowledge*

Advanced knowledge resources, e.g., collections and containers, built with objects and entities can provide an integration of representations of knowledge complements. Therefore, targetting long-term sustainability, knowledge resources can enable an integration of complexities for universal, multi-disciplinary knowledge in a consistent way.

For example, arbitrary length objects and arbitrary number of objects and entities with multi-line formatting (Listings 1 and 2) can be preserved. Scale and number of referenced objects are not limited by the methodology. A small excerpt of a knowledge resources’ object entry (Listing 1) for the ‘Swimming Reindeer’ [Cook 2015] shows some respective features. The representation of the multi-line formatted object can include excerpts of factual knowledge, conceptual knowledge references, georeferences, and citation references. The conceptual knowledge also carries relevant and characteristic relations for the objects.

```
Swimming Reindeer    [Prehistory]:
                     Prehistoric mammoth ivory scrimshaw work.
                     Location: Montastruc region, France.
                     LATLON: 44:06:07N, 01:17:41E
                     Object:              Swimming Reindeer.
                     Object-Type:         Realia object.
                     Object-Age:          (about) 11,000 B.C.E.
                     Object-Location:     Montastruc, France.
                     Object-Relocation: British Museum, UK.
                     %%IML: UDC-Object:[903+903.2]+(44)+(4)+(23)
                     %%IML: UDC-Relocation:069.51+(41)+(4)+(23)
                     %%IML: cite: YES 20161226 {LXK:mammoth ivory; scrimshaw; Holocene}
                       {UDC:903:"323"} {PAGE:--24..--25} LXCITE://Cook:2015:Reindeer
```

Listing 1: Knowledge resources’ object (‘Swimming Reindeer’): Multi-line formatting, conceptual knowledge, facet, and georeferences (excerpt, LX Knowledge Resources, DIMF).

The following excerpt (Listing 2) shows a an entry, a multi-line object representation of an object, which refers to natural sciences, geology, and archaeology.

```
Nisyros              [Volcanology, Geology, Archaeology]:
```

```
                     Volcano, Type: Strato volcano, Island,
                     Country: Greece, Subregion Name: Dodecanese Islands,
                     Status: Historical, Summit Elevation: 698\UD{m}. ...
                     Craters: ..., VNUM: 0102-05=, ...
                     %%IML: UDC:[911.2+55]:[930.85]:[902]"63"(4+38+23+24)=14
                     %%IML: UDC:[912]
                     %%IML: media:...{UDC:[911.2+55]:"63"(4+38+23)=14}...jpg
                     Stefanos Crater, Nisyros.
                     LATLON: 36.578345,27.1680696
                     %%IML: GoogleMapsLocation: https://www.google.com/...@36
                      .578345,27.1680696,337m/...
                     Little Polyvotis Crater, Nisyros.
                     LATLON: 36.5834105,27.1660736 ...
```

Listing 2: Knowledge resources' object ('Nisyros'): Multi-line formatting, conceptual knowledge, media object entities, and georeferences (excerpt, LX Knowledge Resources, DIMF).

The excerpt shows a representation of a 'Nisyros' multi-line formatted object, including respective conceptual knowledge references, media object entities, and georeferences.

Example Cases and Conditions

There are a number cases of prominent and characteristic content / context challenges and long-term issues.

In ***prehistory and protohistory***, information science content and context differ from disciplines with significant historical documentation, in order to list a few: Information on realia is often lost. Information on context is often lost, isolated, or scattered. Historical sources cannot be used in the vast majority of cases. Language-based context is rarely available / preserved. Contextualisation is difficult to achieve. Cognition and insight require and allow multi-disciplinary approaches. Cognition and insight can foster inter- / trans-disciplinary achievements. Realia objects often require special precautions and long-term documentation – and are beyond classical written sources. All participating disciplines, services, and resources have to be prepared for challenges as big data, critical data, accessibility, longevity, and usability.

In ***archaeology***, in context of historical sources, information science content and context show the characteristic: Overall information is widely distributed. Sometimes it can be very difficult and a long lasting challenge not only to create information but even to get access to a few suitable information sources. Digital and realia objects are affected. All participating disciplines, services, and resources have to be prepared for challenges as big data, critical data, accessibility, longevity, and usability.

In both, archaeology of prehistoric and of historic context, the challenges go along with the fact, that even best practice cannot fully preserve realia and data context, context is often destroyed, long-term issues are immanent, and currently there is neither a standard available and used for one discipline nor an international or multi-disciplinary standard. Some essential differences between ***pre- and protohistory*** and ***archaeology in context of historical sources*** may be named, including specialities, goals, and approaches: The search for prehistoric insight can benefit from natural sciences, realia sources, logical / logos-based approaches. Archaeology often benefits from historical sources, realia sources, and further approaches. There is need for an integrated knowledge base for prehistory, archaeology, natural sciences, and humanities. A technical-only approach may target the necessity to collect data from central data centers or registers. Examples of prehistorical, archaeological, and geophysical data [National Park Service 2013] are the North American Database of Archaeological Geophysics (NADAG) [NADAG 2020], the Center for Advanced Spatial Technologies (CAST) [CAST 2020], and the Archaeology Data Service (ADS) [ADS 2020], records as with Center of Digital Antiquity [DigitalAntiquity 2020], and records as with the Digital Archaeological Record (tDAR) [tDAR 2020].

In ***medicine***, information science content and context go along with long-term challenges, e.g., documentation, natural sciences data integration, catalogs (International Classification / Catalog of Diseases, ICD) and universal classification (Universal Decimal Classification, UDC) may require consistent link references, data security, privacy, and anonymity. In ***libraries*** environments, information science content and context go along with long-term challenges, e.g., documentation, catalogues, universality of classification (Universal Decimal Classification, UDC, today about 150,000 libraries are using UDC classification and implementing information systems herewith), referencing, search, and licensing. ***Concordances*** are an important means of bridging implementations when facing heterogeneous realisations and features. For example, this publication / keynote may be associated with various implementations (e.g., Universal Decimal Classification, UDC; American Mathematical Society Mathematics Subject Classification, AMS MSC; Physics and Astronomy Classification Scheme, PACS; ITHEA International Scientific Society), to some extent more or less appropriate:

UDC: 903; 902; 904; 0; 001; 004; 004.01; 004.62; 001.891; 001.92; 021; 165.5; (0.034).

PACS: 02.70.Hm; 89.70.Eg; 93.85.Bc.

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

ITHEA: E.0; I.0; H.1.1; F.2; F.4; F.3.

For many aspects, e.g., formalisation, consistency, and meaning, regarding processing, reuse, knowledge complements, locality, and algorithms it is even preferable to deal with knowledge at the most universal level. If that is not achieved, then tackling and breaking consistency is afoot. Avoiding failure means we have to target knowledge and conceptual implementations in practice.

Knowledge and Conceptual Implementations

The Universal Decimal Classification (UDC) [UDCS 2012] 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. The Universal Decimal Classification (UDC) is a general plan for the knowledge classification. UDC is a hierarchical decimal classification system that divides the main knowledge fields into 10 main categories (numbered from 0 to 9). Each field is in turn divided into 10 subfields, each subfield is inturn divided into 10 subsubfields, and so on. A more extensive classification code in general describes a more specific subject. UDC-based references in this publication are taken from the multi-lingual UDC summary [UDCS 2012] released by the UDC Consortium (Creative Commons license) [Creative Commons 2012]. The classification deployed for a universal documentation [Rückemann 2012] must be able to describe any object with any relation, structure, and level of detail. Objects include any media, textual documents, illustrations, photos, maps, videos, sound recordings, as well as realia, physical objects such as museum objects. "Facetted" and "multi-disciplinary" is synonym to the Universal Decimal Classification (UDC) [UDCC 2012]. UDC uses a special notation in order to indicate aspect. These descriptions are called facets. In multi-disciplinary object context a facetted classification does provide advantages over enumerative concepts. Facets can be created with any auxiliary tables.

Means to achieve overall efficient realisations, even for complex scenarios: Principles of Superordinate Knowledge, integrating arbitrary knowledge. Core assembly elements of Superordinate Knowledge are methodology, implementation, and realisation [Rückemann 2020b]. Comprehensive focussed subsets of conceptual knowledge provide excellent modular, standardised complements for information systems component implementation, e.g., environmental information management and computation [Rückemann 2018b]. Following references' excerpts are taken from The Prehistory and Archaeology Knowledge Archive (PAKA), DIMF, 2020 [Rückemann 2019a].

As different scenarios (Figure 1), e.g., discovery processes, may require manual and automatable characteristics we will take a look into organisation and procedural deployment with what we call conceptual knowledge reference forks.

Code / Sign Ref.	*Verbal Description (EN)*
UDC:5	Mathematics and natural sciences
UDC:51	Mathematics
UDC:53	Physics
UDC:55	Earth Sciences. Geological sciences
UDC:550	Earth sciences
UDC:550.3	Geophysics
UDC:551.2	Internal geodynamics (endogenous processes)
UDC:551.24	Geotectonics
UDC:9	Geography. Biography. History
UDC:902	Archaeology
UDC:903	Prehistory. Prehistoric remains, artefacts, antiquities
UDC:904	Cultural remains of historical times

Figure 1: Conceptual Knowledge Pattern Matching: Relevant UDC reference implementations [UDCS 2012] regarding the respective matching process, illustrating discovery paths in the decimally organised structure of conceptual knowledge, starting with main tables.

The procedural deployment of conceptual knowledge reference forks [Rückemann 2020a] is illustrated by the Conceptual Knowledge Forks Diagram (CKFD), which can be used to represent a discovery process (Figure 2).

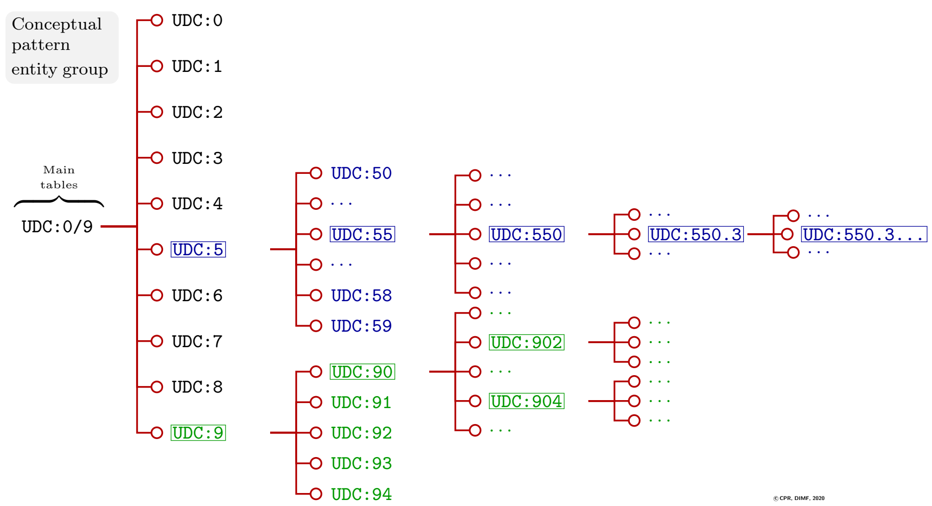

Figure 2: Conceptual Knowledge Pattern Matching: Relevant UDC reference implementations [UDCS 2012] regarding the respective matching process, illustrating discovery paths in the decimally organised structure of conceptual knowledge, starting with main tables.

Resulting Conceptual Knowledge Reference Implementation (CKRI)

The implemented Conceptual Knowledge Reference Implementation (CKRI) as used for pre- and protohistory and arbitrary, universal context from natural sciences to humanities, comprise major divisions of main references. The results are shown in the following excerpts of a core subset. Verbal descriptions are available in 50 languages. The excerpts show verbal descriptions in English language.

CKRI: Universal, main

In these example implementation, universally consistent conceptual knowledge is based on UDC code references for demonstration, spanning the main tables [UDC Consortium 2020h] shown in Table 4.

Table 4: CKRI: Implemented UDC code references, main tables.

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

CKRI: Archaeology, Prehistory, Geography

Major references of geography, biography, history [UDC Consortium 2020e], including prehistory, archaeology, and cultural remains are shown in Table 5.

Table 5: CKRI: Implemented UDC code references of geography, biography, history (excerpt).

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

CKRI: Mathematics and Natural Sciences

Major references of mathematics and natural sciences [UDC Consortium 2020d] are shown in Table 6.

Table 6: CKRI: Implemented UDC code references of mathematics and natural sciences (excerpt).

Code / Sign Ref.	*Verbal Description (EN)*
UDC:51	Mathematics
UDC:52	Astronomy. Astrophysics. Space research. Geodesy
UDC:53	Physics
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:551.21	Vulcanicity. Vulcanism. Volcanoes. Eruptive phenomena. Eruptions
UDC:551.24	Geotectonics
UDC:551.7	Historical geology. Stratigraphy
UDC:551.8	Palaeogeography
UDC:56	Palaeontology
UDC:57	Biological sciences in general
UDC:58	Botany
UDC:59	Zoology

CKRI: Computer Science and Technology, Computing, Data Processing

Major references of computer science and technology [UDC Consortium 2020a] are shown in Table 7.

Table 7: CKRI: Implemented UDC code references of computer science and technology, computing, . . . (excerpt).

Code / Sign Ref.	*Verbal Description (EN)*
UDC:004.2	Computer architecture
UDC:004.22	Data representation
UDC:004.3	Computer hardware
UDC:004.4	Software
UDC:004.41	Software engineering
UDC:004.42	Computer programming. Computer programs
UDC:004.43	Computer languages
UDC:004.45	System software
UDC:004.49	Computer infections
UDC:004.51	Display interface
UDC:004.52	Sound interface
UDC:004.55	Hypermedia. Hypertext
UDC:004.58	User help
UDC:004.62	Data handling
UDC:004.63	Files
UDC:004.65	Databases and their structures
UDC:004.67	Systems for numeric data
UDC:004.7	Computer networks
UDC:004.75	Distributed processing systems
UDC:004.8	Artificial intelligence
UDC:004.91	Document processing and production
UDC:004.92	Computer graphics
UDC:004.93	Pattern information processing
UDC:004.94	Simulation

CKRI: Auxiliaries of Time

Major references from the auxiliaries of time [UDC Consortium 2020g] are shown in Table 8.

Table 8: CKRI: Implemented UDC code references, auxiliaries of time (excerpt).

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

CKRI: Auxiliaries of Spatial Features and Place

Table 9 shows an excerpt of major auxiliaries of spatial features and place implementation of references [UDC Consortium 2020c].

Table 9: CKRI: Implemented UDC code references of auxiliaries of spatial features and place (excerpt).

Code / Sign Ref.	*Verbal Description (EN)*
UDC:(1)	Place and space in general. Localization. Orientation
UDC:(2)	Physiographic designation
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)	North and Central America
UDC:(8)	South America
UDC:(9)	States and regions of the South Pacific and Australia. Arctic. Antarctic

The UDC provides references based on the common auxiliaries of place of the UDC [UDC Consortium 2020c] as excerpted here for facets of place and space, physiographic designation, and places from ancient to modern world.

Tables 10 and 11 provide example excerpts of relevant main conceptual knowledge and details of UDC references used for conceptual mapping. For conceptual knowledge of place and spatial context the implementations requires to provide references to classification codes.

CKRI: Auxiliaries of Boundaries and Spatial Forms

Table 10 shows an excerpt of the major implementation of references of an auxiliary subdivision for boundaries and spatial forms [UDC Consortium 2020c].

Table 10: CKRI: Implemented UDC code references: Auxiliaries of boundaries and spatial forms (excerpt).

Code / Sign Ref.	*Verbal Description (EN)*
UDC:(1-0/-9)	Special auxiliary subdivision for boundaries and spatial forms of various kinds
UDC:(1-0)	Zones
UDC:(1-1)	Orientation. Points of the compass. Relative position
UDC:(1-2)	Lowest administrative units. Localities
UDC:(1-3)	Larger unit within the state
UDC:(1-4)	Units of highest (state) level. Nations. States. Confederations
UDC:(1-5)	Dependent or semi-dependent territories
UDC:(1-6)	States or groupings of states from various points of view
UDC:(1-7)	Places and areas according to privacy, publicness and other special features
UDC:(1-8)	Location. Source. Transit. Destination
UDC:(1-9)	Regionalization according to specialized points of view

CKRI: Auxiliaries of Physiographic Designation

Table 11 shows an excerpt of the major implementation of references of an auxiliary subdivision for physiographic designation [UDC Consortium 2020c].

Table 11: CKRI: Implemented UDC code references of spatial features / place: Auxiliaries of physiographic designation (excerpt).

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

CKRI: Auxiliaries of Form

Table 12 shows an excerpt of the major implementation of references of an auxiliaries of form [UDC Consortium 2020b].

Table 12: CKRI: Implemented UDC code references of auxiliaries of form (excerpt).

Code / Sign Ref.	*Verbal Description (EN)*
UDC:(0.02)	Documents according to physical, external form
UDC:(0.03)	Documents according to method of production
UDC:(0.034)	Machine-readable documents
UDC:(0.04)	Documents according to stage of production
UDC:(0.05)	Documents for particular kinds of user
UDC:(0.06)	Documents according to level of presentation and availability
UDC:(0.07)	Supplementary matter issued with a document
UDC:(0.08)	Separately issued supplements or parts of documents
UDC:(01)	Bibliographies
UDC:(02)	Books in general
UDC:(03)	Reference works
UDC:(04)	Non-serial separates. Separata
UDC:(05)	Serial publications. Periodicals
UDC:(06)	Documents relating to societies, associations, organizations
UDC:(07)	Documents for instruction, teaching, study, training
UDC:(08)	Collected and polygraphic works. Forms. Lists. Illustrations. Business publ.
UDC:(09)	Presentation in historical form. Legal and historical sources
UDC:(091)	Presentation in chronological, historical form. Historical presentation.
UDC:(092)	Biographical presentation
UDC:(093)	Historical sources
UDC:(094)	Legal sources. Legal documents

CKRI: Auxiliaries of Language

Table 13 shows an excerpt of the major implementation of references of an auxiliary subdivision of language [UDC Consortium 2020f].

Table 13: CKRI: Implemented UDC code references of auxiliaries of language (excerpt).

Code / Sign Ref.	*Verbal Description (EN)*
UDC:=1	Indo-European languages of Europe
UDC:=11	Germanic languages
UDC:=12	Italic languages
UDC:=13	Romance languages
UDC:=14	Greek (Hellenic)
UDC:=15	Celtic languages
UDC:=16	Slavic languages
UDC:=17	Baltic languages
UDC:=2	Indo-Iranian, Nuristani (Kafiri) and dead Indo-European languages
UDC:=21	Indic languages
UDC:=29	Dead Indo-European languages (not listed elsewhere)
UDC:=3	Dead languages of unknown affiliation. Caucasian languages
UDC:=35	Caucasian languages
UDC:=4	Afro-Asiatic, Nilo-Saharan, Congo-Kordofanian, Khoisan languages
UDC:=5	Ural-Altaic, Palaeo-Siberian, Eskimo-Aleut, Dravidian and Sino-Tibetan
UDC:=521	Japanese
UDC:=531	Korean
UDC:=541	Ainu
UDC:=6	Austro-Asiatic languages. Austronesian languages
UDC:=7	Indo-Pacific (non-Austronesian) languages. Australian languages
UDC:=8	American indigenous languages
UDC:=81	Indigenous languages of Canada, USA and Northern-Central Mexico
UDC:=82	Indigenous languages of western North American Coast, Mexico and Yucatï£¡n
UDC:=84	Ge-Pano-Carib languages. Macro-Chibchan languages
UDC:=85	Andean languages. Equatorial languages
UDC:=86	Chaco languages. Patagonian and Fuegian languages
UDC:=88	Isolated, unclassified Central and South American indigenous languages
UDC:=9	Artificial languages
UDC:=92	Artificial languages for use among human beings. Int. aux. languages (interlanguages)
UDC:=93	Artificial languages used to instruct machines. Programming/computer languages

CKRI: Operations, Creating Facets, Groups, and References

Table 14 shows common standardised operations with UDC, which can be used with the creation of facets [UDCS 2020]. Facets can be part of the conceptual knowledge of knowledge resources objects as already shown.

Table 14: CKRI: Standard UDC code operations.

Operation	*Symbol*
Addition	+
Consecutive extension	/
Relation	:
Order-fixing	::
Subgrouping	[ ]
Non-UDC notation	*
Alphabetic extension	A-Z

Table 15 shows some basic examples including facets. Ellipses (". . .") indicate reduced depth of shown references.

Table 15: Examples of conceptual knowledge references.

Example Code / Sign Ref.	*Example Description*
UDC:311:903[622+669](4)	Statistics of prehistoric mining and metallurgy in Europe
UDC:004.38:[550.8+903+902]	(Computer) simulation referring to geophysics, prehistory, and archaeology
UDC:[903]:"323"	Prehistoric remains referring to autumn/fall
UDC:7. . .(36)	Prehistoric art in the regions of the so-called barbarians
UDC:[903]:7. . .	Prehistoric remains referring to art, . . .
UDC:53/55	From physics and chemistry, crystallography, mineralogy to earth sciences, geological sciences

The references, e.g., classification, facets, concordances, and textual description, are usable in all the procedures and steps and allow to consider and implement arbitrary flexibility of fuzziness. Entry points to relevant and associated knowledge may be in any disciplinary context due to the consistent framework of the UDC and the multi-disciplinary and multi-lingual Knowledge Resources. In our practical research projects and implementations, deploying a modular integration of consequent knowledge resources' components and their development with means of conceptual knowledge pattern matching have proven to enable valuable solutions for challenging and complex cases in described disciplines and arbitrary context.

Conclusion

It was shown that conceptual knowledge approaches can enable sustainable long-term knowledge creation, development, and integration. The knowledge resources created and developed are successfully used in many application scenarios for more than three decades, including the resources on pre- and protohistory, archaeology with historical context, geosciences, natural sciences, and humanities.

Special focus was taken on universality (multi-disciplinarity, multi-linguality, attributation, time, space, relocation, . . .), consistency (methodologies, methods, approaches, and practice, especially editions), and long-term sustainability (decades, centuries). When dealing with challenges regarding these issues we must be aware that any formalisation means abstraction and reduction. The more, it is important to implement every step knowing that a 'solid' implementation of information science tasks, e.g., information processing require a 'solid' understanding of information science fundaments. Therefore, any software and hardware supported approaches should be considered tools. Especially, we should always remember that formal systems and algorithms are tools, that knowledge itself cannot be created by formal systems, and that algorithms can neither be intelligent nor create intelligence. A recommended best practice is that procedural implementations should not be done without serious consideration of other knowledge complements, respective methodologies, and structural fundaments.

Among many disciplines, prehistory is unique in a way that in many cases neither common approaches using direct comparisons to documented contexts in presence nor historical sources can be used, not for the creation of new insight, not for documenting knowledge objects. Information science can provide long-term strategies and solutions such as demonstrated. A solution for universality, consistency, and long-term sustainability can be provided by recognising knowledge complements being assets of information science. Based on that we can provide solutions to application scenarios and these can provide fundaments for creating new instruments.

Therefore, further recommendations are to consequently foster scientific research, fundamental, epistemologic background – insight, universality, consistency, and sustainability. We should keep in mind that many disciplines, especially prehistory, provide a higher potential of creating insight from multi-disciplinary scientific research. We should enable contextualisation and cognitive insight and create and provide instruments based on knowledge-based standards. We should ensure to enable continuity while creating knowledge-centric, modular implementations and we should consider knowledge targetting implementation aspects, in this context knowledge-centricity, data-centricity, concordances, structure, processing, and computing. In summary, we should involve experienced, dedicated experts in these fields.

When dealing with knowledge and information, participated parties should learn how to decide on multi-dimensional aspects of knowledge complements, how to decide on intrinsic and extrinsic (information) properties, how to deploy logic / logos, how to deploy knowledge complements and conceptual knowledge references, about the hermeticism of 'quality'.

Concrete future research with the presented long-term projects will focus on prehistory knowledge resources, contextualisation, multi-disciplinary perspectives, and documentation.

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Author's Information

Dr. rer. nat. Claus-Peter Rückemann – *Westfälische Wilhelms-Universität Münster (WWU), Münster, Germany; Unabhängiges Deutsches Institut für Multi-disziplinäre Forschung (DIMF), Germany; Leibniz Universität Hannover, Hannover, Germany; Chair of the Board on Advanced Computing and Emerging Technologies and Chair of the Symposia Board, International Academy, Research, and Industry Association; Senior Researcher; Scholar; Senior Lecturer Information Science, Security, and Computing at Leibniz Universität Hannover; IARIA Fellow;*
e-mail: ruckema @ uni-muenster.de
Major Fields of Scientific Research: Information science, prehistory, protohistory, archaeology, geophysics, knowledge-based methodologies, cognostics, logic systems, decision making, geoscientific information systems, mathematics, high end computing, supercomputing.