Allow Knowledge to Prevail: Complements in Information Modelling and Prehistorical Archaeology Cases – Fact-based Contextualisation of Cultural Heritage and Historico-cultural Contexts

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Abstract: *Knowledge complements are a core foundation, a central fundament, when targeting theoretical and practical knowledge. Knowledge complements are inherent with knowledge and all of its contexts. Information modelling based on knowledge complements is not a mono-dimensional venture. Knowledge complements enable fact-based, sustainable contextualisation and analysis. Information modelling in multi-disciplinary contexts, e.g., integrating prehistorical archaeology, natural sciences, and humanities, requires solid methodological approaches and overall systematic courses of action. However, knowledge complements are often successfully neglected, in theory and daily practice. The hiatus in methodological practice between disciplines may mostly result from hermeticism in artificially limited dimensionalism. The more, contextualisation of cultural heritage and historico-cultural contexts, e.g., in prehistorical archaeology, enable fact-based methods and reveal the multi-disciplinary character. Understanding knowledge and structure are essential information science assets for realistic, efficient, and sustainable practice in many scientific disciplines. Starting point for structured data comprehension in theory and practice are the scientists and researchers. Prehistorical archaeology does provide numerous relevant and exemplary cases for employment and integration of multi-disciplinary knowledge, structure, and scientific methods, for gaining new insight and cognition. This paper presents methodological and epistemological fundaments of an advanced multi-disciplinary group of cases of fact-based contextualisation of cultural heritage and historico-cultural contexts in prehistorical archaeology.*

Keywords: *Prehistory; Archaeology; Information Science; Information Modelling; 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.*

DOI*: https://doi.org/10.54521/ijita30-02-p01*

Introduction

Understanding and applying knowledge and structure are essential information science assets. This is the more important when we develop methodological fundaments and have to create and implement theoretical foundations for implementing and realising realistic, efficient, and sustainable practice in many scientific disciplines.

However, information science fundaments and background are often neither understood and taught nor practically respected. Society, academy, education are commonly reacting with simplification and training instead of education. All developments up to now, in data management and deployment, culminate in structure.

We can react with the insight that we have to start far before getting into technical aspects or implementations of application software. Further, knowing that knowledge is not the output or result of a tool and that that ‘information processing’ should be addressed via context of knowledge complements. This should also be true whenever addressing information, e.g., with gathering, filtering, compression of information but also whenever discussing hermetical criteria like quality and optimisation. Nevertheless, we require education for solid information science fundaments, knowledge complements’ integration, and information science based methods. Starting point for structured data comprehension in theory and practice are the scientists and researchers. Prehistorical archaeology does provide numerous relevant and exemplary cases for employment and integration of multi-disciplinary knowledge, structure, and scientific methods, for gaining new insight and cognition.

This paper presents methodological and epistemological fundaments of an advanced multi-disciplinary group of cases of fact-based contextualisation of cultural heritage and historico-cultural contexts in prehistorical archaeology. The methodology allows a wide range of methods to be implemented but in no case should the methodology be addressed a technological approach. Anyhow, we can experience this has become practice more often seen nowadays. It should be emphasised that the disciplines are themselves responsible for creating and developing their theoretical and practical foundations, their methodological fundaments, including the implementations of the resulting methods – every discipline bar none. Nevertheless, when well done, some methodological fundaments may also be useful to other disciplines.

The following sections will introduce into the core basic fundaments and present an excerpt of the essential knowledge related aspects of the methodological approach and an example of successful, sustainable implementations and realisations. These topics have been publicly presented and discussed [Rückemann 2023c]. Please do not expect to find the guide to implement this and different solutions inside this paper. This paper is not a substitute for own practice and experiences. The keys to these are in the cited publications and the referenced theoretical and practical fundaments and documentation of methods, complements, components, and standards, which overall comprises of many ten thousands of pages.

Background and Fundaments – Information, Sciences, Knowledge

From a methodological point of view, the complements of knowledge (FCPMS, factual, conceptual, procedural, metacognitive, structural knowledge) and corresponding example implementations [Rückemann et al. 2021a; Rückemann 2021a, 2020c] are shown in Table 1.

Table 1: Complements of knowledge and corresponding 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 . . .
. . .	⇔	. . .

Based on Knowledge Mapping, [Rückemann 2018a], the fundamental works of Aristotle and Platon's Phaidon [Aristotle 2008b] [Aristotle 2009] [Aristotle 2005], and the extensions of Anderson and Krathwohl [Anderson and Krathwohl 2001]), expertise and skills were compiled in a Best Practice and Definitions Series 'In 80 Words Around The World', created in the Delegates' Summits during The Symposium on Advanced Computation and Information in Natural and Applied Sciences (SACINAS), 2015–2023.

- **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** [Rückemann et al. 2019]
- **Cognostic Addressing of Structure** [Rückemann et al. 2021b]
- **Quality** [Rückemann et al. 2022]
- **Algorithm and Algorithm Signification** [Rückemann et al. 2023]

On the background it can be beneficial to understand the insights and timeless lore from the collection of six Aristotelian opera, which was compiled in later times and became well established under the name 'Organon', [Aristotle 2008a,c,f,e,g,d], and which comprises the fundamental aspects of knowledge, logic, and analytics.

The relevance of the fundamental concepts may be illustrated by a central example. As Aristotle recognises:

a) mental experience → spoken words: spoken words are symbols of mental experience

b) spoken words → written words: written words are symbols of spoken words

What can we learn from this? These putatively 'simple' statements include that we have to be aware of at least two different formalisation processes from mental experiences to written words. This includes that we have a first group of abstraction and reduction processes and after that a second group of abstraction and reduction processes. The two formalisation processes also have different characteristics regarding their properties. The mapping process is not 'bijective', too. The insights have essential consequences of what can be done on the instances or respective symbols. Their understanding is significant because it refers to the general facilities of any type of tools, may it be an algorithm, procedure, and workflow however it is and will be called, e.g., artificial 'intelligence' or 'generative pre-trained transformer'. The application cases in state-of-the-art buzz scenarios are countless. No what so ever 'tool' can overcome these principles but with the methodological employment of knowledge complements we can create solid frameworks providing efficient and scalable solutions, which can be optimally tailored for scenarios in flexible ways. We need to define some basic notions in order to build some common understanding for these topics and examples.

Data is not Information is not Knowledge. 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 [Rückemann 2017].

Definition: Information science is the science of information in theory and practice.

Fundaments The essential fundaments of information science are information and philosophy.

Information are aspects of knowledge, e.g., facts or details, supplied to or learned by someone.
(Latin) formatio :: formation, construction, arrangement, "creation".

Even common and widely known dictionaries and thesauri are most inconsistent and do not provide even basically consistent notions for terms like knowledge, informations, and data for advanced and further use. We can further describe Information Science by its targets, focus, the field it comprises and those associated and interlinked.

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.

In a holistic view, the significance of knowledge should be considered top level.

1. **Episteme** (Greek: $\acute{\varepsilon}\pi\iota\sigma\tau\acute{\eta}\mu\eta$), refers to "knowledge", "understanding", "science".
2. **Techne** (Greek: $\tau\acute{\varepsilon}\chi\nu\eta$), "craft", "art".
3. **Doxa** (Greek: $\delta\acute{o}\xi\alpha$), from "to appear", "to seem", "to accept", "to think".

Understanding the holistic, multi-disciplinary significance of knowledge means that episteme, techne, and doxa are not different disciplines and they are not different types of support for something. These three terms are inherent in every discipline and target to be addressed. The discipline of Information Science comprises all the named theoretical and practical aspects in its curriculum and beyond [Rückemann 2023e,f] and provides links to mostly all scientific disciplines dealing with knowledge in one or the other way.

Knowledge Modelling: Reference Implementations and Resources

Two major practical reference implementations were deployed for full implementations, realisations, and continuous further developments: The latest versions of the prehistory-protohistory and archaeology Conceptual Knowledge Reference Implementation (CKRI) (E.0.4.8) [Rückemann 2022c] and the Component Reference Implementations (CRI) framework (E.0.3.9) [Rückemann 2022a] for conceptual knowledge-based context integration, complements processing, and geoscientific visualisation. The fundaments –non-technical and practical component frameworks– [Rückemann 2021a], have recently been recognised and selected by Hyperion Research as one group of six impactful research endeavors worldwide, for inclusion in the 2023 Hyperion Research special report on recent High-Performance Computing (HPC) centric AI success stories [Sorensen and Joseph 2023] (AI, "Artificial Intelligence"). The special report emphasises the epistemologically relevant methodological fundament 'The Conceptual Knowledge Reference Implementation' (CKRI) and 'The Component Reference Implementations framework' (CRI), providing sustainable standard component groups for implementation.

CKRI provides the universal knowledge framework, including multi-disciplinary contexts of natural sciences and humanities [Rückemann 2020c].

CRI provides the required component groups and components for the implementation and realisation of all the procedural modules. The reference implementations are based on the fundamental methodology of knowledge complements [Rückemann 2020a], considering that many facets of knowledge, including prehistory, need to be continuously acquired and reviewed [Gleser 2023].

Creating contextualisation requires to coherently integrate multi-disciplinary knowledge and to enable symbolic representations [Rückemann 2023b]. Realisations need to integrate a wide range of components as required from participating disciplines, e.g., for dynamical processing, geoprocessing, spatial contextualisation.

Prehistoric object groups and contexts are taken from the latest edition of PAKA, which is in continuous development for more than three decades [Rückemann 2019], and from The Natural Sciences KR (NatSciKR), all released by DIMF [PAKA 2023].

The PAKA and The NatSciKR support FCPMS complements (Factual, Conceptual, Procedural, Metacognitive, Structural knowledge) [Rückemann 2021a] and enable seamless coherent multi-disciplinary conceptual knowledge integration for workflow procedures. systematical and methodological approaches based on CKRI. CKRI references are illustrated for demonstration via the multilingual UDC summary [UDCS 2012] released by the UDC Consortium under Creative Commons licence [Creative Commons 2012].

Collaborative interfaces, e.g., The Archaeological Data Collector (ADC) [ADC 2023], were developed and established for archaeological survey contributions and are used for ongoing data integration and analysis.

CKRI allows a number of standard operations. Standardised operations with CKRI are given in Table 2, for demonstration with this research implemented supporting UDC auxiliaries .

Table 2: The Conceptual Knowledge Reference Implementation (CKRI) operation signs excerpt, integrating UDC Common Auxiliary Signs (English comments version).

Operation	*Symbol*
Coordination. Addition	“+”
Consecutive extension	“/”
Simple relation	“:”
Order-fixing	“::”
Subgrouping	“[ ]”
Introduce non-UDC notation	“*”
Direct alphabetical specification / extension	“A-Z”
[Reference listing, itemisation]	“;”
[Reference listing, sub-itemisation]	“,”

Further auxiliary groups are place, time, nationality, language, form, and characteristics. The Universal Decimal Classification (UDC) [UDCS 2012] used in this example 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. Today about 150.000 institution are using UDC classification and implementing information systems herewith. UDC schedules are organised as a coherent system of knowledge with associative relationships and references between concepts and related fields. CKRI references in this publication, demonstrated via UDC auxiliaries, are referencing the multi-lingual UDC summary [UDCS 2012] released by the UDC Consortium (Creative Commons lic.) [Creative Commons 2012]. 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 have already provided excellent modular, standardised complements for information systems component implementations, e.g., environmental information management & computation [Rückemann 2018b].

Context and Content in Archaeology and Prehistorical Archaeology

Context and content in archaeology has a number of dependencies, e.g., in general, in archaeology:

- Overall information is widely distributed.
- Sometimes 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.
- All participating disciplines, services, and resources have to be prepared for challenges as big data, critical data, accessibility, longevity, and usability.

In prehistorical archaeology and related disciplines the situation can be even more complex:

- Information on realia is often and widely 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/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. . . .

However, both face long-term issues, including technological approaches / digitisation:

- Even best practice cannot fully preserve realia and data context.
- Context is often destroyed.
- Long-term issues.
- Currently neither a standard being used for one discipline nor an international standard. . . .

Specialities, goals, and essential differences for prehistorical archaeology and archaeology in general are multifold:

- Prehistory – context focus natural sciences, realia sources, ‘logos’ (Greek), . . .
- Archaeology – context focus historical sources, realia sources, . . .
- Need of integrated knowledge base for prehistory, archaeology, natural sciences, and humanities.
- Necessary to collect data from central data centers or registers.

  Examples prehistorical, archaeological, and geophysical data:

  - North American Database of Archaeological Geophysics (NADAG).
  - Center for Advanced Spatial Technologies (CAST).
  - Archaeology Data Service (ADS).
  - Records as with Center of Digital Antiquity.
  - Records as with the Digital Archaeological Record (tDAR).
  - Limited resources, domain approaches, museum reference models, . . .
- Complementary knowledge based approaches.
- Integration methodologies (e.g., superordinate knowledge methodologies, “collaboration house” framework) can support many relevant aspects. . . .

Clearly, technology-only approaches themselves cannot provide sustainable solutions. Further background and fundaments have been laid out with previous research on prehistorical contexts, information science, cognition, and contextualisation [Rückemann 2020c, 2021b].

Resulting Factual and Conceptual Complements Blueprint: Contexts and Workflow Logic

Prehistorical archaeology discipline’s resulting contexts and workflow logic are often matter of multi-disciplinary long-term research, which requires universal context identification and assignment to contributing scientific disciplines. The discipline’s factual and conceptual knowledge complements and major logical and formal entities resulting from the long-term surveys and practical implementations are given in Table 3. All knowledge context references’ excerpts are taken from The Prehistory and Archaeology Knowledge Archive (PAKA) [Rückemann 2019] as released by DIMF, 2021 to 2023 [PAKA 2021, 2023]. Procedural knowledge was recently addressed methodologically and an implementation was created. The realisation led to fascinating new insight [Rückemann 2023g] and can be employed for many application scenarios for the analysis of symbolic correlation and insight. Further research was conducted on coherent multi-disciplinary analysis and contextualisation based on CKRI and components of the CRI framework, which enable to contextualise and analyse complex knowledge in efficient and effective ways [Rückemann 2024]. Addressing coherent multi-disciplinary knowledge further enables wider fact-based historico-cultural analysis.

Table 3: Implemented contextualisation: Factual/conceptual matrix for major complements and components in prehistory, archaeology, and contexts (excerpt).

Context / Discipline / Object Group	*Logical / Formal Entities*	*Symb. Repr. (Example)*	*Structure Impl. (Example)*
Factual / Conceptual Domain (Focus Complements: FCPMS)			
Hybrid	(Spatial) structure	Signature / cpt	netCDF, GMT, LX PSCC
		HR DEM	netCDF, GMT, LX PSCC
		SRTM	netCDF, GMT, LX PSCC
		LiDAR	netCDF, GMT, LX PSCC
Point	Singular structure	Signature / Symbol	xyz, GMT, LX PSCC
Prehistorical archaeology		PAKA	xyz, GMT, LX PSCC
Settlements		PAKA	xyz, GMT, LX PSCC
Ritual places		PAKA	xyz, GMT, LX PSCC
Notable objects		PAKA	xyz, GMT, LX PSCC
Geophysics		NatSciKR	xyz, GMT, LX PSCC
Impact craters		NatSciKR	xyz, GMT, LX PSCC
Planetology		NatSciKR	xyz, GMT, LX PSCC
Plate tectonics features		NatSciKR	xyz, GMT, LX PSCC
Geology		NatSciKR, PAKA	xyz, GMT, LX PSCC
Mineral resources		NatSciKR, PAKA	xyz, GMT, LX PSCC
Pedology		NatSciKR	xyz, GMT, LX PSCC
Soil characteristics		NatSciKR	xyz, GMT, LX PSCC
Volcanology		NatSciKR	xyz, GMT, LX PSCC
Volcanological features		NatSciKR	xyz, GMT, LX PSCC
Speleology		NatSciKR, PAKA	xyz, GMT, LX PSCC
Caves		NatSciKR, PAKA	xyz, GMT, LX PSCC
Oceanography		NatSciKR, GSHHG	xyz, GMT, LX PSCC
Bathymetry features		NatSciKR	xyz, GMT, LX PSCC
Hydrology		NatSciKR	xyz, GMT, LX PSCC
Mobility, transport		PAKA	xyz, GMT, LX PSCC
Pre-modern trackways		PAKA	xyz, GMT, LX PSCC
Linguistics		PAKA	xyz, GMT, LX PSCC
Open field names		PAKA	xyz, GMT, LX PSCC
Geography		NatSciKR	xyz, GMT, LX PSCC
Humanities, administrative		NatSciKR, DCW	xyz, GMT, LX PSCC
...	...	...	...
Line / Polygon	Linear structure	Signature	xyz, GMT, LXPSCC
Prehistorical archaeology		PAKA	xyz, GMT, LXPSCC
...	...	...	...
Polygon	Areal structure	Signature	xyz, GMT, LX PSCC
Prehistorical archaeology		PAKA	xyz, GMT, LX PSCC
...	...	...	...
Bathymetry features		GSHHG, DEM	xyz, GMT, LX PSCC
Administrative features		DCW	xyz, GMT, LX PSCC

The excerpts refer to the recent research on prehistorical archaeology and Holocene volcanological features and fact-based contextualisation of cultural heritage and historico-cultural Contexts [Rückemann 2023d] [Rückemann 2023a] [Rückemann 2022d] [Rückemann 2022b]. The fundamental frameworks for the complements enable implementations and realisations, e.g., coherent multi-disciplinary conceptual integration and parallel processing, e.g., OpenMP, satellite data processing, knowledge processing, and creation of artificial instruments and workflows.

All the complements and components are in continuous further development fully integrated with CKRI, enable georeferencing, and can be used in parallelisation.

Employed resources are High Resolution (HR) Digital Elevation Model (DEM) data, e.g., (Space) Shuttle Radar Topography Mission (SRTM) data [Olson et al. 2016], updates [Tozer et al. 2019], and further satellite data.

Common DEM can be supplemented by local Light Detection And Ranging (LiDAR) data for special features and resolutions. DEM data is used via Network Common Data Form (NetCDF) [NetCDF 2023] developed by the University Corporation for Atmospheric Research (UCAR/Unidata), National Center for Atmospheric Research (NCAR) is used for spatial context data.

KR and complement implementations in contributing contexts and disciplines are PAKA and NatSciKR [PAKA 2023] accompanied by HR Digital Chart of the World (DCW) [Wessel 2022], and Global Self-consistent Hierarchical High-resolution Geography (GSHHG) [Wessel 2017].

The symbolic representation of the contextualisation can be done with a wide range of methods, algorithms, and available components, e.g., via LX Professional Scientific Content-Context-Suite (LX PSCC Suite) [LX PSCC 2023] deploying the Generic Mapping Tools (GMT) and integrated modules [Wessel et al. 2020] for visualisation. The GMT suite application components are used for handling the spatial data, applying the related criteria, and for the visualisation. For sustainability we also consequently employ xyz files in GMT, e.g., Point of Interest (PoI) and Point of Discovery (PoD) contexts. Signatures and Colour Palettes (cpt) can also be flexibly integrated via GMT.

Mostly all contexts and object groups are in continuous development, based on their structural implementations. Also, practically all contexts are dealt with employing the CKRI and its facets and operation facilities. Many properties of the contexts, e.g., chorological and chronological properties, can be addressed using international standards, e.g., for georeferencing and time. The consequent knowledge approach enables a wide range of workflow creation and analysis, in the scenarios discussed here ranging from fact-based contextualisation to consequent fact-based historico-cultural interpretation. The results allow even further consequent creative historico-cultural exploitation.

Resulting Procedural Complements Blueprint: Contexts and Workflow Logic

The discipline’s resulting procedural knowledge complements and the corresponding workflow implementation resulting from the long-term surveys and practical implementations are given in Table 4. The implementations are designed for end-user deployment by members of every of the disciplines dealing with their major logical and formal entities.

The sequence of procedure task modules in the discipline’s workflow are marked in dark blue colour. In this case, the modules (CRI framework) allow to address countless many millions of different procedures for solving problems in the discipline. All the complements and components are in continuous further development fully integrated with CKRI, enable georeferencing, and can be used in parallelisation.

The matrix shows context / object groups, required logical and formal workflow entities (major processing groups pre, main, post), examples of their symbolic representation, structure and procedure implementations.

The table confirms that all contexts and object groups are in continuous further development, including the implementations of knowledge complements, e.g., factual, conceptual, procedural, and structural, which is a major achievement for scientific best practice and sustainability. The characteristics include the contexts addressed with CKRI and georeferencing, as well as the potential of mostly all contexts can be deployed in workflow parallelisation.

The components of the workflow blueprint allow very high flexibility for fact-based methods and context integration of scientific, fact-based symbolic representation, e.g., the symbolic representation of archaeological, prehistorical contexts requires the employment of different geographic projections, e.g., geospherical orthographic, isometrical, and equal area. Projections can be flexibly implemented via GMT [GMT 2023] and via PROJ [PROJ contributors 2023].

Besides the implemented components we already named: The workflow allows processing usable for most disciplines, Area of Interest (AoI) calculations, regular expression patterns for context structures, e.g., via Perl Compatible Regular Expressions (PCRE) [Perl Compatible Regular Expressions 2023]. Attributations not applicable (n.a.) are marked accordingly.

Workflow output, e.g., frames and visualisation can be created for many common structures, e.g., Joint Photographic Experts Group (JPG), Portable Network Graphics (PNG), and Portable Document Format (PDF), as well as Motion/Moving Pictures Expert Group, version 4 (MP4). Transformation can also be done for Keyhole Markup Language generation. Multi-dimensional or sequences of view, e.g., focus dependent views for knowledge dimensional computation per object, are implemented via OpenMP [Dagum and Menon 1998] and specifications [OpenMP Architecture Review Board 2020], e.g., . Job parallel procedures, e.g., knowledge objects and resources localities, are supported by respective modular solutions [GNU Parallel 2023].

Table 4: Blueprint of prehistorical archaeology discipline’s workflow logic: Resulting procedural contextualisation matrix, from FC (Table 3), implemented for major complements and components, including parallel frame conversion (excerpt).

Context / Discipline / Object Group	*Logical / Formal Entities*	*Symb. Repr. (Example)*	*Struc. / Proc. Impl. (Example Complement / Environment)*
	Procedural Domain (Focus Complements: FCPMS)		
Selection, preparation (KR)	Pre-processing	Pre-routines	CKRI, PCRE, . . . / LX PSCC
Context resources	Pre-processing	Pre-routines	netCDF, CKRI, PCRE, . . . / LX PSCC
Sequence	Pre-proc., timing structure	Parameter	[FCPMS] / GMT, LX PSCC
Procedure modules	Main processing	Main-routines	[FCPMS)], . . .
Contextualisation Scenario	Integration	Hybrid	. . . / GMT, LX PSCC . . .
Observer path	Path / project	Line	xyz / GMT, LX PSCC
Observer track	Track / project	Line	xyz / GMT, LX PSCC
AoI	Selection, cut	Area	netCDF, xyz / GMT, LX PSCC
Sampling	Resampling	[Raster]	netCDF / GMT, LX PSCC
Canvas mapping	Basemap	[Mapping]	netCDF / GMT, LX PSCC
Gridding	Grid operations, . . .	[Grid]	netCDF / GMT, LX PSCC
Illumination	Height	Singular	netCDF / GMT, LX PSCC
Math operations	Calculation	[Algorithm]	. . . / GMT, LX PSCC
Triangulation	Calculation	[Algorithm]	. . . / GMT, LX PSCC
Regression	Calculation	[Algorithm]	. . . / GMT, LX PSCC
Colour	Colourisation	[Sequence]	cpt / GMT, LX PSCC
Filtering	Selection, select	[Decimation]	. . . / GMT, LX PSCC
Movie module	Iteration, . . .	Parameter	. . . / GMT, LX PSCC
Proc. of knowledge compl.	Calculation	[Algorithm]	CKRI, PCRE, . . . / LX PSCC
Spatial proc. of preh. ctxts.	Selection, calculation	[Algorithm]	CKRI, PCRE / GMT, . . ., LX PSCC
Events	Symbolic, functional	Symb. repr.	CKRI, PCRE / GMT, . . ., LX PSCC
Arbitrary symbols	Symbolic, functional context	Symb. repr.	[vector graphics] / GMT, LX PSCC
Degenerated ellipses	Azimuthal	Area	xyz / GMT, LX PSCC
Range	Azimuthal	Area	xyz / GMT, LX PSCC
Projection	Geospherical, orthographic	[Algorithm]	. . . / GMT, PROJ, LX PSCC
. . .	. . .	. . .	. . .
Resource usage (main proc.)	Main proc., parallelisation	Frame, view	. . . / OpenMP, GNU parallel, LX PSCC
	On-scratch processing	Various	. . . / OpenMP, GNU parallel, LX PSCC
	Model reduction frame, anim.	Various	. . . / GMT, (LX PSCC)
	Live frame control	Various	JPG, PNG, PDF / (LX PSCC)
Transform., symbolic repr.	Post-processing, batch	Post-routines	Scales, KML, . . . / LX PSCC
Visualisation, analysis	Post-processing, interactive	Image, Video	PNG, MP4, . . . / LX PSCC

Discipline’s Workflow: Parallelisation and Results

Table 5 shows the scalability of the example workflow procedure for parallelised processing parts (pre, timing; main, parallelisation; post, batch) of the coherent multi-disciplinary conceptual knowledge. The results are referring to a scenario of a set of 1440 frames created in parallel for 4 k canvas size for a 60 s sequence with a rate of 24 FPS (Frames Per Second). The architecture chosen for this realisation is an efficient 36-core-based Central Processing Unit (CPU) (Intel Xeon), which is taking into account that we commonly use 36 cores for many basic global approaches, e.g., considering 360 degrees of a global model. Precondition for parallelisation is sufficient memory for parallel use of integrated resources. Considering the employed resources, especially SRTM / NetCDF and KR, 128 GB RAM (Random Access Memory) for 36 parallel processes is comfortable when data limits are cut to the limits required for the algorithms with the range of a few hundred kilometres area per object entity.

Table 5: Scalability of discipline’s workflow (example runs, parallelised processing KR and context resources).

Threads (Cores)	*Wall Time*				
	Pre, Timing	*Main, Parallel*	*Post, Batch*	Σ*(Pre, Main, Post)*	
1	1145 s	2581175 s	84972 s	2667292 s	≈741 h
18	526 s	143668 s	4759 s	143668 s	≈40 h
36	262 s	71833 s	2386 s	74481 s	≈21 h

The parallel instances are allowed for 90 GB HDD (Hard Disk Drive) space and separate 50 GB SSD (Solid State Disk) space for highly volatile data of parallel instances. Wall and compute times, especially of multi-dimensional workflow results, can greatly be reduced from the integrated parallelisation, which makes the procedural solution highly scalable. The wall times for thread numbers confirm the high scalability when implementations of the workflow are using higher numbers of threads.

Many practical workflows may contain some parts which cannot be reasonably parallelised. This is especially true for scientific tasks with a certain complexity. Anyhow, the percentage of non parallelised parts is very low with CKRI and the CRI framework. However, individual instances may show non-linear characteristics due to instance content and references, e.g., different satellite data, different data types, and different knowledge complements.

For large sets, hundreds up to thousands of CPU cores were employed, so parallelised wall times per object can be very reasonably reduced from days to hours or even minutes, e.g., for warning and tracking systems. The following results from the above discipline workflow show an excerpt of eight frames from a large frame sequence for calculated Areas of Interest (AoI) contexts in top views (Figure 1). Ellipsoid is World Geodetic System 84 (WGS-84). Projection for frames is Lambert Azimuthal Equal Area. The resolution is drastically reduced for use in this publication.

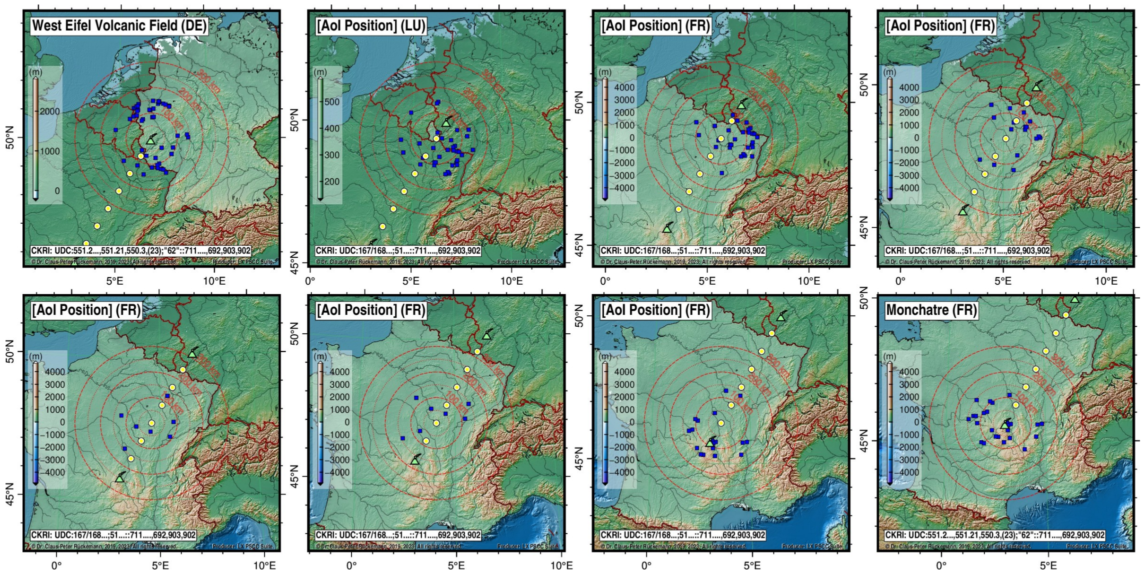

Figure 1: Discipline workflow results of prehistoric settlement infrastructures in factual and historico-cultural chorological and chronological contexts with a volcanological features group (maars, Holocene-historical) and satellite data based on the coherent conceptual knowledge integration and discovery (excerpt) [Rückemann 2022b].

Generated representations include integrated CKRI references, projection of topographic and bathymetric results, and further knowledge for respective areas, based on the coherent conceptual knowledge. The frame sequence of symbolic representations enable to contextualise named factual data, here [Rückemann 2022c]:

- CKRI: UDC:551.2. . .,551.21,550.3,(23);“62” and
- UDC:167/168. . .;51. . . referring to
- CKRI: UDC:711.. . .,692,903,902
- for 150 km radii.

Major multi-disciplinary results are the shown insights regarding the details of prehistoric settlement infrastructures / Holocene maars for which we find larger numbers of prehistorical settlements were set and used in the volcanic regions Eifel (DE) and Auvergne (FR) areas than in the other areas, all of which can be precisely assigned and further contextualised. Ongoing analysis and discussion of the multitude of resulting historico-cultural significance will be given in later publications.

Discipline’s workflow: Frame Conversion Benchmark

The number of parallel cores used for the making of individual frames can be efficiently controlled. The parallel processing itself does not depend on OpenMP. Table 6 gives the dimensions of canvas sizes for an excerpt of common formats, represented by pixel (px) scales. The given formats High Definition (HD), Ultra High Definition (UHD), Ultra Extended Graphics Array (UXGA), Extended Graphics Array (XGA), and Super XGA Plus (SXGA+) are commonly used in resources development and practical high resolution workflows.

Table 6: Canvas sizes and formats used in practical case scenario implementations and realisations (Table 4, excerpt).

Canvas Size (px)	*Format*	
	Format 16:9 (e.g., 24×13.5 cm)	
7680 × 4320	UHD-2	8 k
3840 × 2160	UHD	4 k
1920 × 1080	HD	
	Format 4:3 (e.g., 24×18 cm)	
1600 × 1200	UXGA	
1400 × 1050	SXGA+	
1024 × 768	XGA	

The conversion of frames can be done in parallel using GraphicsMagick [GraphicsMagick 2023]. GraphicsMagick includes Gnu’s Not Unix (GNU) libgomp [GNU libgomp 2023] of the GNU Offloading and Multi-Processing Project (GOMP). Table 7 shows the frame conversion benchmark results for different canvas sizes as used in the parallel implementations of practical case scenarios.

Table 7: Frame conversion benchmark results for canvas sizes used in parallel implementations of practical multi-disciplinary case scenario workflows of archaeological / prehistorical contextualisation (Table 4, excerpt).

Threads	*Iterations*	*User Time*	*Elapsed Time*	*Iterations / s*	*Iterations / CPU*	*Speedup*	*Karp-Flatt*
			7680 px × 4320 px (UHD-2)				
1	2	10.56 s	10.563899 s	0.189	0.189	1.00	1.000
18	26	138.39 s	10.094287 s	2.576	0.188	13.60	0.019
36	41	220.25 s	10.067891 s	4.072	0.186	21.51	0.019
			3840 px × 2160 px (UHD)				
1	8	10.62 s	10.625725 s	0.753	0.753	1.00	1.000
18	104	141.39 s	10.075150 s	10.322	0.736	13.71	0.018
36	166	233.24 s	10.056526 s	16.507	0.712	21.92	0.018
			1024 px × 768 px (XGA)				
1	82	10.08 s	10.078310 s	8.136	8.135	1.00	1.000
18	1191	179.99 s	10.007169 s	119.015	6.617	14.63	0.014
36	1856	358.52 s	10.001333 s	185.575	5.177	22.81	0.017

The results compare number of threads, iterations, user time, total time, iterations per second, iterations per CPU, speedup, and Karp-Flatt result. The conversion uses a common 128×128 granite texture pattern (px) iteration for standardisation. The benchmark uses the Karp-Flatt metric [Karp and Flatt 1990], which is a measure of code parallelisation in parallel processor systems. The resulting implementation is very scalable and can use practical workflow parallelisations from small canvas sizes up to defined sizes even beyond UHD-2. Sizes of UHD are very appropriate for many HR scenarios with commonly available technical infrastructures while being relatively efficient with resources and infrastructures.

Lessons Learned

Coherent multi-disciplinary conceptual knowledge can be efficiently and effectively employed for complex solutions, for gaining new insight and providing long-term fundaments for comprehension and future insight. Multi-disciplinary research, especially, in prehistorical archaeology, geosciences, natural sciences, and humanities benefits from advanced conceptual knowledge approaches. Further, the methodologies enable sustainable long-term coherent multi-disciplinary knowledge development and integration. Complex multi-disciplinary case solutions can be based on creating reference implementations, e.g., for prehistoric archaeology, geosciences, natural sciences, and humanities. Experiences showed that knowledge centric structures are essentially important for prehistorical and archaeological contexts and analysis. This is true for sustainability of research results, reuse and further development of knowledge in all contributing disciplines. Implementations and realisations have shown that a balanced integration of knowledge complements and application components can provide sustainable solutions for targeted application scenarios. Anyhow, long-term sustainable multi-disciplinary solutions require an information science level of understanding knowledge complements including structure: 'intelligence' and knowledge are not 'in' and do not come 'with' or 'from' the technology. In result, all disciplines have to learn the strengths and limitations of (all of) the knowledge complements, application components, and methods employed.

Taking Aristotle's principles and the experiences of this long-term research into consideration, researchers should beware of 'explaining' with formalisation and from formalisation, creating "life-like" and "intelligence" perceptions when dealing with and talking of formalisation results, fixing, describing, defining, up to meanings, unreflected digitisation, semantics, metrics, and ideologies with applications and standards, the more when the contexts are beyond personal expression. With advanced complex scenarios, researchers should beware of limiting methodological work solely to object-oriented, relational, or hierarchical formalisation approaches, beware of everything-is-events views, beware of limiting general approaches to integration and exchange, beware of pathetic claims "Does save years of thinking . . .", beware of (creating) neologisms and mixing up fundaments, and beware of supporting to create a 'religion' from methodologies, which are always clearly tools and should be based on facts.

Conclusions

The long-term surveys and knowledge resource projects have shown that knowledge complements are excellent means for flexible and efficient information modelling. The cases of practical fact-based and coherent multi-disciplinary prehistorical archaeology contextualisation have contributed to new implementations and realisations and provide new fact-based insights for historico-cultural contexts and cultural heritage.

The essential multi-disciplinary achievements and implementations were enabled by the comprehensive in-development reference implementations consequently employed, namely The prehistory-protohistory and archaeology Conceptual Knowledge Reference Implementation (CKRI) and The Component Reference Implementations (CRI) framework. It has further been confirmed by the research and learned from experiences that information science and long-term strategies are important for solutions to complex multi-disciplinary scenarios, especially:

- Structure is essential for complementary knowledge integration benefits.
- Structure carries relevant information.
- Structured data creation and development (including data gathering) are strategic assets.
- Consideration of multi-disciplinary contexts needs to be planned and implemented accordingly.
- Researchers need to learn and understand the psychology of false / fake claims.
- Researchers need to learn and understand the psychology of whatever claims done for attention.
- Target of sustainable multi-disciplinary research should be knowledge-centricity, not data-centricity, which implicitly means research on knowledge should not be data-driven.
- Disciplines should create and employ long-term Knowledge Resources.
- Disciplines should create and employ suitable reference systems based on long-term standards.
- Knowledge-based integration allows knowledge transfer for new insight.
- Knowledge-based integration allows selection criteria for scenarios.
- Requirements should be analysed based on information science fundaments, not on technology only.
- Sustainably stable definitions and consecutive best practices are beneficial for long-term developments.
- Achievements in information deduction (including extraction) should be documented accordingly.
- Researchers should always explicitly, factually, conservatively, and truthfully state the limitations of approaches and components they focus on.

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 targeting 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 coherent multi-disciplinary knowledge framework and realise new component reference implementations and creating knowledge reference based solutions for scenarios and disciplines. Practical scenario focus will be put on prehistorical archaeology, soil science, and historico-cultural analysis.

Acknowledgements

This ongoing research is supported by scientific organisations and individuals. We are grateful to the "Knowledge in Motion" (KiM) long-term project, Unabhängiges Deutsches Institut für Multi-disziplinäre Forschung (DIMF), for partially funding this research, implementation, case studies, and publication under grants D2022F1P05308, D2020F1P05228, and D2022F2P05355 and to its senior scientific members and members of the permanent commission of the science council, especially to Dr. Friedrich Hülsmann, Gottfried Wilhelm Leibniz Bibliothek (GWLB) Hannover, to Dipl.-Biol. Birgit Gersbeck-Schierholz, Leibniz Universität Hannover, for fruitful discussion, inspiration, and practical multi-disciplinary contextualisation and case studies. We are grateful to Dipl.-Geogr. Burkhard Hentzschel and Dipl.-Ing. Eckhard Dunkhorst, Minden, Germany, for prolific discussion and exchange of practical spatial, UAV, context scenarios, and measurement support. We are grateful to Dipl.-Ing. Hans-Günther Müller, Göttingen, Germany, for providing specialised, manufactured high end computation, storage, and visualisation solutions. We are grateful to The Science and High Performance Supercomputing Centre (SHPSC) for long-term support. / DIMF-PIID-DF98_007; URL: https://scienceparagon.de/cpr .

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