# Coherent Multi-disciplinary and Fact-based Contextualisation: Comprehensive Knowledge Complements and Component Frameworks Employed in Prehistorical Archaeology and Historico-cultural Contexts

Claus-Peter Rückemann
Unabhängiges Deutsches Institut für
Multi-disziplinäre Forschung (DIMF), Germany
Universität Münster, Germany
Leibniz Universität Hannover, Germany
Email: ruckema@uni-muenster.de

Birgit Frida Stefanie Gersbeck
Unabhängiges Deutsches Institut für
Multi-disziplinäre Forschung (DIMF), Germany
Email: info@udimf.de

***Abstract*—This extended paper presents the new results of the methodological fact-based knowledge contextualisation, discovery, and parallelisation of workflow logic of prehistorical archaeology discipline's contextualisation, based on coherent multi-disciplinary conceptual knowledge. This research targets coherent multi-disciplinary and fact-based contextualisation, which can provide important new solutions to the challenges of knowledge discovery in many disciplines. The paper includes the comprehensive knowledge complements and component frameworks employed in prehistorical archaeology and historico-cultural contexts. The practical example implementations based on both the knowledge frameworks and the components framework comprise the contextualisation and canvas conversion benchmarks and enable sustainable and efficient realisations. The goal is the creation of efficient, flexible, and sustainable contextualisation workflows, also providing efficient parallelised frame conversion. Implementations and realisations are enabled by the latest versions of the prehistory-protohistory and archaeology conceptual knowledge reference implementation and the component reference implementations framework. The paper provides the results on archaeological / prehistorical facts, universal contexts, and logical and formal entities, factual, conceptual, and procedural complements, components, and results required for exemplary practical hard criteria and fact-based contextualisation by the disciplines and even for consequent creative historico-cultural context exploitation. Future research will address the creation and further development of a conceptual knowledge reference implementation and a component reference framework for coherent multi-disciplinary conceptual contextualisation, enabling multi-disciplinary equal footing with contributions from all scientific disciplines for example for prehistorical archaeology knowledge integration, contextualisation and analysis with prehistorical and archaeological knowledge resources.**

***Keywords*–Fact-based Contextualisation; Benchmarking; Prehistory and Archaeology; Historico-cultural Interpretation; CKRI and CRI Framework.**

## I. Introduction

This research targets coherent multi-disciplinary and fact-based contextualisation, which can provide important new solutions to the challenges of knowledge discovery in many disciplines. This paper is an extended and updated presentation of new research results, based on the research, publication, and presentation at the DataSys / INFOCOMP 2023 co-located group of conferences in Nice, France [1].

The following sections present the comprehensive knowledge complements and component frameworks employed in prehistorical archaeology and historico-cultural contexts.

The examples show advanced contextualisation reference implementation frameworks and coherent multi-disciplinary conceptual knowledge-spatial context discovery in practice. This goes along with a wider range of new survey result groups of archaeological settlement infrastructures and insights based on practical conceptual facets used for on demand contextualisation and symbolic representation [2].

The theoretical and practical developments of this ongoing research are one group of six impactful research endeavors selected worldwide for the 2023 Hyperion Research special report on recent High-Performance Computing (HPC) centric AI success stories [3] (AI, "Artificial Intelligence"). For the inclusion in the special report, Hyperion names the epistemologically relevant methodological fundament The Conceptual Knowledge Reference Implementation (CKRI) and the The Component Reference Implementations framework (CRI), providing sustainable standard component groups for implementation.

The entirety enables a consistent multi-disciplinary conceptual knowledge contextualisation, especially universal knowledge facets, method integration, flexible workflow definition, and parallelisation on HPC resources.

Due to recent interests and inquiries for practical cases of extended multi-disciplinary contextualisation matrices employing the frameworks for knowledge complements and components, we take the chance that this extended paper concentrates on an extension, on both the practical contextualisation matrix and the components, including a major example of sustainable component parallelisation and its benchmark results.

The need to implement workflows of many disciplines beyond 'manual operation' has been continuously increasing over the last decades. In practice, we can also see a strong motivation for sustainable Knowledge Resources (KR) creation and development and efficient employment of resources, e.g., with high performance computation and storage.

After reading, writing, and arithmetic are established and accepted as general competences, the capabilities of achieving efficient analysis and contextualisation solutions are becoming 'state-of-the-art' increasingly important personal competences in the sciences. Efficiently and sustainably organising and de-isolating knowledge complements, the results of research, within a discipline is at least as important as its short term analysis. These organisation processes cannot refer only to the data if they should be useful for reuse of knowledge and insight. Therefore, such organisation can in no ways be seen technically or being task of third parties without risk of losing the competence on fact-based methods, insight, and interpretation. Additionally, organisation of its knowledge complements is a core scientific matter of any discipline and closely associated with the methods employed, with the ongoing analysis processes, and with the further interpretation potential. In accordance with best practice, any scientists dealing with methodological workflows in a discipline, e.g., when applying a method, should know and practise themselves the way steps can be created, organised, and implemented, e.g., the algorithms, symbolic representation, and the structure and computation related characteristics. This practice is especially relevant with all knowledge complements or in other words the non-technical aspects of workflows in prehistorical archaeology. Scientific work, including state-of-the-art practices in archaeological disciplines and humanities, comprise of a number of essential principles, including further continuous employment of valuation methods for new factual knowledge and insights, re-contextualisation and resources development, and consequent fact-based contextualisation, analysis, and interpretation. When done properly, the tasks including contextualisation allow to practise equal footing with contributing scientific disciplines. Numerous surveys and studies were conducted for archaeological and prehistorical cases and multi-disciplinary contexts during the last decades, e.g., specific object groups' contextualisation [4] and discovery [5] and providing factual knowledge for interpretation, including historico-cultural contexts. The Prehistory and Archaeology Knowledge Archive (PAKA) is continuously collecting [6] new knowledge and insight. This research delivers the respective blueprints resulting from previously unpublished contexts and workflows and efficient workflow implementations proven sustainable over many years and widely reusable.

The rest of this paper is organised as follows. Section II presents the fundaments and state-of-the-art methodological implementations and realisations employed. Section III presents the results of the contexts and workflow logic for processes in prehistorical archaeology, factual/conceptual and procedural complements. Section IV delivers the discipline's results, efficiency results, and discussion for the presented contexts and workflow logic cases. Section V summarises lessons learned, conclusions, and future work.

## II. Fundaments and Previous Work

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) [4], [7] and the Component Reference Implementations (CRI) framework [8], [9] for conceptual knowledge-based context integration, complements processing, and geoscientific visualisation. CKRI provides the universal knowledge framework, including multi-disciplinary contexts of natural sciences and humanities [10]. CRI provides the required component groups and components for the implementation and realisation of all the procedural modules.

Both, the ongoing research on the epistemological [4] and the components base [8] and its implementations were recently published and demonstrated at the Lawrence Livermore National Laboratory (LLNL) [11].

The reference implementations are based on the fundamental methodology of knowledge complements [12], considering that many facets of knowledge, including prehistory, need to be continuously acquired and reviewed [13]. Creating contextualisation requires to coherently integrate multi-disciplinary knowledge and to enable symbolic representations. 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 [14], and from The Natural Sciences KR (NatSciKR), all released by DIMF [6]. The PAKA and The NatSciKR support Factual, Conceptual, Procedural, Metacognitive, Structural (FCPMS) knowledge complements [11] and enable seamless coherent multi-disciplinary conceptual knowledge integration and 'systematical' and methodological approaches based on CKRI for creation and development of workflow procedures. CKRI references are illustrated for demonstration via the multi-lingual Universal Decimal Classification (UDC) summary [15] released by the UDC Consortium under Creative Commons licence [16].

It is important to say that the reader cannot expect to understand the implementations in detail beyond the focus of coherent multi-disciplinary contextualisation of knowledge. We also have to use the precise specification 'coherent multi-disciplinary contextualisation' even as it may appear lengthy to today´s reader. It is as well important to emphasise that the sort order of the terms is significant. Informatics and technology is considered only a minor part of holistic information science. Information sciences can very much benefit from Aristotle's fundaments and a knowledge-centric approach [17] but for building holistic and sustainable solutions, supporting a modern definition of knowledge [18], they need to go beyond the available technology-based approaches and hypothesis [19] as analysed in Platon's Phaidon. The references of the employed components or individual implementations provide several ten thousand pages of documentation and thousands of tiny working examples on plain realisation issues.

For sustainable understanding and implementation by researchers new to these topics, it is recommended to include information science fundaments, e.g., epistemology and logic, during all stages of educational processes of all disciplines. Comprehensive studies of the works of the classical Organon, Categories [20], On Interpretation [21], Prior Analytics [22], Posterior Analytics [23], Topics [24], and On Sophistical Refutations [25] and understanding of logical fallacies [26] can be beneficial as starting points. These works deal with many fundaments required for understanding the being of knowledge, e.g., logic, classification, language, and the fundaments of analysis, and create a base for sustainable implementations and realisations. In most cases, it is also recommended to invest in understanding the discussion of unintelligence [27].

## III. Discipline's 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.

### A. Resulting Factual and Conceptual Complements Blueprint

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 I. Employed resources are High Resolution (HR) Digital Elevation Model (DEM) data, e.g., (Space) Shuttle Radar Topography Mission (SRTM) data [28], updates [29], and further satellite data.

Common DEM can be supplemented by local Light Detection And Ranging (LiDAR) data for special features and resolutions. DEM data for spatial contexts is used via Network Common Data Form (NetCDF) [30], developed by the University Corporation for Atmospheric Research (UCAR/Unidata), [31], National Center for Atmospheric Research (NCAR). [32]

KR and complement implementations in contributing contexts and disciplines are PAKA and NatSciKR [6] accompanied by HR Digital Chart of the World (DCW) [33], and Global Self-consistent Hierarchical High-resolution Geography (GSHHG) [34].

Knowledge context, e.g., targeting symbolism and analysis have been integrated from a wide range of cases and disciplines [35] [36] [37] [38] [39] [40] [41] [42] [43] spanning scenarios over the continents and including object security and verification [44].

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) [45] deploying the Generic Mapping Tools (GMT) and integrated modules [46] for visualisation. The GMT [47] suite application components are used for handling the spatial data (longitude, latitude, elevation), 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. For support of many algorithms and features, suites of full on-site on-premise environments and online environments were created, The LX Professional Scientific Content-Context-Suite (PSCC) [45] integrating The LX Professional Scientific Creation Academic Suite (PSCA) [48] supporting the TeX Live [49] and tool components. A good starting point for new projects is to install and configure the latter online [50], available under MIT licence [51], adding additional modules as required, building individual suites for multi-disciplinary use cases.

Mostly all contexts and object groups are in continuous development, based on their structural implementations. 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, addressing the Chorological Domain (ChDo) and Chronological Domain (CrDo). 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.

### B. Resulting Procedural Complements Blueprint

The discipline's resulting procedural complements (the knowledge complements) and the corresponding workflow implementation resulting from the long-term surveys and practical implementations are given in Table II.

The implementations are designed for end-user deployment by members of every responsible discipline dealing with their major logical and formal entities. 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 table especially lists excerpts of embarrassingly (E) and loosely (L) parallelisation features. Both of these types are considered common features with parallelisation. What is special here is that most features can be implemented in either ways due to the component framework so that realisations can cope with many conditions for different environments.

All the CRI 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 [47] and via PROJ [52].

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) [53]. 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),

TABLE I. PREHISTORICAL ARCHAEOLOGY DISCIPLINE'S CONTEXTS AND LOGICAL / FORMAL ENTITIES: RESULTING FACTUAL / CONCEPTUAL CONTEXTUALISATION MATRIX IMPLEMENTED FOR MAJOR COMPLEMENTS AND COMPONENTS (EXCERPT).

| *Context / Discipline / Object Group* | *Logical / Formal Entities* | *Symb. Repr. (Example)* | *Structure Impl. (Example)* | *In Dev.* | *CKRI* | *Georef.* | *Parallelisation* | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | *E* | *L* |
| *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 | ✓ | ✓ | ✓ | ✓ | ✓ |
| Plate tectonic boundary types | | 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 | ✓ | ✓ | ✓ | ✓ | ✓ |
| Bog and peat characteristics | | NatSciKR | xyz, GMT, LX PSCC | ✓ | ✓ | ✓ | ✓ | ✓ |
| Volcanology | | NatSciKR | xyz, GMT, LX PSCC | ✓ | ✓ | ✓ | ✓ | ✓ |
| Volcanological features | | NatSciKR | xyz, GMT, LX PSCC | ✓ | ✓ | ✓ | ✓ | ✓ |
| Strato volcanoes, maars, ... | | 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 | ✓ | ✓ | ✓ | ✓ | ✓ |
| Rivers | | NatSciKR | xyz, GMT, LX PSCC | ✓ | ✓ | ✓ | ✓ | ✓ |
| Lakes | | NatSciKR, DCW | xyz, GMT, LX PSCC | ✓ | ✓ | ✓ | ✓ | ✓ |
| Mobility, transport | | PAKA | xyz, GMT, LX PSCC | ✓ | ✓ | ✓ | ✓ | ✓ |
| Pre-modern holloways | | PAKA | xyz, GMT, LX PSCC | ✓ | ✓ | ✓ | ✓ | ✓ |
| Pre-modern trackways | | PAKA | xyz, GMT, LX PSCC | ✓ | ✓ | ✓ | ✓ | ✓ |
| Pre-modern bog 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 | ✓ | ✓ | ✓ | ✓ | ✓ |
| Topography features | | NatSciKR | xyz, GMT, LXPSCC | ✓ | ✓ | ✓ | ✓ | ✓ |
| Heights | | NatSciKR | xyz, GMT, LXPSCC | ✓ | ✓ | ✓ | ✓ | ✓ |
| Humanities, politics features | | NatSciKR, DCW | 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 | ✓ | ✓ | ✓ | ✓ | ✓ |
| ... | ... | ... | ... | ... | ... | ... | ... | ... |

as well as Motion/Moving Pictures Expert Group, version 4 (MP4). Transformation can also be done for Keyhole Markup Language generation and interactive clipping zooming [54] [55]. Further preferred workflow components, automation, and features are provided by FFmpeg [56] [57], ImageMagick/-GraphicsMagick [58], GIMP [59], SubRip Subtile File (SRT), and VLC media player [60]. For efficiency of data handling, contextualisation workflows can integrate compression modules supporting multi-threading, e.g., pbzip2, using several streams concatenatable into the resulting output [61].

Multi-dimensional or sequences of view, e.g., focus dependent views for knowledge dimensional computation per object, are implemented via OpenMP [62] and specifications [63]. Job parallel procedures, e.g., for knowledge objects and resources

Table II. Blueprint of Prehistorical Archaeology Discipline's Workflow Logic: Resulting Procedural Contextualisation Matrix, From FC (Table I), 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)* | *In Dev.* | *CKRI* | *Georef.* | *Parallel. E* | *L* |
|---|---|---|---|---|---|---|---|---|
| | | | *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 | ✓ | ✓ | (✓) | (✓) | (✓) |
| Limits to cores | [Integer] | Parameter | … / GMT, LX PSCC | n.a. | n.a. | n.a. | n.a. | n.a. |
| Canvas | [Integer×Integer] | Parameter | … / GMT, LX PSCC | n.a. | n.a. | n.a. | n.a. | n.a. |
| Frames | [Integer] | Parameter | … / GMT, LX PSCC | n.a. | n.a. | n.a. | n.a. | n.a. |
| Display rate | [Integer] | Parameter | … / GMT, LX PSCC | n.a. | n.a. | n.a. | n.a. | n.a. |
| Video product selection | [Type] | Parameter | … / GMT, LX PSCC | n.a. | n.a. | n.a. | n.a. | n.a. |
| 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 | ✓ | ✓ | n.a. | ✓ | ✓ |
| | On-scratch processing | Various | … / OpenMP, GNU parallel, LX PSCC | ✓ | ✓ | n.a. | ✓ | ✓ |
| | Model reduction frame, anim. | Various | … / GMT, (LX PSCC) | ✓ | ✓ | n.a. | ✓ | ✓ |
| | Live frame control | Various | JPG, PNG, PDF / (LX PSCC) | ✓ | ✓ | n.a. | ✓ | ✓ |
| Transform., symbolic repr. | Post-processing, batch | Post-routines | Scales, KML, … / LX PSCC | ✓ | ✓ | n.a. | (✓) | (✓) |
| Visualisation, analysis | Post-processing, interactive | Image, Video | PNG, MP4, … / LX PSCC | ✓ | ✓ | n.a. | (✓) | (✓) |

localities, are supported by respective modular solutions [64]. The implementations under Linux in general showed very efficient, both for OpenMP and GNU Parallel (GNU, Gnu's Not Unix).

### *C. Supporting Varieties of Workflows*

As recommended in the blueprint section, several configurations and developments were added for multi-disciplinary contextualisation scenarios employed for prehistorical archaeology and historico-cultural contexts.

Regarding the large scale and long-term nature of this research, collaborative services, e.g., The Archaeological Data Collector (ADC) [65], were developed and established as interfaces deployed for the support of practical workflows in prehistorical and archaeological surveys and excavations and the further and ongoing development of resources.

In this scenario, ADC is developed in order to provide online interfaces to all participating parties, supporting distributed workflow components, e.g., for collection, standardisation, conversion, verification, integration, and analysis of contributions. The components fully support all relevant sustainable structures, formats, and codes, e.g., American Standard Code for Information Interchange (ASCII), UCS (Universal Character Set) / UTF (UCS Transformation Format), and TEX [49] representations.

The services support structured data and formatted data and are used for archaeological survey contributions, data collection, and for ongoing data integration and analysis. For example, context structures of the contextualisation matrix, which comprise of a large number of disciplines contributions and knowledge complements and can be fully integrated with the PSCC [45] and PSCA [48] suites.

## IV. Discipline's Results and Workflow Efficiency

### A. Discipline's Workflow: Parallelisation and Results

Table III 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).

Table III. Scalability of Discipline's Workflow (Example Runs, Parallelised Processing KR and Context Resources).

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

The architecture chosen for this realisation is an efficient 36-core-based Central Processing Unit (CPU) (Intel® Xeon® CPU E5-2695 v4 at 2.10 GHz), 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. Results for trends on other architectures with same numbers of respective cores should be highly comparable.

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. 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). The foci are 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.

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. Each frame is calculated to represent the contextualisation of knowledge complements under chorological and chronological conditions for 150 km radii. 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 (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) [4], demonstrated via UDC [15].

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.

The workflow results are computed for eight equidistant steps for on-track equal-distance AoI locations (yellow symbols), including prehistoric settlement infrastructures (blue rectangular symbols) and volcanological groups (colored volcano symbols), Holocene-historical maars.

Especially, the connection between the dormant West Eifel Volcanic Field maars and the Auvergne (dormant Monchatre maar) shows comparable prehistoric settlement densities for the volcanic regions. Ongoing analysis and discussion of the multitude of resulting historico-cultural meanings will be given in more extensive consecutive publications.

### B. 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 IV gives the dimensions of canvas sizes for an excerpt of common formats, represented by pixel (px) scales.

Table IV. Canvas Sizes and Formats Used in Practical Case Scenario Implementations (Table II, 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 given formats High Definition (HD), Ultra High Definition (UHD), Ultra Extended Graphics Array (UXGA),

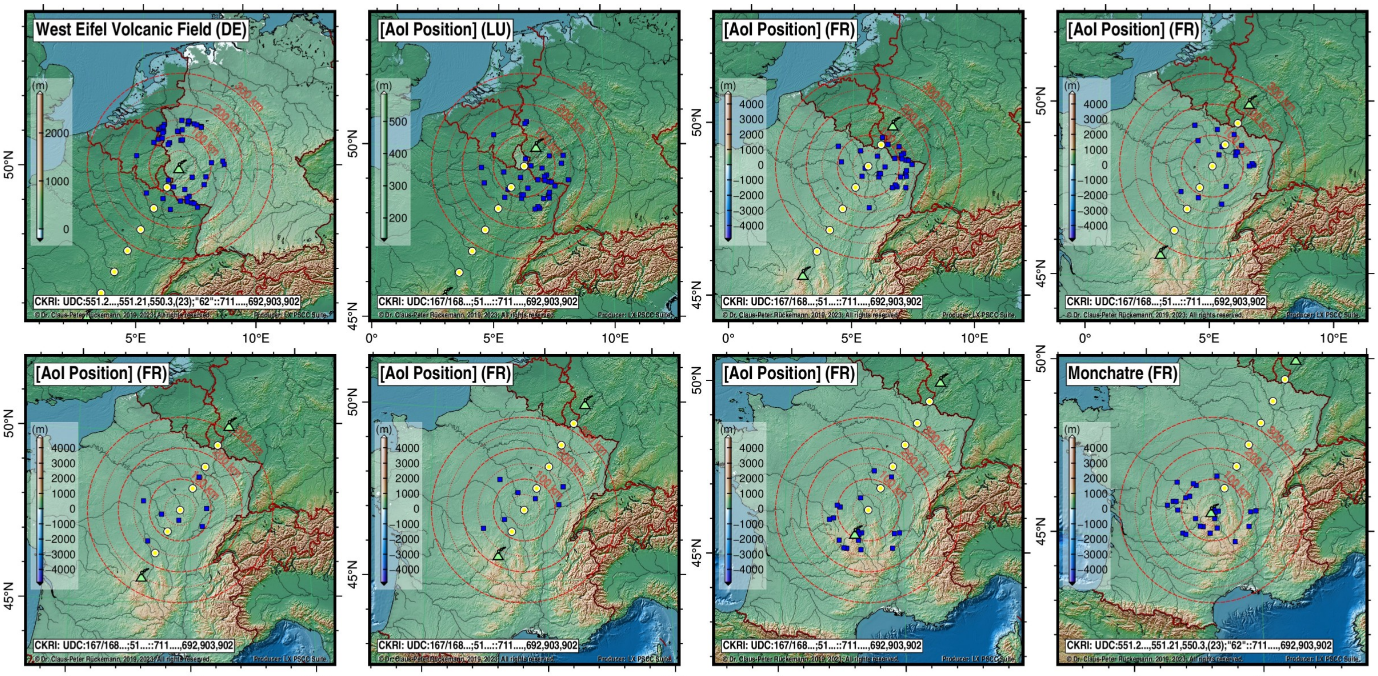


Figure 1. Discipline workflow results of prehistoric settlement infrastructures in factual and historico-cultural chorological and chronological contexts with a volcanological features group (maars, Holocene-historical) and satellite data based on the coherent conceptual knowledge integration and discovery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

Extended Graphics Array (XGA), and Super XGA Plus (SXGA+) are commonly used in resources development and practical high resolution workflows.

The conversion of frames can be done in parallel using GraphicsMagick [58]. GraphicsMagick includes Gnu's Not Unix (GNU) libgomp [66] of the GNU Offloading and Multi-Processing Project (GOMP). All benchmarks were done on a recent Linux multi-core system. Table V shows the frame conversion benchmark results for different canvas sizes as used in the parallel implementations of practical case scenarios.

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 $128 \times 128$ granite texture pattern (px) iteration for standardisation. The benchmark uses the Karp-Flatt metric [67], which is a measure of code parallelisation in parallel processor systems [68].

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.

## V. Conclusion

This extended paper presented the results achieved for the methodological discovery and parallelisation of workflow logic of contextualisation in prehistorical archaeology targeting historico-cultural contexts and based on coherent multi-disciplinary conceptual knowledge. The implemented workflows employed the latest versions of the prehistory-protohistory and archaeology CKRI and the CRI framework. In the center of this research, contextualisation is the target. Contextualisation is not an option. Contextualisation can be dealt with to any depth and width. Therefore, a realisation can take days and even decades of work with ongoing development, which is considered a major benefit for serious knowledge based work. The implemented and realised contextualisation workflows proved efficient, flexible, and sustainable. The presented contexts, entities, and workflow implementations provide solid fact-based fundaments for contextualisation and consequent fact-based historico-cultural interpretation, procedures, which should be deployed by members of the contributing disciplines.

Examples of further realisation are in-time integration of dynamically generated context instances, weather contexts, earthquakes, tsunamis, and wild fires. Full updates can, for example, be shown in about 15–30 minutes per frame view. First response version with reduced context data can be generated in seconds.

Ongoing, the reference implementations and procedures will be extended for generation of symbolic representation for advanced multi-dimensional knowledge models. Future research will address the creation and further development of the prehistory-protohistory and archaeology CKRI and the CRI framework for coherent multi-disciplinary conceptual contextualisation, enabling multi-disciplinary equal footing with contributions from all scientific disciplines, e.g., natural sciences, soil science, and linguistics, especially supporting new advanced methods in prehistorical archaeology for knowledge integration, contextualisation, and analysis.

Table V. Frame conversion benchmark results for canvas sizes used in parallel implementations of practical multi-disciplinary case scenario workflows of archaeological / prehistorical contextualisation (Table II, 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 |
| 4 | 8 | 42.24 s | 11.161860 s | 0.717 | 0.189 | 3.79 | 0.019 |
| 8 | 14 | 74.15 s | 10.476729 s | 1.336 | 0.189 | 7.06 | 0.019 |
| 12 | 19 | 100.79 s | 10.110634 s | 1.879 | 0.189 | 9.93 | 0.019 |
| 16 | 24 | 127.42 s | 10.179369 s | 2.358 | 0.188 | 12.45 | 0.019 |
| 18 | 26 | 138.39 s | 10.094287 s | 2.576 | 0.188 | 13.60 | 0.019 |
| 20 | 28 | 149.43 s | 10.087584 s | 2.776 | 0.187 | 14.66 | 0.019 |
| 24 | 32 | 170.80 s | 10.140287 s | 3.156 | 0.187 | 16.67 | 0.019 |
| 28 | 35 | 187.10 s | 10.011514 s | 3.496 | 0.187 | 18.47 | 0.019 |
| 32 | 39 | 208.90 s | 10.251268 s | 3.804 | 0.187 | 20.09 | 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 |
| 4 | 29 | 38.55 s | 10.156136 s | 2.855 | 0.752 | 3.79 | 0.018 |
| 8 | 54 | 72.25 s | 10.110667 s | 5.341 | 0.747 | 7.09 | 0.018 |
| 12 | 76 | 102.13 s | 10.066204 s | 7.550 | 0.744 | 10.03 | 0.018 |
| 16 | 94 | 128.20 s | 10.001879 s | 9.398 | 0.733 | 12.48 | 0.019 |
| 18 | 104 | 141.39 s | 10.075150 s | 10.322 | 0.736 | 13.71 | 0.018 |
| 20 | 113 | 153.91 s | 10.070419 s | 11.221 | 0.734 | 14.90 | 0.018 |
| 24 | 128 | 176.02 s | 10.071374 s | 12.709 | 0.727 | 16.88 | 0.018 |
| 28 | 141 | 197.50 s | 10.059111 s | 14.017 | 0.714 | 18.62 | 0.019 |
| 32 | 155 | 216.18 s | 10.010670 s | 15.483 | 0.717 | 20.57 | 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 |
| 4 | 313 | 40.03 s | 10.009561 s | 31.270 | 7.819 | 3.84 | 0.014 |
| 8 | 601 | 79.95 s | 10.007529 s | 60.055 | 7.517 | 7.38 | 0.012 |
| 12 | 864 | 119.93 s | 10.000504 s | 86.396 | 7.204 | 10.62 | 0.012 |
| 16 | 1079 | 159.91 s | 10.006024 s | 107.835 | 6.748 | 13.25 | 0.014 |
| 18 | 1191 | 179.99 s | 10.007169 s | 119.015 | 6.617 | 14.63 | 0.014 |
| 20 | 1274 | 199.89 s | 10.003267 s | 127.358 | 6.374 | 15.65 | 0.015 |
| 24 | 1517 | 239.81 s | 10.002562 s | 151.661 | 6.326 | 18.64 | 0.013 |
| 28 | 1674 | 279.97 s | 10.005288 s | 167.312 | 5.979 | 20.56 | 0.013 |
| 32 | 1788 | 319.93 s | 10.001453 s | 178.774 | 5.589 | 21.97 | 0.015 |
| 36 | 1856 | 358.52 s | 10.001333 s | 185.575 | 5.177 | 22.81 | 0.017 |

## Acknowledgements

This paper was deeply gratefully completed in memoriam to our most esteemed friend and scientific fellow colleague, Dipl.-Biol. Birgit Frida Stefanie Gersbeck ((Gersbeck-Schierholz)) (Aug. 14., 1960 – Feb. 2, 2024), who directly contributed to this long-term research. Birgit was a member of the permanent commission and the board of trustees, DIMF, IARIA board member, IARIA Fellow, scientific peer reviewer, and former scientific member of the Leibniz Universität Hannover, Germany. Birgit had dedicated a large part of her scientific career to multi-disciplinary research and providing service to the international scientific community for more than thirty years, having actively contributed to research, results, and success of scientific events and collaborations. Birgit will be unforgotten in our hearts and minds forever!

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, DIMF, 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, Unmanned Aerial Vehicles (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 .

## References


[1] C.-P. Rückemann, "Prehistorical Archaeology Discipline's Contextualisation Facts and Workflow Logic: Complements-Components Blueprints for the Creation of Efficient Coherent Multi-disciplinary Conceptual Knowledge-based Discovery," in Proceedings of The Thirteenth International Conference on Advanced Communications and Computation (INFOCOMP 2023), June 26 – 30, 2023, Nice, France. XPS Press, Wilmington, Delaware, USA, 2023, pp. 7–12, ISSN: 2308-3484, ISBN: 978-1-68558-073-5, URL: https://www.thinkmind.org/index.php?view=article&articleid=infocomp_2023_1_20_60015 [accessed: 2024-05-26].

[2] C.-P. Rückemann, "Coherent Knowledge Structures and Fusion Practice for Contextualisation Insight in Prehistory and Protohistory," in The Eleventh Symposium on Advanced Computation and Information in Natural and Applied Sciences, Proceedings of The 19th International Conference of Numerical Analysis and Applied Mathematics (ICNAAM), September 20–26, 2021, Rhodes, Greece, Proceedings of the American Institute of Physics (AIP), AIP Conference Proceedings 2849, Volume 2849, no. 1. AIP Press, American Institute of Physics, Melville, New York, USA, 2023, pp. 040 001 – 040 004, ISBN: 978-0-7354-4589-5, ISSN: 0094-243X, DOI: 10.1063/5.0162058.

[3] T. Sorensen and E. Joseph, "Recent HPC-centric AI Success Stories," Hyperion Research, Special Report, #HR12.0027.05.02.2023, May 2023, URL: https://hyperionresearch.com/wp-content/uploads/2023/05/Hyperion-Research-HPC-AI-Success-Story-Report-May-2023.pdf [accessed: 2024-05-26] .

[4] C.-P. Rückemann, "Faceting the Holocene-prehistoric Inventory of Volcanological Features Groups Towards Sustainable Multi-disciplinary Context Integration in Prehistory and Archaeology Based on the Methodology of Coherent Conceptual Knowledge Contextualisation," International Journal on Advances in Intelligent Systems, vol. 15, no. 3&4, 2022, pp. 115–129, ISSN: 1942-2679, LCCN: 2008212456 (Library of Congress), URL: http://www.iariajournals.org/intelligent_systems [accessed: 2024-05-26].

[5] C.-P. Rückemann, "Advanced Contextualisation Reference Implementation Frameworks in Practice: Coherent Multi-disciplinary Conceptual Knowledge-Spatial Context Discovery Results from the Holocene-prehistoric Volcanological Features and Archaeological Settlement Infrastructure Surveys," in Proceedings of The Fifteenth International Conference on Advanced Geographic Information Systems, Applications, and Services (GEOProcessing 2023), April 24 – 28, 2023, Venice, Italy. XPS Press, Wilmington, Delaware, USA, 2023, pp. 98–103, ISSN: 2308-393X, ISBN-13: 978-1-68558-079-7, URL: https://www.thinkmind.org/articles/geoprocessing_2023_2_150_30100.pdf [accessed: 2024-05-26].

[6] "The Prehistory and Archaeology Knowledge Archive (PAKA) Licence," 2024, (release 2024), Unabhängiges Deutsches Institut für Multidisziplinäre Forschung (DIMF): All rights reserved. Rights retain to the contributing creators.

[7] C.-P. Rückemann, "Towards Conceptual Knowledge Reference Implementations for Context Integration and Contextualisation of Prehistory's and Natural Sciences' Multi-disciplinary Contexts," International Journal on Advances in Systems and Measurements, vol. 14, no. 1&2, 2021, pp. 113–124, ISSN: 1942-261x, LCCN: 2008212470 (Library of Congress), URL: http://www.iariajournals.org/systems_and_measurements [accessed: 2024-05-26].

[8] C.-P. Rückemann, "Component Framework Implementation and Realisation for Development and Deployment of a Coherent Multi-disciplinary Conceptual Knowledge-based Holocene-prehistoric Inventory of Volcanological Features Groups and Faceting," International Journal on Advances in Intelligent Systems, vol. 15, no. 3&4, 2022, pp. 103–114, ISSN: 1942-2679, LCCN: 2008212456 (Library of Congress), URL: http://www.iariajournals.org/intelligent_systems [accessed: 2024-05-26].

[9] C.-P. Rückemann, "Towards a Component Reference Implementations Frame for Achieving Multi-disciplinary Coherent Conceptual and Chorological Contextualisation in Prehistory and Prehistoric Archaeology," International Journal on Advances in Systems and Measurements, vol. 14, no. 1&2, 2021, pp. 103–112, ISSN: 1942-261x, LCCN: 2008212470 (Library of Congress), URL: http://www.iariajournals.org/systems_and_measurements [accessed: 2024-05-26].

[10] C.-P. Rückemann, "The Information Science Paragon: Allow Knowledge to Prevail, from Prehistory to Future – Approaches to Universality, Consistency, and Long-term Sustainability," The International Journal "Information Models and Analyses" (IJ IMA), vol. 9, no. 3, 2020, pp. 203–226, Markov, K. (ed.), ISSN: 1314-6416 (print), Submitted accepted article: November 18, 2020, Publication date: August 17, 2021, URL: http://www.foibg.com/ijima/vol09/ijima09-03-p01.pdf [accessed: 2024-05-26].

[11] C.-P. Rückemann, "Coherent Knowledge Solutions From Prehistory to Future – Towards Coherent Multi-disciplinary Knowledge Reference Implementation Blueprints for Industrial Learning: Insight from Consistent Coherent Conceptual Integration of Prehistory, Archaeology, Natural Sciences, and Humanities," ML4I – Machine Learning for Industry Forum 2021; High-Performance Computing Innovation Center (HPCIC) and Data Science Institute (DSI), at Lawrence Livermore National Laboratory (LLNL), Aug. 10–12, 2021, Livermore, U.S.A., (Invited Speech), URL: http://www.llnl.gov [accessed: 2024-05-26], 2021.

[12] C.-P. Rückemann, "From Knowledge and Meaning Towards Knowledge Pattern Matching: Processing and Developing Knowledge Objects Targeting Geoscientific Context and Georeferencing," in Proc. GEOProcessing 2020, November 21–25, 2020, Valencia, Spain, 2020, pp. 36–41, ISSN: 2308-393X, ISBN-13: 978-1-61208-762-7.

[13] R. Gleser, Zu den erkenntnistheoretischen Grundlagen der Prähistorischen Archäologie. Leiden, 2023, (title in English: On the Epistemological Fundaments of Prehistorical Archaeology), in: M. Renger, S.-M. Rothermund, S. Schreiber, and A. Veling (Eds.), Theorie, Archäologie, Reflexion. Kontroversen und Ansätze im deutschsprachigen Diskurs, (in print).

[14] C.-P. Rückemann, "Information Science and Inter-disciplinary Long-term Strategies – Key to Insight, Consistency, and Sustainability: Conceptual Knowledge Reference Methodology Spanning Prehistory, Archaeology, Natural Sciences, and Humanities," International Tutorial, DataSys Congress 2020, Sept. 27 – Oct. 1, 2020, Lisbon, Portugal, 2020, URL: http://www.iaria.org/conferences2020/ProgramINFOCOMP20.html [accessed: 2024-05-26].

[15] "Multilingual Universal Decimal Classification Summary," 2012, UDC Consortium, 2012, Web resource, v. 1.1. The Hague: UDC Consortium (UDCC Publication No. 088), URL: http://www.udcc.org/udcsummary/php/index.php [accessed: 2024-05-26].

[16] "Creative Commons Attribution Share Alike 3.0 license," 2012, URL: http://creativecommons.org/licenses/by-sa/3.0/ [accessed: 2024-05-26], (first release 2009, subsequent update 2012).

[17] L. W. Anderson and D. R. Krathwohl, Eds., A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives. Allyn & Bacon, Boston, MA (Pearson Education Group), USA, 2001, ISBN: 978-0801319037.

[18] C.-P. Rückemann, F. Hülsmann, B. Gersbeck-Schierholz, P. Skurowski, and M. Staniszewski, Knowledge and Computing. Post-Summit Results, Delegates' Summit: Best Practice and Definitions of Knowledge and Computing, Sept. 23, 2015, The Fifth Symp. on Adv. Comp. and Inf. in Natural and Applied Sciences (SACINAS), The 13th Int. Conf. of Num. Analysis and Appl. Math. (ICNAAM), Sept. 23–29, 2015, Rhodes, Greece, 2015, pp. 1–7, DOI: 10.15488/3409.

[19] Plato, Phaedo, 2008, (Written 360 B.C.E.), Translated by Benjamin Jowett, Provided by The Internet Classics Archive, URL: http://classics.mit.edu/Plato/phaedo.html [accessed: 2024-05-26].

[20] Aristotle, Categories, 2008, (Written 350 B.C.E.), Translated by E. M. Edghill Provided by The Internet Classics Archive, URL: http://classics.mit.edu/Aristotle/categories.html [accessed: 2024-05-26].

[21] Aristotle, On Interpretation, 2008, Peri Hermeneias, (Written 350 B.C.E.), Translated by E. M. Edghill Provided by The Internet Classics Archive, URL: http://classics.mit.edu/Aristotle/interpretation.html [accessed: 2024-05-26].

[22] Aristotle, Prior Analytics, 2008, (Written 350 B.C.E.), Translated by A. J. Jenkinson Provided by The Internet Classics Archive, URL: http://classics.mit.edu/Aristotle/prior.html [accessed: 2024-05-26].

[23] Aristotle, Posterior Analytics, 2008, (Written 350 B.C.E.), Translated by G. R. G. Mure Provided by The Internet Classics Archive, URL: http://classics.mit.edu/Aristotle/posterior.html [accessed: 2024-05-26].

[24] Aristotle, Topics, 2008, (Written 350 B.C.E.), Translated by W. A. Pickard-Cambridge, Provided by The Internet Classics Archive, URL: http://classics.mit.edu/Aristotle/topics.mb.txt [accessed: 2024-05-26].

[25] Aristotle, On Sophistical Refutations, 2008, (Written 350 B.C.E.), Translated by W. A. Pickard-Cambridge Provided by The Internet Classics Archive, URL: http://classics.mit.edu/Aristotle/sophist_refut.html [accessed: 2024-05-26].

[26] B. Bennett, Logically Fallacious: The Ultimate Collection of Over 300 Logical Fallacies, 1st ed. eBookIt, 2012, ISBN: 978-1-4566-0737-1.

[27] M. Broussard, Artificial Unintelligence, How Computers Misunderstand the World. The MIT Press, Cambridge - Massachusetts, London - England, 2018, ISBN: 978-0-262-03800-3.

[28] C. L. Olson, J. J. Becker, and D. T. Sandwell, "SRTM15_PLUS: Data fusion of Shuttle Radar Topography Mission (SRTM) land topography with measured and estimated seafloor topography," (NCEI Accession 0150537), National Centers for Environmental Information (NCEI), NOAA, 2016.

[29] B. Tozer, D. T. Sandwell, W. H. F. Smith, C. Olson, J. R. Beale, and P. Wessel, "Global Bathymetry and Topography at 15 Arc Sec: SRTM15+," Earth and Space Science, vol. 6, no. 10, Oct. 2019, pp. 1847–1864, ISSN: 2333-5084, DOI: 10.1029/2019EA000658.

[30] "Network Common Data Form (NetCDF)," 2024, DOI: 10.5065/D6H70CW6, URL: http://www.unidata.ucar.edu/software/netcdf/ [accessed: 2024-05-26].

[31] "University Corporation for Atmospheric Research (UCAR)," 2024, URL: https://ncar.ucar.edu/ [accessed: 2024-05-26].

[32] "National Center for Atmospheric Research (NCAR)," 2024, URL: https://www.ucar.edu/ [accessed: 2024-05-26].

[33] P. Wessel, "DCW for GMT 6 or later," 2022, URL: http://www.soest.hawaii.edu/pwessel/dcw/ [accessed: 2024-05-26].

[34] P. Wessel, "GSHHG," 2017, URL: http://www.soest.hawaii.edu/pwessel/gshhg/ [accessed: 2024-05-26].

[35] C.-P. Rückemann and B. F. S. Gersbeck-Schierholz, "Walking With Gods, Scholars, and Caesars in Rodini Park," KiMrise, Knowledge in Motion, September 27, 2013, Circle Summit Workgroup Meeting, "Unabhängiges Deutsches Institut für Multi-disziplinäre Forschung (DIMF)", Rodini Park, Rhodos, Greece, 2013.

[36] B. F. S. Gersbeck-Schierholz and C.-P. Rückemann, "Ageless Elements of Nature - Environments of the Immortals: Rodini Park," KiMrise, Knowledge in Motion, September 27, 2013, Circle Summit Workgroup Meeting, "Unabhängiges Deutsches Institut für Multi-disziplinäre Forschung (DIMF)", Rodini Park, Rhodos, Greece, 2013, URL: https://scienceparagon.de/bgs/bgs_rhodes13_imm.html [accessed: 2024-05-26], URL: https://beckilabs.de/bgs_rhodes13_imm.html [accessed: 2024-05-26], URL: http://www.user.uni-hannover.de/zzzzgers/bgs_rhodes13_imm.html [accessed: 2021-04-30] (Orig.-URL, orphaned link), (Media Presentation).

[37] B. F. S. Gersbeck-Schierholz and C.-P. Rückemann, "Nature in the Light of Gods," KiMrise, Knowledge in Motion, September 27, 2015, Circle Summit Workgroup Meeting, "Unabhängiges Deutsches Institut für Multi-disziplinäre Forschung (DIMF)", Rodini Park, Rhodos, Greece, 2015, URL: https://scienceparagon.de/bgs/bgs_rhyta.html [accessed: 2024-05-26], URL: https://beckilabs.de/bgs_rhodes15_nature.html [accessed: 2024-05-26], URL: http://www.user.uni-hannover.de/zzzzgers/bgs_rhodes15_nature.html [accessed: 2021-04-30] (Orig.-URL, orphaned link), (Media Presentation).

[38] B. F. S. Gersbeck-Schierholz and C.-P. Rückemann, "The Plethora of Rhyta: Art and Use," KiM On-site Summit, Knowledge in Motion, February 25, 2019, On-site Summit Meeting, "Unabhängiges Deutsches Institut für Multi-disziplinäre Forschung (DIMF)", National Archaeological Museum, Athens, Greece, 2019, URL: https://scienceparagon.de/bgs/bgs_rhyta.html [accessed: 2024-05-26], URL: https://beckilabs.de/bgs_rhyta.html [accessed: 2024-05-26], URL: http://www.user.uni-hannover.de/zzzzgers/bgs_rhyta.html [accessed: 2021-04-30] (Orig.-URL, orphaned link), (Media Presentation).

[39] B. F. S. Gersbeck-Schierholz and C.-P. Rückemann, "Life in Sulfuric Environment," KiM On-site Summit, Knowledge in Motion, September 24, 2019, On-site Summit Meeting, "Unabhängiges Deutsches Institut für Multi-disziplinäre Forschung (DIMF)", Nisyros, Greece, 2019, URL: https://scienceparagon.de/bgs/bgs_nisyros.html [accessed: 2024-05-26], URL: https://beckilabs.de/bgs_nisyros.html [accessed: 2024-05-26], URL: http://www.user.uni-hannover.de/zzzzgers/bgs_nisyros.html [accessed: 2021-04-30] (Orig.-URL, orphaned link), (Media Presentation).

[40] C.-P. Rückemann, "Methodology and Integrated Knowledge for Complex Knowledge Mining: Natural Sciences and Archaeology Case Study Results," in Proc. of The 9th Int. Conf. on Adv. Geo. Inf. Syst., Appl., and Serv. (GEOProcessing 2017), March 19–23, 2017, Nice, France. XPS, 2017, pages 103–109, ISSN: 2308-393X, ISBN: 978-1-61208-539-5, URL: http://www.thinkmind.org/index.php?view=article&articleid=geoprocessing_2017_7_10_30036 [accessed: 2024-05-26].

[41] C.-P. Rückemann, "Best Practice 'Golden Spike' Result: Radiocarbon Dating Practice," in Proceedings of The 20th International Conference of Numerical Analysis and Applied Mathematics (ICNAAM), September 19–25, 2022, Heraklion, Crete, Greece . AIP Press, American Institute of Physics, Melville, New York, USA, Apr. 2024, pp. 030 001–1, in: [69], New Methods, Results, and Insights Achieved at The Twelfth Symposium on Advanced Computation and Information in Natural and Applied Sciences, Simos, T. E., G., Tsitouras, C. (eds.), ISBN-13: 978-9925-7552-3-3, ISSN: 0094-243X (American Institute of Physics Conference Proceedings, print), ISSN: 1551-7616 (online) (eISSN), URL: http://proceedings.aip.org/ [accessed: 2024-05-26], (to appear).

[42] C.-P. Rückemann, "From Knowledge and Meaning Towards Knowledge Pattern Matching: Processing and Developing Knowledge Objects Targeting Geoscientific Context and Georeferencing," in Proceedings of The Twelfth International Conference on Advanced Geographic Information Systems, Applications, and Services (GEOProcessing 2020), (FIRST DATES: March 22–26, 2020, Valencia, Spain), (SECOND DATES: June 22–25, 2020, Valencia, Spain), November 21–25, 2020, Valencia, Spain. XPS Press, Wilmington, Delaware, USA, 2020, rückemann, C.-P. and Doytsher, Y. and Ritz, T. (eds.), pages 16–21, 3rd edition, December 12, 2020, ISSN: 2308-393X, ISBN-13: 978-1-61208-762-7, ISBN-13: 978-1-61208-098-7 (Electronic Proceedings), URL: http://www.thinkmind.org/download.php?articleid=geoprocessing_2020_1_30_30035 [accessed: 2024-05-26], URL: http://www.thinkmind.org/index.php?view=article&articleid=geoprocessing_2020_1_30_30035 [accessed: 2024-05-26].

[43] C.-P. Rückemann, "The Abydos Ships Method: New-insight-driven Numeral Systems Approach for Coherent Multi-disciplinary Analysis and Contextualisation," in The Twelfth Symposium on Advanced Computation and Information in Natural and Applied Sciences (SACINAS), Proceedings of The 20th International Conference of Numerical Analysis and Applied Mathematics (ICNAAM), September 19–25, 2022, Heraklion, Crete, Greece. AIP Press, American Institute of Physics, Melville, New York, USA, 2024, ISSN: 0094-243X (American Institute of Physics Conference Proceedings, print), URL: http://icnaam.org/ [accessed: 2024-05-26], (to appear).

[44] C.-P. Rückemann and B. F. S. Gersbeck-Schierholz, "Object Security and Verification for Integrated Information and Computing Systems," in Proceedings of the Fifth International Conference on Digital Society (ICDS 2011), Proceedings of the International Conference on Technical and Legal Aspects of the e-Society (CYBERLAWS 2011), February 23–28, 2011, Gosier, Guadeloupe, France / DigitalWorld 2011. XPS, 2011, pp. 1–6, ISBN: 978-1-61208-003-1, URL: http://www.thinkmind.org/download.php?articleid=cyberlaws_2011_1_10_70008 [accessed: 2024-05-26].

[45] "LX Professional Scientific Content-Context-Suite (LX PSCC Suite) Licence," 2024, (release 2024), Unabhängiges Deutsches Institut für Multi-disziplinäre Forschung (DIMF): All rights reserved. Rights retain to the contributing creators.

[46] P. Wessel, W. H. F. Smith, R. Scharroo, J. Luis, and F. Wobbe, "The Generic Mapping Tools (GMT)," 2020, URL: http://www.generic-mapping-tools.org/ [accessed: 2024-05-26].

[47] "GMT - Generic Mapping Tools," 2024, URL: http://www.generic-mapping-tools.org/ [accessed: 2024-05-26].

[48] "The LX Professional Scientific Creation Academic Suite (LX PSCA Suite) Licence," 2024, (release 2024), Unabhängiges Deutsches Institut für Multi-disziplinäre Forschung (DIMF): All rights reserved. Rights retain to the contributing creators.

[49] The TEX Live Team, TEX Live, 2023, URL: https://tug.org/texlive/ [accessed: 2024-05-26].

[50] D. Carlisle, "The TeXLive.net Server," 2023, (The TeXLive.net server was written by David Carlisle and hosted on a virtual machine provided by Stefan Kottwitz, with financial support from DANTE).

[51] "MIT License," 2024, SPDX License List, spdx.org, SPDX Working Group, URL: https://spdx.org/licenses/MIT.html [accessed: 2024-05-26].

[52] PROJ contributors, PROJ Coordinate Transformation Software Library, Open Source Geospatial Foundation, 2024, URL: https://proj.org/ [accessed: 2024-05-26].

[53] "Perl Compatible Regular Expressions (PCRE)," 2024, URL: https://www.pcre.org/ [accessed: 2024-05-26].

[54] "Google," 2024, URL: https://google.com/ [accessed: 2024-05-26].

[55] "OGC Approves KML as Open Standard," 2008, OpenGeospatial.org, 2008-04-14, Press Release 857, URL: http://www.opengeospatial.org/pressroom/pressreleases/857 [accessed: 2024-05-26].

[56] "FFmpeg," 2024, URL: https://ffmpeg.org/ [accessed: 2024-05-26].

[57] S. Tomar, "Converting video formats with FFmpeg," Linux Journal, vol. 2006, no. 146, 2006, p. 10.

[58] "GraphicsMagick Image Processing System," 2024, URL: http://www.graphicsmagick.org/ [accessed: 2024-05-26].

[59] "GNU Image Manipulation Program," 2024, URL: http://www.gimp.org/ [accessed: 2024-05-26].

[60] VideoLan, "VLC media player," 2024, URL: https://www.videolan.org/vlc/index.html [accessed: 2024-05-26].

[61] "Parallel BZIP2 (PBZIP2)," 2024, URL: http://compression.ca/pbzip2/ [accessed: 2024-05-26].

[62] L. Dagum and R. Menon, "OpenMP: an industry standard API for shared-memory programming," Computational Science & Engineering, (IEEE), vol. 5, no. 1, 1998, pp. 46–55.

[63] OpenMP Architecture Review Board, "OpenMP API 5.1 Specification," Nov. 2020, URL: https://www.openmp.org/wp-content/uploads/OpenMP-API-Specification-5-1.pdf [accessed: 2024-05-26].

[64] "GNU Parallel," 2024, URL: http://www.gnu.org/s/parallel [accessed: 2024-05-26].

[65] "The Archaeological Data Collector (ADC) Licence," 2024, (release 2024), Unabhängiges Deutsches Institut für Multi-disziplinäre Forschung (DIMF): All rights reserved. Rights retain to the contributing creators.

[66] "GNU libgomp – GNU Offloading and Multi-Processing Project (GOMP)," 2024, URL: https://gcc.gnu.org/projects/gomp/ [accessed: 2024-05-26].

[67] A. H. Karp and H. P. Flatt, "Measuring Parallel Processor Performance," in Communications of the ACM, 33, vol. 5, 1990, pp. 539–543, DOI: 10.1145/78607.78614.

[68] M. J. Quinn, Parallel Programming in C with MPI and OpenMP. McGraw-Hill, 2017, ISBN: 978-0-07-058201-9.

[69] C.-P. Rückemann, "New Methods, Results, and Insights Achieved at The Twelfth Symposium on Advanced Computation and Information in Natural and Applied Sciences," in Proceedings of The 20th International Conference of Numerical Analysis and Applied Mathematics (ICNAAM), September 19–25, 2022, Heraklion, Crete, Greece, Proceedings of the American Institute of Physics (AIP) . AIP Press, American Institute of Physics, Melville, New York, USA, Apr. 2024, pp. 030 001–1, ISBN-13: 978-9925-7552-3-3, ISSN: 0094-243X (American Institute of Physics Conference Proceedings, print), ISSN: 1551-7616 (online) (eISSN), URL: http://proceedings.aip.org/ [accessed: 2024-05-26], (to appear).