Procedural Component Framework Implementation and Realisation for Creation of a Coherent Multi-disciplinary Conceptual Knowledge-based Holocene-prehistoric Inventory of Volcanological Features Groups

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***Abstract*—This paper presents the results of the procedural component framework implementation and realisation for creation of a coherent multi-disciplinary conceptual knowledge-based Holocene-prehistoric inventory of worldwide volcanological features groups. The goal is the creation of a sustainable framework of components, which can be employed for multi-disciplinary integration of knowledge contexts, especially from prehistory and archaeology. The component framework has to enable further coherent conceptual knowledge contextualisation and georeferenced symbolic representation. This paper provides the results on experiences of sustainable component integration and practical procedural implementations and realisations. Future research will address the creation of a component framework for a Holocene-prehistoric inventory of worldwide volcanological features, which enables coherent conceptual knowledge integration and contextualisation with prehistorical and archaeological knowledge resources.**

Keywords–Prehistory; Holocene; Knowledge-based Component Integration; CRI Framework; CKRI.

I. INTRODUCTION

Coherent conceptual knowledge resources are results of often complex and long-term multi-disciplinary creation processes. Coherent conceptual knowledge resources may have to achieve an advanced level of implementation before procedural components can be created for sustainably employing these resources. The conceptual knowledge implementation for this inventory is in focus of multi-disciplinary research groups and matter to be reported in separate publications. Motivation is the creation of a sustainable and practical component framework based on coherent multi-disciplinary conceptual knowledge.

This paper presents the results of the procedural component framework implementation and realisation for creation of a coherent multi-disciplinary conceptual knowledge-based Holocene-prehistoric inventory of worldwide volcanological features groups, which are employing respective coherent knowledge resources. The goal of this research is the creation of a sustainable framework of components, which can be employed for multi-disciplinary integration of knowledge contexts, especially from prehistory and archaeology, too. The component framework further has to enable a coherent conceptual knowledge contextualisation and georeferenced symbolic representation. The coherent knowledge resources and the practical realisation are fully based on the Component Reference Implementations (CRI) framework [1], which is employing the main implementations of the prehistory-protohistory and archaeology Conceptual Knowledge Reference Implementation (CKRI) [2]. CRI provides the required component groups and components for the implementation and realisation of all the procedural modules. CKRI provides the knowledge framework, including multi-disciplinary contexts of natural sciences and humanities [3]. Both provide sustainable fundaments for highest levels of reproducibility and standardisation and allow continuous and consistent further development of discipline-centric and multi-discipline development of knowledge resources. Both reference implementations are in continuous further development. The approach conforms with information science fundaments and universal knowledge and enables an integration of the required components from methodologies to realisations for knowledge representations of realia and abstract contexts [4], namely the Conceptual Knowledge Pattern Matching (CKPM) methodology, considering that many facets of knowledge, including prehistory, need to be continuously acquired and reviewed [5].

The rest of this paper is organised as follows. Section II presents the methodological implementation and realisation, workflow procedure, respective component reference implementation and integration and coherent conceptual knowledge implementation for the new inventory. Section III discusses the procedural potential regarding integration of components, parallelisation, and implementation features. Section IV summarises lessons learned, conclusions, and future work.

II. METHODOLOGICAL IMPLEMENTATION AND REALISATION

Implementation and realisation are based on the CKRI [2]. Components outside the core scope of this geoscientific, prehistoric, and archaeological research are employed and can be extended via the CRI frame [1]. The following implementation and realisation start with a description of a workflow procedure for creation of a coherent multi-disciplinary conceptual knowledge-based Holocene-prehistoric inventory of worldwide volcanological features groups, followed by the component implementation and realisation based on the general coherent multi-disciplinary conceptual knowledge implementation.

A. Methodological workflow procedure

A workflow procedure for the creation closely integrates the component framework and the coherent knowledge implementation of the Knowledge Resources (KR):

- (KR/components selection, continuous development.)
- Component implementation and realisation.
    - Scientific parametrisation of components (including algorithms, in each discipline).
    - Workflow decision making.
    - Country identification algorithm.
    - Country representation algorithm.
    - Area of Interest (AoI) representation algorithm.

 ISBN: 978-1-61208-961-4

    - Symbolic representation of country
    - Symbolic representation of AoI.
    - Knowledge and discipline depending algorithm creation.
    - Knowledge Resources processing.
    - Chorological assignment and processing, e.g., spatial calculations, e.g., countries and areas.
    - Chronological assignment and processing, e.g., time related calculations, e.g., geological and prehistoric.
- Coherent conceptual knowledge implementation.
    - Coherent conceptual knowledge references, main tables.
    - Coherent conceptual knowledge references, auxiliary tables.
- Symbolic representation, generation.
    - Context area views.
    - Symbolic representation of features groups, integrated visualisation.
    - (Further symbolic representation of narratives.)
    - (Multitude of further contextualisation and narratives.)
    - . . .

After understanding the selected task-related algorithms and the fundamentals of knowledge complements many different realisations can be done straightforward, deploying the CKRI and CRI framework components.

The symbolic representation of features groups and the integrated visualisation will provide manifold ways of contextualisation. We can only demonstrate a single group of examples here.

Nevertheless, the realisation of the implemented workflow procedure may depend on the capacities the participating disciplines want to invest in their education, scientific research and contextualisation. It should not be uncommon with today's scientific research to invest increasing resources, 25 to over 50 percent of overall project resources, of each participating discipline into multi-disciplinary knowledge integration and contextualisation.

The CKRI and CRI framework can create coherent multi-disciplinary conceptual knowledge references effectively and efficiently and focus on core tasks within available capacities of time and other resources available for a workflow procedure.

B. *Component implementation and realisation*

The following passages give a compact overview of the major component framework integrated with this research. All the components and references are given, which were employed for the implementation and realisation and which are in a continuous further development process towards even closer integration and standards. More detailed, comprehensive discussion and examples regarding fundaments are available with the references on knowledge representations, methodology, contextualisation, and conceptual knowledge.

a) Conceptual knowledge frameworks: The created and further developed reference implementations of conceptual knowledge frameworks (this research major references in Tables I and II) are used with the implementation and realisation *KR* [6]. CKRI can be created by any disciplines and for multi-disciplinary scenarios and coherently integrated, e.g., in contextualisation for prehistorical and archaeological narratives.

b) Conceptual knowledge base: Conceptual knowledge base is The *Universal Decimal Classification (UDC)* [7], a general plan for knowledge classification, providing an analytico-synthetic and *faceted* classification, designed for subject description and indexing of content of information resources *irrespective of the carrier, form, format, and language*. UDC-based references for demonstration are taken from the multi-lingual UDC summary [7] released by the UDC Consortium, Creative Commons license [8].

c) Integration of scientific reference frameworks: Relevant scientific practices, frameworks, and standards from disciplines and contexts are integrated with the Knowledge Resources, e.g., here details regarding volcanological features, chronologies, spatial information, and Volcanic Explosivity Index (VEI) [9], [10].

d) Formalisation: All integration components, for all disciplines, require an *explicit and continuous formalisation* [11] *process*. The formalisation includes computation model support, e.g., *parallelisation standards, OpenMP* [12], [13], Reg Exp patterns, e.g., *Perl Compatible Regular Expressions (PCRE)* [14], and common standard methods, algorithms, and frameworks.

e) Methodologies and workflows integration: Methodologies for creating and utilising methods include model processing, remote sensing, spatial mapping, high information densities, and visualisation. Respective contextualisation of (prehistoric) scenarios should each be done under specific (prehistoric) conditions, especially supported by state-of-the-art methods, e.g., spatial operations, triangulation, gradient computation, and projection. 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) deploying the Generic Mapping Tools (GMT) and integrated modules [15] for visualisation.

f) Prehistory Knowledge Resources: Prehistoric objects and contexts are taken from *The Prehistory and Archaeology Knowledge Archive (PAKA)*, in continuous development for more than three decades [16] and is released by DIMF [17]. The KR support seamless coherent multi-disciplinary conceptual knowledge integration for workflow procedures.

g) Natural Sciences Knowledge Resources: Several coherent systems of major natural sciences' context object groups from *KR realisations* have been implemented, especially Knowledge Resources focussing on volcanological features [9] deployed with in depth contextualisation [10] and with a wide range of contexts [6], [7], [18]. The KR support seamless coherent multi-disciplinary conceptual knowledge integration for workflow procedures.

h) Inherent representation groups: The contextualisation for the inventory can employ state-of-the-art results from many disciplines, e.g., context from the natural sciences resources, integrating their inherent representation and common utilisation, e.g., *points*, *polygons*, *lines*, *Digital Elevation Model (DEM), Digital Terrain Model (DTM), and Digital Surface Model (DSM) representations* sources, e.g., from *satellites*, Unmanned Aerial Vehicles (UAV), *z-value representations*, *distance representations*, *area representations*, *raster*, *vector*, *binary*, and *non-binary data*. Employed resources are High Resolution (HR) (Space) Shuttle Radar Topography Mission (SRTM) [19], [20], HR Digital Chart of the World (DCW) [21], and Global Self-consistent Hierarchical High-resolution

Geography (GSHHG) [22]. SRTM was produced under the National Aeronautics and Space Administration (NASA) Making Earth System Data Records for Use in Research Environments (MEaSUREs) program. The Land Processed Distributed Active Archive Center (LPDAAC), USA [23], operates as a partnership between the U.S. Geological Survey (USGS) and the National Aeronautics and Space Administration (NASA), USA, and is a component of NASA's Earth Observing System Data and Information System (EOSDIS). Resources are released by NASA and JPL Jet Propulsion Laboratory (JPL), USA, [24], [25]. SRTM15 Plus [19], [20] is continuously updated and improved.

i) Scientific context parametrisation: Scientific *context parametrisation of prehistoric targets* can use the overall insight from all disciplines, e.g., parametrising algorithms and creating palaeolandscapes. Parametrisation is supported for all contexts and can consider views of participated disciplines. For the new inventory, parametrisation ranges from contexts, methods, representation of heights, illumination, symbol design, symbolic consistency to data locality and parallelisation.

j) Structures and symbolic representation: Structure is an organisation of interrelated entities in a material or non-material object or system [18]. Structure is essential in logic as it carries unique information. Structure means features and facilities. There are merely higher and lower facility levels of how structures can be addressed, which result from structure levels. Structure can, for example, be addressed by logic, names, references, address labels, pointers, fuzzy methods, phonetic methods. The deployment of long-term universal structure and data standards is essential. Relevant examples of sustainable implementations are *NetCDF* [26] based standards, including advanced features, hybrid structure integration, and parallel computing support (*PnetCDF*) and generic multi-dimensional table data, standard xyz files, universal source and text based structure and code representations.

C. Resulting coherent conceptual knowledge implementation

The CKRI implementations provide the fundament for the coherent multi-disciplinary knowledge based integration and the realisations of the methodological component integration.

Universally consistent conceptual knowledge of CKRI references, based on UDC code references, for demonstration, spanning the main tables [27] shown in Table I. Table II shows an excerpt of universally consistent conceptual knowledge of CKRI references, based on UDC code references, spanning auxiliary tables [28].

The tables contain major UDC code references required for the implementation and realisation of the methodological workflow procedure, especially for place (countries and AoI), time (Holocene), and disciplines (volcanology and prehistory).

D. Resulting symbolic representation of features groups

The procedural component framework implementation and realisation enable the creation of numerous contextualisations and symbolic representations for the coherent multi-disciplinary conceptual knowledge-based Holocene-prehistoric inventory of volcanological features groups.

For this research, we choose the resulting symbolic representation of a volcanological features group, maars, based on the coherent conceptual knowledge integration. The sequence of procedural steps enables contextualisation for flexible larger

TABLE I. CKRI IMPLEMENTATION OF COHERENT CONCEPTUAL KNOWLEDGE CONTEXTUALISATION; MAIN TABLES (EXCERPT).

Code / Sign Ref.	*Verbal Description (EN)*
UDC:0	Science and Knowledge. Organization. Computer Science. Information. Documentation. Librarianship. Institutions. Publications
UDC:1	Philosophy. Psychology
UDC:2	Religion. Theology
UDC:3	Social Sciences
UDC:5	Mathematics. Natural Sciences
UDC:52	Astronomy. Astrophysics. Space research. Geodesy
UDC:53	Physics
UDC:539	Physical nature of matter
UDC:54	Chemistry. Crystallography. Mineralogy
UDC:55	Earth Sciences. Geological sciences
UDC:550.3	Geophysics
UDC:551	General geology. Meteorology. Climatology. Historical geology. Stratigraphy. Palaeogeography
UDC:551.21	Vulcanicity. Vulcanism. Volcanoes. Eruptive phenomena. Eruptions
UDC:551.2...	Fumaroles. Solfataras. Geysers. Hot springs. Mofettes. Carbon dioxide vents. Soffioni
UDC:551.44	Speleology. Caves. Fissures. Underground waters
UDC:551.46	Physical oceanography. Submarine topography. Ocean floor
UDC:551.7	Historical geology. Stratigraphy
UDC:551.8	Palaeogeography
UDC:56	Palaeontology
UDC:6	Applied Sciences. Medicine, Technology
UDC:7	The Arts. Entertainment. Sport
UDC:8	Linguistics. Literature
UDC:9	Geography. Biography. History
UDC:902	Archaeology
UDC:903	Prehistory. Prehistoric remains, artefacts, antiquities
UDC:904	Cultural remains of historical times

TABLE II. CKRI IMPLEMENTATION OF COHERENT CONCEPTUAL KNOWLEDGE CONTEXTUALISATION; AUXILIARY TABLES (EXCERPT).

Code / Sign Ref.	*Verbal Description (EN)*
UDC (1/9)	Common auxiliaries of place
UDC:(23)	Above sea level. Surface relief. Above ground generally. Mountains
UDC:(3/9)	Individual places of the ancient and modern world
UDC:(3)	Places of the ancient and mediaeval world
UDC:(32)	Ancient Egypt
UDC:(35)	Medo-Persia
UDC:(36)	Regions of the so-called barbarians
UDC:(37)	Italia. Ancient Rome and Italy
UDC:(38)	Ancient Greece
UDC:(399)	Other regions. Ancient geographical divisions other than those of classical antiquity
UDC:(4/9)	Countries and places of the modern world
UDC:(4)	Europe
UDC:(5)	Asia
UDC:(6)	Africa
UDC:(7/8)	America, North and South. The Americas
UDC:(7)	North and Central America
UDC:(8)	South America
UDC:(9)	States and regions of the South Pacific and Australia. Arctic. Antarctic
UDC:"..."	Common auxiliaries of time.
UDC:"6"	Geological, archaeological and cultural time divisions
UDC:"62"	Cenozoic (Cainozoic). Neozoic (70 MYBP - present)
UDC:"63"	Archaeological, prehistoric, protohistoric periods and ages

and smaller context scales, e.g., generated symbolic representation (Figure 1) of country identification contexts (Figure 1(a)) and generated symbolic representation of AoI contexts for respective object entities (Figure 1(b)). Generated representations include integrated CKRI references, projection of topographic and bathymetric results, and further knowledge for respective areas, based on the coherent conceptual knowledge.

III. Discussion of procedural potential

Logic is a general limit to many overblown claims, from universal parallelisation to 'Artificial Instruments'.

Therefore, parallelisation can only deliver feasible approaches for simple, formalised cases of contextualisation and small parts of much more complex contexts of knowledge. The goals and complexity of conceptual knowledge-centric tasks and procedural tasks require the insight of eminently suitable structures and resources.

The resources, which provide highest potential for the realisation based on the inventory model are huge, based on quantity and resulting from quality of the contextualisation resources. Models are even continuously growing when considering ongoing state-of-the-art research. In consequence, these scenarios require a high level of scalability. A realistic conceptual-procedural environment for the coherent multi-disciplinary conceptual knowledge-based Holocene-prehistoric inventory of volcanological features groups includes:

- Different object groups, objects and views, e.g., for over 500 volcanological object entities and features.
- Multi-dimensional views, e.g., focus dependent views per objects, e.g., via OpenMP [12] / specifications [13].
- Embarrassingly parallel procedures (e.g., knowledge dimensional computation), e.g., via OpenMP [12] and specifications [13].
- Job parallel procedures (e.g., knowledge objects and resources localities).

Table III shows the inherent representation groups used by the disciplines for the formalised representation of knowledge integrated for the implementation and realisation (serial, parallel, not applicable, n.a.).

The respective locality-license and parallelisation aspects refer to the realisation resources, primarily depending on the respective knowledge and organisation. Therefore, precondition for implementation is a deep understanding of the knowledge complexity within a discipline, which is represented by the task as well as the required formalisations for all the components.

OpenMP is a mature and portable industry standard, which can be efficiently implemented directly by scientists of any discipline in their contextualisation, methodological workflow logic, and for their workflow procedure implementations and realisations.

Organisation of data structure and formalisation of knowledge are core tasks of a discipline itself and not at all a technical task. Nevertheless, the organisation of knowledge also defines feasible data locality concepts. Parallelisation of workflows with plain-dimension and multi-dimension targets can differ regarding their contextualisation results.

For example, a plain-dimension workflow can deliver different contextualisation contexts of an AoI. A multi-dimension workflow can deliver a certain contextualisation context of an AoI, depending on further dimensions, views or chorologies. Therefore, plain- and multi-dimension workflows can complement in chorological and chronological contextualisation while sharing resources, structural and procedural fundaments.

TABLE III. INHERENT REPRESENTATION GROUPS WITH INTEGRATED COMPONENTS INVENTORY OBJECT ENTITY EXAMPLE WORKFLOW.

Inherent Representation Group	*Locality-License Model*	*Parallelisation Plain*	*Parallelisation Multi*
KR preprocessing, conceptual	On-premise	Ser./par.	Ser./par.
Context preprocessing	Restricted	Ser./par.	Ser./par.
KR processing, conceptual	On-premise	OpenMP	OpenMP
Conceptual knowledge processing	On-premise	OpenMP	OpenMP
PoI	On-premise	OpenMP	OpenMP
Point spatial operations	Restricted	OpenMP	OpenMP
Line operations	Restricted	OpenMP	OpenMP
Polygon operations	Restricted	OpenMP	OpenMP
DEM	Restricted	OpenMP	OpenMP
PCRE	Restricted	OpenMP	OpenMP
Editing	Restricted	OpenMP	OpenMP
Projecting	Restricted	OpenMP	OpenMP
Cutting	Restricted	OpenMP	OpenMP
Sampling	Restricted	OpenMP	OpenMP
Filtering	Restricted	OpenMP	OpenMP
Illumination	Restricted	OpenMP	OpenMP
Triangulation	Restricted	OpenMP	OpenMP
Projection	Restricted	OpenMP	OpenMP
Filter operations	On-premise	OpenMP	OpenMP
View/frame computation	Restricted	OpenMP	OpenMP
Model reduction (frames)	n.a.	OpenMP	OpenMP
Model reduction (animation)	n.a.	n.a.	Serial
...	...	...	...

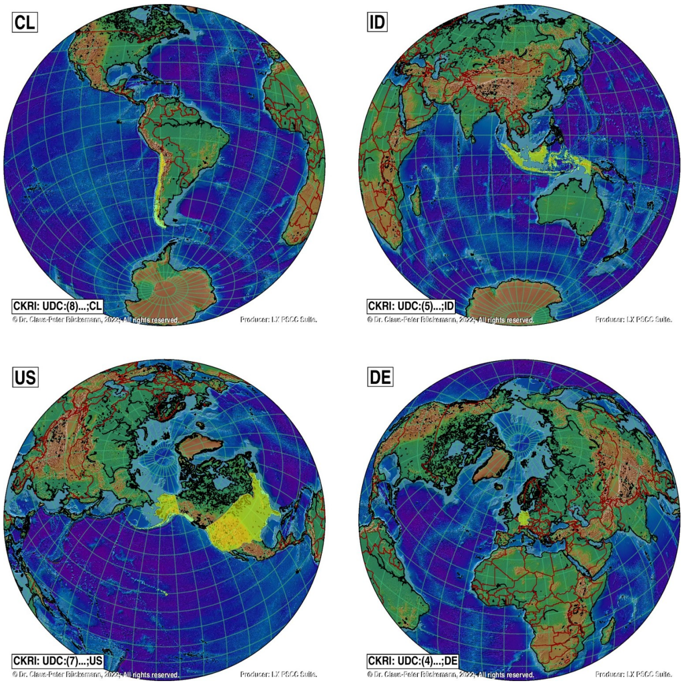
An example for a model reduction in plain-dimension is, e.g., generation of multiple context views. An example for a model reduction in multi-dimension is, e.g., generation of a video of geospherical satellite view frames with moving observer position. It is obvious that the workflow logic of the examples also differ in their ways of parallelisation. The use of on-premise (e.g., in-house) and restricted (distributed) resources is attributable to the licenses of the core assets, the knowledge resources. Inherent representation groups are major matter of scalable processing and conversion (two-dimensional/three-dimensional) and higher multi-dimensional workflow procedures. Table IV shows the scalability of the example workflow procedure for parallelised parts of the coherent multi-disciplinary conceptual knowledge-based Holocene-prehistoric inventory of volcanological features groups, based on mean requirements for an object entity, with numbers of objects entities, n_o, numbers of frames, n_f, and numbers of views, n_v, for $n_f = 1$ and $n_v = 2$ as in the above symbolic representation example of volcanological features groups.

TABLE IV. PARALLELISED PROCESSING OF INVENTORY WORKFLOW (PARALLELISED KNOWLEDGE RESOURCES AND CONTEXT RESOURCES).

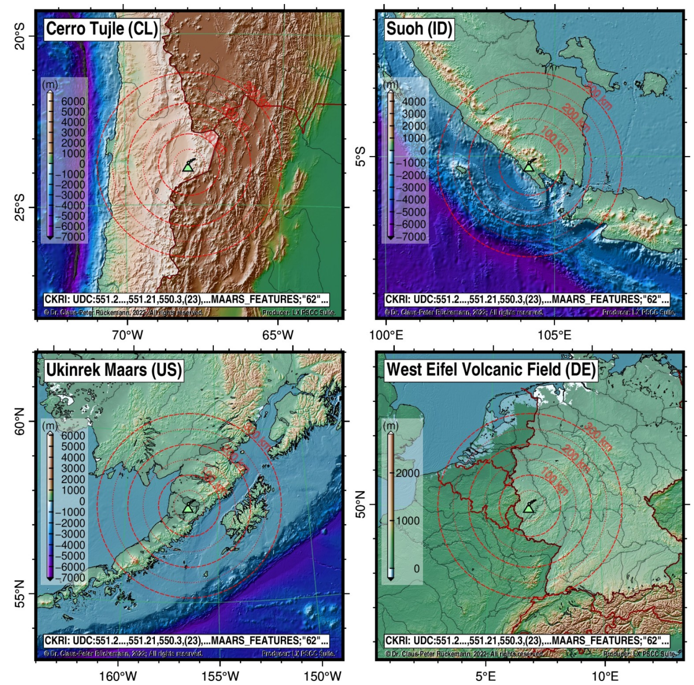
Number of CPU Cores	*Wall Time Workflow (Plain)*	*Number of Object Entities* $n_o = 100$	$n_o = 500$
1	$n_o \cdot (n_v \cdot n_f \cdot 1,680/1)$ s	336,000 s	1,680,000 s
36	$n_o \cdot (n_v \cdot n_f \cdot 1,680/36)$ s	9,333 s	46,667 s

The architecture choosen 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 the 360 degrees of a global model. Results on other architectures with same numbers of respective cores will be highly comparable.

 ISBN: 978-1-61208-961-4



(a) Generated symbolic representation of country identification contexts.



(b) Generated symbolic representation of object AoI contexts.

Figure 1. Resulting symbolic representation of a volcanological features group (maars) based on the coherent conceptual knowledge integration (excerpt). Sequence of procedural steps for larger scale and smaller scale contextualisation, including country identification contexts (a) and AoI contexts (b). Generated representations include integrated CKRI references, projection of topographic and bathymetric results, and further knowledge for respective areas.

Precondition for parallelisation is sufficient memory for parallel use of integrated resources. Considering the employed resources, e.g., SRTM, 128 GB 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.

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 numbers of objects entities, n_o, illustrate the high scalability when the same workflow is using higher numbers of CPU cores. Probably, most practical workflows may contain parts which cannot be reasonably parallelised. This is especially true for scientific tasks with a certain complexity. The percentage of non parallelised parts is very low here. For multi-dimension targets, e.g., animations with $n_f = 1000$ and $n_v = 1$, it may be considered to employ hundreds to thousands of CPU cores so parallelised wall times per object can be reduced from days to hours.

Serial and parallel compute times, e.g., for groups of object entities, are non-linear. For example, mean times for the same workflow realisation may greatly differ for different object entities. To significant extent, this is consequence of the inherent complexity of the knowledge complements, which have to be integrated and analysed. In practice, compute times for object entities may commonly vary to over several hundred percent. Component and knowledge contributions of different disciplines may have different weight in their contributions to the non-linearities. The resulting compute times may even deliver continuously new and non-linear compute times in a dynamical workflow realisation with knowledge resources and components, which are in continuous development.

IV. CONCLUSION

The new approaches for the creation of a sustainable procedural component framework for implementation and realisation of a coherent multi-disciplinary conceptual knowledge-based inventory proved efficient and sustainable. Based on the methodology of coherent conceptual knowledge classification, the CKRI, and the CRI frameworks, the procedural and conceptual implementation and realisation of a Holocene-prehistoric inventory of worldwide volcanological features groups showed very flexible and scalable, supported by many scenarios over the last years. The developed framework of components, can be employed for multi-disciplinary integration of knowledge contexts. Everything has been done to deploy standards and provide maximum flexibility so that context from prehistory, archaeology, natural sciences, and humanities can be be coherently integrated. The component framework showed to enable an effective and efficient coherent conceptual knowledge contextualisation and georeferenced symbolic representation. Researchers from all disciplines already practice the procedural component framework development, coherent conceptual knowledge, and procedure parallelisation in professional long-term research knowledge and data management.

Future research will address the creation of a component framework for a Holocene-prehistoric inventory of worldwide volcanological features, which enables procedural integration and coherent conceptual knowledge contextualisation with prehistorical and archaeological knowledge resources.

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 D2022F1P05312, D2022F1P05308, and D2020F1P05228. 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, and context scenarios. We are grateful to Dipl.-Ing. Hans-Günther Müller, Göttingen, Germany, for providing specialised, manufactured high end computation and storage 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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