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High End Computing Using Advanced Archaeology and Geoscience Objects

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***Abstract*—This paper presents the results from the creation of advanced long-term knowledge resources. Focus goals are multi-disciplinary knowledge documentation, discovery, and sustainability. Application scenarios with complex knowledge architectures require different computational workflows and resources. The paper discusses comprehensive case studies with advanced knowledge objects from archaeology and geosciences disciplines. It delivers results and experiences on creating intelligent and sustainable Integrated Information and Computing System components and systems developed for more than twenty years. The new universal knowledge resources and flexible collaboration framework allow multi-disciplinary documentation for any object as well as advanced scientific computing access and enable overall flexibility for interfacing High End Computing resources, which get increasingly important for integration, improving the quality of result matrices, dynamical tasks and highly efficient discovery workflows and processes. This way, structured objects and universal classification are a central means for long-term integration of information systems and supercomputing resources with any kind of workflow and discipline.**

Keywords–Information Systems; Knowledge Resources; Advanced Scientific Computing; Classification; Archaeology; Geosciences; UDC; Integrated Systems; High End Computing.

I. Introduction

The more the demand increases for creating sustainable and flexible knowledge resources, the more we require long-term conceptional and computational methods for discovery in multi-disciplinary and heterogeneous resources [1]. Even widely accessible common collections of information and data, are missing reliability, validation, and long-term sustainability – problems, which are passed far into the future with long-term tasks. This is resulting from principle problems of implementation: There are no foundations of a suitable long-term strategy, documentation, tools, and resources. This demands static and dynamical components in all parts of an implementation.

Multi-disciplinary knowledge profits from long-term documentation. Creating extensive knowledge resources requires long-term means. Making use of extensive knowledge resources, especially over long periods of time requires the development of information and knowledge itself and an integration of media and features for transporting and working with information. Content has to be developed for long periods of time. This includes new research, including historical information, and extending multi-disciplinary references. The focus question for documentation, operating on information and computing is: How can complex systems be built, developed, and extended over the necessarily long periods of time? With the application components, e.g., information system components like databases, mostly form monolithic and even proprietary blocks. Their life cycle is mostly much shorter than long-term content development. On the side of computing challenges it is possible to create solutions for very perishable present resources. Any more complex problem cannot be considered "solved" for future architectures and applications. Many information and knowledge resources cannot be used without the original context, e.g., computing resources any more. Up to now context of information science cannot be described by common means to a reasonable extend. This leads to another essential question: What information and knowledge on content and context can be preserved for medium- and long-term usage when the complexity of an overall system will be unpredictably high?

The long-term strategy created here is based on an implementation architecture, which includes long-term knowledge resources with the resources and development. In this paper we concentrate on the archaeological and geosciences topics being part of the knowledge resources. The foundations should enable the essential processing of archaeological, geoscientific, geophysical, geological, spatial and other data as well as a thorough documentation of all aspects of content and context and the exploitation of advanced scientific computing methods and resources for maximum flexibility.

Regarding the status of long-term knowledge we have to distinct between two important main parts, which this paper presents: The knowledge resources and the Integrated Information and Computing Systems (IICS), both already used in practice. The presentation of the long-term issues and the new features and results presented in this paper shows the potential of IICS being based on multi-disciplinary documentation for this purpose. Anyhow, it can only describe a tiny fraction of the multitude of possible features.

This paper is organised as follows. Section II describes the motivation and Section III summarises related work. Section IV introduces architecture and implementation for the IICS. Sections V and VI describe the long-term strategy and discuss the advanced knowledge object creation. Sections VII, VIII, IX, and X show high-end implementation case studies of advanced objects in context of a geoscience-archaeology IICS: A digital archaeology library, the computing features and components, the integration of external information, and basic mechanisms and workflows. Section XI presents an evaluation including processing, computing, and classification aspects. Section XII summarises the conclusions and future work.

II. Motivation

For small volumes of data, small numbers of objects or primitive workflows most computing and storage requirements are neglectable. Using available data with complex processing workflows soon shows up with requirements increasing more than exponential. With a large amount of data and large numbers of objects this will become a huge challenge. The more, as commonly there are many different object types and even inside a type any of these objects will differ. One group of objects may consist of some thousand digital samples from a media database, another group may be physical objects carrying specific descriptions, and a third may be data sets and workflows for seismic processing and simulation. Besides that the workflows can be arbitrary complex, the requirements on the groups can widely differ. With one group the permanent storage may involve Terabytes of data and less computation. With another group the input data and parametrisation may be much smaller in size but the computational requirements can take up to several days per workflow step.

Currently, other approaches fail on integrative multi-disciplinary concepts as well as on the integration of structure, long-term preservation, and computational and information system facilities. An important reason is that those available approaches start from an implementation of features and not from the knowledge itself. There are no frameworks providing the necessary concepts and features for integration of data, workflows, knowledge and computing resources, and operation. For example, a lot of advanced geoscientific processing cannot be reproduced after a few years, even if the data and results are still existing. Means for extended long-term interpretation and analysis are missing.

It is a huge challenge that, besides data creation not being able to support sufficiently comprehensive documentation, the widely used technology, e.g., document formats, Uniform Resource Locators (URL), and Web Services are not persistent over longer periods of time, e.g., for static objects file formats do change, for applications and services the implementations and features will change. Therefore, information structures built from such technologies will become inaccessible. Long-term knowledge creation cannot rely on this. From the complex systems' point of view any of those building elements are not suitable for describing objects and creating long-term knowledge resources. Anyhow the original sources and building elements are needed for documentation of the original content and context. Therefore, knowledge creation has to separate the essentials of knowledge from technology, resources, and other tools while at the same time respecting their importance. Even worse, that workflows, algorithms, resources and their management cannot be guaranteed for long-term availability.

The topic is very complex and experiences with long-term knowledge creation are out of scale of the time interval of most researchers. Especially, it has been found to be less difficult for groups with a strong background of classical academic education to understand the problem itself, than it is for groups with a "technical-only" background to realise the multiple benefits of classification.

Examples of long-term creation of knowledge and the implementation of applications building on these resources are presented in the following sections, showing that such scenario can hardly be managed in a comparable way with other available methods and concepts. The case studies from archaeology and geosciences disciplines are using the architecture, knowledge resources, computing interfaces, and features. The resources and interfaces have been continuously developed and improved for more than twenty years already. The following passages describe the requirements in the context of this new study and implementation. Further details on requirements have been described in several case studies cited.

A. *Value of data*

The value of data is a central driving force for creating sustainable knowledge resources, the more as data is increasingly important for long period of times. Long-term in cases of sustainable high-value data means many decades of availability and usability. Therefore, usability, security, and archiving are most important aspects of the value of data sets. Value is not the price a data set can be sold as there are many individual factors. The long-term studies, as the "Cost of Data Breach" study initiated by Symantec at the Ponemon Institute [2] summarise that the costs related to data loss are high and do increase every year [3]. Straight approaches for calculating individual risks and data loss, as with the Symantec Data Breach Calculator [4] illustrate the effects.

B. *Sustainability and long-term issues*

1) Recommendations of the German science council: With information systems containing content that has to be created and cared for a sustainable long-term operation and provisioning, the main aspect is not the technology for a limited implementation. The focus is the specification and structure of the knowledge, which must be defined with the owner of the data. In many cases an exploitation for scientific discovery is imperative. The German science council (Wissenschaftsrat) recommends the exploitation of content and its public provision for content of special significance [5].

The science council provides recommendations for information infrastructures, which should be considered for wider implementation. The central aspects are exploitation, standardisation, and long-term archiving and archival storage. This is of prescind importance as far as the content and services are of public interest and can be defined core business of an institutional body. As from the recommendations, the planning phase for infrastructures should at least consider medium duration. Project funding of existing structures is not adequate. Regarding the context of the information, the operation must be considered a permanent task. Nevertheless, the German science council recommends an accompanying, infrastructure related research, which may be considered on a project base. This can be especially suitable for the component development, whereas data, content, and structures are non project matter. Aspects of funding, profiles, and digitising are of special concern within federal structures [6].

2) Experiences from national an international studies: Up to now, knowledge integration and its discovery aspects are widely discussed within national and international context. The existing concepts the data on knowledge and accompanying recommendations are too specialised and too strict [7], [8], [9], [10], [11], [12], [13], especially for the required long-term and multi-disciplinary use. As the concepts are artificial, the integration with natural structures is most difficult. Even if developed over years, the basic concepts and structures rarely fit for many disciplines, services, and resources. Neither creation nor operation can profit from the existing practice and frameworks. Knowledge resources have to be considered universal, for any data as well as any workflow. Practically, there is no difference between explicit and tacit knowledge as promoted with various previous approaches. Auditing is not depending on a special kind of knowledge resources and from knowledge resources point of view it cannot be practically separated into asset structures, data auditing for projects, organisations or maintenance.

Knowledge resources should be defined for sustainability and long-term aspects. The most important aspect for decision making is experience. This has to be considered for creating all aspects of knowledge resources. Universal knowledge resources require a high level of multi-disciplinary comprehension. The workflows may not influence the structures of the knowledge resources. They should be created for selecting a focus. They should be able to incorporate and handle data of disciplines, content, algorithms, and documentation. They should allow integration with implementation and operation. They should allow for different required views.

III. Related Work

There is no wider concept and implementation known comparable to the solution presented, described and implemented here. Nevertheless, there are concepts for components, implementations, and terminology. Previous work [14], [15], [16], [17], [18] has delivered important basic concepts and components, e.g., Integrated Information and Computing Systems, dynamical components, and taxonomy. Efficiently structuring, classifying, e.g., with UDC, and storing data are key issues with flexible and sustainable long-term knowledge resources. Taxonomy is the science and practice of classification. An important facetted classification is the Universal Decimal Classification (UDC) [19]. According to Wikipedia currently about 150000 institutions, mostly libraries, are using basic UDC classification worldwide [20], e.g., with documentation of their resources, library content, bibliographic purposes, for digital and realia objects. This is mostly restricted to publications and references but not of general knowledge and applications. Some aspects can be studied from the goals of knowledge discovery [21], which is becoming increasingly important. Other aspects are handled with search algorithms, which currently are still very primitive regarding knowledge creation and usage. Developing general categories and classifications is a long-term process [22]. Many generations of researchers and institutions have contributed to its development [23], [19]. A general usage for any kind of objects as it had been originally intended with the "universal" classification is still not practiced. A significant part of the long-term problem for putting a general application into practice is the complexity of multi-disciplinary knowledge and workflows.

IV. Architecture and implementation

As far, it is not commonly possible to treasure content currently used for being preserved in order to create really long-term usable content. Even much more difficult that an implementable solution for any form of long-term context is even in wide distance. In general, only a very small percentage of disciplines and researchers are familiar with knowledge classification and applications. The more, multi-disciplinary classification is currently only in the focus of third parties. Operational resources and features are considered to be short-term issues whereas information, knowledge, and respective resources and features must be considered of long-term significance. Case studies showed that long-term development requires a strong sustainability of content, context, and computation. This means, the most important part of these systems is the knowledge resources containing the content and context documentation to any extent necessary for describing the activities and isolating the perishable components for context documentation.

A solid classification cannot be done automatically. The more, it cannot be done automatically for use with IICS. This does not interfere with or limit in any way the amount of data handled by a workflow making use of classified knowledge resources. Anyhow, in fact that different views are possible, it is reasonable to have classification views from the origin, from main disciplines or from the developers in order to increase the quality of references. The architecture respects these conditions. The architecture integrates several components especially developed for long-term integration:

- Universal classification,
- Structure,
- Multi-disciplinary knowledge documentation,
- Resources support, e.g., computation and storage,
- Creating, describing, executing workflows, ...

All the implemented components have proved to fulfill the requirements for long-term vitality and extendability.

The following sections explain in detail how a successful implementation of an integrated system has been created and operated using knowledge resources and classification for information system usage.

A. Architecture for documentation and development

The architecture implemented for an economical long-term strategy is based on different development blocks. Figure 1 shows the three main columns: Applications resources, knowledge resources, and originary resources. The central block in the "Collaboration house" framework architecture [18], are the knowledge resources, scientific resources, databases, containers, and documentation (e.g., LX [14], databases, containers, list resources). These can be based on and refer to the originary resources and sources (photos, scientific data, literature). Application resources and components (Active Source, Active Map, local applications) are implementations for analysing, utilising, and processing data and making the information and knowledge accessible. These three blocks are supported by services interfaces. The interfaces interact with the physical resources, in the local workspace, in the compute and storage resources the knowledge resources are situated, and in the storage resources for the originary resources. All of these do allow for advanced scientific computing and data processing as well as the access of compute and storage resources via services interfaces. The resources' needs depend on the application scenarios to be implemented for user groups.

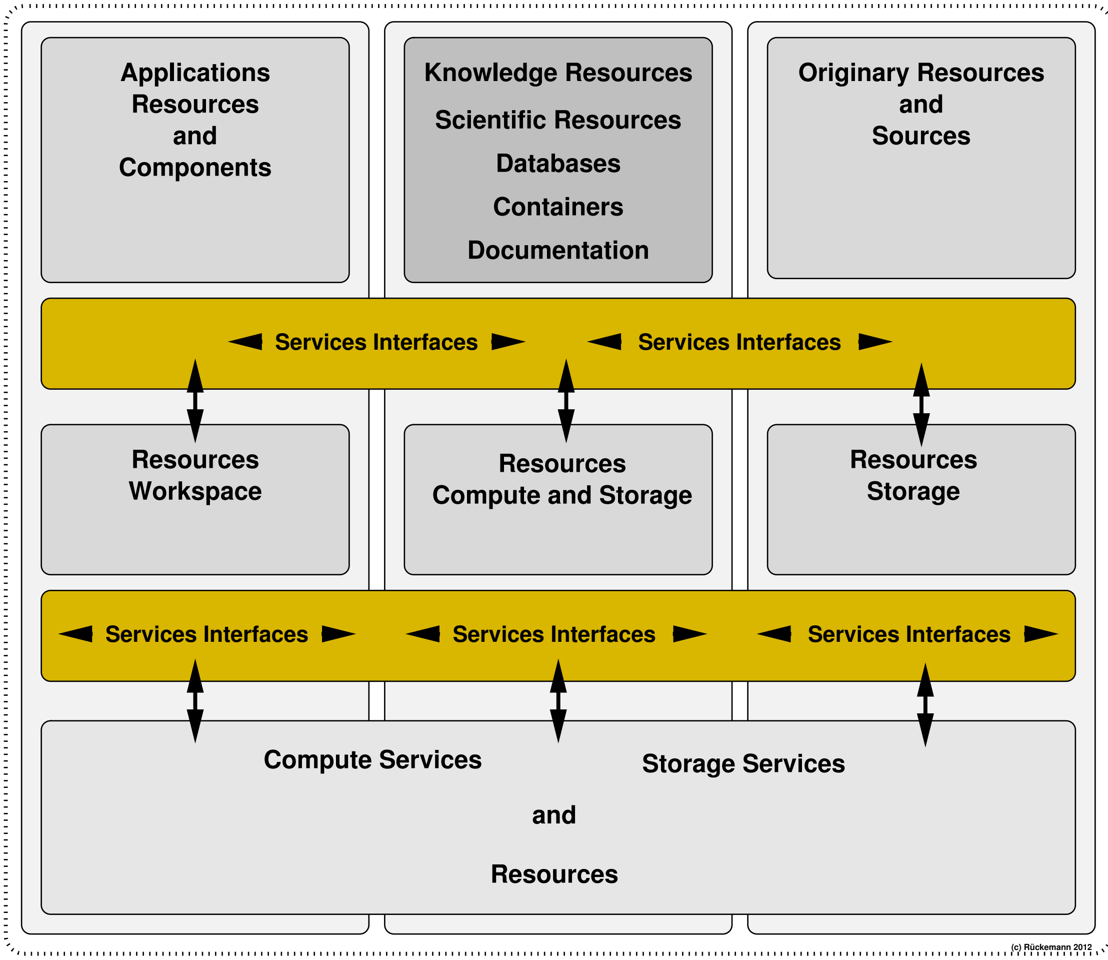


Figure 1. Architecture: Columns of practical dimensions. The knowledge resources are the central component within the long-term architecture. They are aligned by application resources and originary resources. The knowledge resources are used as a universal component for compute and storage workflows.

B. Components: Applications, knowledge, and sources

The main information, data, geo-referencing, and algorithms for all presented components and examples are provided by the LX Foundation Scientific Resources [14]. This deploys the structure and classification of objects necessary for a reasonable implementation. Besides the LX structure the already established Universal Decimal Classification (UDC) [19] has been integrated for objects [15] as it provides a hierarchical and multi-lingual, faceted classification for any topic and allows implementing a faceted analysis with enumerative scheme features, as well as to create new classes by using relations and grouping. In multi-disciplinary object context, this empowers to use workflows combining keywords, enumerative concepts and full-text analysis with a faceted analysis.

Besides the academic, industrial, and business application scenarios in focus of the GEXI collaborations' case studies [16] it is an important factor to integrate the necessary documentation and computing facilities with systems like an Universal IICS (UIICS). An implementation of interfaces for using structure and classification with appropriate Archaeological IICS system components has been created for several simple (SAMPLE, COLLECTION, CONTEXT, DISCIPLINE) and slightly more complex workflows (CONNECT, REFERTO-TOPIC, REFERTO-SPATIAL, VIEW-TO, VIEW-FROM) [18].

For the topics and content discussed here, geoscientific and archaeological information and processing are the core content. Data in this context necessarily includes applications and algorithms. Besides the above implemented features, it is optional to support any visualisation tool, processing algorithms, cartographic and mapping features and many more tools from secondary sciences, e.g., spatial algorithms and components, UDC (1-0/-9). These features can be used with the objects in any way that will be necessary to describe data and automate workflows.

C. Classification, keywords, and interfaces

The interfaces allow to use the various resources. A central element is the classification and structure of the knowledge resources as it increases the flexibility of the long-term development. Table I compares some features of classification and keywords used for object description.

TABLE I. UDC CLASSIFICATION AND KEYWORDS COMPARISON.

UDC	*Keywords*
Internationalisation	Methodical support, partial internationalisation
Codes	Code table support
High level of detail	Medium level of detail

Interfaces can be used in order to access and use objects. This includes filtering, combination, workflow and data processing and so on. In summation, this allows the integration of all data, objects, and resources available: scientific and discipline data, lexicographical and bibliographical data GPS data, geospatial information, processing algorithms, executable software, and many more, including realia objects.

The result means, we need to integrate multi-disciplinary information, allowing different views on the same context and allow even different paths for exploring knowledge.

V. Long-term strategy

The immanent attribute of preservation is time. Time is one of the factors limiting life and existence, e.g., of realia objects in archives, museums, and libraries as well as with implementations of mathematically based electronical machines and components.

Whereas looking from inside a traditional discipline, information seems to be complete and appears to increase slowly. On the other hand there is huge complementary information that cannot be described isolated by one discipline and tendency is increasing over the time and complexity.

Table II presents the result of a reasonable categorisation that has been found from practicing the knowledge resources creation and use for several decades. It shows a more detailed compilation of categorised features and components for an expected actuality time range. In this context, the goal for long-term means > 50 years, medium-term > 15 years, and short-term < 15 years.

Table II. Time-range goals with IICS components (selection).

Long-term	*Medium-term*	*Short-term*
Knowledge	Applications	Context
Containers	Interfaces	Sources
LX Scientific Resources	DOI, URN, PURL	URL
UDC	Converters	Media
Keywords	Active Source	Converters
Virtualisation information	Storage resources	Computing resources
Algorithms	Distributed services	Compiler, Executables
Content	Virtualisation	MPI, OpenMP
Context information	Complex implement.	Batch systems
Relations & references	Application features	Web Services
Internationalisation	OS features	Communication
Processing & workflows	Library features	Middleware

These components, described by a representative selection in Table II, can cover all aspects of knowledge creation, application, and system implementation. For example, with the implementation, the resources and containers are consisting of thousands of pages. For the presentation within the following sections a small excerpt of the objects and classification can be shown.

The long-term objects must be able to contain the essential knowledge, even as medium- and short-term objects cannot be preserved or made persistent as, e.g., DOI (Digital Object Identifier), URN (Uniform Resource Name), URL (Uniform Resource Locator), and PURL (Persistent Uniform Resource Locator) will vanish and context and sources may fade away as well as OS (Operating System) features used. Therefore, we have to distinct between the real instance of a DOI and URL or a context situation and a descriptive reference of these objects. These descriptive references can contain as much information and knowledge as possible (for example DOI, URL, context description, sources).

VI. Advanced knowledge object creation

A. Knowledge objects

The LX Scientific Resources [14], [18] are used as base knowledge resources for the following case studies, delivering structure, content, classification, and providing methodologically exploitable information. The elementary knowledge objects can have any required extent. Some objects are naturally small, e.g., translations or acronym expansions, others can have hundreds of pages with references and an arbitrary number of subobjects.

An object may contain any number of subobjects. As soon as it seems reasonable from the content and context a subobject can become an object or a number of subobjects can be grouped into a container. The object data excerpts show source, structure, references, and other features used. Media samples are referenced, but the extensive data is not explicitely given here.

Objects and information are naturally distributed, for example, spatially and logically. Ranking within any object matrix is subjective, especially when only the information from a few isolated and not comprehensive sources is considered. This holds true for any object referred to, for example, media objects, sources and publication. In the end, the isolated subset leads to a reduced quality within the selection. Therefore, some external resources have been included as examples.

B. Classification

The operated knowledge resources, based on the LX Foundation Scientific Resources [18], incorporate UDC classification for any discipline and purpose, e.g., for knowledge discovery and workflows.

A practical summarising excerpt subset of UDC codes used for computation with the available knowledge resources is given in Table III. In this context, the following examples explain multi-disciplinary documentation, views, and computational issues from several disciplines and topics, grouped by application:

- Digital archaeological library examples,
- Computing aspects,
- Knowledge resources and external information,
- Mechanisms and workflow case study on geo-objects.

TABLE III. ARCHAEOLOGY KNOWLEDGE RESOURCES CLASSIFICATION.

UDC Code	*Description*
UDC:902	Archaeology
UDC:903.2	Artefacts
UDC:904	Cultural remains of historical times
UDC:738	Ceramic arts. Pottery
UDC:738.8	Various ceramic objects
UDC:629.5	Watercraft engineering. Marine engineering. Boats. Ships ...
UDC:656	Transport and postal services
UDC:741	Drawing in general
UDC:691.2	Natural stones. Other mineral materials
UDC:664.7	Cereal technology. Flour and corn milling. Grain processing
UDC:664	Food industry
UDC:641.5	Preparation of foodstuffs and meals. Cookery
UDC:(32)	Ancient Egypt
UDC:(37)	Italia. Ancient Rome and Italy
UDC:(38)	Ancient Greece
UDC:(4)	Europe
UDC:(44)	France. French Republic. République Française
UDC:(450)	Italy. Republic of Italy. Republica Italiana
UDC:(460)	Spain. Kingdom of Spain, Reino de España
UDC:(495)	Greece. Hellenic Republic. Elliniki Dimokratia
UDC:(23)	Above sea level. Surface relief. Above ground ...
UDC:(24)	Below sea level. Underground. Subterranean
UDC:069.51	Museum pieces
UDC:002	Documentation. Books. Writings. Authorship
UDC:770	Photography and similar processes

The figures shown in the case study examples are computed from the content of knowledge resources and filtered with the Integrated Information and Computing Systems (IICS), using photo media samples (media samples and object entries © C.-P. Rückemann, 2011, 2012, 2013). It must be emphasised that the applications can provide any type of objects, high resolution media, and detailed information. An example how an environment and context can look like has been shown and discussed with special features of the knowledge resources and IICS (Figure 1 in [24]).

On the one hand, the object entries demonstrate the structure and references, e.g., to the attributes of the objects as classification, form, material, and location. On the other hand, the figures illustrate the result matrices for collections, context, and integration of multi-disciplinary information.

VII. DIGITAL ARCHAEOLOGICAL LIBRARY EXAMPLES

In combination with the above shown features, objects in digital archaeological libraries have been enriched with various information, e.g., on museum, library information, archives, network information, mapping services, locations and Points Of Interest (POI).

Due to the knowledge resources organisation, the objects can be used in references as well as in the cache for interactive components at any stage within the workflow process. Combining the structure and classification with the silken selection algorithms leads to very flexible, multi-disciplinary interfaces.

Each group of digital images shows a result matrix from a selection process. The following figures illustrate resulting objects from the digital library of the LX Scientific Resources with multi-disciplinary background, in these examples regarding material, function, and model or reconstruction purposes.

A. *Knowledge objects, classification, and computation*

The following example (Figure 2) shows two result matrices from the pottery and amphores context for the presentation of realia objects (row 1) and available documentation and reconstruction presentation of realia objects (row 2). Both rows of media samples in the computed result matrices are by option aligned left to right from West to East:

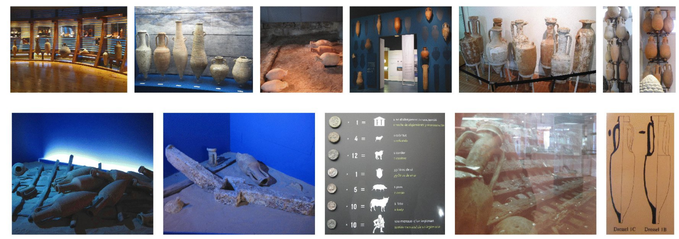


Figure 2. Result matrices – Pottery, `UDC:902,738,069.51,002,...`
Row 1: Realia objects presentation, aligned West to East.
Row 2: Documentation and reconstruction presentation, aligned West to East.

Listing 1 shows the associated knowledge object entries for the realia objects. in Figure 2, row 1.

```
Valentia  [Archaeology, Geophysics, ...]:
          Object:            Amphores.
          Object-Type:       Realia object.
          Object-Location:   Valentia Edetanorum,
           València, Spain.
          Object-Relocation: Museum, Diputacio de
           Valencia, Centre Cultural la Beneficencia,
           València, Spain.
          %%IML: media: ... img_7454.jpg
          %%IML: UDC-Object
           :[902+903.2+904]+738+738.8+(37)+(4)+(24)
          %%IML: UDC-Relocation:069.51+(4)+(460)+(23)
Valentia  [Archaeology, Geophysics, ...]:
          ...
Valentia  [Archaeology, Geophysics, ...]:
          ...
Barcino   [Archaeology, Geophysics, ...]:
          ...
          Object-Type:       Presentation, arrangement.
          Object-Location:   Museu d'Arqueologia de
           Catalunya, Barcelona, Spain.
          %%IML: UDC-Object:002+770
          %%IML: UDC-On-Content
           :[902+903.2+904]+738+738.8+(37)+(4)+(24)
          %%IML: UDC-Location:069.51+(4)+(460)+(23)
Cemenelum [Archaeology, Geophysics, ...]:
          Object:            Amphores.
          ...
          Object-Location:   Cemenelum, Nice-Cimiez,
           France.
          Object-Relocation: Musée et Site Archéologique
           Cemenelum, Nice-Cimiez, Ville du Nice, France.
          %%IML: UDC-Object
           :[902+903.2+904]+738+738.8+(37)+(4)+(24)
          %%IML: UDC-Relocation:069.51+(4)+(44)+(23)
Altinum   [Archaeology, Geophysics, ...]:
          Object:            Amphores.
          ...
          Object-Location:   Altinum, Altino, Venice,
           Italy.
          Object-Relocation: Museo Archeologico Nazionale
            di Altino, Venice, Italy.
          %%IML: UDC-Object
           :[902+903.2+904]+738+738.8+(37)+(4)+(24)
          %%IML: UDC-Relocation:069.51+(4)+(450)+(23)
Altinum   [Archaeology, Geophysics, ...]:
          Object:            Amphores.
          ...
```

Listing 1. Knowledge resources – Entries for realia objects.

The computation attributes are: Realia objects, presentation, Greek, Roman, pottery, amphores, ships, Mediterranean, location West to East.

For this example, the object entries are reduced to the significant information used for the computation. The sort order has been decided from the geo-coordinate latitudes of the location information references by the knowledge objects.

The first row (Figure 2 and Listing 1) show the resulting objects: Valentia Edetanorum (València), Barcelo (Barcelona), Barcelo (Barcelona), Cemenelum (Nice-Cimiez), Altinum (Venice), Altinum (Venice).

Second row: 3× Valentia Edetanorum (València), 2× Cemenelum (Nice-Cimiez). Computation attributes are: Documentation, reconstruction presentation, Greek, Roman, pottery, amphores, ships, Mediterranean, location West to East. Listing 2 shows associated knowledge object entries for the documentation entries in Figure 2, row 2.

```
Valentia  [Archaeology, Geophysics, ...]:
          Object:             Amphores in ship wreck.
          Object-Type:        Documentation, arrangement.
          Object-Location:    Valentia Edetanorum,
           València, Spain.
          Object-Relocation: Museum, Diputacio de
           Valencia, Centre Cultural la Beneficencia,
           València, Spain.
          %%IML: media: ... img_7455.jpg
          %%IML: UDC-Object:002+770
          %%IML: UDC-On-Content
           :[902+903.2+904]+738+738.8+(37)+(4)+(24)
          %%IML: UDC-Location:069.51+(4)+(460)+(23)
Valentia  [Archaeology, Geophysics, ...]:
          Object:             Amphores and anchor and ship
            wreck.
          ...
Valentia  [Archaeology, Geophysics, ...]:
          Object:             Amphores, values, coins.
          ...
Cemenelum [Archaeology, Geophysics, ...]:
          Object:             Amphores in ship wreck.
          Object-Type:        Documentation, photo.
          Object-Location:    Cemenelum, Nice-Cimiez,
           France.
          Object-Relocation: Musée et Site Archéologique
           Cemenelum, Nice-Cimiez, Ville du Nice, France.
          %%IML: media: ... img_0017.jpg
          %%IML: UDC-Object:002+770
          %%IML: UDC-On-Content
           :[902+903.2+904]+738+738.8+(37)+(4)+(24)
          %%IML: UDC-Location:069.51+(4)+(44)+(23)
Cemenelum [Archaeology, Geophysics, ...]:
          Object:             Amphores type.
          Object-Type:        Documentation, sketch.
          ...
```

Listing 2. Knowledge resources – Entries for documentation objects.

Special external media material from digital libraries and private collections [25] can be referenced from within the knowledge resources, too.

B. Classification and painted pottery

Figure 3 presents the computed result matrix for painted pottery. The example shows a result matrix on painted vases and amphores. The knowledge resources provide information that within ceramic products the amphores is a subgroup of vases, both being pottery.

Figure 3. Result matrix – Painted pottery. `UDC:902,738,741,...`.
Row 1: Vases, painted, various types, Greek.
Row 2: Vases, painted, amphores type, Greek and Etruscan.

The results in the first row show painted vases whereas the results in the second row show painted amphores only.

C. Classification and transport pottery

Figure 4 shows the computed result matrix on pottery used for transport of products. The knowledge resources provide additional object information, e.g., on the cultural background.

Figure 4. Result matrix – Transport pottery. `UDC:902,738,656,...`.
Row 1: Amphores, transport, Roman.
Row 2: Amphores, transport, Visigoth.

All objects show transport amphores. The results in the first row show Roman transport amphores whereas the results in the second row show Visigoth transport amphores. For these groups, the Listings 3 (Figure 3, row 2, objects 2 and 3) and 4 (Figure 4, row 1, objects 1, 2, and 3), show excerpts of several amphores object entries, containing additional media data.

```
Object:            Amphora, painted.
Object-Type:       Realia object.
Object-Location:   Unknown.
Object-Relocation: Museu d'Arqueologia de Catalunya,
 Barcelona, Spain.
%%IML: media: ... img_5673.jpg
%%IML: media: ... img_5673.jpg
%%IML: UDC-Object:[902+903.2+904]+738+738.8+741+(37)+(4)
%%IML: UDC-Relocation:069.51+(4)+(460)+(23)
%%IML: labellanguage: Catalan
%%IML: labelcomment: written label, documentation on
 photo media
%%IML: label: {MUSEUM-Description: Àmfora grega de
 figures negres}
%%IML: label: {MUSEUM-Date:        Cultura grega (s. VI
 aC)}
%%IML: label: {MUSEUM-Material:    Ceràmica}
%%IML: label: {MUSEUM-Origin:      Procedeix d'un taller
 d'Atenes}
%%IML: label: {MUSEUM-Inventory:   Nùm inv. 11311}

Object:            Amphora, painted - decorated. ...
%%IML: label: {MUSEUM-Description: Àmfora etrusca}
%%IML: label: {MUSEUM-Date:        Cultura etrusca (final
  s. VII aC)}
%%IML: label: {MUSEUM-Material:    Ceràmica de bucchero
 lueido}
```

Listing 3. Knowledge resources – Entries for painted amphores objects.

```
Object:            Amphora, transport.
Object-Location:   Unknown.
Object-Relocation: Museu d'Arqueologia de Catalunya,
 Barcelona, Spain.
%%IML: media: ... img_5831.jpg
%%IML: media: ... img_5831.jpg
%%IML: UDC-Object:[902+903.2+904]+738+738.8+656+(37)+(4)
%%IML: UDC-Relocation:069.51+(4)+(460)+(23)
%%IML: labellanguage: Catalan
%%IML: label: {MUSEUM-Description: Àmfora per a vi}
%%IML: label: {MUSEUM-Date:        Cultura romana (
 primera meitat s. I aC - I dC)}
%%IML: label: {MUSEUM-Material:    Ceràmica}
%%IML: label: {MUSEUM-Origin:      Procedència
 desconeguda}
%%IML: label: {MUSEUM-Inventory:   Nùm inv. 27701}

Object:            Amphora, transport. ...
Object-Location:   Southern Italy.
Object-Relocation: Museu d'Arqueologia de Catalunya,
 Barcelona, Spain. ...
%%IML: label: {MUSEUM-Description: Àmfora per a vi}
%%IML: label: {MUSEUM-Date:        Cultura romana (inici
  s. II aC - inici s. I aC)}
%%IML: label: {MUSEUM-Origin:      Sud d'Italia}

Object:            Amphora, transport. ...
Object-Location:   Andalusia, Spain.
Object-Relocation: Museu d'Arqueologia de Catalunya,
 Barcelona, Spain. ...
%%IML: label: {MUSEUM-Description: Àmfora per a salaò}
%%IML: label: {MUSEUM-Date:        Cultura romana (finals
  s. I aC - I dC)}
%%IML: label: {MUSEUM-Origin:      Andalusia}
```

Listing 4. Knowledge resources – Entries for transport amphores objects.

D. Discover, Complete, Explore

1) Knowledge attribute based discovery: The knowledge resources allow to create references by specifying criteria and associations. With the criteria `Leibniz; pottery; Italy; economy` and the association `pottery : amphores : storage : transport` the following reference (Listing 5) can be computed.

```
POI-person-place-date-comment: Gottfried Wilhelm Leibniz
 :: Venedig (Venezia, Venecia, Venice), Italien (Italy,
 Italia) :: \isodate{1689}{03}{} :: Rome Travel, Italy,
 Travel to Rome
POI-person-place-date-comment: Gottfried Wilhelm Leibniz
 :: Venedig (Venezia, Venecia, Venice), Italien (Italy,
 Italia) :: \isodate{1690}{02}{} :: Rome Travel, Italy,
 Travel from Rome
...
POI-person-place-date-comment: Vespasian; Cesar :: Roma (
 Rom, Rome), Italia (Italy, Italien) :: \isodate
 {0069}{}{}--\isodate{0079}{}{} A.C. :: reign
POI-person-place-date-comment: Vespasian; Cesar :: Roma (
 Rom, Rome), Italia (Italy, Italien) :: :: Amphoras.
POI-person-place-date-comment: Vespasian; Cesar :: Roma (
 Rom, Rome), Italia (Italy, Italien) :: :: Taxes.
POI-person-place-date-comment: Vespasian; Cesar :: Roma (
 Rom, Rome), Italia (Italy, Italien) :: :: Clothiers.
POI-person-place-date-comment: Vespasian; Cesar :: Roma (
 Rom, Rome), Italia (Italy, Italien) :: :: (lat.) ``
 pecunia non olet''. A saying that may have been created
 in this context.
POI-person-place-date-source: Sueton, Vespas. 23 :: Roma
 (Rom, Rome), Italia (Italy, Italien) :: :: Vespasian to
 his son Titus.
```

Listing 5. Pottery and associations (LX Resources).

The reference computed from the resources contains context associated with the criteria and association.

2) UDC based completion: The potential to dynamically create combined classification and context information does provide huge benefits. The example 'amphores in the net' will show how to find classified information. There is no general method nor a tool for systematically discovering classified material in the Internet. Even the amount of material available is not known as the awareness about classification and as an result the demand is not very developed. When looking for information a search even not supporting classification can give some hints. Looking for examples of UDC amphores classification we have currently (2013-08-11) retrieved a few slightly complex classifications via Google (Listing 6).

```
904:738(497.5-37 Rovinj)
904:738.8(497.5 Dalmacija)"-04/-01"
904:738.8(497.5 Vinkovci)"652"
```

Listing 6. Amphores UDC classification (retrieved via Google).

All three showing UDC classifications regarding amphores context in Croatia, mediterranean area, using an explicit specification of the respective location. The classification usage is very well comparable with those commonly used for amphores objects within the objects of the knowledge resources. This increases the numbers of suitable positive results within the results matrices, especially for the documentation information on references and sources.

3) Knowledge based exploration: Listing 7 shows an excerpt of several amphores object entries. These object entries do contain various information. In context with the request on a certain region, these objects build a group by their classification and context and the information that additional media data for these objects is not available and target of further investigation.

```
Akandia    [Archaeology, Geophysics, ...]:
           Greek city, Rhodos Island, Dodekanese, Greece.

           Object: Ship wreck.
           Object-Location: 550\UD{m} NE of Akandia Harbor
            .
           %%SRC: ...
           %%IML: UDC-Object:[902+903.2+904]+629.5+(38)
            +(4)+(24)

```

```
          Subobject: Amphoras.
          Subobject-Find-Depth: 36\UD{m}. ...
          Subobject-Description: Rhodian type.
          Subobject-Date: 1st century B.C. -- early 2nd
           century A.C.
          %%IML: UDC-Object
           :[902+903.2+904]+738+738.8+(38)+(4)+(24)
          %%IML: UDC-Relocation:069.51+(4)+(495)+(23)
Lindos    [Archaeology, Geophysics, ...]: ...
          Object: Ship wreck.
          Object-Location: 500\UD{m} SE of Hagios Pavlos
           Harbor.
          %%IML: UDC-Object:[902+903.2+904]+629.5+(38)
           +(4)+(24) ...
Rhodos    [Archaeology, Geophysics, ...]: ...
          Object: Ship wreck.
          Object-Location: Rhodes Merchant Harbor. ...
          %%IML: UDC-Object:[902+903.2+904]+629.5+(38)
           +(4)+(24) ...

          Subobject: Pottery.
          Object-Relocation: 20 objects in Archaeological
            Museum Rhodos City ...
          %%IML: script: {INSCRIPT: APICTAPXOC}  {
           TRANSCRIPT: Aristarchos}
          %%SRC: Nikos Th. Nikolitsis: Archäologische
           Unterwasser-Expedition bei Rhodos ...
```

Listing 7. Knowledge resources – Amphores exploration context.

E. *On-water transport and utilisation*

The knowledge resources provide information that amphores are tightly associated with on-water transport. Especially, the associations are:

- Amphora sites :: finding historical transport routes.
- Amphores :: geographic origin of the cargo.
- Amphores :: valuable means for dating ship wrecks.

Selecting archaeological objects, watercraft engineering, marine engineering, boats, ships, boat building, ship building, and being models having origin from ancient Egypt and the Mediterranean (`UDC:902+629.5+(32),(37),(38)`) results in a subset from the ship model collection. The following examples (Figures 5 and 6) show two subsets.

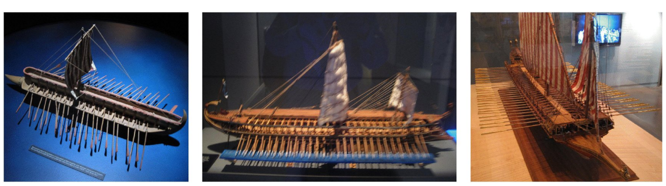


Figure 5. Result matrix – Ship + war.

Figure 5 presents a result matrix of media samples for ancient war ships whereas Figure 6 presents a result matrix for ancient civil transport ships.

Figure 6. Result matrix – Ship + civil transport.

Going into this result matrix, the first sample shows a Greek ship used for commercial trading, including amphores. The classification refers to this ship model into the amphores context as it also carries amphores in this model. The second sample shows a Roman commercial transport ship, also associated with amphores transport. The third and fourth sample are a Llagut type and an Egyptian ship.

F. *Objects and geological information*

Figure 7 excerpts a result on mills, stone, and crop. Adding `volcanic` to the target matrix delivers a more specific object (Figure 8), a rotary mill made from volcanic stone, found at an excavation at Badalona, the historical Baetulo.

Figure 7. Result matrix – Mills + stone + crop.

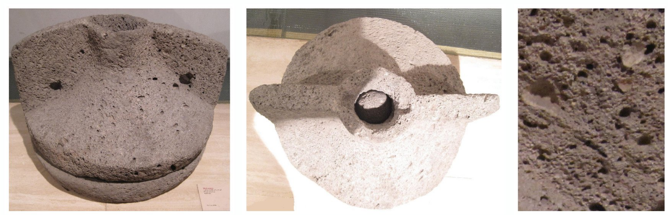


Figure 8. Result matrix – Mills + stone + crop + volcanic (one object).

The object entry contains a reference to appropriate media objects showing the realia object. The original label does not contain the information on the specific material. The computed object entry also holds the reference to an appropriate material sample of the volcanic stone. It identifies the stone as Basalt and refers to further relevant geological objects. The computed object also links to comparable material and sources where those materials can be found and in this case it delivers reasons why this material might have been used for this product. Listing 8 shows an excerpt of the first media object being a subobject entry of the more comprehensive `Baetulo` object.

```
Baetulo   [Archaeology, Geophysics, ...]:
          Object:            Rotary mill.
          Object-Type:       Realia object.
          Object-Location:   Baetulo, Spain.
          Object-Relocation: Museu d'Arqueologia de
           Catalunya, Barcelona, Spain.
          %%IML: media: ... img_5833.jpg
          %%IML: UDC-Object
           :[902+903.2+904]+664.7+691.2+664+641.5+(37)
           +(4)+(23)
          %%IML: UDC-Relocation:069.51+(4)+(460)+(23)
          %%IML: label: {MUSEUM-Description: Moli
           rotatori}
          %%IML: label: {MUSEUM-Date:        Cultura
           romana (s. I-II dC)}
          %%IML: label: {MUSEUM-Material:    Pedra
           volcànica}
          %%IML: label: {MUSEUM-Origin:      Badalona}
          %%IML: label: {MUSEUM-Inventory:   Nùm inv.
           22038}
          %%IML: objectcomment: {MATERIAL-class:
                              Igneous rock, volcanic}
```

```
          %%IML: objectcomment: {MATERIAL-stone:
                         Basalt} ...
          %%IML: objectcomment: {MATERIAL-usage:
                         Basaltic mill stones sharpen
           themselves with ongoing usage.}
          %%IML: objectcomment: {MATERIAL-comparable:
                  Basalt lava stones from Mendig,
           Eifel, Germany, have been exported in Roman
           times for producing mill stones.}
          %%IML: objectcomment: {MATERIAL-comparable-
           attributes: Basalt lava stone from Mendig,
           Eifel, Germany, are of grey colour and rich or
            pores.}
          %%IML: objectreference: s. Basalt ...
```

Listing 8. Knowledge resources – `Rotary mill` subobject.

The object refers to other objects `Basalt` and `Mendig`, in the text as well as with explicit references. These are integrated into the volcanology and geology context, which can deliver more detailed references and information.

VIII. Computing: Features and components

The knowledge resources can be flexibly accessed and used for computational purposes. They have been used with processing components on High End Computing resources, e.g., dynamical and interactive support on the one hand and diffraction support and seismic stacking on the other hand [26], [18] and may be used for comparable concepts, e.g., the Smart Stacking [27].

A. Selected features

The following passages present some features implemented for processing of objects, e.g., translations and transcription support, support of exceptions or correction, historical writing support, and ranking. Many compute intensive methods of extending the object pool for specific discovery workflows use the modification within the available resources. These can include correction or modification of typographical appearances. These methods can be used for content as well as for keywords or classification, in centralised or distributed resources. For computational issues with data and computing centred workflows dynamical process communication as well as batch and envelope support is shown with the later examples.

1) Computing translations and transcriptions: The translation resources are one option to use translation and associated transcription data (Listing 9, excerpt). The workflow components can support computing references and links into multilingual context by exploiting these resources.

```
Catalan:   {àmphora}
English:   {amphore, amphorae / amphoras (pl.)}
French:    {amphora}
German:    {Amphore}
Greek:     {amphora, amphoreas}{$\alpha\mu\varphi o\rho\
 epsilon\alpha\varsigma$}
Italian:   {anfora, anfore}
Latin:     {amphora}
Spanish:   {àmfora}

Catalan:   {basalto}
Danish:    {basalt, mørk vulkanske bjergart, vulkanske
 klipper}
English:   {basalt}
Finish:    {basaltti}
French:    {basalte}
German:    {Basalt}
Greek:     {basaltes, eidos petromatos}{$\beta\alpha\
 sigma\alpha\lambda\tau\eta\varsigma$, $\epsilon i\delta
 o\varsigma$ $\pi\epsilon\tau\rho\omega\mu\alpha\tau o\
 varsigma$}
Icelandic: {basalt}
Italian:   {basalto}
Norwegian: {basalt}
Russian:   {bazalt}
Cyrillic:  {bazalt}{\setcyr{bazal\soft t}}
Spanish:   {basalto, basanita}
```

Listing 9. Object translation and transcription data (LX Resources).

The entries `amphores` and `basalt` are examples from knowledge resources objects. They show a subset of languages and translation and transcription data. The data sets are integrated within the appropriate knowledge objects and referenced from an arbitrary number of associated objects. As shown in the example, the transcriptions can be defined generic and portable. The data itself can be handled by various algorithms. For example, the transcription data can be iterated automatically with special algorithms in order to generate alternatives for adding references as well as using the information for typesetting or character replacements. Listing 10 shows an excerpt of retrieved examples (`lxaztrdb`) from the general purpose translation and transcription database.

```
Catalan: Ceràmica
Spanish: Cerámica
English: ceramics
German:  Keramik
French:  céramique

Catalan: antiga salsa romana
Spanish: salsa romana antigua
English: ancient Roman sauce
German:  antike römische Soße

Catalan: Moli rotatori
Spanish: Molino rotatorio
English: Rotary mill
German:  Drehmühle

Catalan: volcànica
Spanish: volcánico
English: volcanic
German:  vulkanisch
French:  volcanique
```

Listing 10. Translation and transcription database (LX Resources).

The translation and transcription database allows to have an arbitrary algorithm and structure for an implementation within a workflow. It can also associate terms with the translations, like associating “Garum” with “ancient Roman sauce” or creating black lists for translations.

2) Computing keyword translation terms: Listing 11 shows generated (`lxazkw_de2en.sh`) keyword translations.

```
s/\[\(.*\)Archäologie\(.*\)\]:/\[\1Archaeology\2\]:/g
s/\[\(.*\)Geologie\(.*\)\]:/\[\1Geology\2\]:/g
s/\[\(.*\)Geophysik\(.*\)\]:/\[\1Geophysics\2\]:/g
s/\[\(.*\)Mineralogie\(.*\)\]:/\[\1Mineralogy\2\]:/g
s/\[\(.*\)Vulkanologie\(.*\)\]:/\[\1Volcanology\2\]:/g
s/\[\(.*\)Fernerkundung\(.*\)\]:/\[\1Remote Sensing\2\]:/
 g
s/\[\(.*\)Seefahrt\(.*\)\]:/\[\1Seafaring\2\]:/g
s/\[\(.*\)Etymologie\(.*\)\]:/\[\1Etymology\2\]:/g
s/\[\(.*\)Einheit\(.*\)\]:/\[\1Unit\2\]:/g
```

Listing 11. Keyword translation terms (LX Resources, excerpt).

Keywords have a prominent role with objects and can be used independently from other parts and attributes. Their translation and definition can therefore be separated from other translations.

3) Computing translation groups: Comparable to the keyword handling the resources allow for definition of translation groups for strings, which might even not be translations. Listing 12 shows an excerpt of translation groups.

```
Archaeology; Archeology; Archäologie; Archaeologia;
 Archeologia;
...
Volcanism; Vulcanism; Vulkanismus;
...
Vulcanologia; Volcanology; Vulkanologie; Vulcanology;
```

Listing 12. Translation groups (LX Resources, excerpt).

These groups can be used for defining various character strings being used alternatively for a term.

4) Computing ligatures: Listing 13 shows an excerpt of the ligature handling algorithms (`lx_ligature`) generated from the knowledge resources components.

```
if (/([Aa]uf)(falt)/) { ...
if (/([Aa]uf)(füll)/) { ...
if (/([Rr]elief)(f[oö]rm)/) { ...
if (/([Ss]umpf)(fieber)/) { ...
```

Listing 13. Ligature handling algorithms (LX Resources, excerpt).

For providing a means for any purpose, the algorithms can be used in both directions, separating and ligating. For example, the ligating direction can be helpful for even finding links that would not be recognised with a regular expression search on documents coded with different ligations.

5) Computing on historical writing objects: Listing 14 is an excerpt (`lx_histcorr.sh`) of a historical writing algorithm used for the Leibniz cases presented here.

```
auff :: auf
Cammer :: Kammer
darff :: darf
delinqventen :: Delinquenten
Galeren :: Galeeren
gemischet :: gemischt
Golphe :: Golf (von Venedig)
Gondolier :: Gondoliere
mußen :: müssen
navis :: Schiff
niederlaßet :: niederläßt
salviren :: salvieren; retten
schiffe :: Schiffe
sizend :: sitzend
trincken :: trinken
ufer :: Ufer
verfertiget :: verfertigt
waßer :: Wasser
wirfft :: wirft
```

Listing 14. Historical writings algorithm, Leibniz texts (LX Resources).

The example lists historical notation and spelling from transliterations of original handwritten documents from Gottfried Wilhelm Leibniz (1646–1716).

6) Computing typographical corrections: Listing 15 shows examples (`lxazkw_tycorr.sh`) from the correction algorithms generated via the available typographical database.

```
iab archäology archaeology
iab Archäology Archaeology
...
iab laoratories laboratories
iab Laoratories Laboratories
...
iab vulkanology volcanology
iab Vulkanology Volcanology
```

Listing 15. Typographical correction algorithms (LX Resources, excerpt).

The `tycorr` routines based on this database can be used for extending workflows at any step, from input, content, context, intermediate data up to finals results. With non-batch workflows the same database is used for editing corrections and publishing support. Any object, attribute or component can be handled that way. On the one hand, even objects or keyword labels as generated for special languages only can be integrated into a regular discovery. On the other hand, original and historical writing, different transcriptions or "authentic" errors can be included in the discovery process and used within workflows. With the existing components many thousands of variants, transcription sets, and automatic corrections have been created and build an extended representation of the knowledge resources content. Applying these within the workflows can improve the quality of the discovery, exactly for the purpose of the application scenario.

7) Ranking: Algorithms applied to isolated input data stored in proprietary database cannot result in a generally valid data ranking. This ranking is only appropriate for the specific limited context of the collected data. Any comparisons of the ranking between separate groups of data is not reasonable.

The basic environment is made up by the algorithm and the input data. Input data consists of the knowledge resources and external data. Everything that may be used for discovery can be integrated with the knowledge resources. Besides data sets from natural sciences modelling or simulation, and documentation also references, descriptive data, citations, publications with content and bibliographic information can be exploited.

- Alphanumeric ranking,
- Ranking based on context,
- Ranking based on classification,
- Ranking based on number of items, like regular expressions or references,
- Silken selection, like phonetic algorithms support.

B. Components

Using the following concepts, we can implement for mostly any system:

- Application communication via IPC.
- Application triggering on events.
- Storage object requests based on envelopes.
- Compute requests based on envelopes.

For demonstration and studies flexible and open Active Source Information System components have been used for maximum transparency. This allows OO-support (object, element) on application level as well as multi-system support. Listing 16 shows a simple example for application communication with framework-internal and external applications (Inter-Process Communication, IPC).

```
catch { send {rasmol #1} "$what" }
```

Listing 16. Application communication (IPC).

This is self-descriptive Tcl syntax. In this case, the IPC `send` is starting a molecular graphics visualisation tool and catching messages for further analysis by the components.

Listing 17 shows an example of how the communication triggering can be linked to application components.

```
text 450.0 535.0 -tags {itemtext relictrotatex} -fill yellow -text "Rotate␣x" -justify center
...
$w bind relictrotatex <Button-1> {sendAllRasMol {rotate x 10}}
$w bind relictballsandsticks <Button-1> {sendAllRasMol {spacefill 100}}
$w bind relictwhitebg <Button-1> {sendAllRasMol {set background white}}
$w bind relictzoom100 <Button-1> {sendAllRasMol {zoom 100}}
```

Listing 17. Application component triggering.

Tcl language objects like `text` carry tag names (`relictrotatex`) and dynamical events like `Button` events are dynamically assigned and a user defined subroutine `sendAllRasMol` is executed, triggering parallel visualisation. Storage object requests for distributed resources can be done via OEN. Listing 18 shows a small example of a generic OEN file.

```
<ObjectEnvelope><!-- ObjectEnvelope (OEN)-->
<Object>
<Filename>GIS_Case_Study_20090804.jpg</Filename>
<Md5sum>...</Md5sum>
<Sha1sum>...</Sha1sum>
<DateCreated>2010-08-01:221114</DateCreated>
<DateModified>2010-08-01:222029</DateModified>
<ID>...</ID><CertificateID>...</CertificateID>
<Signature>...</Signature>
<Content><ContentData>...</ContentData></Content>
</Object>
</ObjectEnvelope>
```

Listing 18. Storage object request (OEN).

OEN are containing element structures for handling and embedding data and information, like `Filename` and `Content`. An end-user public client application may be implemented via a browser plugin, based on appropriate services. With OEN instructions embedded in envelopes, for example as XML-based element structure representation, content can be handled as content-stream or as content-reference. Algorithms can respect any meta-data for objects and handle different object and file formats while staying transparent and portable. Using the content features the original documents can stay unmodified. The way this will have to be implemented for different use cases depends on the situation, and in many cases on the size and number of data objects. However, the hierarchical structured meta data is uniform and easily parsable. Further, it supports signed object elements (`Signature`), validation and verification via Public Key Infrastructure (PKI) and is usable with sources and binaries like Active Source. Compute requests for distributed resources are handled via CEN interfaces [28]. Listing 19 shows a generic CEN file with embedded compute instructions.

```
<ComputeEnvelope><!--(CEN)--><Instruction>
<Filename>Processing_Batch_GIS612.pbs</Filename>
<Sha512sum>...</Sha512sum>
<DateCreated>2013-09-15:210917</DateCreated>
<Signature>...</Signature>
<Content><DataReference>https://doi...
<Script><Pbs>
<Shell>#!/bin/bash</Shell>
<JobName>#PBS -N myjob</JobName>
<Oe>#PBS -j oe</Oe>
<Walltime>#PBS -l walltime=00:20:00</Walltime>
<NodesPpn>#PBS -l nodes=8:ppn=4</NodesPpn>
<Feature>#PBS -l feature=ice</Feature>
<Partition>#PBS -l partition=hannover</Partition>
<Accesspolicy>#PBS -l naccesspolicy=singlejob ...
<Module>module load mpt</Module>
<Cd>cd $PBS_O_WORKDIR</Cd>
<Np>np=$(cat $PBS_NODEFILE | wc -l)</Np>
<Exec>mpiexec_mpt -np $np ./dyna.out 2>&1</Exec>
</Pbs></Script></Instruction>
</ComputeEnvelope>
```

Listing 19. Compute request: Compute envelope (CEN).

Content can be handled as content-stream or as content-reference (`Content`, `ContentReference`). Compute instruction sets are self-descriptive and can be pre-configured to the local compute environment. In this case, standard PBS batch instructions like `walltime` and `nodes` are used. The way this will have to be implemented for different use cases depends on the situation, and in many cases on the size and number of data objects. An important benefit of content-reference with high performant distributed or multicore resources is that references can be processed in parallel on these architectures. The number of physical resources and the transfer capacities inside the network are limiting factors.

IX. Integration of external information

Besides the computational aspects, it had to be analysed if and how external structures of traditional information sources can contribute to the knowledge resources. The following example describes how an intelligent use of Integrated Information and Computing Systems knowledge resources can support on-site knowledge discovery as well as external distributed discovery. Regarding the examples in the last section, information from an external resource has been analysed and compared for finding complementary references for objects and result matrices of the knowledge database and for detecting targets for future enhancements of the object and media database. Using the LX Scientific Resources and data from external sources, in this case the publicly available Leibniz information (concept glossaries [29], manuscript collections and catalogues [30], [31], and critical editions [32], emended and commented), several new references can be created for the resources. The critical editions contains the texts on base of the original drafts. As there is no flexible interface or standard format available, the referenced files have to be fetched, processed, and evaluated in order to retrieve the required information.

A. Leibniz and archaeology case

The knowledge resources have been used for discovering paths into external resources. Listing 20 shows an excerpt of the object paths used in context with Gottfried Wilhelm Leibniz (1646–1716).

```
Ceramics : Keramik : Tonerde, Material, Porzellan
Amphoras : Amphoren : Transport, Lastentransport
Venice : Venedig : Schiff, Schiffsbau
Ship : Schiff, navis, Ägypten
```

Listing 20. Object paths for discovery (LX Resources).

The general knowledge resources translation component implicitely supports a significant number of the gathered terms (Listing 21, excerpt), translating from German into English.

```
Ägypten   :: Egypt
Keramik   :: Ceramic
Porzellan :: Porcelain
Schiff    :: Ship
Ton       :: Clay
Tonerde   :: Alumina
Transport :: Transport
```

Listing 21. Relevant terms from the translation component (LX Resources).

An excerpt of complementary information regarding references from the external resources is shown in Listing 22.

```
Transportwesen - chinesische Methoden
Transportwesen - technische Lösungen, Lastentransport
Transportwesen - technische Lösungen, allgemein
```

Listing 22. Knowledge object references on "transport" in Leibniz context.

These refer to the appropriate descriptions and sources, e.g., [33]. Complementary associated information regarding ceramics, ships, and "Venice" is shown in Listings 23, 24, and 25.

```
Schiffsankerfunde
Schiffsentführung
Schiffsfunde - Niedersachsen, Schweden
Schiffsreste - Funde
```

Listing 23. Knowledge object references on "ship" in Leibniz context.

```
Frankreich - Flotte - Schiffe, Golf von Venedig
Griechen - in Venedig
```

Listing 24. Knowledge object references on "Venice" in Leibniz context.

```
Ton, Tonerde
Tonerde
```

Listing 25. Knowledge object references on "clay" in Leibniz context.

```
Ägypten - Altertümer
Ägypten - Erdbeben
Ägypten - Kornkammer
Ägypten - Weltwunder
Ägypten - Wissenschaft
Ägypten - Transport von Schiffen
```

Listing 26. Knowledge object references on "Egypt" in Leibniz context.

These refer to the appropriate descriptions and sources, e.g., [34], [35], [36], [37] and [38], [39], [40], [41] as well as [42]. It is significant that some important passages are not containing the terms in either language or transcription but some context of these. In the case of [36] neither "Venedig", "Venice" or another term is mentioned in the texts but the term "Golphe", which in this case refers to the "Gulf of Venice". Therefore, it is most important to have a context description and to process this description for a successful discovery.

B. Leibniz and geo resources case

The knowledge resources not only enclose textual references. They can also deliver references and context for non-textual material, different terminology, and sources:

Within the knowledge resources, the context of the "Leibniz" object also delivers references to non-textual material Gottfried Wilhelm Leibniz had access to, e.g., the Witsen Map [43]. The knowledge resources can provide transfer of context and terminology, e.g., for different disciplines, epochs, languages, and cultures. For example, it refers the term "seismology" to the term "terrae motus" used in that time [44], [45], as has been shown in [24]. It further links the term to the "Vesuvius" and earthquake related context and from this delivers source, e.g., for the correspondency Leibniz had regarding geoscientific phenomena [46], [47].

C. Integration of the Leibniz resources

The external resources themselves have revealed some deficits, especially the do not use a unique terminology. In addition, the structure of these resources is not unique. There is no general harmonisation of the implementations. The implementations show that different institutions and projects with different intentions have been working on the topic. Only a low level of interoperability is available. The preparation of the data in its current organisation and formatting is not well suited for further electronical use in information systems. The numbering of sources and references is not intended to be used automatically. The provided implementation of transcriptions, translations, and references to original sources, scans, and bibliographic data is not consistent. In addition, it cannot be interfaced in order to enable a full discovery of the content.

X. Mechanisms and workflows case study

A filter chain can be used to compute resulting object sets. Based on the available system the following steps can be separated, in an example from geosciences and archaeology:

- Select topic from knowledge base (volcanology).
- Select region from results (Europe, Caribbean).
- Select volcano from results (Vesuvius, La Soufrière).
- Select object entries (geosciences and archaeology).
- Select media objects and references.
- Select application resources and interfaces.

A. Workflows and algorithms

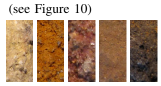
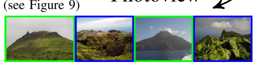
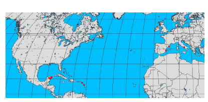
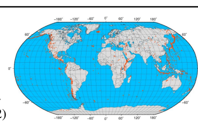
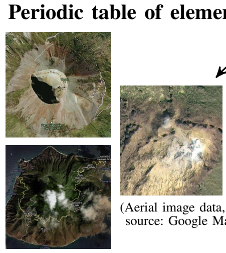
The knowledge resources block is the central resource in the long-term strategy. The knowledge resources can contain any kind of content. Application components can be migrated into the knowledge resources for documentation purposes and re-use. The services can access archived and historical data as well as live data and feed it into the workflows. Services interfaces allow to build complex workflows using arbitrary algorithms. The knowledge resources can be accessed from applications to extract suitable information and trigger the use of compute and storage resources. Objects can be selected by any algorithm, e.g., combinatory, search, and filter algorithms. Examples for the universal use of documentation and algorithms as used with the disciplines presented here are media data like digital images, video, hypertexts, Portable

Document Format (PDF) documents, LaTeX documentation and sources, implementations of algorithms in Perl, Tcl, Fortran, and C programming languages as well as references to digital object and realia objects. The results can be delivered to a defined location or service.

B. Resulting cross-links calculated

The knowledge resources organisation allows to create all structures and references possible for information science purposes, besides content and taxonomy. Table IV shows an excerpt of the references and cross-links calculated from the knowledge resources for a "Vesuvius" object with some applications and originary resources, media information and illustrative examples.

TABLE IV. EXAMPLE CROSS-LINKS WITH SECONDARY REFERENCES FOR "VESUVIUS" OBJECT AND GENERATED VIEWS (EXCERPT).

Knowledge Resources	*Applications Resources*	*Media Inform.*	*Originary Resources*
Vesuvius LX Resources	actmap	photo	samples
•◦**volcano**	`1 Vesuvius %-GP%-XX%---: Vesuvius [Volcanology, Archaeology]:` `2 %-GP%-XX%---: (lat.) Mons Vesuvius.` `3 %-GP%-XX%---: (ital.) Vesuvio.` `4 %-GP%-XX%---: (deutsch.) Vesuv.` `5 %-GP%-EN%---: Volcano, Gulf of Naples, Italy.`	object	[on-site]
•–•–◦ **climatology**		object	–
•–•–◦ **magma chamber**	(see Listing 31)	object	[on-site]
•–•–•–◦ **Thrihnukagigur**		links	[on-site]
•–•–•–•–◦ **Þríhnúkagígur**	Transcription	links	[on-site]
•◦**super volcano**	[interfaces]	object	[on-site]
•–•–◦ **Yellowstone**	(see Figure 10)  	object	[on-site]
•–•–•–◦ **Liparite**		object	samples
•–•–•–◦ **Rhyolithe**		object	samples
•◦**Soufrière**		object	samples
•◦**La Soufrière, Guadeloupe**	Movieview	video	samples
•–•–◦ **Lava sand, black**		object	samples
•–•–•–◦ **Plage de Grande-Anse**		object	samples
•◦**Mt. Scenery, Saba**	Topicview	object	samples
•◦**archaeology**	Photoview	photo	–
•–•–◦ **Pompeji**	(see Figure 9) 	object	museum
•–•–◦ **Herculaneum**		object	museum
•–•–◦ **Hephaistos**		object	–
•–•–◦ **Vulcanus**	(see Figure 11) 	object	–
•–•–•–◦ **Puteoli**		object	–
•–•–◦ **Zipacná**		object	–
•–•–◦ **Cabrácan**		object	–
... [cut] ...	Objectmap		–
•◦**Volcano compendium**	Volcanomap 		
•–•–◦ **VNUM**			
•–•–◦ **Location**			
•◦**Archaeological compendium**			
•◦**Geological table**	(see Figure 12)		
•◦**Stone table**	Stonetab	object	samples
•◦**Mineral table**	Mintab	object	samples
•–•–◦ **Periodic table of elements**	Elemview	object	samples
...  (Aerial image data, e.g., source: Google Maps)	Mapview	image	–
	Satelliteview	service	–
			–
	Index	service	–
	Dynasearch	service	–
	Dynacompute	service	–
	Dynaprocessing	service	–
	Dynaindex	service	–
	Dynatypeset	service	–
	Dynastat	service	–
[compute and storage resources]	[workstation]		

A small subset of knowledge space objects is less suitable for providing the necessary depth for building facets and referring to appropriate multi-disciplinary objects. Therefore, even a basic example needs an extended knowledge environment. The secondary references (symbol: •◦) for an object are calculated from the respective reference matrix in the knowledge resources. The cross-links are extracted from the long-term knowledge resources and are usable with available data by any application components. Available example instances from the application components set, media resources, and originary sources (realia) are listed. In this context cross-linked subentries, keys and, for example, in case of volcanic features the classification (UDC) and the Volcano Number (VNUM) can be integrated in the analysis for computation and processing via the reference to the appropriate container, the volcano compendium. Applications and interfaces (e.g., Active Source, actmap [17]) can access any available data, as creating index compilations, retrieving online maps and satellite imagery. Media are, e.g., video data and photo images. Originary sources of objects are, e.g., realia, in the case with the volcanic material here, the objects are volcanic samples, respective stones. These objects are referred to in an appropriate archive, e.g., a collection, library or museum. The bottom row shows how the services and resources are used (e.g., local workstation access, special compute and storage resources).

C. Resulting object classifications and processing

Listing 27 shows a simple UDC-Context sample subentry from the LX Resources. This example expresses a basic "Europe : America" relation.

```
UDC-Context:(4):(7)
```

Listing 27. UDC-Context sample (LX Resources).

Classification patterns are suitable to select objects with any algorithm and pattern matching rules. Listing 28 shows a basic grep-filter within a classification set of UDC samples.

```
... | egrep "\([0-9]\):\([0-9]\)" | grep "(4):(7)"
```

Listing 28. Search grep sample within classification (LX Resources).

The result is a set of objects with a context relation between the continents Europe and America. Listing 29 shows an excerpt of an UDC table used with the examples.

```
UDC:55      :: Earth Sciences. Geological sciences
UDC:56      :: Palaeontology
UDC:57      :: Biological sciences in general
UDC:911.2   :: Physical geography
UDC:902     :: Archaeology
UDC:903     :: Prehistory. Prehistoric remains, ...
UDC:904     :: Cultural remains of historical times
UDC:930.85  :: History of civilization. Cultural ...
UDC:"63"    :: Archaeological, prehistoric, ...
UDC:(4)     :: Europe
UDC:(7)     :: North and Central America
UDC:(23)    :: Above sea level. Surface relief. ...
UDC:(24)    :: Below sea level. Underground. ...
UDC:=12     :: Italic languages
UDC:=14     :: Greek (Hellenic)
UDC:=84/=88:: Central and South American ...
```

Listing 29. UDC classification table, English (LX Resources, excerpt).

For a Topicview, corresponding object classes are processed and media objects are computed. Listing 30 shows the core data generated from the filtered media data, processing images for a sample Topicview as listed in Table IV.

```
create_archaeology_planet_view_topic.sh \
   volcano_guadeloupe_soufriere_viewto.jpg \
   volcano_guadeloupe_soufriere_viewfrom.jpg \
   volcano_saba_mtscenery_viewto.jpg \
   volcano_saba_mtscenery_viewfrom.jpg
```

Listing 30. Generated core data for Topicview processing.

As the knowledge resources' objects carry references to any kind of detailed processable data, distribution maps and satellite views can be computed and passed on.

D. *Resulting object entries on geosciences and archaeology*

The following object entries are excerpts from the calculated cross-links table (Table IV). The excerpts contain some, structure, UDC classification, keywords, references, and satellite image reference. The references for the geopositioning are created via classification and can be used for any purpose. Listing 31 shows an excerpt of an LX Resources object entry [14], "Vesuvius" volcano.

```
Vesuvius [Volcanology, Geology, Archaeology]:
         (lat.) Mons Vesuvius.
         (ital.) Vesuvio.
         (deutsch.) Vesuv.
         Volcano, Gulf of Naples, Italy.
         Complex volcano (compound volcano).
         Stratovolcano, large cone (Gran Cono).
         Volcano Type: Somma volcano,
         VNUM: 0101-02=,
         Summit Elevation: 1281\UD{m}.
         The volcanic activity in the region is observed
          by the Oservatorio
         Vesuviano. The Vesuvius area has been declared a
           national park on
         \isodate{1995}{06}{05}. The most known antique
          settlements at the
         Vesuvius are Pompeji and Herculaneum.
         Syn.: Vesaevus, Vesevus, Vesbius, Vesvius
         s. volcano, super volcano, compound volcano
         s. also Pompeji, Herculaneum, seismology
         compare La Soufrière, Mt. Scenery, Soufriere
         %%IML: UDC
          :[911.2+55]:[57+930.85]:[902]"63"(4+23+24)
          =12=14
         %%IML: GoogleMapsLocation: http://maps.google.de
          /maps?hl=de&gl=de&vpsrc=0&ie=UTF8&ll
          =40.821961,14.428868&spn=0.018804,0.028238&t=h&
          z=15
```

Listing 31. Knowledge resources – object entry "Vesuvius" volcano.

The example contains a reference and VNUM for the Vesuvius volcano, various secondary objects, UDC classification, satellite image reference (Satelliteview in Table IV). It refers to "Soufriere", "La Soufrière", and "Mt. Scenery". Listing 32 shows an excerpt of the "Soufriere" object entry.

```
Soufriere     [Volcanology, Geology]:
              A common name for a volcanic feature
               resulting from the
              french term for \periref{tgt:PeriSulfur}{
               Sulfur}.
              The name soufriere is used for a volcanic
               crater
              or other area in combination with solfataric
                activity.
              The name is mostly used in French speaking
               regions,
              especially in the West Indies.
              Very well known are, for example:
              La Soufrière volcano, Guadeloupe, F.W.I.
              Soufriere Hills, F.W.I.
              Soufriere St. Vincent, F.W.I.
              Syn.: Soufrière
              s. also La Soufrière, F.W.I., volcano,
               seismology
              %%IML: UDC
               :[911.2+55]:[57+930.85]:[902]"63"(7+23)
               =84/=88
```

Listing 32. Knowledge resources – secondary object entry "Soufriere".

This secondary object entry, "Soufriere", also refers to the La Soufrière volcano (Listing 33), which itself refers to various data and objects, e.g., satellite image references.

```
La Soufrière [Volcanology, Geology]:
              La Soufrière volcano, Guadeloupe, F.W.I.
              Volcano Type: Stratovolcano,
              Country: France,
              Subregion Name: West Indies, Caribbean,
              VNUM: 1600-06=,
              Summit Elevation: 1467\UD{m}.
              Syn.: Soufriere
              s. volcano
              s. also Soufriere, F.W.I., lava,
               lava sand, OVSG
              %%IML: UDC:[911.2+55]:[57+930.85]:[902]"63"
               (7+23+24)=84/=88
              %%IML: GoogleMapsLocation: http://maps.
               google.com/?ie=UTF8&ll
               =16.043153,-61.663374&spn
               =0.003088,0.003262&t=k&z=18&vpsrc=6&lci=
               weather
```

Listing 33. Knowledge resources – secondary object "La Soufrière".

The secondary object entry "Mt. Scenery" (Listing 34) also contains classifications and media, and further data references for the Mt. Scenery volcano on Saba. Extracted examples are volcano type, VNUM, region, status, elevation, and UDC classification views as well as the geo-references, which with this request are used to automatically compute views and distribution maps for classified objects in the result matrix.

The classification groups themselves show references to associated objects. The data and media object in a processed reference chain can be used for further analysis, creating special features. That way, using UDC classifications, e.g., places from a region or context that can be associated with volcanology and associated with archaeological sites can be selected and media objects can be processed and realia referred.

```
Mt. Scenery  [Volcanology, Geology]:
              Volcano, Saba, Netherlands Antilles, D.W.I.,
                The Netherlands
              Volcano Type: Stratovolcano,
              Country: Netherlands,
              Subregion Name: West Indies, Caribbean,
              VNUM: 1600-01=,
              Volcano Status: Historical,
              Last Known Eruption: in or before \isodate
               {1640}{}{},
              Summit Elevation: 887\UD{m}.
              %%IML: UDC
               :[55+56+911.2]:[902+903+904]:[57+930.85]
               "63"(7+23+24)=84/=88
              %%IML: GoogleMapsLocation: http://maps.
               google.com/maps?f=q&source=s_q&hl=en&
               geocode=&q=mt+scenery,+saba+netherlands+
               antilles,+google+maps&aq=&sll
               =17.633225,-63.236961&sspn
               =0.048997,0.052185&vpsrc=0&t=h&ie=UTF8&hq=
               mt+scenery,+saba+netherlands+antilles,&
               hnear=&z=14&lci=weather
              s. also Saba, D.W.I., volcano, seismology
```

Listing 34. Knowledge resources – object entry "Mt. Scenery".

Dynamical components can even benefit from precalculation and precomputation of objects. This includes precalculated classification and weights ("PreUDC"). The following section presents examples calculated from the above classified objects and the figures are showing the results of selected attributes, including the classification and geo-references used basic visualisation.

E. Resulting features selection for cross-links processing

The following (Figure 9) is an excerpt of the secondary objects computed above for the Caribbean region volcanoes and a selection with "`UDC:(23),(24)`".

Figure 9. Topicview – volcanoes, La Soufrière (left), Mt. Scenery (right), VIEW-TO (green), VIEW-FROM (blue).

Figure 10 illustrates the computed objects (Topicview), e.g., here volcanic samples after processing, all showing the variety of material from the top of the La Soufrière volcano.

Figure 10. Topicview – related volcanic samples (La Soufrière, 2011).

Any of these objects being part of the resulting matrix for a request, e.g., photos for object entries as well as media data for physically available samples, have been found via references and UDC from the knowledge base. The realia references for the objects refer to a collection where the samples are stored. Further analysis for the samples is available via the knowledge resources. Figure 11 shows the geo-locations [14] for computed geoscientific and archaeological object samples on a configurable object map.

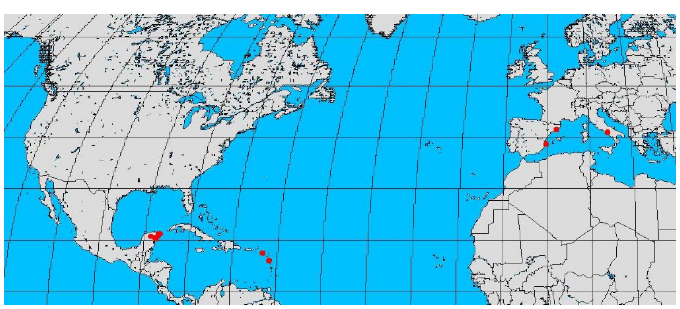


Figure 11. Objectmap – computed map for related objects (red, excerpt).

A sample distribution of volcanic features is depicted in Figure 12. It shows a comparison of volcanic data in a projection identical to the computed Objectmap (Figure 11). Although the knowledge matrix of this example is most complex (Table IV), the workflow for producing a view can be specified very easy like for spatial presentation. The map generated with the workflow as described with the case study presents the related objects from the context available in the geophysical research database. It can visualise various aspects of the classified objects. In this case of volcanoes and geological samples a reasonable view is the spatial distribution of the referenced selection.

Anyhow it must be emphasised that the number of possible views is not limited, neither from the knowledge base nor from the implementation. Spatial and cartographic methods provide only a very restricted tool set for supporting sciences for their complex tasks. For example, more complex examples from the same context could use more advanced presentation methods than available from spatial procedures. As it is obvious from this, the implementation of the knowledge resources architecture can be used for any purpose.

With the suggested workflow, the objects from the knowledge resources can be processed by any means like phonetic search, e.g., via classical or modified Soundex algorithms. This includes the flexible development of a non-limited number of extensions for dynamical search and analysis. It, too, provides a multiplicity of granularity regarding objects and classification.

Any features and data shown, based on the knowledge resources [14] and further sources, even if much less structured like online encyclopedia material, are resulting from the request and workflow, e.g., selection of classification, topics, object, secondary data, area, map projection, applications and so on [48], [49], [50].

One possible example of an algorithm for the interface workflow, with one request iteration is:

- Knowledge base request,
- Keyword filtering,
- Object processing,
- UDC filtering,
- Object element processing,
- Object container retrieval,
- Media retrieval,
- Media and
- Container processing,
- Building resulting media,
- Visualisation,
- Provisioning results.

This can be used to create multi-disciplinary text and media results, e.g., dynamical distribution maps, from requests, using calculation, processing, and computation of objects. A workflow can enter the knowledge matrix from different directions, e.g., from topic to related topic or from overview to detailed view as well as vice versa.

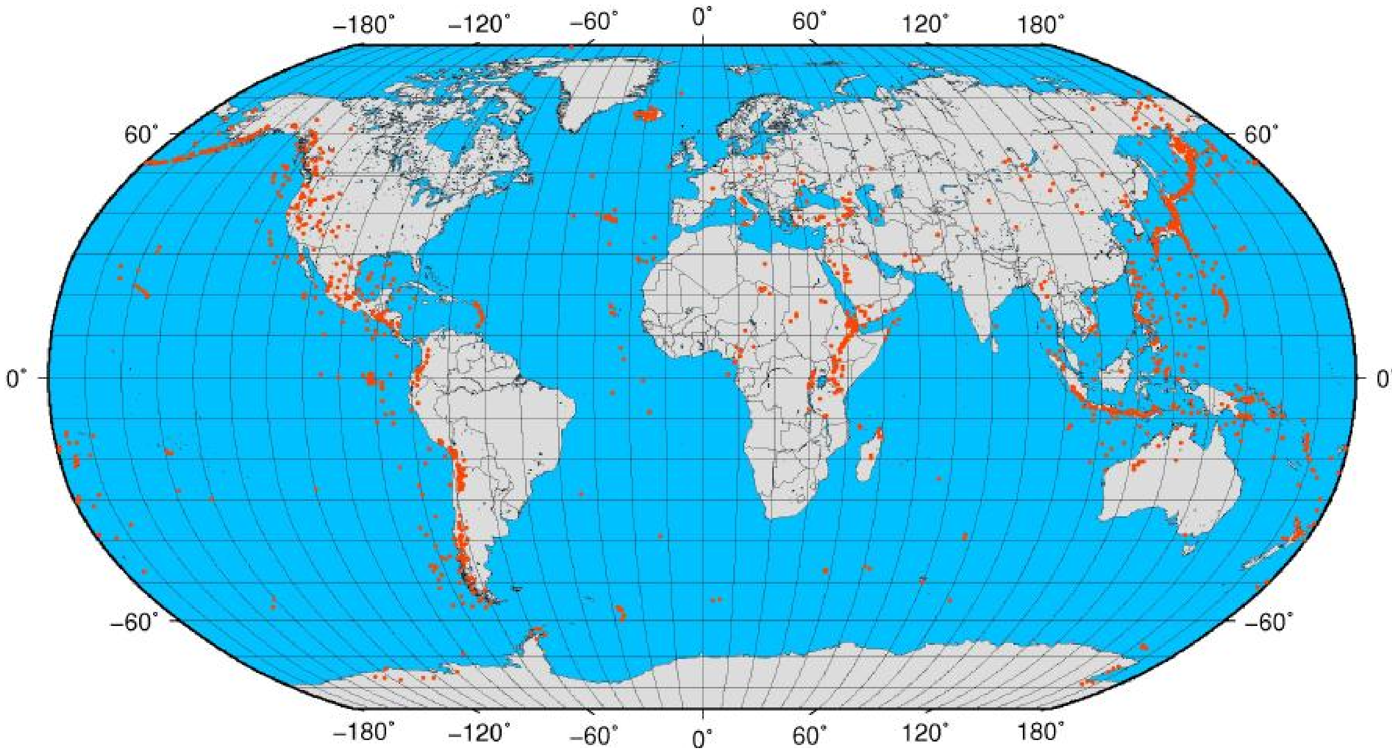


Figure 12. Volcanomap – worldmap of referenced volcanoes (orange). The computed spatial distribution map shows the selection of those object entries classified as volcanic features within the knowledge resources.

XI. Evaluation

The architecture and resources have been able to support any development required so far. Even as it is not possible in any paper to describe all disciplines and features, the case study shows the important features of the solution regarding the involved disciplines! Especially, the solution including the appropriate architecture and implementation does have all the required features, presented and discussed in the case studies allowing:

- A universal classification of all possible multi-disciplinary objects and views,
- To integrate and use any known type of document and structure, e.g., media and realia,
- Multi-disciplinary knowledge documentation, e.g., with archaeology and geosciences,
- To address any type of resources, e.g., computation and storage, including a feasible concept for collaboration and operation,
- To create, describe, and execute workflows, e.g., for discovery and development.

The means are not limited in any way to the presented examples. The facilities are only limited by the inventive spirit of the implementing groups.

The integration of structure and classification allows to use the benefits of algorithms like filtering for any possible use of processing and computing. Structuring the content and context documentation allows a flexible balance for redundancy of data and compute requirements for various application scenarios, even with identical data.

The facetted classification and multi-disciplinary data have proved to provide significant benefits for knowledge re-use and discovery. This includes various ways of describing aspects correctly. From one view a glass of water is half full. From another view the same glass of water is half empty. The two groups representing the classical views might argue that the other view is unintelligible. Both are generally not good as they only represent views. An alternative view will be describing the status giving a filling percentage. In addition, this reduces the limitation of unprecise references.

Most content, tasks, and developments handled with information and computing systems are not suitable for any long-term use, the more there are requirements for functional long-term documentation. The use of the universal knowledge resources and collaboration framework has shown to be very flexible and extendable with implementations and technologies over several decades.

It has been found that standard search and pattern recognition on information is by far not sufficient to gain reasonable results for long-term knowledge herding and evaluation processes. In contrast, the implementation shows excellent results with opening multi-discipline data for IICS, advanced computing, and processing. Statistically, filtering 1 GB of unstructured data delivers less quality than using 10 MB structured classified knowledge base data. The Quality of Data (QoD) must be drastically improved in order to get better results. This can help to reduce compute times, storage volume, and besides overall costs it can help to decrease energy consumption in the end. Using UDC in this context, the availability of a full UDC catalog, and an implementation allowing classification views, combined classification, and ranking priority has proven to drastically increase the QoD. With multi-disciplinary networks, there is even need for a tolerance of individual classification.

In common environments it is only feasible to do one implementation for a specific application, as has been done with these components. Anyhow it has been possible to implement the applications on various architectures providing different resources. Workflows support the use of remote resources (Table V). In case of a 1000 knowledge-objects reference chain, with 1–10 elements per object, performance will increase much with low latencies.

TABLE V. WORKFLOW PROCESSES (REMOTE, ETHERNET, 1000 NODES).

Remote Workflow Process	*Elements*	*Response Time*
Knowledge base request	1000	5 s
Processing (object, media)	10	7 s
Building result	10	5 s
Visualisation	2	25 s

When using one of the described very basic application scenarios on a certain resources architecture the efficiency mostly depends on the decision for the depth of the cross-links to be considered and on the processing requirements for the media data for the originary resources. With current sizes for digital photos and a low depth of five to ten for the cross-links a medium sized application can easily use about one-hundred parallel processes. On a common compute resource without a queue configured for the jobs the response time will be less than a minute.

That way, implementing components with IICS on many compute nodes can profit from using various technologies as suited for different purposes, using task and thread parallelism to the extend needed to handle a problem remotely:

- *High level*: Integrated Systems, collaboration frameworks, dynamical application components, Partitioned Global Address Space (PGAS) models.
- *Virtualisation level*: Parallel Virtual Machine (PVM).
- *Low level*: Message Passing Interface (MPI), OpenMP, and comparable.

Increasing requirements on resources are mostly focussed on compute, communication, and storage. The requirements can increase by various reasons, from classical High End Computing, currently Peta-Scale or towards Exa-Scale, or Advanced Scientific Computing components up to multi-user performance within an application or resource. The concept can handle

- many computation tasks associated with a process,
- many processes associated with a workflow,
- many workflows associated with an application instance,
- many application instances associated with an application scenario.

The integrated and dynamical concept allows a scalable use of components, implementing components based on the appropriate level. Besides this, the components, which require an appropriate physical configuration of the resources, for example, in order to be usable with interactive dynamical applications are considered are considered challenging at the lower level.

XII. CONCLUSION AND FUTURE WORK

It has been demonstrated how complex systems for multi-disciplinary documentation and computing can be built, developed, and extended based on creating long-term-knowledge resources supported by a universal classification and implementing IICS systems. This paper presented the successful implementation of a new universal framework for an integrated system, integrating knowledge resources and implementation components for long-term knowledge creation and use, including the facilities for High End Computing and processing resources.

The geoscientific and archaeological knowledge resources have been, structured, extended, and developed for several decades now, having been successfully used with various technology over time. Huge benefits creating new instances of objects and components result from enabling a long-term stepwise development for all parts of the knowledge and application space and a free extendability of the knowledge base. The previous work, which this implementation is built on has been discussed.

The architecture allows any kind of documentation and algorithm for content, context, information and resources usage. The services and resources usage is very economic and only limited by the limiting implementation factors, e.g., capacities and policies. This solution goes far beyond data and text mining or image analysis and pattern recognition. As shown, classification, as well as spatial data should be integrated with the objects. In no case is it suitable regarding the long-term goals of knowledge creation to “fix” knowledge objects with an application or implementation, neither simple or complex, nor closed or open licensed.

The comparison showed that the possibility of combining methods (UDC, keyword, full-text analysis) does lead to unique benefits. Comparable precision, reliability, performance, and scalability is not available from any isolated method. For any advanced knowledge resources and improved QoD, a flexible classification is undispensable. Bringing the integration of universal classification and IICS into wider acceptance can provide a time-capsule against the transience of knowledge and open new synergetic long-term possibilities.

Complex systems can be created and extended over the necessarily long periods of time, using IICS and UDC. Advanced scientific computing is supported by interfaces, accessing compute and storage resources. With the available architecture implementations of these compute and storage resources are meant to be short- to medium-term tools for supporting the long-term knowledge resources. Further it has been shown what information and knowledge on content and context can be preserved for medium- and long-term usage even for large complexity of an overall system.

With collaborative implementations a catalog of universal criteria is needed for feature development and exploitation of knowledge resources. This catalog has to consider long-term multi-disciplinary and international aspects. The overall operative system components must be self-learning. Anyhow, central components will always afford an editorially managed operation.

The case study on knowledge resources and external information showed a number benefits. Especially the workflows and results can very much profit from an integration. Regarding the external Leibniz resources, an impressive amount of valuable data has been collected by various institutions within the last decades. Currently, only a small percentage is being developed for exploitation and further integration. Based on the vast experiences gathered within the last generations, clearly structured resources, interfaces, and tools are required for future knowledge discovery. For sustainability issues it will be very desirable to see a suitable long-term data structure being created in the future, using a unique terminology and supporting an improved knowledge discovery and reuse.

Workflows utilising future storage and computational resources can profit from autonomous intelligent units, e.g., multi-agent system components [51].

The basic architecture has been presented using a long-term knowledge base (LX), documentation, and classification of objects, the "Collaboration house" framework, flexible algorithms, workflows and dynamical and Active Source components for creating future IICS. Besides that, there is a strong demand for future education and teaching in all disciplines of academia and research in order to mediate and disseminate the basics of knowledge creation and classification.

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