# Enabling Dynamical Use of Integrated Systems and Scientific Supercomputing Resources for Archaeological Information Systems

Claus-Peter Rückemann
*Westfälische Wilhelms-Universität Münster (WWU),*
*Leibniz Universität Hannover,*
*North-German Supercomputing Alliance (HLRN), Germany*
*Email:* ruckema@uni-muenster.de

***Abstract*—This paper presents the results from combining Integrated Information and Computing System components with classification for the purpose of enabling multi-disciplinary and dynamical use of information systems and supercomputing resources for Archaeological Information Systems. The essential base are a flexible collaboration framework, suitable long-term documentation, structuring and classification of objects, computational algorithms, object representations, and workflows as well as portable application components like Active Source. Case studies of the successful implementation of integration of archaeology and geosciences information and facilitation for dynamical use of High End Computing resources are discussed. The implementation shows how the goal of integrating information and systems resources and advanced scientific computing for multi-disciplinary applications from natural sciences and humanities can be achieved.**

***Keywords–Integrated Systems; Information Systems; Scientific Supercomputing; Computing Systems; Archaeology; Geosciences; High Performance Computing.***

## I. INTRODUCTION

In order to overcome many of the complex scientific impediments in prominent disciplines we do need mighty information systems but the more they are used for interactive use they show up needing capabilities for dynamical computing. The studies and implementations of Integrated Information and Computing Systems (IICS) have shown a number of queuing aspects and challenges [1], [2]. In the case if archaeological information systems needed for multi-disciplinary investigation the motivation is the huge potential of integrative benefits and even more pressing that archives are needed for multi-disciplinary records of prehistorical and historical sites while context is often being changed or destroyed by time and development. Besides the academic, industrial, and business application scenarios in focus of the GEXI collaborations [3] in order to integrate the necessary computing facilities with these systems, on the technical side the recent implementations for spatial control problems, e.g., for wildfire control [4], integrating GIS, and parallel computing are promising candidates for future support.

This paper is organised as follows. Section two introduces with the complexity of required information and structure. Section three shows the essential prerequisites for integrated information and computing. Section four describes the basics of Archaeological IICS. Section five discusses the implementation of the components: information sources, structure and classification, communication and computing. Section six presents the system implementation in practice, with various views from the components. Section seven evaluates for the lessons learned and summarises conclusions and future work.

## II. INFORMATION AND STRUCTURE

It must be emphasised that the complexity of the ecosystem of algorithms and disciplines necessary to achieve an integration of multi-disciplinary information and components is by nature very high so besides the system components we have not only to integrate unstructured but highly structured data with a very complex information structure.

The overall information is widely distributed and it is sometimes very difficult and a long lasting challenge even to get access to a few suitable information sources. The goal for these ambitions is an integrated knowledge base for archaeological geophysics. Example data resources and methods are [5], [6], [7], [8], [9], [10], [11]. For all components presented, the main information, data, and algorithms are provided by the LX Foundation Scientific Resources [12].

Structuring information requires a hierarchical, multilingual and already widely established classification implementing faceted analysis with enumerative scheme features, allowing to build new classes by using relations and grouping. This is synonym to the Universal Decimal Classification (UDC) [13]. In multi-disciplinary object context a faceted classification does provide advantages over enumerative concepts. Composition/decomposition and search strategies do benefit from faceted analysis. It is comprehensive, and flexible extendable. A classification like UDC is necessarily complex but it has proved to be the only means being able to cope with classifying and referring to any kind of object.

## III. INTEGRATED INFORMATION AND COMPUTING

The integration issues of information, communication, and computing are well understood [1], [14], [15] from the "collaboration house" (Figure 1) framework.

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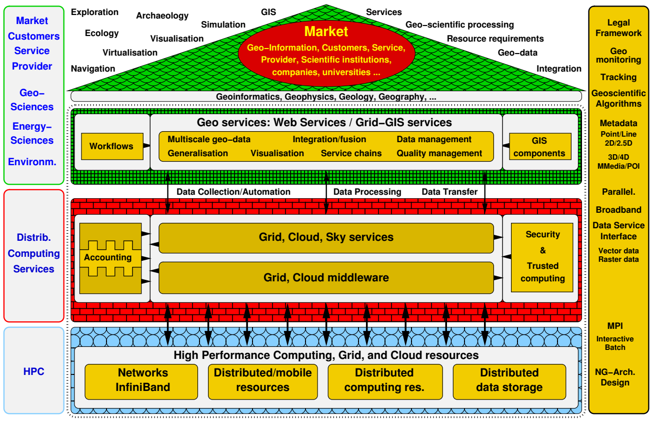


Figure 1. Collaboration house framework, integrating information and scientific computing. Resources (blue), services (red), disciplines (green).

### A. Collaboration and multi-disciplinary workflow

Based on the collaboration framework the IICS enables to collaborate on disciplines, services, and resources and operational level. It allows disciplines to participate on multi-disciplinary topics for building Information Systems and to use scientific supercomputing resources for computing, processing, and storage, even with interactive and dynamical components [16]. The screenshot (Figure 2) illustrates some features, as with Active Source, computed and filtered views, LX information, and aerial site photographs, e.g., from Google Maps. Many general aspects of dynamical use of information systems and scientific computing have been analysed with the collaboration house case studies.

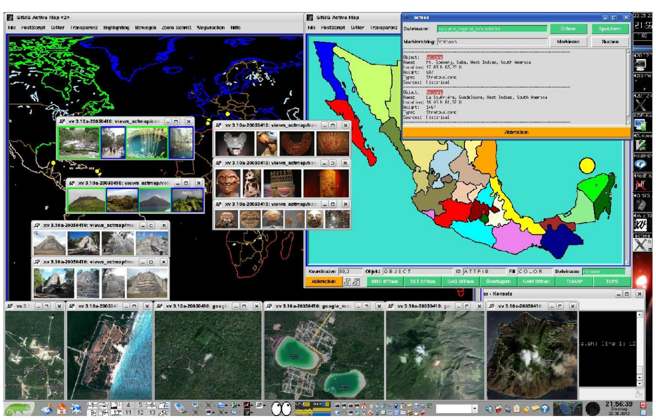

Figure 2. Dynamical use of information systems and scientific computing.

### B. Integrative and synergetic effects

With IICS we do have integrative as well as synergetic effects from the participating disciplines. For example, the Roman city of Altinum, next to Venice, Italy, would not have been discovered without the combination of archaeological information, aerial photographs, satellite images, and digital terrain models [17]. Even in unorganised circumstances, like with this discovery, the multidisciplinary cooperation can lead to success. The more we need an integrated information system approach for "disciplines on demand". On the other hand we have a synergetic effect with the same scenario of archaeology and geosciences, too, the research does have benefits for archaeology and geosciences as the collection of information from archaeological probing will help to describe the underground, which is of immense importance for the future of the area [18] and it's attractiveness [19].

## IV. Archaeological Information Systems

Anyway there should be a principle solution, considering the hardware and software if so individually available, without restructuring complex data all the time when migrating to different architectures or to be prepared for future resources.

### A. Archaeology and geosciences

So in case of Archaeological IICS, cultural heritage, and geoscientific information, and computing systems, there is a strong need for integration and documentation of different data and information with advanced scientific computing, e.g., but not limited to:

- Object, site, artifact, spatial, multi-medial, photographical, textual, properties, sources, referencial information.
- Landscape and environmental information, spatial, photographical information.
- Geophysical information, geological information.
- Event information.

Important aspects with all this information are the distribution analysis and spatial mapping. With dynamical information systems for this scenario the components must enable to weave n-dimensional topics in time, use archaeological information in education, implement n-dimensional documentation, integrate sketch mapping, provide support by multidisciplinary referencing and documentation, discovery planning, structural analysis, multi-medial referencing.

### B. Creating metadata for documentation and computing

It will need a number of metadata types, depending from the variable type of content, describing all kind of relevant information regarding the data and the use of this data. Some important groups are category, source, batch-System, OS version and implementation, libraries, information on conversion, virtualisation environment, and automation. Currently only a few projects in some disciplines have worked on long-term content issues [20], [21], [22], [23], [24]. Commonly only three categories are relevant to archaeological projects, project level metadata (e.g., keywords, site, dates, project information, geodata), descriptive and resource level metadata (e.g., comprehensive description, documents, databases, geo-data), and file level metadata (software, hardware, accompanying files). As we saw above, from information science point of view this is by far not sufficient as there are, e.g., licensing and archiving restrictions, precision restrictions, network limitations, context of environment, hardware, and software, hardware restrictions, tools and library limitations and implementation specifics. The long-term aspects for big heterogeneous data hold very difficult and complex challenges as big data storage facilities, for users there are, e.g., free public access and long-term operational issues, for context provisioning huge amount of work have to be done, e.g., handling licensing, archiving, context, hardware availability and many more.

## V. Implementation of components

### A. Targets and means

The main target categories and means of information to be addressed are interdisciplinary, multidisciplinary, intercultural, functional, application, and context information. The main functional targets with IICS are integrative knowledge, education, technological glue, linking isolated samples and knowledge databases, language and transcription databases, classified Points on Interest (POI), InfoPoints, multimedial information. The organisational means are commonly grouped in disciplines, services, resources and operation.

### B. Information sources

All media objects used here with components and views are provided via the Archaeology Planet and Geoscience Planet components [12]. The related information, all data, and algorithm objects presented are copyright the LX Foundation Scientific Resources [12]. It provides multidisciplinary information and data, e.g., for archaeology, geophysics, geology, environmental sciences, geoscientific processing, geoprocessing, Information Systems, philology, informatics, computing, geoinformatics, cartography.

### C. Information, structure and classification

The following examples illustrate the retrieved object information, media, and sources with examples for their multi-disciplinary relations. The information is retrieved from the LX Foundation Scientific Resources [12], [1], [25] and categorised with means like UDC. Listing 1 shows an excerpt of a LX object entry used with IICS. Listing 2 shows a classification set of UDC samples used with IICS.

```
Cenote Sagrada [Geology, Spelaeology, Archaeology]:
               Cenote, Yucatán, México.
               Holy cenote in the area of Chichén Itzá.
               ...
               %%UDC:[55+56+911.2]:[902+903+904]:
                [25+930.85]"63"(7+23+24)=84/=88
```

Listing 1. Structure of object entry (LX Resources, excerpt).

```
UDC:[902+903+904]:[25+930.85]"63"(7)(093)=84/=88
UDC:[902+903+904]:[930.85]"63"(23)(7):(4)=84/=88
UDC:[55+56+911.2]:[902+903+904]:[25+930.85]"63"
 (7+23+24)=84/=88
UDC:[25+930.85]:[902]"63"(7)(093)=84/=88
UDC:[911.2+55+56]:[57+930.85]:[902+903+904]"63"
 (7+23+24)=84/=88
UDC:[911.2+55]:[57+930.85]:[902]"63"(7+23+24)=84/=88
```

Listing 2. Classification set (UDC samples, excerpt).

The classification deployed for documentation [26] must be able to describe any object with any relation, structure, and level of detail. Objects include any media, textual documents, illustrations, photos, maps, videos, sound recordings, as well as realia, physical objects such as museum objects. A suitable background classification is, e.g., the UDC. The objects use preliminary classifications for multidisciplinary content. Standardised operations with UDC are, e.g., addition ("+"), consecutive extension ("/"), relation (":"), subgrouping ("[]"), non-UDC notation ("*"), alphabetic extension ("A-Z"), besides place, time, nationality, language, form, and characteristics.

### D. Communication and computing

The central component groups for bringing multidisciplinary information systems into practice are IICS and documentation of objects, structure, and references. Listing 3 shows an example of a dynamical dataset from an Active Source [16] component provisioning information services.

```
#BCMT--------------------------------------------------
###EN \gisigsnip{Object Data: Country Mexico}
#ECMT--------------------------------------------------
proc create_country_mexico {} {
global w
$w create polygon 0.938583i 0.354331i 2.055118i ...
...
proc create_country_mexico_autoevents {} {
global w
$w bind legend_infopoint <Any-Enter> {set killatleave [
 exec ./mexico_legend_infopoint_viewall.sh $op_parallel
  ] }
$w bind legend_infopoint <Any-Leave> {exec ./
 mexico_legend_infopoint_kaxv.sh }
$w bind tulum <Any-Enter> {set killatleave [exec
 $appl_image_viewer -geometry +800+400 ./
 mexico_site_name_tulum_temple.jpg $op_parallel ] }
$w bind tulum <Any-Leave> {exec kill -9 $killatleave }
} ...
```

Listing 3. Dynamical data set of Active Source component.

Batch and interactive features are integrated with Active Source event management [16], e.g., allowing structure and UDC based filtering. Taking a look onto different batch and scheduling environments one can see large differences in capabilities, handling environments and architectures. In the last years experiences have been gained in simple features for different environments for High Throughput Computing like Condor, workload schedulers like LoadLeveler and Grid Engine, and batch environments like Moab / Torque.

## VI. Resulting implementation in practice

### A. Scientific documentation

Scientific documentation is an essential part of a Universal IICS (UIICS), revealing associations and relations and gaining new insight. Handling the available information does provide transparent how puzzle pieces of a scientific context do fit, e.g., not only that terms like Bronze Age, Ice Age, Stone Age are only regional but in quantity and quality how the transitions and distributions in space and time are. Information on objects, archiving, analysis, documentation, sources and so on will be provided as available with the dimension space. Besides the dynamical features the objects carry information, e.g., references, links, tags, and activities.

### B. Dimension space

The information matrix spans a multi-dimensional space (Table I). It illustrates the multi-faceted topic dimension containing important cognitive information for disciplines and applications. Examples of multi-disciplinary information in archaeological context are stony and mineral composition, e.g., of dead freight or ballast in ship wrecks, mineral material in teeth, fingerprints of metals used in artifacts, and genetic material of biological remains. Further there exists a "vertical" multi-dimensional space to this information matrix, carrying complementary information, e.g., color, pattern, material, form, sound, letters, characters, writing, and so on. The documentation can handle the holistic multi-dimensional space, so we can flatten the views with available interfaces to three or four dimensional representations.

Table I
DIMENSIONS OF THE INFORMATION MATRIX (EXCERPT).

| *Dimension* | *Meaning, Examples* |
|---|---|
| Time | Chronology |
| Topic | Disciplines |
| | Purpose (tools, pottery, weapons, technology, architecture, inscriptions, sculpture, jewellery) |
| | Culture (civilisation, ethnology, groups, etymology) |
| | Infrastructure (streets, pathways, routes) |
| | Environment (land, sea, geology, volcanology, speleology, hydrogeology, astronomy, physics, climatology) |
| | Genealogy (historical, mythological documentation) |
| | Genetics (relationship, migration, human, plants) |
| | Biology (plants, agriculture, microorganisms) |
| | Trade (mobility, cultural contacts, travel) |
| Depth | Underground, subterranean |
| Site | Areal distribution, region |
| ... | ... |
| Data | Resources level, virtualisation |

The dimensions are not layers in any way so it would contradict to percept their documentation with integrated systems in data or software layers. With these IICS we are facing a multi-dimensional volume, like a multi-dimensional "potato shapes". Layer concepts are often used with cartographic or mapping applications but these products are infeasible for handling complex cognitive context.

### C. IICS dimension view

As with the structure the communication and compute processes are getting resource intensive, the available storage and compute resources are used with the IICS. The following small example shows an excerpt of a tabulated dimension view (Table II). The last column shows if an object is deposited on site (O) or distributed (D) and if additional media is available and referenced. The table shows if a storage or and additional compute request has been necessary for the resulting object or media. Information is given if primarily a storage request (S) for persistant media or a compute request (C) deploying High End Computing resources is dynamically used for creating the appropriate information.

Table II
DIMENSION VIEW WITH ARCHAEOLOGICAL IICS (EXCERPT).

| *Topic* | *Purpose / Environment / Infrastructure* | *Ref.* |
|---|---|---|
| Egypt | Architecture | |
| Rome | Architecture | |
| Catalonia | Architecture | |
| | Monument de Colom, Port, Barcelona, Spain | OC |
| Maya | Architecture | |
| | Kukulkán Pyramid, Chichén Itzá, Yucatán, México | OC |
| | Nohoch Mul Pyramid, Cobá, Yucatán, México | OC |
| | El Meco Pyramid, Yucatán, México | OC |
| | El Rey Pyramid, Cancún, Yucatán, México | OC |
| | Pelote area, Cobá, Yucatán, México | OS |
| | Pok ta Pok, Cancún, Yucatán, México | OS |
| | Templo del Alacran, Cancún, Yucatán, México | OS |
| | Port, Tulúm, Yucatán, México | OC |
| | Infrastructure | |
| | Sacbé, Chichén Itzá, Yucatán, México | OS |
| | Sculpture | |
| | Diving God & T. Pinturas, Tulúm, Yucatán, México | OC |
| | Diving God, Cobá, Yucatán, México | OC |
| Precolombian | Architecture | |
| Caribbean | Environment (volcanology, geology, hydrogeology) | |
| | La Soufriére Volcano, Guadeloupe, F.W.I. | OC |
| | Mt. Scenery Volcano, Saba, D.W.I. | OC |
| | Cenote Sagrado, Chichén Itzá, Yucatán, México | OC |
| | Ik Kil Cenote, Yucatán, México | OC |
| Arawak | Architecture | |
| Prehistory | Architecture | |
| *Topic*: | architecture mythology environment infrastructure | |
| *Entity:* | Object Location: O On site, D Distributed; Object Media: C Compute, S Storage. | |
| *Compute:* | CONNECT REFERTO-TOPIC REFERTO-SPATIAL VIEW-TO VIEW-FROM | |

The following examples explain views from disciplines and topics (Figure 2) as computed and filtered with the IICS, using photo media samples. It must be emphasised that the applications can provide any type of objects, high resolution media, and detailed information. The first view (Figure 3) is a simple example from the above table for an excerpt of the computed class of regional pyramid object representations (Yucatán Peninsula, provinces Yucatán and Quintana Roo).

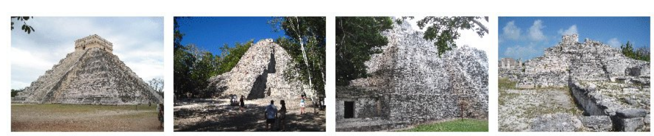

Figure 3. Object SAMPLE – regional Pyramid of Maya, Yucatán, México.

Figure 4 illustrates the computed objects for the above REFERTO-TOPIC and REFERTO-SPACE chain classification, e.g., here via UDC "`(7):(4)`" relation.

Figure 4. Cross-purpose REFERTO – Diving god, Tulúm, Colom.

Besides that, viewing directions can be referred, e.g., "view to", "view from", "detail" as shown with a VIEW example (Figure 5) for the above selection with UDC "`(23)`", "`(24)`".

Figure 5. In-purpose: VIEW-TO VIEW-FROM – Volcanoes and Cenotes.

### D. Topic view and object representation

The following sample excerpt tabulates a topic view (Table III) and shows the computed object representation (Figure 6) for an in-topic CONNECT example. From the eight samples of Chichén Itzá shown, the Sacbé pathway connects the Kukulkán Pyramid with the Cenote Sagrado. The table shows a sample of referred (Geo) information.

Table III
TOPIC VIEW WITH ARCHAEOLOGICAL IICS (EXAMPLE, CHICHÉN ITZÁ).

| *Site* | *Topic / Purpose* | *Selected: Geo* | *Ref* |
|---|---|---|---|
| Chichén Itzá | | | |
| | Kukulkán Pyramid, El Castillo | Limestone | OC |
| | Sacbé | Limestone | OC |
| | Cenote Sagrado | Doline, hydrology | OC |
| | Jaguar temple | | OS |
| | Tzompantli | | OS |
| | Temple of the warriors | | OS |
| | Caracol | | OS |
| | Chac temple | | OS |

Figure 6. In-topic CONNECT – Kukulkán, Cenote, connected by Sacbé.

### E. Object space grouping

The objects are linked by relations in the n-dimensional object space. The slices with a selected number of dimensions carry the common information, e.g., "Stone Age flint arrow heads" in a specific area. It is essential not to sort objects into layers within a database-like structure. So vectors and relations can help to represent their nature in a more natural way. The views, even traditional layered ones, are created from these by appropriate components. The following figures illustrate structure and references for collections, context, and integration of multi-disciplinary information: museum topical collection (Figure 7), context of amphores (Figure 8), and geology information (Figure 9).

Figure 7. Sample COLLECTION – Precolombian Museum.

Figure 8. Sample CONTEXT – Pottery (amphores).

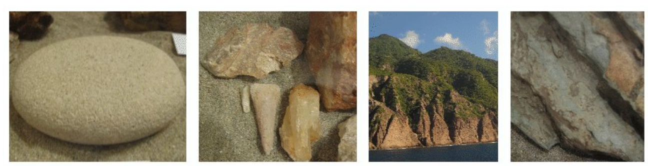

Figure 9. Sample DISCIPLINE – Geology (Caribbean limestone and tuff).

## VII. CONCLUSION AND FUTURE WORK

Structuring and classification with LX and UDC support have provided efficient and economic means for using Information System components and supercomputing resources. With these the solution scales, e.g., regarding references, resolution, and view arrangements. The concept can be transferred to numerous applications in a very flexible way.

The successful integration of IICS components and advanced scientific computing based on structured information and faceted classification of objects has provided a very flexible and extensible solution for the implementation of Archaeological Information Systems. It has been demonstrated with the case studies that Archaeological IICS can provide advanced multi-disciplinary information as from archaeology and geosciences by means of High End Computing resources. The basic architecture has been created using the collaboration house framework, long-term documentation and classification of objects, flexible algorithms, workflows and Active Source components. For future applications a kind of "tooth system" for long-term documentation and algorithms for use with IICS and the exploitation of supercomputing resources will be developed.

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