

The Digital Behaim Globe (1492)

Günther Görz, Norbert Holst
University of Erlangen-Nuremberg
FORWISS and IMMD VIII (Computer Science — Artificial Intelligence)
Am Weichselgarten 9, D-90425 Erlangen
Phone: (+ 49 9131) 85-9909; Fax: 85-9905
E-Mail: goerz@informatik.uni-erlangen.de

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Abstract

The goal of most hypermedia systems is to open up complex information spaces through the use of associative networks of nodes containing texts, images, and acoustic signals. The power of such information systems can be considerably enhanced by the integration of knowledge representation. We illustrate this claim with an example hypermedia information system about the oldest existing globe of the earth whose creation was initiated by Martin Behaim in 1492. Displaying the pre-columbian image of the earth, the Behaim globe is a cartographical masterpiece of German humanism in the Renaissance age; nowadays the globe is exhibited in the Germanisches Nationalmuseum in Nuremberg.

From the user viewpoint, our hypermedia information system offers two paths for information access, one through a graphical visualization component which can produce images of the globe from any desired viewpoint, and a graphical query interface to a hypermedia network which provides structured information units consisting of texts and images. These units contain descriptions of the different globe regions and their map image, various readings of its numerous inscriptions, comments on the texts and miniatures on the globe, images of contemporary globes and maps, a comprehensive record — in part on-line accessible — of important scientific publications on the globe, and cultural and historical background information. Particular attention is paid to the broad variety of relations between images and texts.

For the information system, a new distributed software architecture based on WWW technology has been specified and implemented. The server component consists of the system kernel and several server components, to which the kernel dispatches upon request. Among the components are an object-oriented database system with a specific query component (via CLOS, the Common LISP Object System and Allegro/Object Store), an image database and preprocessing component, and a component for generating hypertext (HTML) pages from database contents. The object-oriented database system holds all data objects describing the globe, its parts, and background information, as well as descriptors for all kinds of media data. Immutable image data and text files (scanned documents) are kept separately, but are accessible only through these descriptors.

The query interface as well as local image processing operations are implemented as Java applets running locally with a WWW-Browser. To display bird-eye views on the globe from the image database, which contains wavelet encoded high resolution images, a new visualization component based on OpenGL has been implemented. With sufficient hardware support, real time animation is possible. The structure of the information space is described in an object-centered representation which is — due to the use of CLOS — identical with the database schema. In modelling we followed the goal to define an open terminological hierarchy of sufficient generality for historical cartography in general. In particular, we are currently working on a spatial reasoning component operating on representations of topographical objects and some general reasoning operations — like consistency, classification, etc. — through an interface to a description logic system.

1 Introduction

The goal of most hypermedia systems, which are a synthesis of hypertext and multimedia systems, is to open up complex information spaces through the use of associative networks of nodes containing texts, images, and acoustic signals. In those systems, usually little or no use is made of Artificial Intelligence (AI) techniques, in particular of knowledge representation, to model semantic relations between the information elements. We argue that the power of hypermedia information systems can be *considerably enhanced through the integration of knowledge representation*. The representation formalisms available in most hypertext systems — if one can speak of such at all in a strict sense — are not expressively and inferentially powerful enough to provide a deep model of the object domain. So users can access information only along paths which have been either explicitly or implicitly given by the system authors, a restriction which can be overcome by integrating knowledge representation and processing techniques.

We illustrate our claim with an example hypermedia information system about the oldest existing globe of the earth whose creation was initiated by Martin Behaim in 1492. Displaying the pre-columbian image of the earth, the Behaim globe is a cartographical masterpiece of German humanism in the Renaissance age. Today it is one of the most attractive objects in the collections of the Germanisches Nationalmuseum in Nuremberg.

To celebrate the 500th anniversary of the Behaim globe in 1992, an exhibition had been prepared for which research activities began in 1987. The results were presented to the public with the two-volume exhibition catalog [Willers 1992a]. New insights about the production of the globe were gained through the application of innovative scientific methods like microchemical analysis, endoscopy, and computer tomography. Furthermore, a complete photographic record of the globe has been taken. Based on planar segment images which were derived from these photographs, a simple computer animation of the globe has been developed for the exhibition.

The rich image and text material resulting from these research activities was the starting point for a new

project at FORWISS and the University of Erlangen-Nuremberg in cooperation with the Germanisches Nationalmuseum, Nuremberg, aiming at the construction of a comprehensive hypermedia system to provide in-depth information on the Behaim globe.

Our interdisciplinary project was initiated in 1993 with a feasibility study for hypermedia information system [Görz 1994] and is now being continued as a basic research activity at our center, supported by the Fritz Thyssen Foundation. Intended users of this system are historians, cartographers, map collectors, and the interested public. The prototype system was conceived as an experimental and open development environment in the manner of an electronic encyclopedia, where images and texts are being organized as a hypermedia network, and it presents to its users comprehensive textual and graphical information about the globe and its cultural and historical background.

We begin with a short description of Martin Behaim's globe and the investigation done within our project. The next section describes the image and text data base and its conceptual structure. The presentation of the information system has been split in two parts: First we look at the system from the users' perspective. We conclude with a description of the system architecture design and its implementation.

2 Martin Behaim and his "Erdapfel"

The Behaim Globe was built in Nuremberg around the year 1492 by a group of scholars and craftsmen. The few temporary sources still existing clearly show the spirit of Martin Behaim in the elaboration of the so called "Erdapfel". This work is an early masterpiece of many kinds of scientific and technological achievements, establishing the intellectual and economic leadership of Nuremberg in late medieval Germany.

Martin Behaim was born in 1459 as a son of a noble Nuremberg family. Later he received professional training as a textile merchant in the Netherlands. Since 1484 he lived in Portugal, the reasons which led him to this foreign country are unknown. Quickly playing an important role at the court of King João II., he probably had been there in contact with prominent cartographers and navigators. Later Behaim was knighted by the emperor, often seen as a reward for his supposed participation in the expedition of Diogo Cão along the African coast in ca. 1485; an assertion for a long time accepted by many historians. Indeed the life of Martin Behaim and his globe give clearly evidence, that he was not the great navigator, mathematician and cosmographer [Bräunlein 1992, Kellenbenz 1969, Willers 1992b], as many publications still celebrate him in our times.

In 1490 Behaim visited the city of his fathers to settle a will case. He stayed in Nuremberg for three years and got involved in the manufacturing of the globe. Obviously the geographical information on the globe is based on his knowledge. He laid out an image of the world which may count as an important example of the cartography in Central Europe of that time — a complex mixture of reborn ancient ideas, still vivid medieval thinking, and a reception of the new explorations, that was shadowed by a strong persistency of

the old image of the world.

The famous globe contains 2000 place names, 100 pictorial illustrations and more than 50 long legends. Many of them deal with peculiarities and fabulous monsters of foreign countries, their inhabitants, plants and animals, in particular with overseas trade, explorations and famous travels like that of Marco Polo. Not the quality of the information, but its quantity and selection make the globe an important primary source for historical research. Probably Behaim had no main source for his "Erdapfel". He gathered the geographical information from different sources, probably from a nowadays missing Portuguese sea chart, travel narratives like that of Marco Polo, Mandeville and the Portuguese explorer Diogo Gomes, and using traditional cosmographical writings like Ptolemy's "Geographia" ([Ravenstein 1908], 62–71). For that reason the Behaim Globe is one of the very few existing cartographical works where different academic "schools" of mapmaking are bound together.

Nevertheless the construction technology of the globe always impresses historians. Results of a material investigation, made by the Germanisches Nationalmuseum Nuremberg for the exhibition in 1992, laid out the complex production procedure. A ball of clay with a diameter of 51 cm was covered with laminated stripes of linen, afterwards the ball of clay was taken out and the two halves were put together again with a wooden ring. Then it was covered with parchment, and another layer of paper — six segments and two polar caps — was glued on that. At last the globe was painted by the artist Georg Glockendon [Hering 1992]. Although Behaim was probably the main supplier of information, other Nuremberg scholars contributed to the final appearance of the globe. Later the globe has been restored several times, not always in a satisfying manner.

Perhaps Martin Behaim has made more maps or globes; a few traces are given in historical documents. Maybe that these ones got lost like so many other cartographical works of the 15th and 16th century. However Behaim does not belong to the great mapmakers of this time like Gerard Mercator, Fra Mauro or Martin Waldseemüller. Finally he died as a poor man in Lisbon in the year 1507.

3 Goals and Methods of the Investigation

The historical investigation of the Behaim Globe, headed by Prof. Ulrich Knefelkamp of the University of Frankfurt/Oder, tries to combine general and scientific information about historical geography and the age of the early discoveries with a user friendly representation of the globe in a multimedia network.

For this reason the information is built up in a hierarchical manner. Globe objects or texts with a direct regard to Martin Behaim and his globe get a high degree of detailed information and are linked to further hypertext pages. On the contrary, most of the the nearly 200 short articles about the cultural and historical background present overview information and summaries.

Every object on the globe is classified in terms of concepts (see section 4.2), which enable an easy comparison

between the objects of each group, maybe if a user is only interested in drawings of animals on the globe. Furthermore, objects of special interest have a scientifically based commentary. For example, these short texts compare the geographical position of an object with reality, correct false terms of distance and time, and indicate striking variations in the several historical readings of the globe.

As a supplement to this branch the hypermedia system offers descriptive units, organized as a little encyclopaedia about elements of 15th century history with regard to Martin Behaim and his globe. The units are classified in 19 topics, where each of them offers an introduction and bibliographical references to the user. The topics concerning the life and work of Martin Behaim: biography, documents, art und popular view, history of the globe, facsimile editions, historical sources, and research history. And as a main part of this section we try to appraise the value of Behaim's work in the history of cartography. General historical background is presented in the fields: cartography, astronomy, geography, history of ideas, humanism, travel, discovery, trade, instrument (for navigation and astronomy), ship building and biographies about important people of the 15th century (cf. fig. 1). Subjects of the encyclopedical writings are for example the ancient scholar Plinius, the great discoverer Vasco da Gama, the famous world map of Fra Mauro, or the astrolabe, an astronomical instrument.

Fig. 1: The concept tree

In addition to background articles and object descriptions the system offers, as a help for the user, a glossary for basic terms. Furthermore, a huge bibliography with about 500 titles, each labelled with keywords, is integrated in the information network. We also offer a service which gives updated informations about exhibitions, new literature and Internet links in the field of historical cartography. To resume, we try to present the user a clearly structured information net, supplied by various help services in order to avoid the problem of user's disorientation in complex information systems [Nielsen 1995].

In contrast to modern cartographical maps the symbols on the globe are used in a confusing manner. Unfortunately, countries, regions, islands, towns, forests, rivers, mountains and icelands are represented in various ways. There are also no standards for the different meanings of the nomenclature. So we have to identify place names, written identically on different parts of the globe, sometimes referring to a town, and sometimes to a landscape or a kingdom. Border lines are missing as well. For example historical African regions like "Agisimba" or "Cinomomifera" mark only small areas on Behaim's globe, but in contemporary geography they mean large parts of the continent, whose southern and eastern regions were unknown to Europeans until the end of the 15th century. In such cases we decided to follow strictly the image of the world presented by the globe — and not modern knowledge or what we have learned about the ideas of that age.

To give an authentic view on the globe's world we have laid out strict standards for the identification and localization of every object on the globe. For example, all nameless or in part corrupted objects will only be identified, if there exists no doubt implied by spatial position, cartographical symbol, clear out-

line or contemporary sources. In other cases such objects will remain anonymous. Assertions and almost hypothetical references to real geographical elements are always explicitly characterized in the commentary. By its careful standards to prevent speculative assertions and identifications the new investigation of the Behaim Globe differs strongly from Ravenstein's work, published in the beginning of our century [Ravenstein 1908]. Notwithstanding all criticism, this last historical reading of the globe represents still a milestone in the history of cartography.

Some difficulties were raised by spatial neighbourhood with respect to the conceptual model because of the high number of objects on small globe areas. Just for the western and southwestern parts of Europe nearly 300 geographical elements are marked. The result was a hierarchical model, which classifies the objects by their spatial dimension in four groups. By convention, a neighbourhood relation is only possible between two elements within a group.

Furthermore we established special transcription rules for the actual reading of the inscriptions and legends on the globe. In this way we try to guarantee an almost authentic transcription of the texts in agreement with the general conventions of historical transcription. These rules allow to handle the specific features of the globe, that are inscriptions and legends of different age, often in parts or entirely corrupted (cf. fig. 2). Such information is given in footnotes, as well as historical idioms, places, person names, distances and measures get an explanation (cf. fig. 2).

Fig. 2: Transcript of an inscription

Still working on the globe, we can present a few early results from the investigation. For example, a detailed comparison between Behaim's delineation of the earth and Ptolemaic maps and cosmographies showed clearly that the influence of these sources is less important than usually supposed. Special attention is paid to the paleogeographical analysis. It is too early for empirically based statements, but the following results become more and more evident:

- Only a few original inscriptions from 1492 survived on the globe, its number can be called marginal.
- The number of various handwritings and their timespan is larger than supposed until now.
- In some of the texts even different types of handwritings are mixed.
- The investigation of fragmentary original legends proves that idioms, kind of writing and the make-up of the texts follow the original appearance; there are no hints of later falsification or added parts.

4 The Data Base and its Conceptual Structure

The data base of the information system is built up from *descriptive units*, containing information about the globe in general, on the objects visible on its surface and on its cultural and historical background,

as they have been characterized in the previous section. The texts and further formal classificational information which are original results of our historical research have to be combined with a variety of already acquired texts in machine readable form, like historical readings of the inscriptions, bibliographical records, important scientific publications, etc. as well with digitized images of the globe and related maps and graphics.

The Behaim globe contains a large number of inscriptions which we divided into three classes: inscriptions which are only one word long like names of cities, regions, etc., legends of the length of a phrase or a sentence, and long texts which comprise more than one sentence. Of these texts seven historical readings from the 16th to the 20th century are available which exhibit remarkable differences. The secondary literature provides numerous comments on the texts and also on the miniatures painted on the globe, dealing with their readability and state of conservation, with the different handwritings which can be recognized, and with the sources like Ptolemy, Marco Polo, Mandeville, etc. All of these texts are now available in machine readable form, most of them for the first time.

The most important part of the image data base is a complete high resolution scan of the globe's surface. After a short characterization of the image data base we describe the conceptual structure of the data base according to which the set of descriptive units has been organized.

4.1 THE IMAGE DATA BASE

The image data base was generated from high resolution orthophotographs covering the globe, which were preprocessed, assembled, and finally encoded by a wavelet transformation (cf. [Daubechies 1992]) into a quadtree representation [Zeilner 1997].

The original pictures of the globe, made by the Germanisches Nationalmuseum in Nuremberg, are 34 photographs shot in polarized light with a *Linhof Technica* camera with a format of 6 by 9 cm. 32 of the pictures, showing the different segments of the globe, were taken with a constant offset of 30 degrees, providing a certain overlap. The remaining two pictures show the polar caps.

After 500 years the globe differs from the shape of a sphere at many points. For further image processing planar images of the globe are a prerequisite. Therefore, first a contour map of the globe was generated by applying a triangulation procedure. On the basis of this map, an analog computer driven photogrammetric differential mapping process was used to produce orthophotographs of 24 segments of the globe and of the two polar caps. Planarity of the segments has been achieved by projecting every segment on an elliptic cylinder. This normalization procedure, which is normally applied to process satellite images of the earth, was carried out at the Technical University of Vienna [Kraus 1992].

We received the resulting 26 orthophotographs of segments covering the globe, where each slide has the size of a A4 page, and scanned them with high resolution and 24 bit color depth corresponding to professional

PhotoCD quality. After a few preprocessing steps like cutting, size correction, and distortion, the digitized images were assembled and encoded by a wavelet transformation — similar to JPEG — into a database in quadtree representation. This database provides the textures for the visualization component, which can produce bird-eye views of the globe from any desired viewpoint, as well as detailed views of certain sections of the globe as requested by the query component.

Furthermore, our image database contains digitized images of important contemporary maps and globes, historical facsimiles of the Behaim globe, in particular Ravenstein's globe segments [Ravenstein 1908] — the latter encoded in the same way as the orthophotographs —, and MPEG encoded animated images. These comprise a synthesized video showing the rotating globe and an image sequence taken when the globe was moved through a computer tomograph in 1992. The latter sequence of cross cuts exhibits clearly the different layers of the globe providing new insights about the techniques used in its production.

4.2 THE CONCEPTUAL STRUCTURE OF THE DATA BASE AND ITS IMPLEMENTATION

For the task of structuring the huge amount of text, formal descriptive, and image data whose elements contain a lot of mutual references to each other, it is useful to provide a systematic phenomenological model of the domain in the first place. In order to provide a general solution we decided to combine knowledge representation techniques with traditional hypermedia technology [Görz 1995]. In this way, the power of a hypermedia system can be augmented considerably by adding a possibility to process complex queries which reach far beyond the associations stored in its links. For the choice of an adequate representation formalism we followed two goals: On one hand all information units should be stored in a database system which allows flexible and efficient access methods and on the other hand the representation formalism should facilitate the integration of logic-based inference methods in order to process complex queries.

We decided that an object-oriented representation would be the best choice to fulfill our needs. From an implementation viewpoint we were interested to use a representation language which allows to express the conceptual structure of the domain in a direct and cognitively adequate way and which has a clear and well defined interface to an object-oriented database scheme. Therefore we decided to use one of the most powerful yet open object-oriented languages available: CLOS, the Common LISP Object System. In its Allegro implementation for Unix systems by Franz Inc., it has the particular advantage that there is already a powerful interface to the ObjectStore database system by Object Design Inc. This interface has the pleasant property that nearly no extra effort for database programming is required, i.e., our domain model written in CLOS is identical with the database schema, that no extra data dictionary has to be provided, and that the whole expressive power of Common LISP as the database query language can be used.

Structuring the information space means that we had to develop first a *concept tree* which represents a com-

plete classification of our domain in terms of concepts and subconcepts, each of which has a rich structure given as a set of *attributes*. The concept tree, shown in fig. 1, exhibits on its first level a distinction between “globe objects” and “globe info” (and furthermore also the concepts “bibliography”, “hypertext” and “media object”). The “globe object” concept subsumes all concepts required to describe the globe itself, whereas “globe info” subsumes concepts for the description of background information on the Behaim globe and on its cultural and historical context.

All distinctions made by concepts contained in the subtree under the “globe object” concept are in fact what we called a phenomenological model of the domain, because they describe comprehensively all kinds of objects which are represented pictorially on the globe’s surface. It is phenomenological in the sense that it deals primarily with the visual appearance of the globe. Because all objects displayed occupy spatial regions, we first distinguished regions which have a geographical meaning — contiguous and non-contiguous parts of the surface representing land or sea — from regions which carry texts or miniatures. The leaves of the tree are those concepts of which our database holds descriptive units, e.g. the Indian ocean, the African continent, the region of central Europe, the Atlas mountains, the city of Venice, the Portugese flag, the apostle St. Mathew, etc. The same holds for the second big branch, “globe info”. A *descriptive unit* of an object is a structured formal representation of the object which describes, classifies and comments on its appearance and its contents.

Each concept in the tree has specific attributes of certain types. So, e.g. each geographical object has a color, a conservation state, coordinates, the values of which must be taken from predefined ranges, but also a commentary attribute whose value is a whole hypertext, i.e. an unrestricted text which may contain links to other object descriptions. An important property of object-oriented systems is that attributes of a concept are automatically *inherited* to all its subconcepts such that attributes can always be defined at the most general place in the hierarchy. This means in our case that all attributes of globe objects are also attributes of e.g. oceans, continents, mountains, cities, flags, etc. in addition to specific attributes of the resp. subconcepts. So flags are a special case of political icons which have the attribute of an “owner”, an attribute which does not make sense for other miniatures and of course not for globe objects in general.

From a methodological perspective, in modelling the globe domain we followed the guidelines proposed by [Brachman 1991]. This knowledge engineering method proceeds systematically in a sequence of steps in the following order: Starting with an enumeration of object types, and a distinction of concepts and “roles” (attributes), it continues with the development of a concept hierarchy, the determination of individual objects and composite objects and their parts, and the specification of type and number restrictions for role values. So, for example an object type would be “geographical object”, a concept would be “island”, a role “geographical name” with the restriction that it has to be a string, and an individual object (descriptive unit, instance) is Iceland.

A decisive step in the knowledge engineering process was the development of a catalog of typical ques-

tions users might address to an information system of this kind. Basically, one can distinguish between two classes of questions: Whereas simple questions, typically regarding single objects, can be directly answered by navigating along links in the hypermedia network, complex questions, e.g. for sets of objects or properties, require more complex inferential capabilities. The two classes of questions define two different types of access to information, *access by navigation* and *access by descriptive conceptual queries*, which require different processing methods. In order to process queries of the second type, an explicit (logical) domain model is required, upon which conclusions can be drawn by an inference mechanism.

Although all of the globe object categories were defined with the particular map image of the Behaim globe at hand, our experience showed that this particular structure can be applied to a broad variety of historical maps. Therefore our description hierarchy seems to be well suited to be extended to a general representation schema for historical cartography.

Technically speaking, we specified a data base on the basis of a subsumption (superconcept-subconcept) and an aggregation (part-of) hierarchy which provides a conceptual model of the globe. The nodes of the subsumption hierarchy represent concepts, the edges an inheritance relation, and the terminal nodes point to corresponding instance objects, given as descriptive units containing texts or images. The same holds in analogy for the aggregation hierarchy. In the world of object-oriented programming languages, in our case CLOS, concepts are directly mapped to classes, attributes to instance variables and what we called *descriptive units*, the detailed structured descriptions of all objects which can be recognized on the globe, are nothing but instances. For the representation of large immutable data objects like digitized images or complete scientific publications, we decided to store them separately, but each of them is represented by a descriptive unit, an instance, in the data base which provides the only access path to them. In this way we have a uniform representation for all data in our system in terms of instances: descriptions of the different globe regions and their map image, various readings of its numerous inscriptions, comments on the texts and miniatures on the globe, images of contemporary globes and maps, on-line accessible scientific publications on the globe, and cultural and historical background information. Thanks to the mentioned database interface, these instances, given as CLOS expressions, can be directly read into the database system, which functions as a persistent instance store.

The biggest effort which has to be spent in the construction of the knowledge base is “programming” the descriptions of hundreds of instances. All attribute values have to be recorded manually with the exception of coordinate data which are gathered automatically through the graphics component of the system by pointing to the corresponding pictorial instances on a globe segment image.

So far, our system is able to retrieve descriptive units either by following hypertext links or by specifying logical combinations of concepts or attributes on the basis of the domain model given by the concept tree. But one might wish to execute more complex queries which require logical inferences beyond the simple case of the inheritance relation, e.g., given an instance, is it consistent with the domain model, and if yes,

which is the closest place in the hierarchy where it belongs to (classification)? Or, if we propose an extension to the concept hierarchy — a situation which occurs in ongoing research —, is it consistent with the given hierarchy? How can we answer queries which deal with topological relations, e.g. which region is north of Italy? Such questions seem to indicate a need for a more powerful knowledge representation framework. A particular approach which allows to express and process queries of this kind are Description Logic (or Terminological Logic) systems (cf. [Brachman 1991]). Description Logic systems are a specialized version of first order logic based on an object-centered representation which can be seen as a generalization of the object-oriented representation we use. In Description Logics, knowledge bases consist of two parts: The conceptual or terminological part consisting of the subsumption and aggregation hierarchies, and the assertional part containing the instances and the relations which hold among them. The implementation of a conceptual model with a Description Logic system provides just the mentioned inferential services: Besides typical inferences like complete inheritance and consistency tests complex queries of the types shown above can be posed in a logical interface language and are executed by a specialized prover.

On the other hand, we got the impression that for our application we do not need the full power of Description Logics like classification in general, so that it seems reasonable to investigate whether we can keep the benefits of our approach, in particular the use of a database system, by implementing some of the inferential capabilities of Description Logics within our framework. Furthermore, we would have to introduce a powerful logical interface language which would be too complex for the average user. So our current research aims at a simple and easy to handle extension of our current representation scheme which allows for restricted, less powerful inferences than a full Description Logic. In particular, we are presently implementing a module for spatial reasoning which is able to process queries of the kind just mentioned. It uses geometric inference algorithms which operate on the qualitative and quantitative topological attributes in the present descriptive units of geographical objects.

5 The Hypermedia Information System from a User Perspective

The use of a hypermedia network as the basis for an information system provides a convenient way to represent relations between text and images — and other media as well. First of all, texts and images can both be content elements of hypermedia nodes, whereas their relations with each other can be expressed by typed links.

To enable an open and platform independent access to information systems for in-house and external use, state of the art graphical user interfaces use World Wide Web browsers like Netscape. A browser displays text and graphics in a layout which results from processing HTML pages with embedded graphics on the local client computer, and it offers the most elementary functions for navigation like following hypertext links, bookmarking, text search, or keeping a history list from which the user can select previously dis-

played pages. More complex forms of presentation and interaction are possible with *applets*, pieces of code written in the object-oriented programming language Java, which are transmitted through HTML pages. Performance depends primarily on network speed and the local processing power of the user's client computer.

In a first step the "home page" of the system is presented to the user which gives a short overview and provides a set of links to the various services offered by the system. There are links to further HTML pages which give detailed information on the research project, an introduction on how to use the system, an overview of how the information has been structured, etc. For the exploration of the globe, several introductory "guided tour" units are available:

- *The globe and its time*: General information about the globe, its map image, the technology of its production, and the cultural and historical background,
- *The biography of Martin Behaim*, its originator,
- *Cosmography and geography around the year 1500*: the knowledge about the world at the end of the Middle Ages,
- *Travels and discoveries*: Europeans explore the world,
- *Trade*: start of a new epoch in world economy,
- *Myths and monsters*: imaginations of the 15th century.

So far, we have a structure which is rather traditional and can be found at many places.

What makes our system unique is that it offers in addition two new mutually connected information access paths which go far beyond these possibilities: one through a graphical visualization component which can generate high resolution images of the globe from any desired view, and a query component which provides in-depth information about the globe and the objects represented on it through a hypermedia network of descriptive units according to the conceptual structure described above.

When a user asks for "free access", first of all a login applet asks him to identify himself. This step is necessary for two reasons: Because the globe images are copyright protected by the Germanisches Nationalmuseum, they are not publicly available, but only to registered users. Anonymous users are only permitted to access the texts which were written within our project. Furthermore, user identification is a prerequisite for session management and, in the long run, for user modelling which allows a system to interact in a more flexible way adapted to certain user profiles.

The visualization component offers a three dimensional view of the globe (fig. 3) which can be moved and zoomed in real time with the mouse; once the user clicks on a particular region, a hypertextual information unit describing the selected region, identified by its coordinates, is being displayed. Such units are retrieved

from the database, preprocessed for display into an HTML page and shown in the same answer window which is also being used by the query component. This is the kind of information access which has been characterized as *access by navigation* in a twofold sense: navigation on the globe image on the one hand and navigation by following hypertext links in the displayed information unit.

Fig. 3: A 3D view of the globe as displayed by the visualization component

For *access by descriptive conceptual queries*, systems based on complex representations will only be accepted by average users if they offer a graphical query interface which allows to formulate queries by selecting items from a graphical representation of the conceptual structure. A further advantage of graphical selection is that mistaken or erroneous inputs can hardly be made; typing from a keyboard should be avoided wherever possible. In our case, a Java applet opens a query window which shows the concept tree in a scrollable pane and alphabetical lists of the concepts and their attributes in separate scrollable panes (fig. 4). All panes are mouse sensitive — for the concept tree, it can be expanded and shrunk by means of mouse clicks, and selections from the lists can also be made with the mouse. Combinations can be selected by using “and” and “or” buttons. Of course, in some cases input from the keyboard is necessary for e.g. specifying the value of an attribute like the author of a bibliographical reference. Exact text matching is obviously insufficient. In the near future, it will be extended by three matching variants: regular expression, phonetic, and fuzzy matching — particularly important for robustness against typing errors as well as for queries regarding texts which do not follow a standardized orthography. The information items supplied by the user are translated into a statement of the query language and executed by the database system. Query results are displayed in an answer window as links — annotated by instance names — for further selection by the user.

Fig. 4: The query window

This access path allows the user to retrieve descriptive units for all regions and objects on the globe — explanations, descriptions, comments, transcripts of inscriptions — together with a high resolution image of the resp. region of the globe’s surface, which is generated dynamically from the image database. In the same way, descriptive units for background information with corresponding images like those of contemporary maps or drawings, if available, can be accessed as well as bibliographical entries, in some cases with links to on-line versions of the selected publications. Fig. 5 shows the result of a query for *skiapodes* — monsters with a fish tail —, the indicated comment is a hypertext the selection of which leads to the display of fig. 6.

Fig. 5: Result of a query for *skiapodes*

Fig. 6: The comment of fig. 5 as a hypertext

As far as images of the globe surface are concerned, the system provides a variety of graphical operations like zooming (down to the resolution of the film), color and contrast variation, and filtering. The application of image processing techniques makes it possible to exhibit details which can only partially or not at all be recognized on the original object. These operations are available through a navigator applet by means of a

few buttons and sliders which are as easy to use as the corresponding buttons of a color TV set (fig. 7).

Fig. 7: The navigator applet window for image manipulation

A similar navigator applet allows to move the image section in four directions or to apply zooming, and a third one allows to superimpose several raster images. Applications of the latter one would be to exhibit the modern contours of a continent on its representation of the globe, or to indicate the routes of Marco Polo or Columbus. Future work will also include methods to recognize specific contours and to highlight particular features, icons, or map elements belonging to a certain map type like portulans, etc.

Furthermore, we implemented a cartographical toolbox which allows to produce different projections of a map from a standardized vector or bitmap representation. Currently, these algorithms are being integrated into a general morphing tool for map distortion. A long term goal is to facilitate the comparison of historical maps by applying distortions which are selected either graphically or by name from one of a dozen map projections — modern ones as well as historical ones like Ptolemy's. In the first case, a map is shown with a square coordinate grid in one pane, and the user may draw a distorted grid in a second pane to which the map is being adapted.

6 Architectural Design and Implementation of the Information System

The information system has been designed as a modular distributed system with a webserver architecture according to the current state of the art ([Zeilner 1997], cf. fig. 8). Client computers running a WWW browser access the HTTP (HyperText Transfer Protocol) demon running on a server machine through a standard network connection. Hence, an arbitrary number of client computers may connect to the system at the same time. Besides displaying HTML pages, the browser executes Java applets for the query component, image manipulation, etc., locally such that a fair distribution of processing load is achieved.

Fig. 8: The communication model of the information system

6.1 THE COMMUNICATION MODEL

Whereas from the user's perspective the information system as a whole consists of a local client part, the browser, and the remote system "kernel" to which he is connected through the HTTP demon interface, from an internal point of view the information system itself has a distributed client-server architecture. Each component of the system is implemented as a (software) server:

- The CLOS server, a Common LISP process which constructs queries, executes them by querying the object-oriented database system through the AllegroStore interface. The database system in turn runs as a separate process. The query results are sent to the CLOS Server which builds HTML pages containing the results. It is also responsible for session management.

- A PIC server which accesses the image database to generate images of the regions in question.
- The GL server, the visualization component, which generates 3D views of the globe on the local client computer. It uses the OpenGL graphics program library and a texture database which has to be kept on the client computer for performance reasons.

Because we use the PVM (Parallel Virtual Machine, cf. [Dongarra et al. 1993]) library for message passing between the components, the components may run on one or on different computers as it is the case with the current system. The system can be dynamically reconfigured by just modifying a configuration file. Depending on the actual configuration, PVM chooses automatically the most efficient communication protocol. This structure offers optimal flexibility because new components can easily be added to the system.

For each of the servers, there is a CGI script for the HTTP demon — a CLOS client CGI, a PIC client CGI, and a GL client CGI, which preprocess the messages received by the HTTP demon and pass them to a central message dispatcher component, which in turn addresses the resp. servers. In fact, the servers are started automatically on demand by the message dispatcher. An advantage of the CGI communication model is that the client programs can be kept rather small.

Whereas the HTML pages containing the results of database queries are being constructed by the CLOS server, the images to be inserted into those pages are provided by the PIC (image) client CGI; an example is shown in fig. 5. For the presentation of raster images, the PIC server has tools for conversion into either GIF (8 bit) or JPEG (24 bit) format. The requested image sections of the globe surface are generated dynamically by the PIC server (image database) which can retrieve — uncompressed as well as compressed — images in different resolution steps due to the underlying wavelet encoding. For performance reasons, static images are delivered by default. If the user wants to manipulate images, he has the choice to replace the static display by a dynamic one, where the image is being displayed by Java applets which allow navigation and image manipulation, but with a considerable loss of speed. In the near future, we expect that faster processors and progress in Java compilation technology will catch up so that the static image display option can be abandoned. For dynamic display, our wavelet program code has been ported from C++ to Java; the applet can load either a wavelet quadtree or, if navigation is not desired, GIF or JPEG images. Image manipulation is possible in three different color models: RGB, YIQ (NTSC) or HSV (like on a color TV set). Last, but not least, there is also an option to generate overlays of raster images.

The guideline for design and implementation of all of these software tools was to achieve a maximum of generality and adaptability so that they can easily be reused for other applications.

6.2 THE VISUALIZATION COMPONENT

The visualization component displays the globe in a separate graphics window on the screen of the client computer. In order to achieve animation in real time, with the current state of technology a powerful work-

station with particular hardware support is required. In our particular setting, we use a Sun UltraSPARC Creator 3D workstation with 312 MB of RAM, running the OpenGL graphics library. Although the size of the image data had be reduced by an order of magnitude, this application has still a high demand of memory and disk space, the latter to hold a local copy of the image (texture) data (500 MB).

The images are being mapped on a sphere using the *texture mapping* function of OpenGL. The view is oriented towards the middle of the globe, but currently no special illumination effects are taken into account ([Schüller 1993, Zeilner 1997], cf. fig. 3). The user can choose an arbitrary view either by pointing with the mouse into the graphics window or by specifying the viewpoint graphically from within the browser. The globe can also be moved and zoomed with the mouse in real time. Graphical selection within the browser window leads to a transmission of coordinate data to the GL server, producing an appropriate view of the globe. It is also possible to transmit coordinate data in the inverse direction: If the user selects a position on the globe in the graphics window, an access to the database system with the resp. coordinate data is issued to retrieve a descriptive unit of the closest matching region.

6.3 USER MODELLING

A long term goal of our project is to augment the flexibility of the user interface by user modelling. Within our application, it is still an open question whether a very fine grained type of user adaptive system behavior would be useful, but we believe that a prototype-based approach with only a few predefined user types would be a gain for amateur as well as for expert users. If e.g. a user asks several times for a certain object type — a merchandise like pepper — the system could take an active role by providing hints about other information units on overseas trade. As a prerequisite, we are already recording all dialogues in the database system, separately for each user. This opens an opportunity for statistical evaluation, but also to enhance the user interface by offering a more fine grained reference to previous dialogue steps than the browser's history list does. We also plan to include a feature which allows a user to store annotations of his own at any place of his dialogue.

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Günther Goerz, Prof. Dr., university professor of Computer Science (Artificial Intelligence) since 1989 at the University of Hamburg, since 1991 at the University of Erlangen-Nuremberg and member of FORWISS (Bavarian Research Center on Knowledge-Based Systems). Research stays at UCLA, Los Angeles, and at CSLI, Stanford University. 1987–1989 visiting scientist at the LILOG project (Linguistic and Logical Methods) of IBM Germany in Stuttgart. Organizer of several workshops and conferences on AI and Computational Linguistics. Main research areas: (1) natural language and speech processing, in particular parsing; (2) knowledge representation, logic and hypermedia systems, and (3) parallel processing in AI.

Norbert Holst, M.A. Born 1963 in Bremervörde (North Germany), historian and newspaper journalist, 1987–1993 study of medieval history, modern history and geography at the University of Bamberg, since 1995 involved in the investigation of the Behaim Globe at the Bavarian Research Center for Knowledge-Based Systems (FORWISS) in Erlangen; special interests: historical cartography, history of expansion, American Indian history.