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The Four Dimensional Visual Information Universe: An Illustration

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1. Information Visualization for Enterprise Management.

Information technology is rapidly reshaping Corporate America. Traditional industries of computing, publishing, entertainment, mass media, marketing, and education are converging to common enterprises; and traditional corporations are embracing such information-based visions as concurrent engineering, enterprise re-engineering, virtual corporations, agile manufacturing, and distributed global enterprises. Within an enterprise there is the emerging emphasis on global query capabilities for enterprise users sharing information resources throughout.

One key area that has not received adequate attention - or more accurately, has not been sufficiently understood - is the next generation user-interface for the information-integrated enterprises. We submit that this next generation technology will and must go beyond the present concept of GUI (graphical user interface) and VR (virtual reality). It should: (1) feature a new paradigm of information visualization with metaphors suitable for cyberspace type of ideas and applications; (2) possess contextual knowledge of the underlying information resources to assist end users acquire and assemble any pieces of information desired from everywhere needed; and (3), thereby, effect a virtual environment for information access over networks where the user navigate freely and query globally with little or no prior technical knowledge about the system. The new concept will be exemplified as the Visual Information Universe (VIU) in this paper, using the new Globe metaphor (representing information resources), some basic VR tools (for direct spatial manipulation), and a metadatabase (containing models and other contextual knowledge).

An Assessment of GUI and Other Emerging Technology.

Traditionally, users interact with and receive information from computers in a linear formalism which is both based on and bounded by textual constructs. This is the case even for sophisticated GUI-based systems which support 2-dimensional and even 3-

dimensional graphics (such as tables, charts, and icons), since these images typically rely on textual annotations. The fundamental disadvantage of this linear formalism is the segmentation of information into fragments and thus leaves their synthesis and comprehension to the user to joggle through [2, 12, 14]. This is further exacerbated with the growing quantity of data resources available to the users. The convenience of the latest GUI in direct manipulation of input with mouse, iconic representations, and windows does not solve the problem, however. Users are still left to "read" information that is presented in overlaying windows, regardless of the convenience garnered. Actually, the notion of graphical user-interface is a misnomer. Few, if any, GUI's are purely graphical in that all input, output, and user interaction are conducted through a graphical language [5, 6]. Albeit well understood, the value of employing graphics as a highly effective medium of information transfer is unfortunately under-utilized in today's user-interface designs.

Contextual knowledge, on the other hand, is non-existent not only in today's GUI technology, but also in new technologies that have extended GUI in visual capabilities. Cases in point are scientific visualization and Virtual Reality (VR). The former has been applied with impressive success to illuminate physical objects and phenomena too costly to build or too difficult to view directly [1, 5]. Yet, all of these objects and phenomena do exist outside of the computer and can be displayed to the user with conventional techniques such as illustration, photography, or physical model. These applications of visualization do not offer new interpretive capabilities to the user such as visualizing (logical) information and provide additional insights and other utilities or assistance. Rather, they tend to merely mimic on the computer what the user has always known and been able to visualize in his/her mind. VR has precisely the same challenges: (1) how to visualize logical objects and concepts that do not directly render themselves to a physical world, and (2) how to augment interpretive power to the visual environments of information for the user?

To best illuminate the deficiencies in the existing technologies of user-interface one only needs to examine an exceptional application of knowledge in medical visualization and user interface, that of CATSCAN and Magnetic Resonance Imaging (MRI) medical imaging systems. This breakthrough in the use of anatomical knowledge combined with visualization technology provided new capabilities for medical diagnostics. Such capabilities could not be provided by traditional X-rays and are unattainable without the computed imagery technology.

VIU for Enterprise Information Management

The above assessment is particularly relevant to enterprise information management (EIM) where the users' needs for information access are not confined to mere retrieval of files, but require seamless sharing of pertinent information across the enterprise and tailored to particular tasks. Visual technologies are crucial to enterprise users, yet a survey of the literature on graphical support for information resources management [4, 15, 16] produced none that provided any contextual knowledge-supported visual interfaces. The potential benefits and opportunities in providing this long-overdue visualization technology are significant.

We envision VIU to be readily compatible with VR implementation. In a way, VR and information visualization go hand-in-hand; when information is adequately visualized through some interpretive models and integrating metaphors, this visual world is ready to be viewed through any basic VR tools. The predicament to creating virtual environments for information access is, in this sense, information visualization using contextual knowledge. Information visualization itself can be undertaken in three incremented steps: progressing initially from the simple employment of a visual paradigm replacing GUI, to incorporating a basic metadatabase for standard on-line assistance (for navigating), and finally to providing global query capabilities for enterprise application development.

The VIU model is discussed next in Section 2. The major components of VIU are discussed respectively in Sections 3, 4, and 5. A brief conclusion is provided in Section 6.

2. The VIU Model.

The overall architecture of VIU is depicted in Figure 1 below. The core, which is independent of specific VR tools and network application programs, is comprised of the Universe Paradigm defining the visual constructs using the Globe metaphor, the Metadatabase representing contextual knowledge, and the Visual Language interpreting information resources into the visual information universe constructs. This core is then connected to network interface programs such as Netscape (HTML, CGI, and JAVA) for immediate application to the Web on Internet and other systems. On the user side, the VIU core is connected to off-the-shelf VR tools such as 3-D position trackers, head-mounted displays, and data gloves. This connection can also be extended or changed for other particular VR technology.

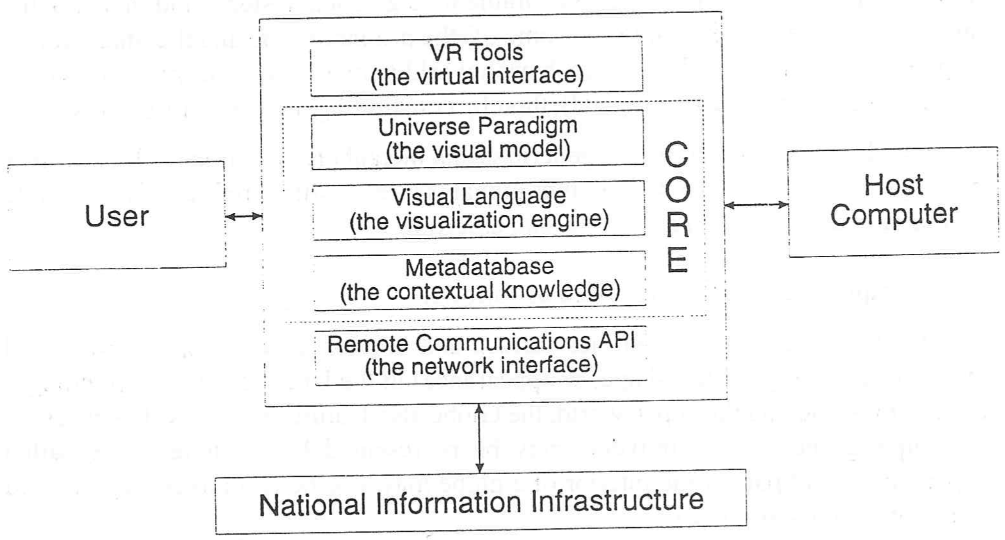

Figure 1. VIU Architecture

One important benefit of this architecture using a VIU core is what might be referred to as **interface independence**. That is, the core provides a neutral visualization paradigm and coupled with an independent repository of models and other contextual knowledge to effect an engine that can be plugged to common classes of VR tools and network interfaces. The resulting adaptability will not only be sound theoretically, but also be desirable in the commercial marketplace. The only other dimension that needs to be worked out for maximum portability is the adaptability with host computers. This problem is rapidly vanishing in today's industry as vendors and manufacturers are consolidating their operating systems and at the same time enhancing interoperability throughout. Hopefully, the complete VIU software can either be standardized on the basis of industrial interoperability, or be simply consolidated into a handful of versions each of which recoupled with a major class of operating systems.

We now discuss each component individually.

3. The Universe Paradigm for Information Visualization.

A central element of the VIU model is a visualization paradigm for information. We propose using the notion of the universe in which we both physically live and logically conceptualize our existence for the paradigm. Its basic elements are stated below.

(1) The logical world of human enterprises will be interpreted into an information universe(s), which, whenever necessary and appropriate, will be extended to include a similar representation of the physical universe.

(2) The Universe consists of worlds: the primary world (the information world which represents the utilization and management of information resources surrounding the users; compared to the earth), the other worlds (representing all functional and application systems concerned; comparable to, e.g., solar systems and planets), the sub-world or the world containing (some of) the primary world and the other worlds (e.g., the universe as a whole); which each world may exist in multiple spaces (i.e., contexts such as physical or logical), thereby constituting multiple virtual universes.

(3) Each world is represented with a generic visual metaphor: the Globe, which further employs color, light, sound, and other human senses to allow reference to multiple virtual universes through a single visual assertion.

The Globe metaphor itself is characterized as follows:

(4) The Globe represents a world, has surface and interior, and will spin, travel, and evolve (e.g., change color, shape, or appearance) in the Universe. Correspondingly to the sub-world and the super-world, the Globe also features respectively sub-globe and super-globe (e.g., a universe may be represented by a single globe called super-globe, and part of the interior of a globe may also be recursively represented as a globe, or a sub-globe).

(5) The interior of the globe in general represents information resources, systems, and other logical contents of the enterprise; while the surface typically represents user's needs of the interface, such as applications, management, and other utilization of these information contents for the enterprise.

(6) The detailed design of the metaphor, such as the shape of the application continents on the surface and the particular symbols of the information resources in the interior of the Globe, is application domain-specific. However, the design (including also the use of contextual markers such as color and sound) will (a) be based in part on and computationally coupled with the contextual knowledge that the user-interface contains, and (b) generally should allow for direct input from and output to the user (e.g., touching on the globe surface and virtually traversing its interior).

These concepts are illustrated in Figures 2a to 2l. They respectively show a fly-by-view of universe, a globe for the metadatabase, and close-up images on the interior (representing an overview of information resources) for model traversal in query formulation.

This representation model facilitates a visual and virtual two-way user-interface environment for general information processing and management activities. The Universe serves as the unifying domain for globes of information resources and applications, analogous to the universe and planets we understand and experience. A benefit of the paradigm is that it affords an open and extensible framework for information representation that can encompass notions of aggregation, generalization, concurrency and a variety of complex logical and physical relationships. Models can be represented into sub-universe, multiple-universes, and super-universe. The globe with which we build the information universes also allows for sub-globe and super-globe definition. Drawing symbolism from the planet earth, the surface of the globes represents information functions that operate on the information elements which are encapsulated within the globe. Activities such as browsing, query, and process monitoring are done by traversing in the geometric space within the confines of the information globe.

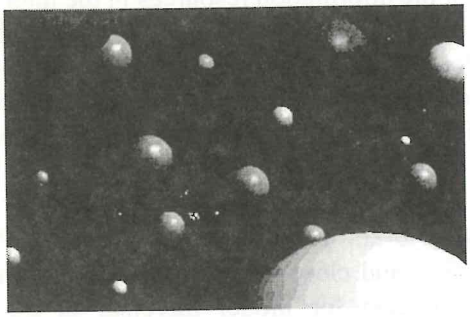

Figure 2a. Viewing A Universe: Each Globe World Represents an Information System

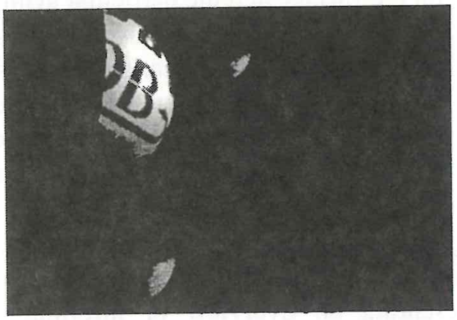

Figure 2b. The Metadatabase World Emerging from the Horizon

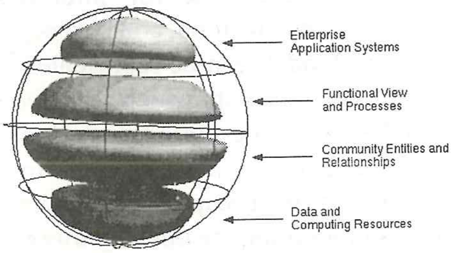

Figure 2c. Visiting a Globe: The Metadatabase World

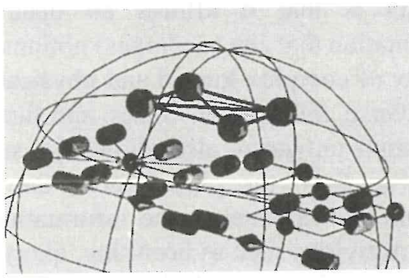

Figure 2d. Closing on View of Application and Functional Model Layers

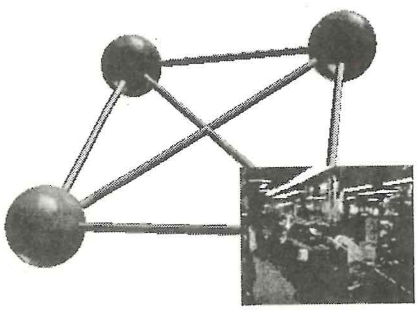

Figure 2e. Exploding Close-up View of Shop Floor System and Application Layer

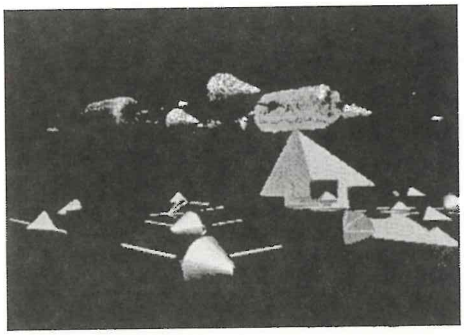

Figure 2f. Exploring Relationships Between Functional and Structural Models

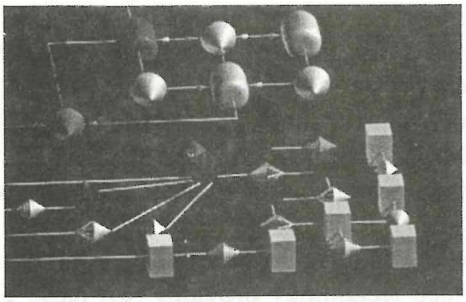

Figure 2g. Navigating the Close-up View of Structural and Functional Models

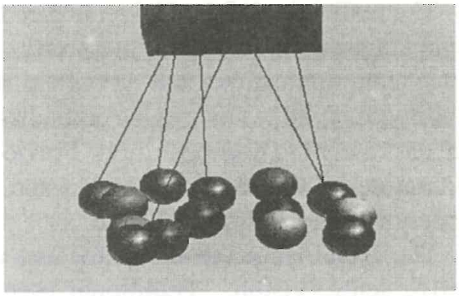

Figure 2h. Identifying Entity and Related Data Items

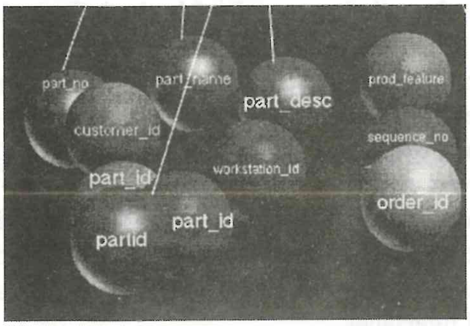

Figure 2i. Examining Data Items Identified Identified by Text Labels

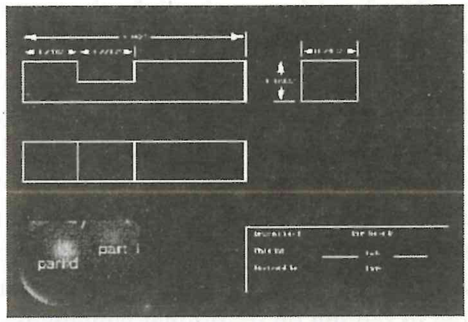

Figure 2j. Instance of Data Item - Blueprint of a Puzzle Piece

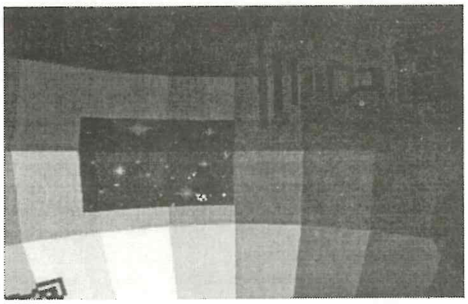

Figure 2k. Zooming out of the Metadatabase World

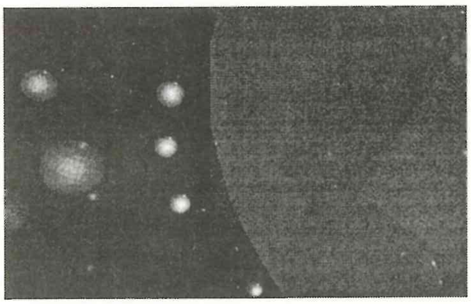

Figure 2l. Returning to the Information Universe for Other Applications

4. The Visual Language and Visual Interpreter.

The realization of the Universe paradigm in software environments is made through a visual language and a visual interpreter. The visual language defines the primitives for two-way communications and drives the information visualization and the translation of user protocol [8, 18]. This engine embodies a model of the domain knowledge with design principles catered to user cognition. Previous examples of visual language can be found in the literature of visual programming and scientific visualization systems such as Data Explorer of IBM and LYMB of GE.

The visual language allows the user to accept and generate meanings with his most receptive sense, vision. Traditional user-interface technology provides two basic and different modes of operation: keyboard and mouse for input, and terminal screen/windows for textual and simple graphics output. What is missing is communications with a visual vocabulary similar to that of our daily life with gestures, expression, movements and drawings. The provision for this capability will allow for complex input without the significant overhead as in traditional user interface protocols.

The visual interpreter links the contextual knowledge contained in the information models with the visual language; or more specifically, it maps metadata in the system to and from a defined visual vocabulary for context dependent activities. This is significant in that the distributed and vastly heterogeneous nature of information resources on networks makes the total picture too complex and extensive. Regardless of the paradigm for representation, be it textual, graphical or visual, the disposition of comprehension and experience from the user must also be considered. The visual interpreter further provides for the capability to utilize knowledge about the user in context-adjusted visualization. This capability is just beginning to be addressed in some systems [13, 17], which are limited to relying on traditional window/textual interfaces.

An inherent benefit with a visualized information access system is the uniform representation environments afforded by a standard visual language that is extensible for classes of users. This provides a congruence in user activities for information browsing, global query, simulation, and systems management not available with existing systems that have the most advanced GUI's [9]. This congruency reduces the overhead required of users from viewing and comprehending data in different formats; especially since the format themselves provide no more significant meanings.

5. The Metadatabase.

Contextual knowledge in the form of models of the information resources, operating rules, and other metadata about the systems concerned is stored in the metadatabase as depicted in Figure 3. A complete structure for representing these metadata is illustrated in Figure 4. It should be noted that the whole model can be implemented on an incremental basis. For instance, the basic metadatabase required for the second technical objective of this research/effort in the preceding section requires only a subset of the models; while a full VIU with global query capabilities will use the model in its entirety. Each construct in the structure can be implemented as a flat file (or relational table) with metadata populated into these files like tuples. Based on the general concept of information universe and globe metaphor discussed above, a specific visual globe model for metadatabase [11] is developed.

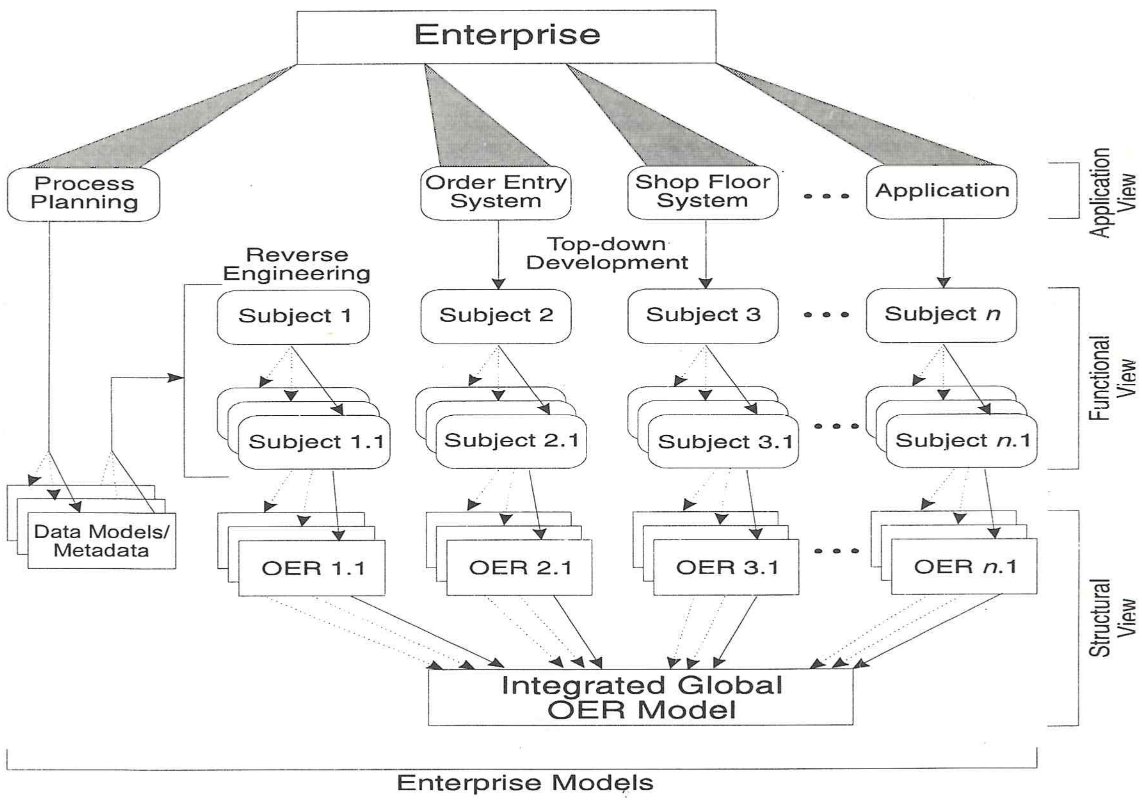

Figure 3. The Metadatabase: A Meta-Model for Information Modeling

Characteristically, this metadatabase globe (Figure 2c-2k) aggregates four layers in the encompassed geometric space to represent four categorical views of system information resources. The four layers are 1) network source/enterprise application systems, 2) functional views and processes, 3) community entities, relationships, and rules, and 4) data and computing resources. The surface of the globe has specific areas representing the applications of the metadatabase: information resource browsing, global query, systems simulation, and systems management.

This globe is fully integrated in that a user can navigate through the model to identify relationships of information in the network and review the information model for details. The logical relationships among the information resources are interpreted through the visual language of shapes, colors, lighting, sounds, and other markers. The dynamics are driven by the information model and processed with the underlying knowledge-based visual interpreter, resulting in an animated presentation which helps alleviate users of the interpretation overhead in computing technology and guide them in the varied tasks of information access.

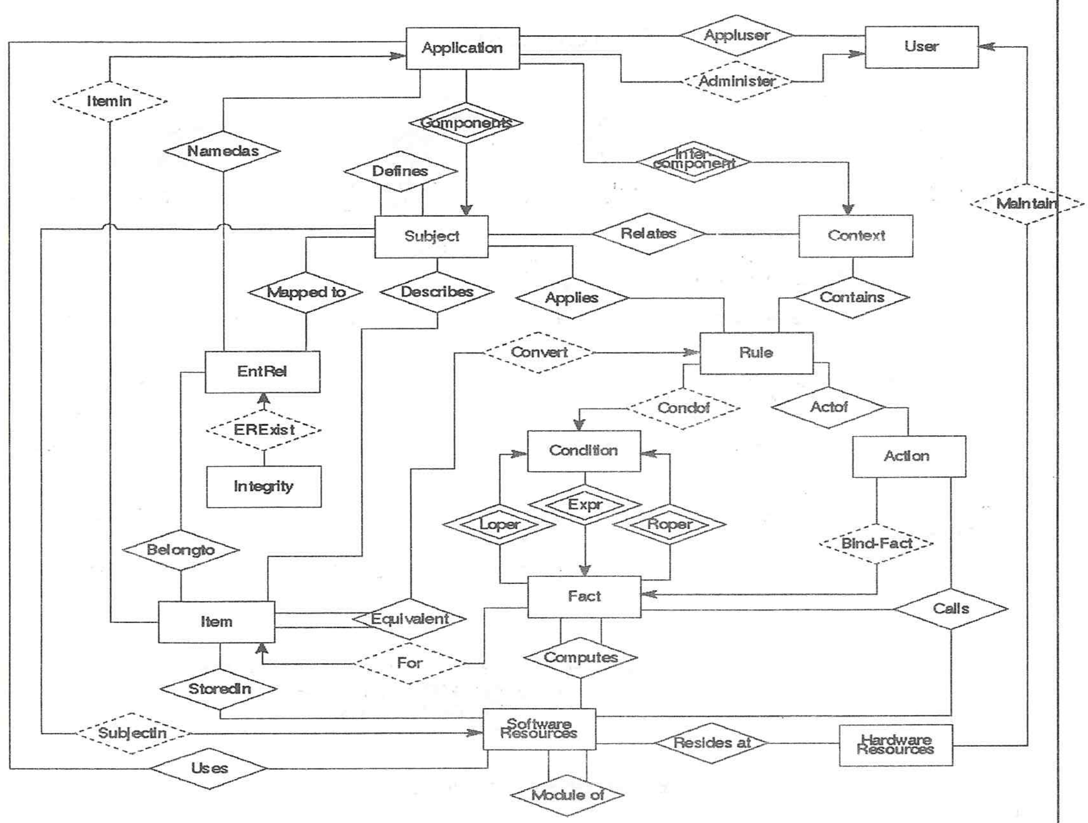

Figure 4. The Structure of the Metadatabase

The full VIU with global query capabilities will require a full metadatabase supporting query formulation and processing. Such a design is reported in [3, 7, 10] for Computer Integrated Manufacturing (CIM). The global query system is supported by two additional elements: a processing system and a modeling system. Figure 5 shows the processing system, while the modeling system is documented in [9]. Both embedded to the core VIU in Figure 1 with custom development efforts.

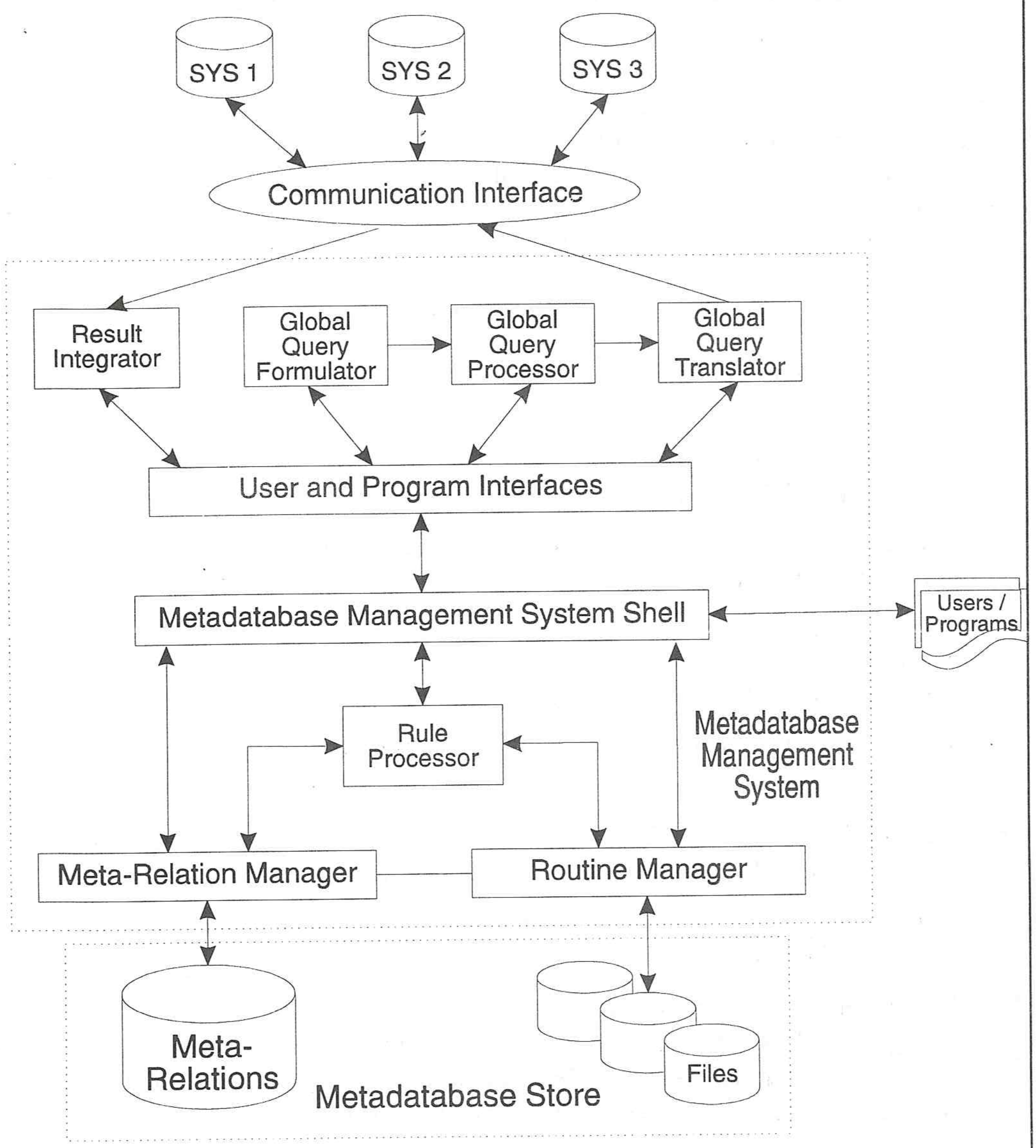

Figure 5. The Architecture of the Model-assisted Global Query System

6. Conclusion.

Comparatively, there are three key advantages that the VIU model promises over existing graphical user-interface designs; namely synthesis, dimensionality, and scope.

Synthesis allows the system information resources to assume an integrated global form which is presented as a unified continuum. Dimensionality - the addition of contextual knowledge - brings depth into user-interface beyond current scientific visualization and VR. Both of these elements contribute to enhancing user cognition. Scope, based on the uniformity and dynamism of the Universe paradigm, allows for simultaneous and continual viewing and browsing of all sources in the network.

The VIU model is prototyped at Rensselaer using an industry-sponsored Adaptive Integrated Manufacturing Enterprises (AIME) scenario. Both traditional environments such as RISC workstations and SGI visualization machines are employed. Continuing efforts are currently focused on linking the visual front-end with the metadatabase and the distributed application databases that the metadatabase manages, in the AIME laboratory.

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