Mapping Information onto 3D Virtual Worlds

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Abstract

This paper presents a strategy for automatically mapping information onto visual parameters in the field of three-dimensional (3D) information visualization. The work presented here is done in the context of researching how 3D information visualization may help when trying to visualize large volumes of dynamic data. The application field within which this work has been conducted is using 3D information visualization for network monitoring and management. Nonetheless, the framework and mapping strategy is application domain independent.

In this paper we focus on the process of automatically mapping data values onto graphical parameters, in order to construct 3D virtual worlds that convey network data for network monitoring and management. We present the criteria that are used to find the best mapping and the strategy taken to implement those criteria. We describe our use of visual metaphors and the graphical components that we utilize and we give some examples of different mappings.

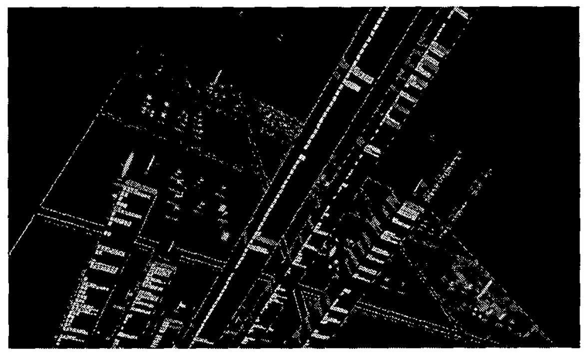

Figure 1. Example of the city metaphor for NFS data visualization (CyberNet project).

1. Introduction

The core of information visualization is finding a way of visually representing information in a manner that is most effective and pleasing for the user comprehension. This involves mapping data values onto visual parameters. Our goal is to automatically provide the best mapping, given a certain data set and a number of different visual metaphors.

Metaphors provide a way of conveying information visually in a representation that the user is familiar with or can more easily understand. Metaphors can be based in the real word or based on abstract concepts. Figure 1 shows an example of the former, depicting the information as a virtual city; Figure 2 is an example of the latter, using the cone-tree metaphor to visualize information.

In order to be able to do an effective automatic mapping of information onto visual metaphors and visual parameters we have identified the following needs: an effective data characterization, a visual metaphor characterization and a visual parameters taxonomy. Along with this we also have to characterize the network management services.

The organization of this document is as follows: firstly, in section 2 we do a brief presentation of the CyberNet project, that serves as test-bed for the research presented herewith. In Section 3 we discuss the process of mapping, which we have divided into two major steps. In Section 4 we present the definition of a service. In the next section, Section 5, we discuss the data characterization. Section 6 is dedicated to the metaphor characterization and Section 7 to the graphical components characterization. In Section 8 we give some examples of different mappings. The conclusions are in the last section, Section 9.

2. The CyberNet Project

The aim of the CyberNet project [1] is to automatically build three-dimensional virtual worlds that are used to visualize network data and analyze network services. As

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the network behavior is constantly changing, the 3D virtual world will continuously evolve in order to represent the modifications that take place. The major problems we had to solve, regarding information management, were related to the distributed nature of the data and to the high level of dynamics that typically characterizes this application field.

The network management data that has to be monitored is spread all over the network. In traditional systems, this information is usually supplied by SNMP agents that run on every network device. The network management tools are then required to "pull" the data by using SNMP requests to query the agents. The network status information is usually presented to the user using tables and/or graphs. When there is a change in the network status, the interface signals it to the user, usually using some kind of dialog box. The user can then make a new request and, acting upon it, the system updates the user interface content.

Since we want to present all the information in a 3D virtual world, and we want that world to be updated without requiring user intervention, the CyberNet project uses a different approach. We use a distributed object framework composed of three distinct parts:

- *The collecting layer* is used to gather the raw network data from the monitored devices.
- *The structuring layer* is the kernel of the system. It structures the raw information according to the service being monitored.
- *The presentation layer* maps the structured information onto the graphical components according to the metaphor chosen for mapping. It is also responsible for presenting the 3D world and provides the user interaction and navigation.

In this paper we will only discuss the responsibilities of the presentation layer (for further information on the collecting and structuring layer, see [1]); more specifically, the process of mapping the network data onto the visual elements. In CyberNet information is visualized with the help of metaphors, mostly real world based. Layout managers and 3D glyphs are the graphical elements (see Section 7) of the presentation layer and are used to construct the metaphoric virtual worlds.

The presentation layer has also another type of components, non graphical, named adaptors that are responsible for doing the information mapping between the structured information, that is outputted by the structuring layer, and the visual parameters of the world. In the next section we will describe the mapping rules. The adaptors task is to implement these rules.

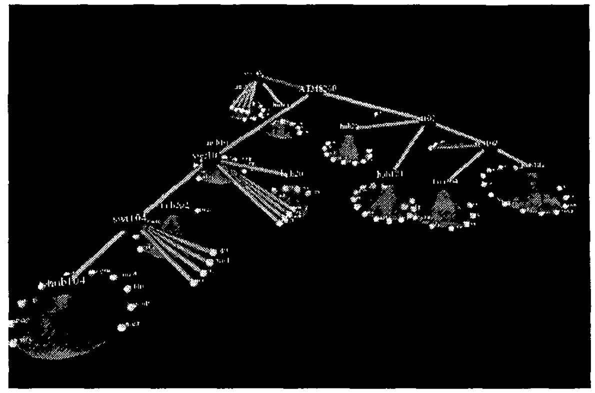

Figure 2. Example of the cone-tree metaphor for network topology visualization(CyberNet project).

3. The Mapping Process

We can divide the process of mapping data values onto visual parameters in two major steps: firstly, the mapping of a service on a metaphor and then, the mapping of the data onto the visual parameters available for the chosen metaphor. We will now describe both steps in some detail.

3.1. Mapping a Service on a Metaphor

The first step of the mapping process in our system is the mapping of a service on a metaphor. For this we consider two criteria by which we evaluate the mapping process: expressiveness and effectiveness. These criteria were already used by [2] on work done regarding mapping data values onto two-dimensional visual parameters.

Expressiveness refers to the capability of the metaphor of visually representing all the information we desire to visualize. This accounts for a first level of mapping. For instance, if the number of visual parameters available in the metaphor for displaying information is fewer than the number of data values we wish to visualize, the metaphor will not be able to meet the expressiveness criterion. This is due to the fact that we cannot map more than one data value onto one visual parameter.

The relationship between data values and visual parameters has to be a univocal relationship; otherwise, if more than one data value is mapped onto the same visual parameter, then it will be impossible to distinguish one value's influence from the other. On the other hand, there can always be visual parameters that are not used to map information, as long as there is no need for them to be utilized.

The second criterion, effectiveness relates to the efficacy of the metaphor as a means of representing the information. This criterion accounts for the second level of the mapping. Along the effectiveness dimension we can further distinguish several criteria: effectiveness regarding the information passing as visually perceived, regarding aesthetic concerns, regarding optimization (e.g., number of polygons needed to render the world).

3.2. Mapping the Data onto Visual Parameters

This is the second step of the mapping process. As in the first step, first we have to consider the criterion of expressiveness, i.e. there has to be a sufficient number of visual parameters in order that we can map all the data desired. Not only the number of visual parameters has to be sufficient to map all the data, but also, they must be able to map the right data (i.e., there are visual parameters that are not able to map a specific category of data; for instance, shape is not useful for mapping quantitative data).

The second criterion is, as in the case above, the one of effectiveness. This criterion implies the categorization of the visual parameters according to its capabilities of encoding the different types of information. Moreover, this also implies categorizing the information according to its importance so that more important information can be encoded more efficiently when options must be taken.

This categorization of the importance of the information has two expressions: one is a assigned importance of the information in the context of a service; the other is a preference of the user. In other words, the context of the data within a given service defines the importance of that data and, consequently, determines the information encoding priorities. Nonetheless, the user may choose to override this and define his own importance of the data, according to his priorities when visualizing a service.

4. Services

In our terminology a service defines the information that we want to visualize. In other words, the information that is to be visualized is the information that characterizes a given service (e.g., NFS service). The service data retrieved by the collecting layer is then structured in a service graph, in the structuring layer.

A service can be represented by a direct acyclic graph that comprises entities and relations (see example for the NFS service in Figure 3, on the left). Entities represent the smallest units of raw data and relations express relationships, either of groupness or dependency, between entities. In other words, we may say that entities are the building blocks and relations provide the glue to construct the service graph.

The description of the service can be made as a composition (enumeration) of entities and relations. Thus, a service expresses fundamentally a combination of relationships amongst entities that, together with filtering parameters, as a whole constitute the description of a service. The actual state of the service is characterized by the information retrieved from the collecting layer.

The description of the service also contains the importance weight that each of the specific data has for that service. This weighting of the information, provides the means to achieve the most effective visual mapping: the data that is more significant is encoded more effectively. The importance of a given data depends on the service (e.g. the percentage of CPU usage maybe more important for a workstation supervision service that for the NFS service).

There are predefined services described as an enumeration of relations, entities and filtering parameters. The user is then free to change the parameters of a determined service. This does not correspond to the creation of new services but only to add some different filtering values, or to change the existing ones.

5. Data Characterization

Data characterization is usually the first step to understand a phenomenon or system. Developing a taxonomy helps making sense of information. Some research has already been done on data characterization for automatic presentations of information. Although almost all the previous work done in this area, only considered static two-dimensional visualizations, and we are interested in 3D visualization for dynamic data, most of the data characterization work is still interesting for our purposes. In the next sections we are going to present the previous work done in this area and then the CyberNet system's preliminary data characterization.

5.1. Previous Work

The SAGE system work on data characterization for automatic presentations [3] extends and generalizes the work previously done by [2]. Firstly, four criteria are identified in order to evaluate the relevance of data characteristics: characteristics necessary for distinguishing graphical techniques information expressiveness; characteristics to help ordering graphical techniques effectiveness at conveying information; characteristics useful for determining how information could be integrated within a display; and characteristics that users could easily apply.

Based on these criteria [3] defines several dimensions along which data can be characterized: data types, properties of relational-structure, expressing relations among relations, distinguishing unary, binary and N-ary relations, and

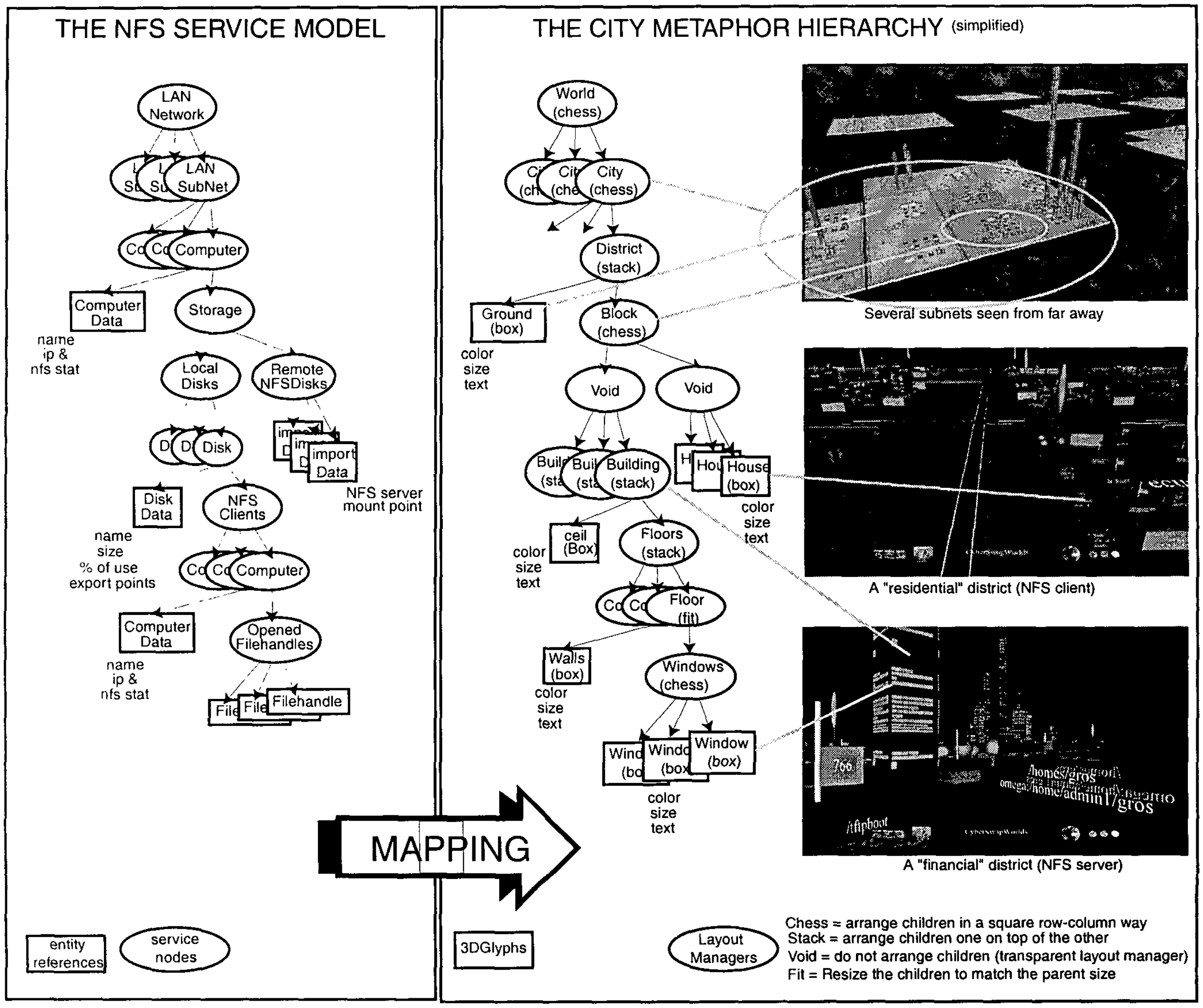

Figure 3. Example of a mapping between the NFS service and the city metaphor (CyberNet project).

user information seeking goals. In data types, sets ordering (possible values being quantitative, ordinal, and nominal), coordinates versus amounts, and domain of membership, are identified.

The Vista system [4] follows the sequences that are generally present in a visualization system, that converts a data set into a displayable image: data manipulation, visualization mapping, and rendering. For the visualization mapping - data variables mapping onto visual parameters - it is necessary to characterize data and visual parameters/techniques.

Knowing the data characteristics relevant to visualization mapping is the first important step in designing an effective visualization technique. Usually data can be divided into two major categories: qualitative and quantitative. Qualitative data further subdivides into nominal and ordinal. Quantitative data is more common on scientific domains than qualitative data. Quantitative data can be scalar, vector, or tensor.

The IMPROVISE system [5] advances further in characterizing data for automatic presentations. It uses six dimensions to describe data characteristics: data type, which relates to the atomicity of the data; data domain, that categorizes information semantically; data attributes, that distinguishes data properties; data relations, which specifies relations between data; data role, for characterizing data based on user information seeking goals; and data sense, that differentiates data based on user visual interpretation preferences.

The system makes use of an object-oriented approach: each piece of information is an object. Each object belongs to a data domain and has a data type, properties (data attributes) and connections to other objects (data relations).

5.2. CyberNet System

We think that the best approach is to keep the data characterization as general as possible, so that it can be easily applied to other application domains not necessarily related to network monitoring and management. An excessively complex and detailed data characterization will most probably be application domain dependent. This concern is relevant since the CyberNet system's framework was designed so that it can be used in other application domains for 3D information visualization of dynamic data, such as web management or stock exchange visualization, for instance. The only part of the CyberNet system that is application domain dependent are the collecting agents in the collecting layer and, evidently, the services.

For the moment, we classify information along three principal dimensions: type, time and semantics. The data type dimension essentially relates to the basic data types that are cited in [2] and that appear in more or less all the systems that were developed afterwards. Basically, information can be divided into two major types: quantitative and qualitative; the latter can be further divided into nominal and ordinal information.

- Quantitative information: is defined by a scalar value (e.g., percentage of CPU used by a process).
- Qualitative information:
  - Nominal information: is an unordered set of nouns and does not possess units (e.g., names of the machines).
  - Ordinal information: is an ordered set but the ordering gives no information about the difference in magnitude between any different values belonging to the set (e.g., the disk size may be defined as small, medium or large, but it gives no insight regarding the actual values for small, medium, or large).

These two data types are only a first division of the data types. For the moment, they seem sufficient for a general classification and from an analysis of the services created so far, every data seems to fall in these basic categories. In fact, most of the data encountered in network management systems is quantitative data. But for an efficacious mapping, the data characterization will eventually have to be finer tuned. For instance, for quantitative data we can devise data characteristics that are important for the visual mapping such as is the quantity a percentage, a margin, a limit (lower or higher) and so on.

The time dimension does not appear in any of the previous systems cited before since those systems only deal with static visualizations of information. For our system it is of major importance to characterize information according to its time-dependent behavior. We want to visualize information that is highly dependent on time and we want the information being displayed to be dynamically updated in real-time. The information is thus classified not only whether it is time dependent or not (i.e., static or dynamic) but also according to more specific behavior (e.g., continuous or discrete, the frequency of change).

The semantic dimension exists to provide for a semantic context. For each data characteristics there is a field that specifies in which services (or services) it is to be used (e.g., size of disk is used by the workstation monitoring service). This introduces a semantic context in the data characterization that allows for the automatic construction of the network services.

It should be stated that one piece of data (entity) may belong to more than one service. For instance, size of disk may also be a relevant data for the NFS service, eventually with a different degree of importance. The relative importance of the data for each of the network services is specified in the service description, as already described in Section 4.

6. Metaphor Characterization

In order to comply with the criteria of expressiveness and effectiveness introduced in section three we characterize metaphors in terms of the information that they are able to display and provide interaction for.

Visual metaphors in our system are constituted by two graphical elements: layout managers and 3D glyphs. Layout managers are responsible for arranging their children, either other layout managers or 3D glyphs, in space (e.g., an orbital layout manager places all of its children revolving around a center). 3D glyphs are the actual 3D visual components and the number of visual parameters that they provide for information mapping is directly related to their complexity.

As a visual metaphor is basically a scene description it can be represented by an acyclic scene graph (see example in Figure 3). In our terminology the layout managers are the first and middle nodes of a graph and the 3D glyphs can only be leaves nodes (i. e., a glyph never has children). The fact that the metaphor is described by an acyclic graph constituted by layout managers and entities is useful. In fact, since the service is also described by an acyclic graph, the mapping of the service onto the metaphor becomes easier.

Since a visual metaphor is composed by layout managers and 3D glyphs, in order to characterize a metaphor we need

Figure 4. Example of the city metaphor for NFS data visualization (CyberNet project).

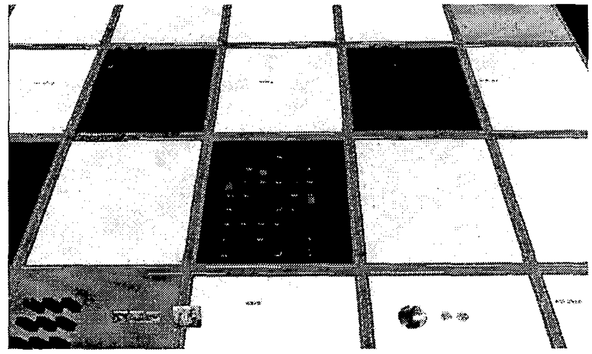

Figure 5. Example of the city metaphor for NFS data visualization (CyberNet project).

to classify also those components. But the components classification is not enough; there are some constraints either in the capacity of displaying the information or relating to the efficacy of that presentation that do not arise from the metaphors components, but from the metaphor structure.

In the next subsection we are going to present the constraints to which a graphical metaphor must obey in order to consistently display visual information. The layout managers and 3D glyphs characterization is presented afterwards in a separate section, dedicated to the graphical components.

6.1. Metaphor Constraints

There are some constraints imposed in the virtual world that derive from the metaphor itself and not from its components abilities for displaying information. Nonetheless, these constraints have an impact on the visual presentation and thus condition the ability of the metaphor to visually display the information.

The added value from using real world based metaphors for visualizing information comes from the fact that the user can relate to the way the information is being presented, since it uses the same underlying rules that are present in the real world. For instance, in the city metaphor (where information is mapped onto districts, blocks, streets, buildings and so on) there is a natural hierarchy between the different elements (e.g., buildings belong to blocks, blocks are part of districts and districts belong to a city; see Figure 3).

On the other hand, a service is also defined, via the service graph, in a hierarchical manner, with several levels of hierarchy. In the first step of mapping, mapping a service on a metaphor, the number of hierarchical levels present in the service must be, at least, equal (or fewer) than the number of hierarchical levels of the metaphor. Otherwise, the mapping cannot take place, as there would be some different service levels that would have to be mapped onto the same hierarchical level of the metaphor, thus losing the service hierarchy identification.

There is also another type of constraints that may restrict the metaphor ability, taken as a whole, for visually presenting information. We already have referred that the added value from the use of real world based metaphor is the user's inherent capacity of relating to the way the information is presented. This is due to the fact that the user can make use of its prior knowledge of how the elements of the metaphor are spatially arranged in the real world and thus use that knowledge to understand the relation between the different elements.

The quality of preserving the same spatial relations and underlying notions between the real world and its virtual counterpart is called consistency. Thus, a virtual world must be created and remain consistent, even if the data that is being displayed is constantly changing. This obviously poses restrictions on the information mapping. For instance, in a city, buildings are usually tall and thin. Even when they are wider than taller, this ratio is never a big one. If in a mapping choices are made so that a data value with a wide range is mapped onto the width of a building, for instance, and a lower range data value is mapped to its height, we risk losing the resemblance of the visual element with an actual building (since it will look more like a wide platform), thus risking the metaphor usefulness.

7. Graphical Components

We present the graphical components characterization regarding information mapping in the next two subsections. This classification constitutes the last step needed for a fully description of the mapping process.

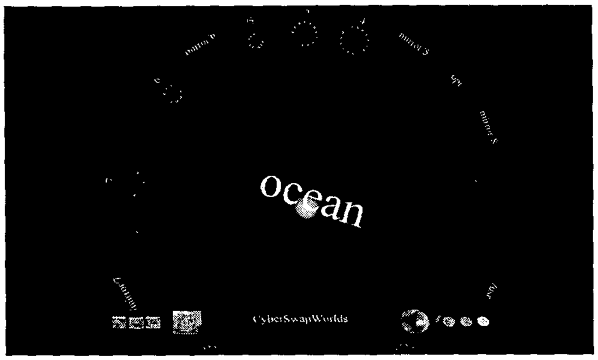

Figure 6. Example of the solar system metaphor for NFS data visualization (CyberNet project).

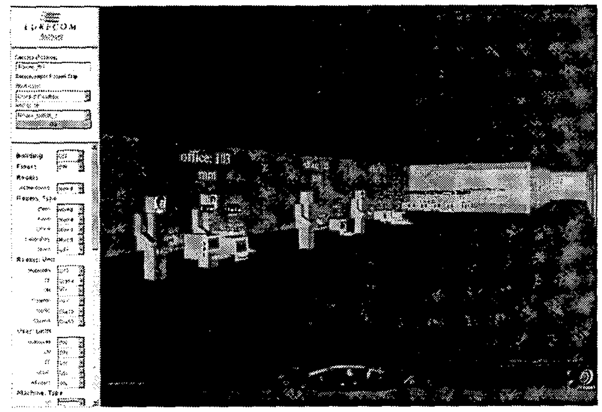

Figure 7. Example of the building metaphor for geographical information (CyberNet project).

7.1. Visual Parameters Characterization

The objective of a visual parameters characterization is to classify 3D visual parameters (e.g., size, color, transparency) according to their ability for displaying data values. Some previous work has already been done for 2D visual parameters characterization, as in [2]. This work, which was based in usability studies, can be used in our system since 2D visual parameters are a subset of the 3D set, and we feel that the perception of the user regarding information mapped in a 3D world will not substantially change.

In the case of visual parameters that exist only in three-dimensional virtual worlds, we believe that for most of them their ability to display information can, with a certain degree of confidence, be inferred by the ability of the 2D parameters that are related to them. For instance, color is not usually very useful for displaying quantitative data [2]; we feel that we can safely infer from this that transparency, as a related parameter to color, is should also be used for mapping quantitative data in 3D. Nonetheless, we think that usability studies with users are desirable to validate our classification. We are still working towards achieving a fully detailed 3D visual parameters characterization.

7.2. Layout Managers Classification

Three-dimensional layout managers are the components that arrange graphical components, either 3D glyphs or other layout managers, in the 3D space; in other words, they intervene by placing their children in the virtual world according to the metaphor rules. For instance, a solar system metaphor uses an orbital layout manager for placing elements in an orbit around a specified center, in the way the satellites orbit around the planets.

The classification of layout managers we have devised is essentially based on their skills for placing elements in space. We have also found that there is a need for layout managers that have different skills that those of only spatially placing children. In particular, we have felt the need for the existence of layout managers that are able to scale visual elements, thus doing more than just placing elements since they interfere in their dimensions, in order that the metaphor's consistency is not lost due to the dynamic character of the information being presented. Examples of layout managers skills are: fit[one dimension], fit[two dimensions], stack, orbit, row, grid, among others. For example, in the city metaphor the chess layout manager is used to place the buildings in space and the stack layout manager is used to place the floors in the buildings (see Figure 3).

8. Mapping Examples

We have already developed several examples of different metaphor mappings and different visual parameters mappings within the same metaphor. The choice of the metaphor is intimately related to the task the user wants to accomplish.

For network topology analysis, the network topology is visualized with the help of a cone-tree metaphor (see Figure 2) where the use can easily grasp the entire network topology and see what elements are connected to where.

In this visualization, switches are displayed as the red boxes, hubs as cones, with a blue box on top and the workstations that are connected to that hub presented as spheres at the base of the cone. Links between the switches and hubs are represented by cylinders, whose diameter and shade cor-

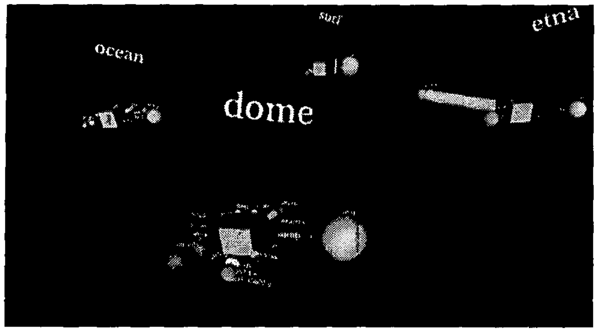

Figure 8. Example of the solar system metaphor for workstation monitoring (CyberNet project).

respond, respectively, to the bit-rate loss of the link and to the packets loss for that link. The shade of the cone corresponds to packet loss for the respective hub.

The city metaphor (see Figure 1, Figure 4, and Figure 5) is used to visualize the NFS service. Although all the visualizations presented use the same visual metaphor, a virtual city, each one uses different data encoding for the visual parameters.

Since this visualizations encode a large number of data, we are not going to detail here all the individual data mappings. However, we should refer that the mappings were done in a way that Figure 1 is mostly used to get a general overview of the system, Figure 4 is more useful to view the size of the machines disks and which disks are partitions and Figure 5 is more valuable for an overview of the status of the physical disks and to know how many users are mounting a disk and how many file-handles they have opened. Figure 6 shows yet another visualization for the NFS data but with a different metaphor: a solar system metaphor. The user is able to switch between the different visualizations by using the icons that are visible at the bottom of the figures.

Figure 7 shows an example view of the geographical tool that is used to visualize information about the Eurecom Institute building. This tool allows the user to get information on real world offices' location, staff, physical place of network static elements and so on. In this mapping, the color of the elements encodes the Dept. to which the elements belong. Other mappings are straightforward as they follow the real world locations of the objects.

This visualization uses a real world based metaphor, a virtual building, since it is very easy for the user to relate to the actual building. Nonetheless, the virtual building does not reproduce faithfully the reality. The user can interact with the virtual building for different purposes: make the walls transparent to have a global view from the outside, choose to display only the offices belonging to a certain Dept. and even redesigning the whole building by choosing to view one Dept. per floor, among other possibilities.

Figure 8 represents another visualization using yet another visual metaphor based on a solar system. This tool is used for workstation supervision. This tool allows visualizing a workstation with all the users that are currently logged on it. Workstations are represented as planets (the cubes in the center) while the users are represented as satellites (the spheres orbiting around the center). Further mappings are the sphere's color that encodes the Unix group of the user, the size encodes the memory and the color saturation encodes the CPU time. Between the workstation and the users, the corresponding user processes are displayed as cylinders. The cylinder's visual parameters use the same encoding (i.e., size for memory and color for CPU).

9. Conclusions

We have presented a strategy for automatic information mapping onto 3D virtual worlds. For the 3D visualizations we use the concept of visual metaphors, either real world based or abstract. We have described the mapping process, with the corresponding mapping criteria. The description of the services that are to be visualized was also presented.

For the mapping process to be successful we found that the characterization of the data, the metaphors and the graphical components was necessary. All these characterizations were described with some detail. Finally, we referred some implementation details and we have presented numerous examples of different mappings.

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