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DESIGNING USER MODELS IN A VIRTUAL CAVE ENVIRONMENT

by

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In this paper, the results of a first study into the use of virtual reality for human factor studies and design of simple and complex models of control systems, components, and processes are described. The objective was to design a model in a virtual environment that would reflect more characteristics of the user's mental model of a system and fewer of the designer's. The technology of a CAVETM virtual environment and the methodology of Neuro Linguistic Programming were employed in this study.

INTRODUCTION

About twenty-five years ago, researchers began immersing human operators in visually coupled teleoperated environments (Kalawsky, 1993) which have evolved into what are now called "virtual environments" or "virtual reality" (VR). These environments are generated with technology that ranges in power and expense from personal computers to graphic supercomputers (the CAVE(TM) (Cruz-Neira et al 1992)). These environments impart an effect of artificial sensory experience usually generated by computer systems that approximate several attributes of the real world.

Virtual reality is a human-computer interface technology whose hallmark is the immersion of the user in the interface. This is an interface in which the individual has presence because the three dimensional (3d) interface space can be mapped directly to the person's 3d physical space. The user can interact with their computer data similar to the way the can with objects in the physical world, since the data is part of the interface.

The user's presence in this virtual world, where the person's data model resides, is established by having the computer track the individual's location and orientation in the scene. This tracking data is used to render the scene at all times from the user's point of view. The individual's interaction with this model is made possible by tracking and reading input from an input device usually held in the individual's hand. The results are; (1) as the user walks around, the user always sees the scene as part of the real world, and (2) with the input device, the user can manipulate objects in the scene.

EXPERIMENTAL BREEDER REACTOR-II MODEL

An AutoCADTM model of Argonne National Laboratory-West's (ANL-W) Experimental Breeder Reactor-II, and it's fuel-handling sequence, were selected for modeling in a virtual environment. The objective was to determine whether a virtual environment would be feasible in the areas of human factors, system models, system design, training, and operations.

The initial EBR-II model was designed by Linda Hansen and Charles Weigand of ANL-W and converted to the CAVE environment by Randy Hudson of Argonne National Laboratory-East (ANL-E). The VR model consisted of the 15 reactor components significant in the fuel handling process including the primary tank, the reactor vessel, and the fuel subassembly. Each reactor segment was modeled in great enough detail for spatial realism, but in little enough detail for temporal realism (real-time interaction).

Operation of the reactor fuel handling system is based primarily on tactile feedback during fuel handling operations, and conceptual visualization based on photographs, blueprints, training and operational manuals and verbal communications. Lack of direct visual examination over the past 30 years is due to the configuration of the reactor. The intention, therefore, was to create a VR model from blueprints, and the operators' mental models of the system. The outcome is a realistic view of the reactor, and visualization of the fuel handling process.

Construction of the model began at the University of Illinois-Chicago (UIC), and was completed and evaluated at ANL-E in Chicago, at the Math and Computer Science Division.

CAVE

The CAVE, developed at the Electronic Visualization Laboratory (EVL) at UIC, is a 10ft x 10ft x 9ft room whose walls and floor display computer-generated (or video) images. "The field of view of the CAVE display achieves a full 360° for the entire display... The CAVE shows all views from a fixed location simultaneously," (Cruz-Neira et al 1992).

The walls are translucent vinyl whose images are projected from behind, and the floor's image is reflected from above. The images are integrated across walls and floor and give the user the illusion of being immersed in a seamless world. The computer-generated scene is projected from the point of view of the user, who wears a magnetically-tracked pair of stereo glasses. The user interacts with the virtual scene via a magnetically-tracked 3d mouse called a "wand." This device can be used to manipulate objects in the environment and navigate through the virtual scene. The computer that drives the CAVE is the Silicon Graphics, Inc. (SGI) ONYX™ graphics supercomputer. A separate ONYX graphics engine supplies the image for each CAVE display surface.

Magnetic tracking is currently provided by Ascension Technologies Flock of Birds™ system. Figure 1 depicts the CAVE.

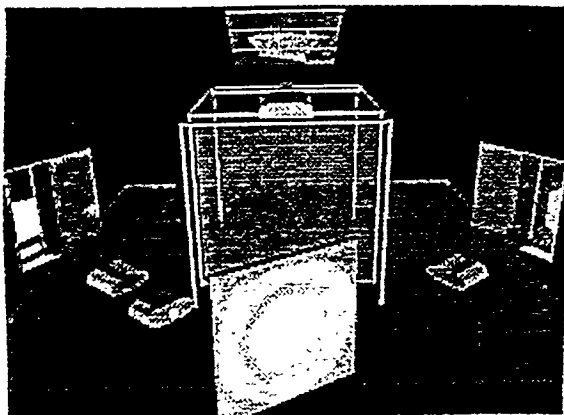


Figure 1: The CAVE

VEBR

The Virtual Experimental Breeder Reactor consisted of the virtual model of EBR-II, and the CAVE application (VEBR) for exploration and manipulation. VEBR, written in C, enables the user to manipulate the model's components, navigate through the virtual scene, and simulate the fuel-handling sequence. A schematic representation of VEBR is shown in Figure 2.

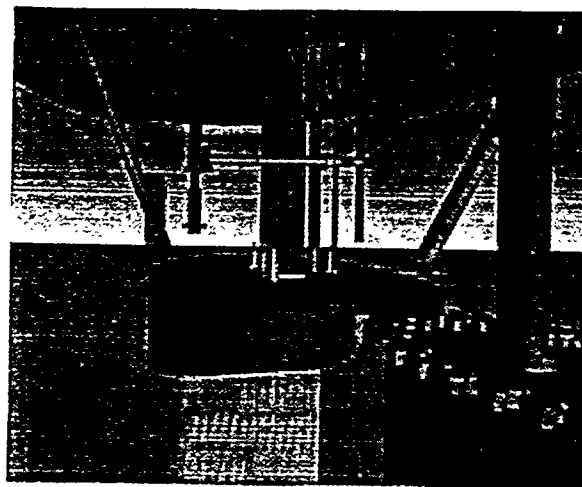


Figure 2: Schematic of VEBR

CAVELib is the software portion of the CAVE that normally controls the VR hardware. In addition to the two layers of software found in most CAVE applications— the application layer and CAVELib, which is called by the application layer —VEBR uses PerfCAVE, a third layer that acts as a meta-CAVE (see Figure 3). PerfCAVE runs the VR hardware via a combination of calls to CAVELib and Performer™. (The application layer can also access both of these libraries if necessary.) Performer is a virtual-scene- and simulation-design tool from SGI. It was designed to optimize the use of the graphics hardware and the higher-level manipulation of the scene database; thus, hiding the details from the virtual world designer. PerfCAVE was written by Milana Huang at EVL with the help of the first co-author author, Randy Hudson.

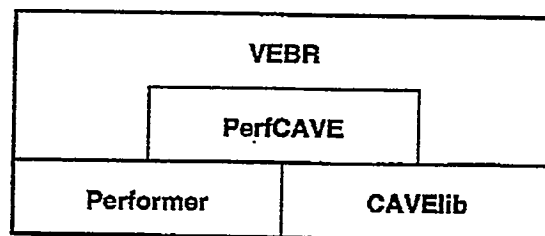


Figure 3: PerfCAVE

TEXTURE AND LIGHTING OF THE MODEL

Texture and surface lighting effects were incorporated into the model to give a stronger illusion of 3d, metallic gray

pipng, and shadows. A low "humming" sound was implemented to enhance the effect of immersion within the liquid sodium chamber. The "realistic" model could be augmented by rendering certain walls transparent. This portion of the project was conducted by the second co-author of the paper, Nihar Gokhale.

CONCLUSION

The model started as paper blueprints that were converted to an AutoCAD model in the DXF format. Once these DXF files had been transferred from ANL-W to EVL, the components of the reactor were broken down into hierarchical layers for ease of processing by the multiple graphics engines. These were then massaged and converted into SGI's proprietary Inventor(TM) format so that the model could be displayed in the CAVE. Once this was completed, the human-interactive study to the model was conducted.

HUMAN FACTOR STUDY

"The decisions made to model systems into image displays have a disadvantage because of the cognitive phenomena that decisions are unobservable internally to the mind, so there is no completely empirical way to describe and measure decision processes. However, we can use several other types of methods, one of them being mental representations of how people make decisions based not on the actual data available to them, but on how they represent or perceive the data presented to them," (Helander 1991).

A methodology known as Neuro Linguistic Programming (NLP). allows for the designer to define how each subject represents or perceives the data presented to them. The results can then be incorporated into a model such as the VR model of EBR-II.

NEURO LINGUISTIC PROGRAMMING

Background

The basic premise of NLP is that the individual behavioral indicators are indicative of their neurological indicators. By observing the two, the designer can establish the user's "favored representational system (FRS)" and cultivate a rapport with which to attain explicit information about an experience, system or situation from a willing operator or user.

Favored Representational System

"The concept of a 'favorite representational system (FRS)' asserts that many individuals tend to value and use one representational system: visual, auditory or kinesthetic, over the others to perform their tests and operations. This kind of preference is often generalized to many different types

of tasks, even to those for which the preferred representational system is inappropriate or inadequate" (Bandler et al 1980).

In other words, most of us are multisensory, we use all three representational systems to gather information. However, we tend to favor (or be oriented towards) one of the representational systems over the other two. (There are those who habituate in one modality.) This preference establishes our non-verbal and verbal communication (strategy) cues which may or may not match the FRS of person we are speaking with. The outcome is either a match in rapport or mismatch in communication which results in incorrect or deficient data. By knowing a person's representational strategy (visual-auditory-visual or kinesthetic-visual-kinesthetic), we can understand how a person constructs his or her model of a system.

Once general patterns can be detected, then more explicit distinctions can be generated which reveal strategies that are outside the normal, conscious awareness of the subject. These strategies can then be utilized in assessing a variety of necessary categories of information with respect to the user's total experience of the system. The means by which all this information is gathered from a user is through the utilization of several NLP techniques: *meta-model, synesthesia and the seven categories of an experience.*

Meta-Model

This model "is a linguistic tool for using portions of a person's spoken or written behavior to determine where he has generalized, deleted, or distorted experiences in his model of the world." (Lewis & Pucelik 1982)

The meta-model is "a model of a model." It is a technique which makes explicit those semantic and syntactic contexts in which meta model violations occur through the categories of gathering data, expanding limits of the communication and changing meanings. Within each of these categories is a set of eight linguistic variations: *referential index, nominalizations, unspecified verbs, modal operators, universal quantifiers, mind reading, cause and effect and lost performative.* And, it is these variations that limit the user's ability to provide critical responses during the description feedback process.

Therefore the meta model works to replace or repair deficient communications with that which is more explicit. The results are then used in constructing a system model.

Synesthesia

Synesthesia "is the crossover connections between representational system complexes, such that the activity in one representational system initiates activity in another system".

These synesthesia patterns constitute a large portion of how the human processes the information while communicating with others. The correlations between representational system activities are at the root of such complex processes as **knowledge, choice and communication**. By replacing missing information (given by the user) in its most concise possible form, specific details (that are required for diminished "error-free" systems) are gathered and incorporated into the system's model.

Seven Categories of An Experience

The seven categories of an experience is a framework which from the designer can elicit detailed description of ongoing experiences in order that sufficient, high quality, reproducible data, *insofar as that is possible when dealing with human subjects*, is obtained for the calibration process.

It is believed that this model was inspired by Miller's theory of plus or minus seven bits of information possible to be processed by humans. This technique is designed to evoke responses to supply specific answers describing: (1) what the person is doing; (2) how that information is stored by sensory based; (3) what impact the experience has internally; (4) the precise situation in which the person is involved, which includes, but is not limited to: location, time, persons other than subject with whom engaged, etc.; (5) how important the experience is in personal terms for the subject - a rank ordering; (6) what, exactly, *makes* the experience occur, and (7) what it all *means*, to the subject.

Derived from these NLP efforts is the expectation of developing specific (accurate) VR models based on the user's mental model.

STUDY

The human factor study involved two phases. Phase one required six operators from ANL-W to describe their experiences and understanding of Argonne's EBR-II primary tank, reactor vessel and fuel handling system as it "*looked, felt and sounded like to them*." Phase two required two of the six operators to be flown to ANL-East to evaluate the EBR-II VR model.

Subjects

The subjects were grouped into three categories, (a) operators who were employed before the reactor was filled with sodium, (b) operators who were employed immediately after the reactor was filled with sodium, and (c) operators who have been employed at Argonne between three and fifteen years. The reasoning behind the categories was to examine and compare the different experiential bases of each operator based on their specific training and experience with the reactor.

The subjects' experiences with the EBR-II reactor ranged from four to 33 years. Based on their FRS, the operators described the system in very "detail" or "general" visual terms of the components and process, or by kinesthetic terms of component functionality and process flow. The

following is a brief illustration of each subject's (reactor operators') description of EBR-II.

Each of the subjects described the reactor system in terms of color, shapes, sizes, component locations, and spatial relations. Some of the subjects described the system from the perspective of process flow, others added sounds, and how the system *felt* to them. For example, colors ran from dull grays to bluish-grays to reds and yellows, and texture of the components ranged from rough to a glossy, smooth, shiny finish to tactile feeling similar to that of paper.

While one subject was describing the inner building casket in visual terms (shapes, colors, etc.), he continuously accessed his feelings. When asked what he felt about the picture he was describing, the response was, "the feeling of a seven ton metal object coming at him." Therefore, if possible, the model should impress upon the viewer that the system is not only large, but extremely heavy. In the virtual environment, this image is achievable.

Another subject described his experience based on a "we" reference. Further investigation showed the "we" was a complex equivalent to "me." This subject had several "mes" that performed specific tasks. So in acquiring precise information about certain tasks, I needed to address the proper "me."

The subject with less than five years of experience, was not as thorough in visual or kinesthetic descriptions as though with 15 plus years of experience.

The final phase of the project involved the evaluation of the VR reactor model. Two subjects were selected to evaluate the EBR-II virtual reality (VR) model at ANL-E.

Background of the Two Subjects

Subject One. This subject was one of the original reactor operators who had worked inside the primary tank and reactor vessel before the sodium fill in the early 1960's. The FRS of this individual was established to be "*detail*" visual. This is where the subject communicates experiences in very explicit visual details. The system described by the individual was portrayed in different shades of color, shapes, sizes, component locations, spatial relationships, and the *feel* of the environment with respect to how the environment was *seen*. Colors ran from stainless steel of dull grays to blue-grays.

Texture of components was described based on recall of how he physical saw and felt the touch of the hardware such as; the pipes were shiny or glossy looking and smooth to rough in touch. An example of size was illustrated by the extension of the subject's arms around the storage basket as he saw himself extend his arms around the basket.

The fuel handling equipment and process was recounted in just as great visual detail. Tactile remembrance was occasionally referenced for description of the system, but never sound.

Subject Two. This subject has operated the reactor over the last sixteen years. The subject was employed after the primary tank was filled with sodium. The FRS of this individual was established to be more "*general*" visual. This

is where the individual communicates experiences thoroughly, but not in explicit or precise detail. The overall system was described by the subject in more general visual terms from such materials as photographs, blueprints, and training and system manuals which had been studied over the years. For example, colors of the reactor were defined as different shades of grays of stainless steel, and other colors equated or related to temperature. The individual related the subassemblies to be blue-grays in color, except for the upper portions of some subassemblies which were red, blue, and yellow. This latter corresponded to heat generated by the fuel pins. Distance between components related to what had been seen in the design prints, i.e., the basket was as wide as *probably* his two arms extended.

The subject thought he mentally heard an audible sound generated from the induced vibration of the transfer arm and subassembly connecting. The first participant stated that the only sound that may exist in the primary tank was the pumping of the sodium coolant.

This subject also described the reactor and the fuel handling system by functionality and process flow. This subject used multisensory cues: visual, auditory and kinesthetic, to relate how he imaged the reactor worked and looked like.

Evaluation of the VR Model by the Two Subjects

The first participant described the CAVE VR model as very recognizable. The shades of gray were close to what was remembered, however, certain components needed to be a little more shiny or glossy to reflect a more stainless steel effect. There also needed to be more explicit detail to the storage basket and the neutron shield. The dynamic segments of the VR model (fuel handling process) required minor changes with respect to elevation of the gripper to the hold down mechanism, and the retrieval of the subassembly from the core.

The second participant described the CAVE VR model as *"just what he had imagined the internals of EBR-II would look like if he could see it."* However, he felt that more color should be added to the fuel pin area of the subassembly. The dynamics of the model made the image in his mind more realistic and uniform. He felt that overall the model was what he had described, and that sound and touch would be significant enhancements to the model. (Both attributes are being researched at this time.)

The experience of an immersion effect with the reactor model was captivating for both subjects. They expressed, unequivocally, that the model would be an excellent tool for training and operations in developing accurate user mental models. They remarked how much more comprehensive this type of model would be in explaining to new operators and engineers how the system operated.

They considered this type of tool excellent for troubleshooting areas which restrict entrance to humans and/or can not be seen by direct visual examination.

Both participants felt that the learning curve would be greatly enhanced through this type of visual feature.

Conclusion

The work for this study is complete, with the exception of the data analysis. What has been found is that a user can be asked to describe his/her model of a system in which all deletions, distortions and generalizations are replaced or explained using NLP. Designing successful models requires that the designer be taught not only the technical tools, but an effective means of communicating with the user. Through this latter tool, the designer would be able to accurately "characterize" or "map the territory" of the user's model of the system.

By understanding the user's mental model, the designer can then identify and minimize any system or operator error at the on-set of the initial design. Combined with that of the designer's blue print model, the outcome is a more "realistic" model which is closer in actuality to that of users'.

The feasibility and usability of a virtual reality environment for implementing the users' models is a positive step in the direction of system modeling. All modalities: *visual, auditory and kinesthetic*, are taken into account; thereby encompassing all the representational systems that people use to model the world around them.

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