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THREE DIMENSIONAL VISUALIZATION.
BREAKTHROUGH IN ANALYSIS AND COMMUNICATION
OF TECHNICAL INFORMATION FOR NUCLEAR WASTE
MANAGEMENT.

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THREE-DIMENSIONAL VISUALIZATION: BREAKTHROUGH IN ANALYSIS AND COMMUNICATION OF TECHNICAL INFORMATION FOR NUCLEAR WASTE MANAGEMENT

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ABSTRACT

Computer graphics systems that provide interactive display and manipulation of three-dimensional data are powerful tools for the analysis and communication of technical information required for characterization and design of a geologic repository for nuclear waste. Greater understanding of site performance and repository design information is possible when performance-assessment modeling results can be visually analyzed in relation to site geologic and hydrologic information and engineering data for surface and subsurface facilities. In turn, this enhanced visualization capability provides better communication between technical staff and program management with respect to analysis of available information and prioritization of program planning.

A commercially-available computer system was used to demonstrate some of the current technology for three-dimensional visualization within the architecture of information systems for nuclear waste management. This computer system was used to interactively visualize and analyze the information for two examples: 1) site-characterization and engineering data for a potential geologic repository at Yucca Mountain, Nevada; and 2) three-dimensional simulations of a hypothetical release and transport of contaminants from a source of radionuclides to the vadose zone. Users may assess the three-dimensional distribution of data and modeling results by interactive zooming, rotating, slicing, and peeling operations. For those parts of the database where information is sparse or not available, the software incorporates models for the interpolation and extrapolation of data over the three-dimensional space of interest.

INTRODUCTION

Three-dimensional visualization technology represents a significant breakthrough in the analysis, integration, and communication of technical information. While a multitude of computer technologies have been developed to model, assess, and simulate highly complex phenomena, these results contribute to the success of a technical program only to the degree to which they can be communicated. The application often depends upon a fixed system

definition that explores optional configurations, system constraints, functions and sequences which are then permuted and assessed with respect to performance, cost, schedules, and efficiency. Technical staff categorize and simplify the results to enhance their own understanding and to present their findings to management for review and prioritization. Increasingly, this communication relies on graphics and visualization {e.g., see Watson et al. [1]}.

Our paper describes the application of visualization technology within the architecture of information systems for nuclear waste management. The nuclear waste disposal system includes the sources of nuclear waste such as utilities or hospitals; waste-packaging considerations; transportation links to temporary storage; and finally transportation to and permanent storage in a geologic repository or burial site. These complex components are interdependent and require a vast amount of information. The topographic, geologic, hydrologic, and geochemical data for a candidate disposal site must be integrated with engineering data for packaging, transit, and storage of the waste. And, as in all real world problems, the most natural framework for this representation is a three-dimensional structure; however, the structure must be manipulable through time. It must 1) provide access to the data and simulation results, 2) document the integrity and quality of the data, and 3) allow for continual refinement of data and simulations.

OBJECTIVE

The Office of Civilian Radioactive Waste Management (OCRWM) in the U.S. Department of Energy (USDOE) and its contractors are planning and conducting site-characterization, engineering, and performance-assessment studies of the Yucca Mountain site in Nevada, as a potential geologic repository for high-level nuclear waste [2,3]. Site-characterization efforts are scheduled for the next several years to examine its suitability.

Two-dimensional graphics have previously been employed to integrate results from computer simulations of processes, such as hydrologic flow and contaminant transport, and design parameters for the proposed repository and surface-support facilities. However, this representation requires the generation of a suite of two-dimensional images built on a subjective set of parameters and results to adequately represent the input data and modeling output. Therefore, a method was sought that could couple directly to the output of simulation models, as well as manipulate and examine images in real time. Technical concerns considered during this assessment included:

- the capacity of current technology to meet visualization needs,
- the ease of importing site information and computer-modeling results into the software package for visualization,
- the extent of real-time graphic manipulations available to analyze the information,
- the simultaneous inspection of three-dimensional scenes and data documentation, and
- the management of information for those portions of the three-dimensional database having incomplete data.

An assessment of computer work stations consisting of commercially-available, graphics hardware and software was conducted using two examples of technical information typical for the OCRWM's Geologic Repository Program.

COMPUTER SOFTWARE AND HARDWARE

The Interactive Volume Modeling® (IVM®)^(a) software [4,5,6] by Dynamic Graphics, Inc. provides capabilities for input, volume modeling, analysis, and display of properties that vary continuously in three-dimensional space. A complementary package, Interactive Surface Modeling® (ISM®), also by Dynamic Graphics, Inc., provides capabilities for data capture (including digitizing), surface modeling and analysis, and map generation. The demonstration work was conducted on Silicon Graphics, Inc.® (SGI®),^(b) Personal IRIS® 4D/25TG with a 20-MHz processor and 760-Mb disk, and an IRIS® 4D/210GTXB with a 25-MHz processor and 780-Mb disk. Both computer work stations used the SGI®-modified version of the UNIX®^(c) operating system. Each system included 32-Mb of main memory, a standard data cartridge tape unit, a floating point co-processor, and a separate geometry processor for improved graphics performance.

Images are processed for interactive, three-dimensional viewing within a few minutes and can be stored for viewing at a later time using 5 to 40 Mb of disk. Users assess the three-dimensional distribution of both data and modeling results by interactively zooming, rotating, slicing, and peeling the visualizations. They can also print a static image or "snapshot" of the screen on a color printer or capture the image with video recording equipment. The figures in this paper and the poster session were created by dumping screen images to a color thermal wax printer with a resolution of 300 dots per inch. Photographs of the thermal wax pictures were then made for display and reproduction.

Site-characterization data are often sparse. Some regions may be inaccessible, while in others good test results produce few data points. The software used for this demonstration includes models for interpolation and extrapolation of information over the three-dimensional space of analysis, while preserving the location and density of the original data for later evaluation. The IVM® modeling procedure calculates a three-dimensional

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representation of property values using a variation of a minimum tension surface algorithm [7]. The grid can be calculated 1) throughout the volume defined by the input data, 2) in a volume restricted by previously defined surfaces in dimensions x and y, or 3) in a volume bounded in dimensions x, y, and z by previously calculated faulted or unfaulted two-dimensional structural surfaces.

Data values can be retrieved from the database for any user-selected x,y,z coordinate from the three-dimensional model, and displayed at the associated point on the screen. The user may assign documentation information to any x,y,z point of data, and view and modify this information as part of the data retrieval process.

EXAMPLE 1: SITE-CHARACTERIZATION AND DESIGN INFORMATION FOR A GEOLOGIC REPOSITORY FOR NUCLEAR WASTE

Image Construction

The topographic, geologic, geochemical, and hydrologic characteristics of a site being characterized are major factors that impose constraints on the location and configuration of a potential repository and the design and distribution of the emplacement of nuclear-waste packages. A three-dimensional computer image model of the candidate repository site at Yucca Mountain, including its geologic structure and the hypothetical mined repository, was constructed and examined interactively using three-dimensional visualization techniques described above. Two views of the model, captured from the computer screen during interactive sessions, are shown in Figures 1 and 2.

For this demonstration, the data file representing the surface of the mountain was created by digitizing contours from topographic maps given in the Site Characterization Plan (SCP) for the Yucca Mountain site [3], and then constructing the surface with the ISM* software. The surfaces of the major stratigraphic units of the mountain were constructed using digitized geologic cross sections of the mountain and major borehole locations from data given in the SCP [3] and the SCP Overview [2]. A line model of the repository was produced using data from the SCP [3], the SCP Overview [2], and the Yucca Mountain Project Site Atlas [8]. The repository model shows design features, such as major shafts, drifts, and ramps, and the Ghost Dance Fault, an important feature of the geologic system. These components were integrated into a single three-dimensional image of the mountain (Figure 1).

Although data were not available for some regions or were collected at differing spatial densities in the vicinity of the Yucca Mountain site, the IVM* software interpolated and extrapolated site-characterization information over the complete three-dimensional space.

Figure 1. 3-D model of Yucca Mountain.

Figure 2. 3-D model of Yucca Mountain with cutaway revealing design of repository with shafts and ramps.

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Visualization

The model of Yucca Mountain site integrates the proposed mined repository system and geologic structures in three dimensions. This powerful representation can be interactively examined and manipulated in real time by rotating, zooming, or peeling away layers to reveal inner structures, and slicing to reveal cross-section detail. Geologic units may be stripped away to reveal intersections with proposed shafts, ramps and drifts to evaluate adequacy of design; or the geologic features themselves may be examined in detail (Figure 2). The depth of understanding from these analyses from both the macroscopic, total system perspectives, or the microscopic perspective of a single component is vastly superior to that obtained from inspection of a static, limited, selection of maps, charts, diagrams and pictures.

Visualization also provides an excellent means to assess the adequacy and completeness of the database. The better, and more complete the data, the better the images and understanding of the repository system. The development of an optimal, or at least, practically optimal database requires a systematic, thoughtful definition and prioritization of studies to obtain the required data values. A lack of adequate data, which can have significant impact on a technical program, is readily detected using visualization technology.

EXAMPLE 2: TRANSPORT MODEL SIMULATIONS OF THE EVOLUTION OF A RADIONUCLIDE-RELEASE PLUME

Contaminant-Plume Simulations

The PORFLO-3^(d) flow and transport code (Version 1.0) [9,10] was used to simulate the evolution of a hypothetical contaminant plume of dissolved radionuclides released from a source term into a geologic media in three dimensions as a function of time. The PORFLO-3^{*} code solves problems of single-phase fluid flow, heat transfer, and mass transport in partially- or fully-saturated geologic media using an integrated finite difference technique. Solutions are obtained for either transient or steady-state conditions. The geologic medium may be heterogeneous and anisotropic, and may contain linear and planar features such as boreholes and fractures. Magnuson et al. [11] recently completed verification and benchmark testing of the code. Their results indicate that PORFLO-3^{*} simulates uncoupled processes with reasonable accuracy, acceptable speed, and excellent stability. The code appears operational for simulating isothermal fluid flow and contaminant transport for both saturated and partially unsaturated conditions and for simulating conductive heat transport in a soil system [11].

Contaminant transport simulations used for this visualization example, are adapted from a transport modeling study by Smoot and Sagar [12], related to waste-disposal activities at the USDOE's Hanford Site in south-central

(d) PORFLO-3 Version 1.0 is copyrighted by Analytic and Computational Research, Incorporated, subject to the Limited Government License.

Washington State. The simulations were based on a discharge of radionuclides into unsaturated, coarse-grained sediments that underlie the source of the wastes. The transient concentrations of dissolved radionuclides and locations of the contaminant plumes were calculated in three dimensions using soil and hydrologic properties characteristic for that site. The source term in the adapted simulation was distributed to represent leakage from several sources.

Image Construction

Results from the simulations of contaminant transport using the PORFLO-3* code were imported to the work station in ASCII format on a standard magnetic tape data cartridge. The numerical information was taken from sixteen time frames of the modeling results which were selected to characterize evolution of the contaminant plume. The data had the general format of $x, y, z, p_1, p_2, \dots, p_n$, where x, y and z are the spatial coordinates and p_n represents a property value. These results were introduced to the IVM* modeling procedure to process into visualization scenes. Re-gridding the data and assigning property value ranges for the depiction of volumetric concentration shells were readily accomplished with the menus provided by the IVM* software. Parameters and option selections interactively entered by the user were stored by the software for processing subsequent sets of data.

Visualization

The results of the contaminant-transport simulations were a set of three-dimensional scenes interactively examined by the user in real time. The contaminant plumes were interactively examined by rotating and zooming the scene, as well as slicing and removing concentration levels to reveal inner structural details. Evolution of the plume was examined by studying the sequence of scenes generated from successive time slices. A representative image showing quarter slicing is shown in Figure 3. The colored regions represent levels of concentration as described in the figure legend.

Figure 4 shows the plume at a different time with dots representing locations of model grid points which can be queried for concentration values and documentation. The ability to display the hydrologic data and radionuclide concentrations associated with each x, y, z coordinate point assisted in detailed inspection of the plume structure. The images of the plumes were well in agreement with two-dimensional slices of the independently plotted output.

The analysis of high concentration regions of the plume took much less time than previously required using two-dimensional techniques through iterative cross-sectional imaging of the plume. Previously, the location of high concentration portions of the plume had to be ascertained to obtain an image of a cross section of the plume. This tended to be a highly interactive process that would be unnecessary if the complete three-dimensional data set could be viewed. The data preparation stage for three-dimensional visualization, however, tends to consume more time than two-dimensional

visualization because a full three-dimensional data set must be rendered graphically rather than just a plane through a three-dimensional data set.

Interactive three-dimensional visualization enabled us to readily locate and follow the high concentration zones. First we eliminated the lower concentration shells from the first plume image in the time sequence. Then we rotated the image for a good viewing angle, and sequenced through sixteen time frames. The effects of contaminant advection, dispersion, dilution, and radioactive decay were observed. The interactive three-dimensional process provided a nonabstract visualization of the simulated plume migration.

CONCLUSIONS

Characterization of a candidate site for the safe management and storage of nuclear waste relies on complex scientific and technical studies and designs. Massive amounts of data must be generated, organized, modeled and integrated in order to understand the processes operating throughout the total system. In the examples in this paper, a complete understanding of these processes can only come from the integration of geometric and property relationships of geologic, hydrologic and geochemical data with surface and subsurface information for the engineered repository system.

A sound, technical understanding and communication is greatly enhanced by using three-dimensional visualization instead of the traditional two-dimensional slicing of three-dimensional data sets. Such visualization of scientific and engineering information may be used to 1) prioritize site characterization studies, including the laboratory measurements needed for geologic materials and waste package components, and performance-assessment modeling studies; 2) evaluate alternative approaches for site-characterization studies and facility designs; and 3) assist in the verification and notation of quality levels of data in geologic information databases.

In summary, the interactive three-dimensional visualization process provided an effective way to organize, analyze, and communicate simulation results. Such information could be used to manage a nuclear-waste technology program. In the OCRWM, decision makers at all levels, presented with more complete and readily understandable information, will be better equipped to find the optimal solution for the disposal of our nation's high level nuclear waste.

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