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COMPUTER AIDED SYSTEMS HUMAN ENGINEERING: A HYPERMEDIA TOOL

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ABSTRACT

The Computer Aided Systems Human Engineering (CASHE) system, Version 1.0, is a multi-media ergonomics database on CD-ROM for the Apple Macintosh II computer, being developed for use by human-system designers, educators and researchers. Co-developed by agencies of the US Government and industry it will initially be available on CD-ROM and will allow users to access ergonomics data and models stored electronically as text, graphics, and audio. The* ***CASHE*** *CD-ROM, Version 1.0 will contain the Boff & Lincoln (1988)* ***Engineering Data Compendium, MIL-STD-1472D*** *and a unique, interactive simulation capability: the* ***Perception & Performance Prototyper.*** *Its features also include a specialized data retrieval, scaling, and analysis capability and the state-of-the-art in information retrieval, browsing, and navigation.*

INTRODUCTION

Background

The design of effective human system interfaces requires consideration of the variables influencing the operator's ability to acquire and process task-critical information. The basic research literature contains a large body of relevant data regarding human perceptual and performance capabilities and limitations. Too frequently, however, designs have failed to capitalize on the skills of the operator or have made unreasonable demands on the user. The causes are twofold: first, the sheer volume of existing data makes it hard for designers to review or keep abreast of all the relevant literature; and, second, the form in which these data appear makes it difficult for designers to access and interpret them (Boff, 1990).

Over the past decade, a multi-agency US Government supported effort, the Integrated Perceptual Information for Designers (IPID) Project has been underway to aid the accessibility and use of ergonomics data in system design (Boff, 1987a,b,c; Rouse & Boff, 1987; Rouse, Cody, & Boff, 1990). It is formulated around information management objectives geared toward: (1) Identifying, collecting and consolidating human performance data of potential value to human-system design; (2) "Human engineering" the representation and presentation of these data to enable their effective use by system designers (Lincoln & Boff, 1988); (3) Sponsoring of training opportunities to sensitize system designers to the value and application of ergonomics data in the design of human-systems; and (4) Defining and evaluating of integrated media options for aiding system designers in the access, interpretation and application of ergonomics data. Taken together, these efforts at understanding and remediating problems in the transition of ergonomic research to applications have coalesced into a new model -- CASHE -- for the communication of scientific information to practitioners, educators, and researchers.

CASHE System Concept

The long-range goal of Computer Aided Systems Human Engineering (CASHE) is to integrate ergonomics into human-system design decision making. Achieving this objective will require innovative methods and media for enhancing the accession, assimilation, and application of ergonomics that is consistent with accepted system design practice. Over the next five years, CASHE will focus on conducting exploratory R&D to provide a technology basis and to lower technology risks that we anticipate in the full-scale development of a CASHE environment. During this R&D phase, the project is documenting and disseminating its research efforts while producing, in parallel, an evolving series of commercial quality software products delivered on CD-ROM and other advanced media.

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CASHE Version 1.0 for the Apple Macintosh computer is the first of these products and is described in detail in this paper. In the development of this product, we have explored a range of issues concerned with:

- Conversion of text to hypertext;
- Alternative representations of complex graphics, tables, and illustrations in small desktop displays;
- Information transformation, analysis, and correlation techniques;
- Aids to help users ask "correct" questions of the system;
- Strategies for multi-document portrayal and integration;
- Incorporation of pedagogical aids for system users;
- Navigation in large-scale hypermedia.

Subsequent versions of the CASHE system will migrate to CAD/CAE work station platforms and incorporate advanced capabilities allowing human-system designers in the future to match equipment and workplace characteristics to human behavioral and anthropometric capabilities and limitations.

CASHE VERSION 1.0 SYSTEM DESCRIPTION

Configuration

CASHE, version 1.0, is under development, scheduled for a late 1992 delivery. The target computer platform is the Macintosh II family of computers equipped with, at least, a 13" monochrome monitor and a CD-ROM drive. A hard disk is recommended for storage of user-defined files. Memory requirements have not yet been determined, although it is expected that at least 2 Mb of RAM will be required, 1 Mb for the application program and 1 Mb for the system and finder. The display interface is being developed to accommodate screen sizes of 13" diagonal and larger. Users will be able to manipulate and move windows on the desktop as in other Macintosh applications. This system (a Mac II with 2 Mb memory, 13" monochrome monitor, and CD-ROM disk drive) will run a minimal CASHE Version 1.0. However, at least two other peripherals will be needed for complete CASHE Version 1.0 operation. A color monitor will be required to view color demonstrations. Some auditory phenomena (e.g., stereo effects) will require use of dual speakers and headphones. Users lacking these optional peripherals will be able to access the entries about color or auditory processes, but will not be able to hear/see the associated phenomena in full detail.

Concept of Operations

Similar to other current Macintosh software, we have adopted a metaphor that our primary users should find familiar and which, therefore, will promote learning and ease-of-use. CASHE Version 1.0 is oriented around a desktop metaphor of the system designer's workplace comprised of four major elements: 1) Bookshelf comprised of the Boff & Lincoln, (1988) ***Engineering Data Compendium***, ***MIL-STD-1472D***, *the* ***Perception & Performance Prototyper*** (P^3) and user ***Project Files***, 2) file management system, 3) file viewer interface, and 4) visualization tools.

At the most basic level, product functions will be integrated through the use of the desktop. Users will access system functions and information through windows, several of which will be specialized to file type (e.g., data viewing and manipulation, outline viewing, entry viewing, interaction with simulations, etc.). Windows can be opened, sized, and positioned on the desktop to permit easy comparison and data transfer among windows. Users will be able to control the number, size, location, and spatial relations (e.g., tiled vs. overlapped) among as many windows as memory limitations will permit, through a window management system similar to other Macintosh applications.

To take advantage of users' knowledge of and operations with the hardcopy media on which the present product is based, we have adopted a book metaphor for the information sources showcased in CASHE Version 1.0. Hence, the *Compendium*, *MIL-STD-1472D*, P^3 and user Project Files each emulate books on a shelf. The first three volumes may be opened and closed, leafed through, annotated, tagged with bookmarks, and include a facility for comparing "pages," etc. The fourth volume may only be opened, closed, and leafed through. The many operations that one normally performs with books are retained or augmented, as feasible.

The file management system will be consistent with that used for all Macintosh applications (documents stored within named folders, and folders embedded within folders). In addition, the product supports many functions that are unique to electronic documents including rapid information retrieval through query and search, linking, merging with other documents and software, etc.

The file viewers are the primary user interface to view, interact, manipulate, and analyze the information contained in the document entries. Each viewer provides specific functionality aimed at providing the user easy access to information in a logical and coherent framework. Control of the interface abides by Macintosh guidelines to the extent possible and desirable for our users' needs (Apple Computer, 1987).

Visualization tools are provided to aid the user's understanding and application of the information available within the reference sources on the Bookshelf. First, users are able to manipulate and transform quantitative and graphical relationships contained in the information base or brought in from external sources through a DataViewer interface. Secondly, we have provided the user with a test bench

simulator that we refer to as the "Perception and Performance Prototyper" (P^3). With the aid of a test bench metaphor, P^3 allows the user to manipulate and interactively test experimental variables discussed in references on the Bookshelf. In addition to direct accessibility of P^3 from the desktop, the P^3 test benches will also be available as a browsable reference on the Bookshelf. Finally, we have augmented many existing illustrations, data functions and tables found in the *Compendium* and *MIL-STD-1472D*. Our objective here was to aid the user to understand the illustration or data while keeping faithful to the intent of the original documents. Hence, all original figures and tables are fully available to the user and are augmented by animations and alternative representations that can be "activated" at the user's option. For example, audio illustrations are provided of aural phenomena that exist only as text descriptions in the original sources.

1. Bookshelf

The Bookshelf in Version 1.0 (See Figure 1), is comprised of four volumes:

A. The *Engineering Data Compendium* (Boff and Lincoln, 1988) was developed through the joint efforts of multiple agencies within the Department of Defense, NASA and NATO AGARD as a standardized ergonomics data resource for system designers. In particular, systematic attention was given during the development of the *Compendium* to: (1) defining approaches to communicate human factors data to designers -- that is, to determine appropriate level of technical content and presentation format, style, and terminology; and (2) enhancing the accessibility of specific technical information relevant to design problems -- that is, providing the user with a reliable and simple means for obtaining the specific data needed. It provides reliable information gleaned from over 70 research areas dealing with performance capabilities and limitations of the human operator. Supplemented by over 2,000 figures, tables and illustrations, 1136 individual entries treat parametric data, models, principles, and quantitative and non-quantitative laws.

B. *MIL-STD-1472D* (Department of Defense, 1989) is a military standard for human engineering design criteria for systems, equipment, and facilities. This standard is a legal reference of human engineering design criteria, principles, and practices. The information contained in this standard is typically referenced by government specifications to ensure human-system integration and enhanced system efficiency, reliability, safety, trainability and maintainability in acquired systems. The standard includes over 80 figures and tables.

C. The *Perception & Performance Prototyper* (P^3) is an interactive simulator that enables users to experience and explore behavioral phenomena

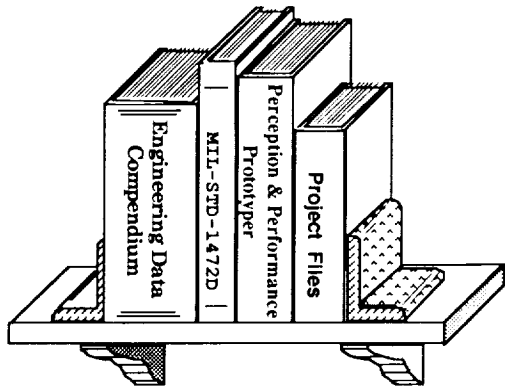

Figure 1. The CASHE Bookshelf

contained in the *Compendium* and *MIL-STD-1472D*. By means of a "test bench" metaphor, users can tailor a simulation to match the conditions of a specific application and immediately experience its effects on their own performance. Collectively, these simulations may be accessed as an independent volume on the Bookshelf through which users may browse or search.

D. The *Project File* is the collection of information which the user may add to customize the system, store files and annotations created during a session, and otherwise augment the information from the other three volumes. Project files may be created, saved, and retrieved in much the same way as documents in word processing applications or data files in database applications. Upon initiating the program, the user will have the option to open a new project file or select from a list of existing project files created in prior interactions.

2. File Management System

The file management system allows the user to access and navigate the CASHE information base found in the four Bookshelf volumes. Access into the information base is accomplished via browsing and search/query results. Users can browse the table of contents, index, design checklists, author references, glossaries, and general access taxonomies. In addition, Boolean logic applied to full text search commands can be used to locate text anywhere in the selected document or documents.

Users may annotate the information base to enhance its personal meaning and value. Annotations will include attaching notes to information objects (notes may contain text and graphics), linking together objects that the user associates, marking objects for subsequent recall, and developing personal indices of terms and then linking these terms to objects in the information base. These annotations are contained in the fourth volume on the Bookshelf, *Project File*.

In addition to accessing, navigating, and annotating the information, users may also access objects (other applications, system services, Macintosh desk accessories, etc.) external to our product. Files from other applications that can be recognized by our software may be imported. Files that are produced in the course of using the product may be saved and/or exported. Users will be able to copy most read-only files (not programs) that reside on the compact disk. They will also be able to perform a full range of editing functions on their own files generated within the application.

3. File Viewer Interface

Our interest in providing users with a uniform interface to the reference sources on the Bookshelf eventually raised serious pragmatic and philosophical questions regarding the extent to which we should port documents intact into the hypermedium versus augmenting their presentation to take full advantage of the hypermedium. Re-authoring documents is a costly and highly uncertain process. On the other hand, as ergonomists, we could see the potential lost opportunities of not capitalizing on the advantages of hypermedia.

Given the R&D basis of this project, we decided to experiment with augmentation of ill-structured documents. The granular level at which reference sources on the CASHE Version 1.0 Bookshelf are accessible to the user is the "entry." It is a self-contained unit of information that is addressable by key terms and cross-referencing. Since the *Compendium* was originally designed as a computer-accessible document, it is already parsed into consistent entry units with a highly uniform substructure (See Table 1) that is amenable to conversion to hypertext. *MIL-STD-1472D* is a hierarchically-structured document without a consistent entry level substructure. With the aid of subject matter experts, we augmented the existing document with an entry-like structure that we believe is naturally implied by its content.

To help the user locate and interpret pertinent information, a standardized presentation format was developed for entries in the *Compendium* which is tailored to the needs of the design engineer. This format, has evolved over several years through an iterative process of review and discussion with the user community, sponsors, and consultants. In hard copy form, it represents our best attempt at "human factoring" the presentation of relevant perceptual and performance data. All of the data contained in the hardcopy edition are included in the electronic version. Although the physical layout differs from the hardcopy edition, a format was developed to optimize the information requirements of designers within the limited physical screen size. This electronic entry allows us to make use of advanced techniques for data retrieval, browsing, navigation, and display.

Table 1. Modular substructure of an entry from the Engineering Data Compendium

Title - The title provides a concise description of the entry content.

Key Terms - This section lists terms that relate to the topic discussed in the entry. Along with key words in the entry title, these key terms can be used to verify entry content and serve as access terms in an index search for related information.

General Description - In entries presenting basic data, this section summarizes the general findings, conclusions, and trends in the data. For entries presenting perceptual/performance models, laws, or principles, it provides a precise description or definition and indicates the general purpose for which the model, law, or principle was developed.

Applications - This section describes general areas of application for the information in the entry; specific types of displays, control systems, task environments, etc., for which the information might be useful; and, where pertinent, general procedures for application.

Methods - Entries presenting basic data contain a Methods section that describes how the data were collected.

Experimental Results - When an entry reports findings of a research study, it contains an Experimental Results section that provides a more detailed discussion of the data than the General Description. The Experimental Results includes graphics or tabular presentation of the data, an enumeration of the major findings and trends in the data, and an indication of their meaning or significance.

Empirical Validation - This section is found in entries that treat a model, law, or principle. It includes a description of the methods used in empirical tests of the model, law, or principles and reports the results and scope of the validation studies.

Constraints - This section describes features or limitations of the information in the entry that may affect its application; stimulus or subject characteristics, environmental conditions, etc., that may influence the results or effect reported; criteria that must be met for proper application; and limits on the class of response, stimulus, task environment, etc., to which the information can be applied.

Key References - This section provides full bibliographical data for several reference sources that contain more detailed information on the entry topic. The original source of the data, model, etc., presented in the entry is marked with an asterisk. References are listed alphabetically and numbered consecutively.

Cross References - This section cites Compendium entries that treat related topics or provide pertinent background information useful in understanding or interpreting the information in the entry.

Each electronic entry is composed of the following elements:

• Identification region. At the top of each entry is its title, its section, and the grouping within the section where the entry is located. Disorientation is a major problem in hypermedia databases. This on-screen verbal format design, along with hierarchical maps (not shown), are designed to minimize disorientation. By selecting one of the arrows to the left of the entry title, the user may browse the next or previous entry.

• User annotation region. This region allows access to user-created annotation in the form of bookmarks, links, and notes.

• "Brass Plate". The brass plate allows access to the four primary elements of an entry: (1) Figures, (2) Text, (3) Tables, and (4) Prototypers. Each of these four elements has an independent "viewer" associated with it. Designers tend to be data rather than text oriented. Hence, the brass plate icons for figures, text, tables, and prototypers are prominently placed in the EntryViewer to draw user attention. By clicking on these icons, the user can quickly jump to the appropriate graphic or table.

• Element viewer. This viewer displays the selected figure, text, or table in a large window covering about 60% of the screen.

• Options panel. For each element viewer, there is an options panel, customized for each document. Here the user can select the various options associated with each viewer and with that document. Each of these viewers and associated option's panel are described in detail below.

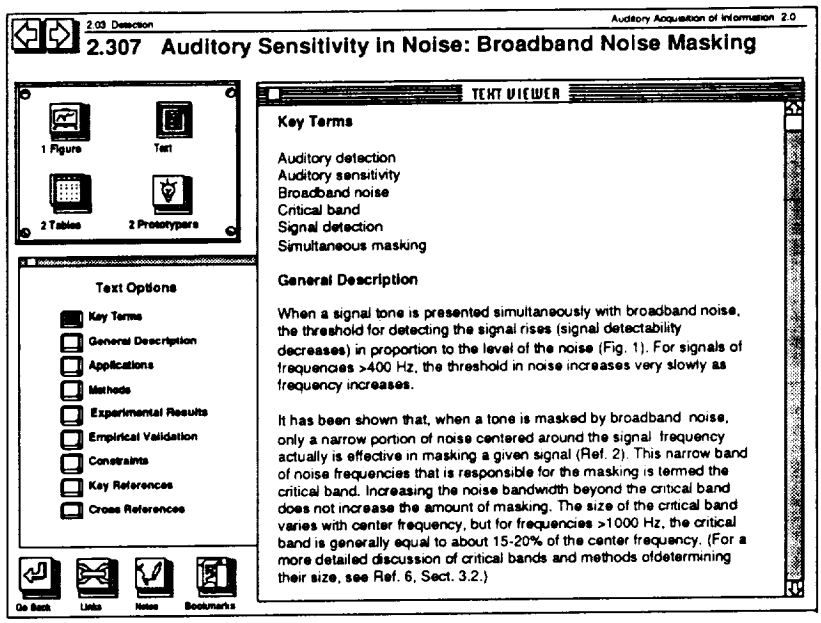

Figure 2. Electronic representation of an entry from the *Engineering Data Compendium* showing TextViewer.

A. TextViewer: TextViewer (Figure 2) displays the text portions of an entry. A large text window is available for displaying substructural components of any of the reference sources on our Bookshelf. Figure 4 exemplifies TextViewer for the substructural components of a typical *Compendium* entry. Users can select among the nine components shown by clicking the desired radio button. Subsequent navigation is accomplished by either reselecting a radio button or by clicking on one of the two arrows below the text window to move to the previous or next component. This data entry format is designed to facilitate quick and efficient viewing of the data entries and navigation to other pertinent entries. From the displayed Cross References component, the user may go to any of the given cross references by simply double clicking on the reference.

B. FigureViewer: FigureViewer (Figure 3) displays both data graphs and illustrations. Its associated options panel allows the user to select figure panels, control the display of overlays, zoom the figure scaling in or out, and turns the figure caption on or off. If demonstrations are available for the figure, then the user can select the demo button for either an animation or interactive demonstration which further illustrates the entry. If the figure is a data graph, then by pressing the data analysis button, the user can access DataViewer to further explore analytic relationships.

C. TableViewer: TableViewer (Figure 4) displays entry tables. The first row and column of a table contain the row/column titles. If the user scrolls horizontally through the table, then the first column remains fixed with the remaining columns "sliding under" the column titles. Likewise, if the table is scrolled vertically, then the top row of titles remains fixed. The table options panel allows the user to select multiple table panels and turn the table caption on or off.

4. Visualization Tools

Two specialized human perception and performance visualization tools (DataViewer and P^3) exist to further aid the user's understanding of the data.

A. DataViewer: DataViewer provides the user with the capability to view, manipulate, and display data. Multiple DataViewer windows may be opened (with only one active), and multiple DataViewer windows may be associated with a single entry.

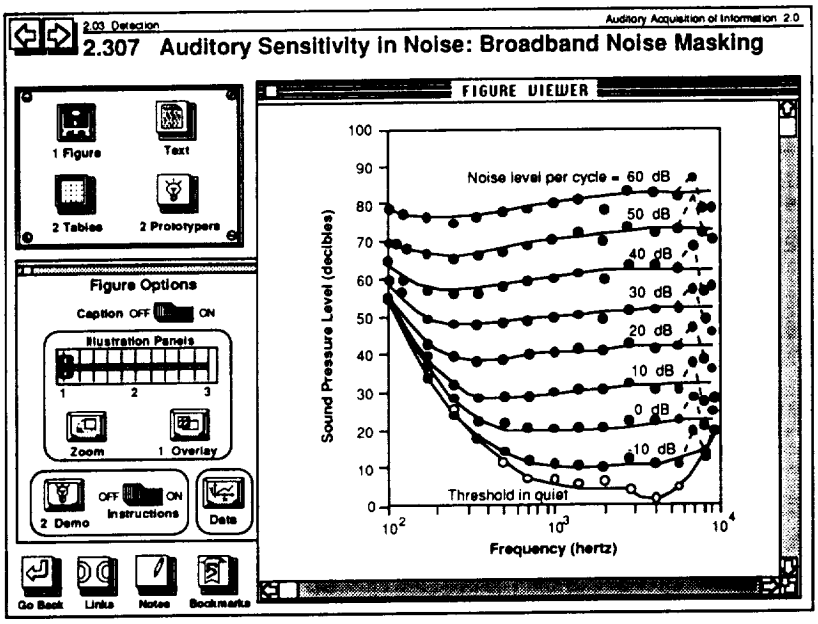

Figure 3. Electronic representation of an entry from the *Engineering Data Compendium* showing FigureViewer.

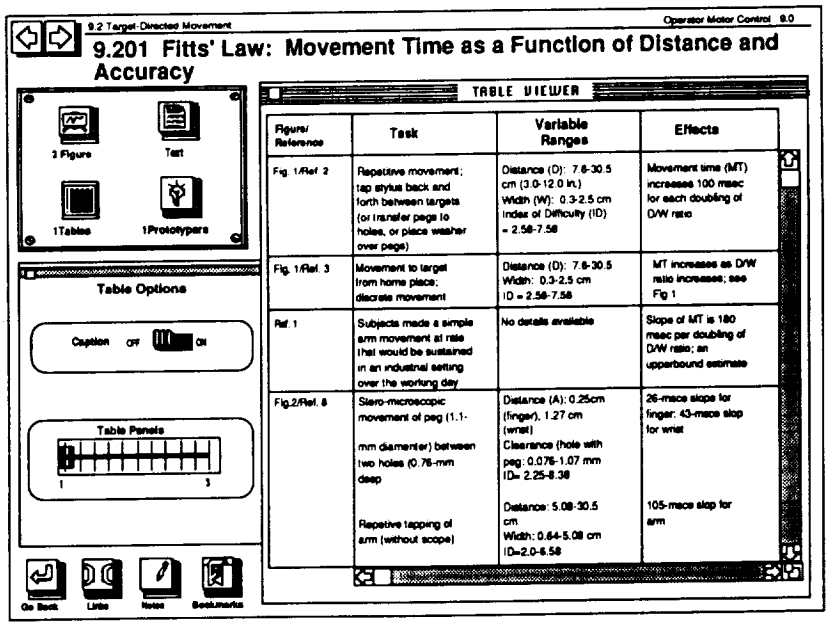

Figure 4. Electronic representation of an entry from the *Engineering Data Compendium* showing TableViewer.

Figure 5 portrays the selection of an existing XY graph, definition of its axes, digitization and storage of the resulting XY values in a table, and transformation of those data values into a new function, Z. Figure 6 illustrates this concept of data transformation available to the users of "DataViewer."

Four primary functions are available in DataViewer: 1) Data Definition, 2) Data Acquisition, 3) Data Transformation, and 4) Data Presentation. The data transformation function will support the user in exploring a phenomenon's mathematical relationships. Three classes of transformation will be supported: 1) monadic, single variable, operations, 2) dyadic, two variable, operations, and 3) analyses including descriptive statistics and linear/nonlinear polynomial curve fitting.

The data presentation function will support the user in exploring a phenomenon's graphical modes. Five display formats will be offered: 1) histograms, 2) scatterplots, 3) line graphs, 4) pie charts, and (5) tabular. For each of these formats, the user will be able to directly manipulate the graphs to perform such functions as rescale axes, crop or refocus the area of interest, and select/code a point or group of points.

B. Perception & Performance

Prototyper (P^3): The P^3 is a unique feature of Version 1.0 which allows the user to manipulate and experience alternative representations of the technical data found in the reference sources on the Bookshelf. Figure 7 shows an example of how a user may use the Perception and Performance Prototyper:

After consulting data in the *Compendium* concerned with how noise level may affect audio sensitivity, the user may have residual uncertainty regarding the relevance of the data to specific conditions. Using the P^3, users will actually be able to access a test bench and custom control panel that will support test and experimentation with the combinations of variables with which they are more directly

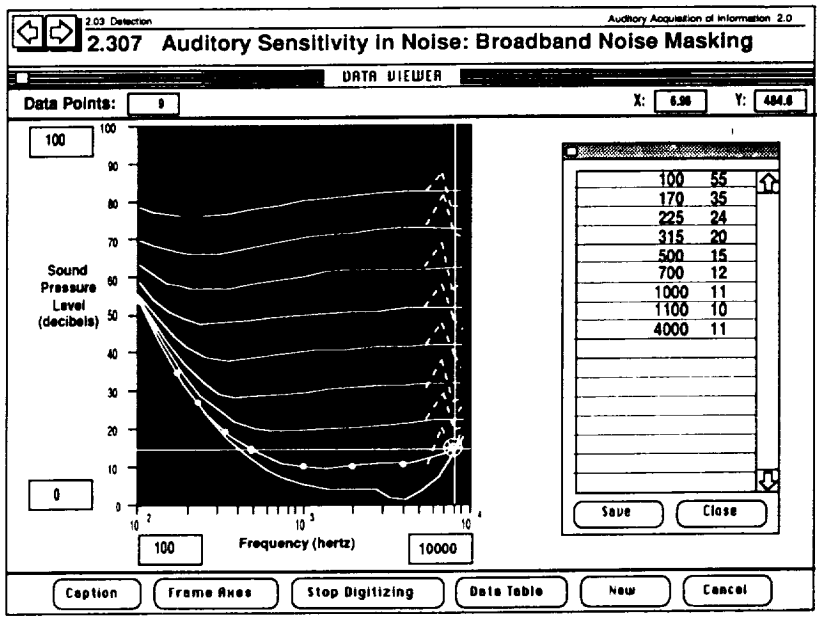

Figure 5. Electronic representation of an entry from the *Engineering Data Compendium* showing DataViewer.

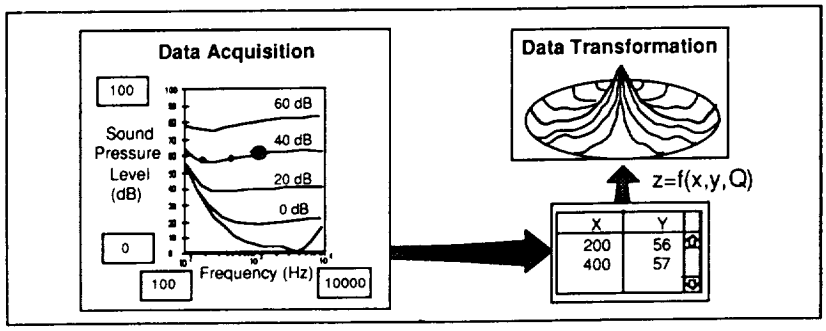

Figure 6. Concept of data transformation available to the users of "DataViewer."

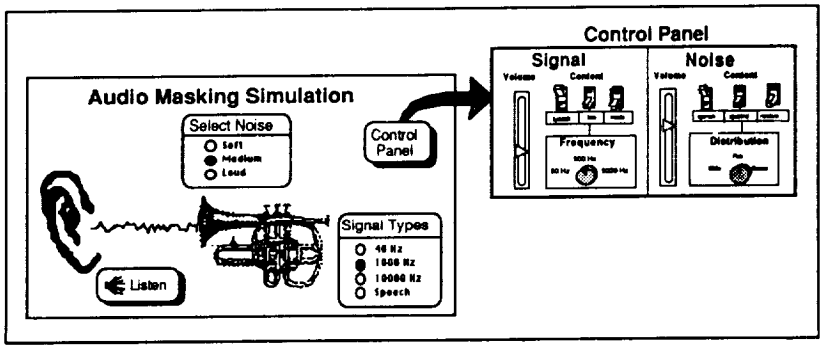

Figure 7. Operation of the *Perception & Performance Prototyper*: The audio masking test bench.

concerned. In the instance illustrated in Figure 7, the user can dial up relevant signal-to-noise conditions and can then experience the resulting aural phenomenon, first-hand. Minor variations in the phenomenon can be explored by selecting different noise levels or signal types.

If conditional variables can be veridically portrayed, then users will be able to directly experience resultant phenomena. If, on the other hand, conditional variables cannot be faithfully represented, as a result of software or hardware limitations, P^3 will simulate cause and effect relationships with strict adherence to the published data. This approach is employed in CASHE Version 1.0 wherever its availability can be justified by pedagogical criteria. In all instances, users will be able to easily link from and to relevant supporting data found in references on the Bookshelf. In addition to direct accessibility of P^3 from the desktop, the P^3 test benches will also be available as a browsable reference on the Bookshelf.

CONCLUSIONS

In sum, CASHE Version 1.0 offers human-system designers, researchers and educators an unprecedented and unique capability. CASHE supports:

- Rapid and effective access to ergonomics data and models
- Interpretation and application of this information by providing the ability to manipulate and experience alternative representations of these data.

In the future, we will continue to develop CASHE capabilities and implement these through interim commercial products including special purpose software, CD-ROM hypermedia databases, and publications in the open literature which document our ongoing R&D efforts.

ACKNOWLEDGMENTS

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