Interdisciplinary methodology supporting the design research & practice of new data representation architectures

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ABSTRACT

Data representation architecture **can be defined as the organizational, functional, experiential, and media-technological order defining the interaction between data, representation, and user. This paper presents an interdisciplinary methodology to develop such architectures in order to significantly improve decision making in real time, abstract data environments. We have reported in some aspects of this work elsewhere [1]. In this occasion, we will describe our methodology and briefly share examples of our efforts in Finance and Anesthesia. The long term goal of our work is to design a new generation of data representation architectures that is applicable to diverse fields.**

1. BACKGROUND

As we speak, millions of labs and scientists across the planet are conducting millions and millions of experiments, tests, analysis, etc. in uncountable number of fields generating terabits of data waiting to be deciphered. The situation of other decision makers is similar. Every minute, high ranking personnel must go through mountains of data in order to run factories, computer networks, oil refineries, business transactions, military operations. It is a difficult challenge facing those in fields or activities in which high risk decision making must take place in real time. Worse still is the fact that the production of data and technology in all areas of human endeavors is accelerating so rapidly that it has outpaced our capacity to manage it [2]. This situation demonstrates that our monitoring tools have developed to a much larger extent than the representational instruments necessary to make sense out of what our apparati are finding and doing [3]. So, here is the problem: there is too much data that is too complex, accumulating too fast and changing too quickly to have much hope of understanding, let alone making use of it [4].

2. DECISION MAKING WITH MULTI-DIMENSIONAL REAL-TIME DATA

Current methods for presenting abstract data (e.g., heart rate, stock price, network traffic volume, a reactor's temperature and pressure) in real time are waveforms, pie charts, diagrams, icons, matrices, trees, graphs, etc. These methods have limitations with scaling amounts of information, and tend to ignore the influence among different data. (See Figures 1 and 2 below) Sifting and integrating through screens full of raw data and traditional non-intuitive visualizations produce information overload instead of insight and decision-making power.
There is clearly a need for new data representations that augment human ability to use abundant data to (1) make more accurate decisions, (2) decrease response time, (3) reduce cognitive fatigue, and (4) reduce training time.

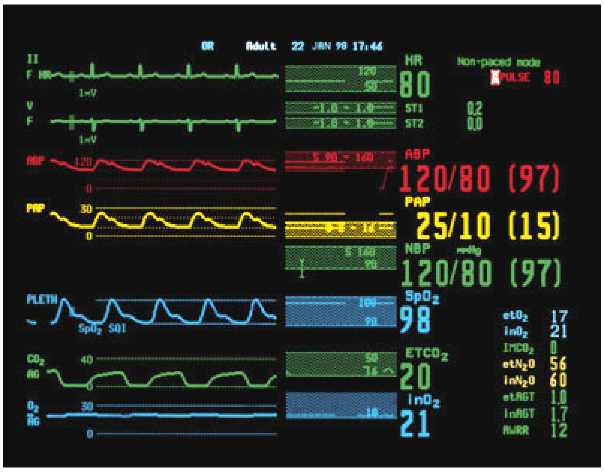


Fig. 1 (left): A traditional Anesthesiology display (Datex-Ohmeda) is a good example of the current paradigm of real time data representation. Shortcomings include (1) not grouping of variables in cardiac and pulmonary sub-systems, (2) providing no priority and hierarchy to variables, (3) recognizing no functional relationship of variables, (4) color and other design attributes serve no particular meaning, and as a result (5) experts (i.e., anesthesiologists) have the cognitively demanding and error-causing task of associating the variables in real time to correctly diagnose clinical scenarios.
Fig. 2 (right): Current representations of financial data show information primarily in alpha-numerical form or through simple graphs or bar charts (YAHOO).

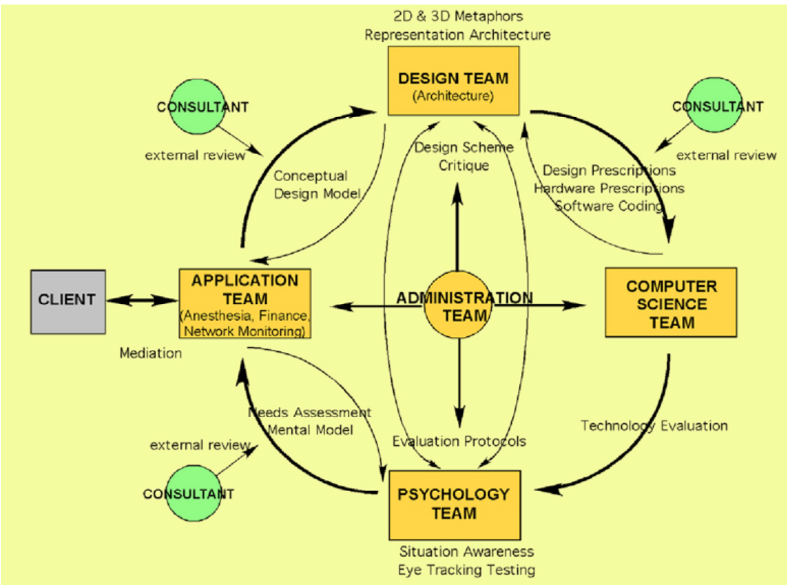
3. DESIGN PROCESS & DATA REPRESENTATION ARCHITECTURE

For the past 7 years, our group CROMDI (Center for the Representation of Multi-Dimensional Information) at the University of Utah (USA) has been trying to develop a new paradigm of data representation that is based on intuitive, multidimensional, and interactive audio-visual representations. We have found that effective decision making tools, especially if used by broad user bases, are more effective if developed with an iterative design process that involves apprehension and congruence [1]. In other words, effective data representation architectures need to equally satisfy:

- the ***congruence*** principle: user's internal data representations (mental model) need to be consistent with the displayed external representations;
- the ***apprehension*** principle: the representations need to be intuitively apprehended [5].

In addition, we have grown to trust the design process as our fundamental and leading system of operation that bridges widely different domains. The design process is a systematic and experimental procedure for advancing, developing, testing, selecting and communicating hypotheses. Design inquiry is the normal methodology for conducting architectural work and its results cover both basic and applied types of knowledge. The validity of this type of inquiry has been amply demonstrated. Research on complex problem solving, learning, and communication keep pointing to the design studio model in general and the design process in particular as successful working laboratory and methodology for addressing open-ended, fuzzy, and multi-variable problems [6]
Given the size and expertise of our interdisciplinary research group, the logic of the design process phases and the nature of the problem, we break down the group into several teams, each one addressing the problem from their specialty but in direct collaboration with other teams according to needs. The Design Team establishes the overall rhythm and schedule of the process and is to whom all the other teams interact with at different times in a modality similar to that of the traditional design studio setting. Following is a description of the groups and their tasks involved in the design process (please, refer to Figure 3):

(1) the ***Client*** is the actual institution or corporation asking/supporting the development of a new data representation solution to a particular information problem.
(2) The ***Application Team*** takes the role of the specialist and works as middle-person between the Client and the Design and Psychology Teams (3 and 4). This team 'translates' the client needs and requirements into programmatic needs. This teams also works as critic and adviser to our research group at large during the design process. Application teams have been in Anesthesia, Finance, and Network Monitoring & Security.
(3) The ***Design Team*** is in charge of developing the data representation scheme following a collaborative design process and using special principles and techniques discussed elsewhere [see reference 1]. During the initial phases, the design team works very closely with (2) and (4). As the schemes become more final, the design team begins to have direct contacts with (1) but always with (2) present
(4) The ***Psychology Team*** is devoted to extract the mental model experts in the field of application use to make sense and act upon the data. During the initial phase, (4) works in close relationship with (2) to study (1). In later phases, this team is heavily involved in the evaluation of the representation schemes developed by (3).
(5) The ***Computer Science Team*** addresses software, network, and hardware considerations. This team is particularly involved during the final phases of a project. At that time, it works closely with (3) and receives advise from (2) and (4). Its initial input consists of providing prescriptive and 'budgetary' advise regarding actual computer implementations of the data display. Of course, in areas of application relating to computing (e.g., networking monitoring), this team may become (2).
(6) The ***Administration Team*** is focused in supporting the day-to-day operation of our research group as well as seeking new areas of work, recruiting consultants and collaborators, following up patent development, etc.
(7) ***Consultants***: External reviewers enter the process at critical times to evaluate the ongoing results.



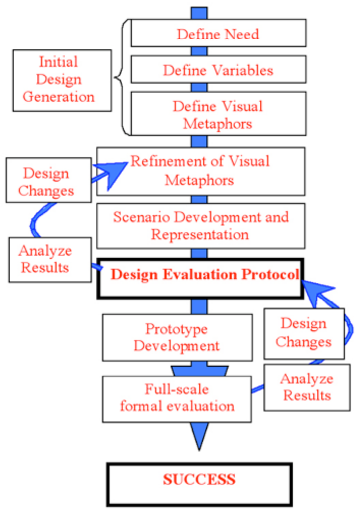


Fig. 3 (left): Interdisciplinary Design Methodology . Fig. 4 (right): CROMDI's Data Representation Architecture Design Process

The interactive work of all these people and disciplines occurs within an over reaching ideology of design as a function of human needs and behavior and the interaction between operator and display. As a result, the design process follows the concept of a "hermeneutic circle". This concept involves an iterative process of implementing a design, learning and understanding from discussion and feedback from the targeted users, and subsequent design refinement. First, the problem and the metaphors for the information that will be displayed are defined. Next, an iterative process via "dialogical exchanges" is used to gain additional insight into the design. New interpretations are discovered and the design is refined. The design development process, shown in Figure 4 contains a second feedback loop of iterative evaluation for design usability and intuitiveness.

Each design refinement is evaluated using a testing protocol. The results of these evaluations are methodically analyzed to elucidate design changes while minimizing designer bias. This process also minimizes alterations to the requirements and the design, late in the display design's lifecycle, when changes are more costly (e.g. a change during the design phase is less costly than a change after the display has been deployed). This methodology is successful because the design is evaluated and redesigned during each phase of development, with the intent that the majority of design changes occur in the early stages of development.

4. EXAMPLES OF DESIGN WORK

Our group implemented this general methodology successfully for the development of information displays in the domain of anesthesiology. The recent commercialization of our medical displays proves this point. We have also used this methodology to guide the design effort in Finance and are beginning to apply it to our research work in Network Monitoring & Security. Below are two examples of our data representation architecture in Medicine and Finance. We are only showing minimal information to provide the reviewer some design proof of our work. For details and descriptions refer to [1]

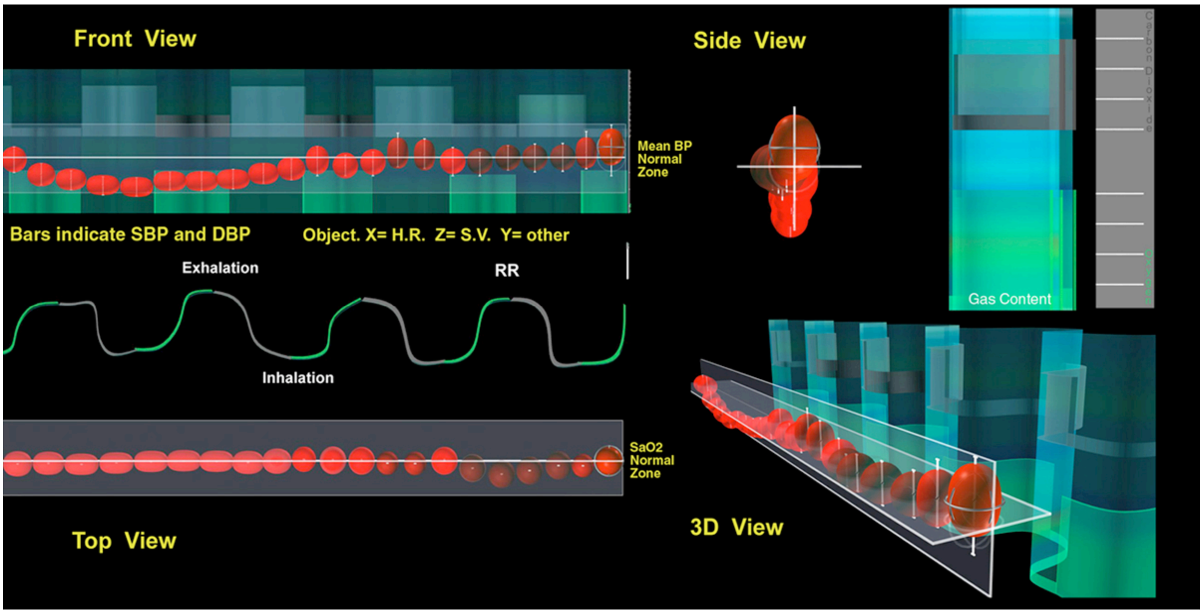


Fig. 5: CROMDI's visualization system for displaying physiologic data in real time. (© copyright 2000 CROMDI, all rights reserved). Compare to existing display shown in Figure 4. Spherical object represents cardiac variables, Stroke Volume, Cardiac Output, and Heart Rate. Each ellipsoid shows the efficiency of a heart beat: deformations from normal spherical shape show non-optimal efficiency. Movements up and down allow the association of the state of that object (and its variable relationships) to Blood Pressure. Similarly, by establishing a figure-ground relationship with the "curtain" object (in the background) that integrates respiratory data (Tidal Volumes, Respiratory Rate, Nitrous Oxide, Oxygen, etc.) and by incorporating color to depict Arterial Oxygen Saturation into the spherical object, there is an immediate perceptual realization of the health state of both essential physiologic functions. Please, compare to Figure 1.

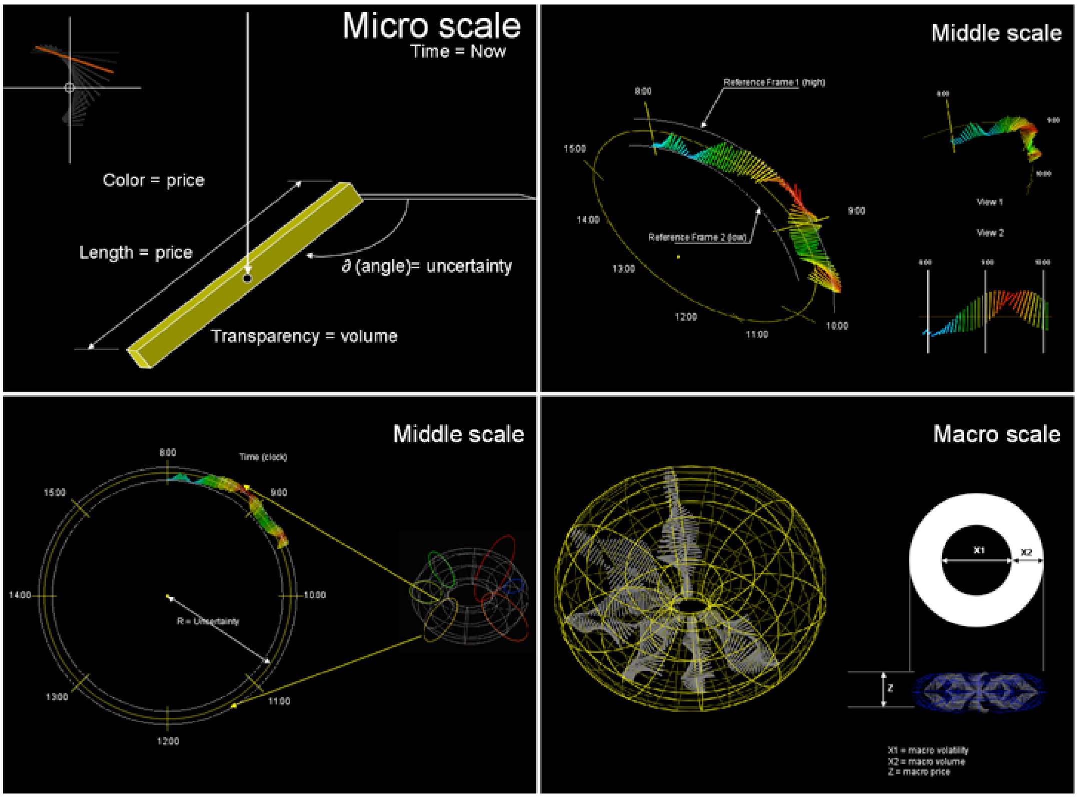


Fig. 7: CROMDI's Data Representation Architecture for Finance. Financial information is organized in 3 different layers according to data scale, relationships, hierarchy and use. The *Micro-scale view* shows the current information on a single stock .The *Middle-scale views* show the day's performance of one stocks within a particular sector. The *Macro-scale view* shows whole market behavior (full torus) as well comparative sector performance. (© copyright 2003 CROMDI, all rights reserved). Please, compare to Figure 2.

5. EVALUATION PROCESS

One very important difference between our design work in data representation design and that of many other groups is our fundamental reliance on an evaluation/testing process. [7] Cognitive Psychology provides the methodological knowledge necessary to evaluate the efficiency of new ways of information representation. We use a traditional experimental approach with confirmation to evaluate the effectiveness of the designs. We compare performance success between a group of subjects using the new data representation and a group of subjects using more traditional ways of presenting data. In addition to more traditional measures like quality and time of performance, we use eye tracking to assess gaze and focus of viewing. Using this multi-methodological approach helps us to evaluate the performance in a broad range of domains.

6. CONCLUSION

We profess a new representation architecture made out of data, fluctuating with its rhythms, occupying digital space and aimed at improving the decision making experience of its users, whom often spend several hours a day dwelling in its midst.

Manifesting this belief into a full-fledged interdisciplinary research effort has proven laborious but extremely rewarding. Succeeding meant to overcome these challenges (several of which we continue to face):

(1) Working within a university structure that does not encourage interdisciplinary work because it doesn't fit traditional academic and administrative boundaries.

(2) Convincing funding agencies, peers, and journal publications of the value of interdisciplinary work in the face of a widespread attitude that working across widely different fields is less scientifically rigorous (or suspect design-wise).

(3) Struggling through disparities in salary and academic recognition among the different disciplines.

Despite these and other hardships, CROMDI has done well at obtaining research grants (over $4.5 millions) and publishing its work. In fact, our work have produced data representation architectures in Anesthesia that significantly improve the accuracy and speed of decision making while reducing the cognitive load of individuals whom confront complex abstract data. This important milestone has led to the successful commercialization of some of our research output and recently to a spin-off business enterprise.

By sharing this experience we would like to encourage others to undertake the challenging, stimulating and rewarding interdisciplinary path. A path that has a wide open horizon for designers, architects and all the creative fields.

7. ACKNOWLEDGEMENTS

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