Information Visualization Design: The Growing Challenges of a Data Saturated World

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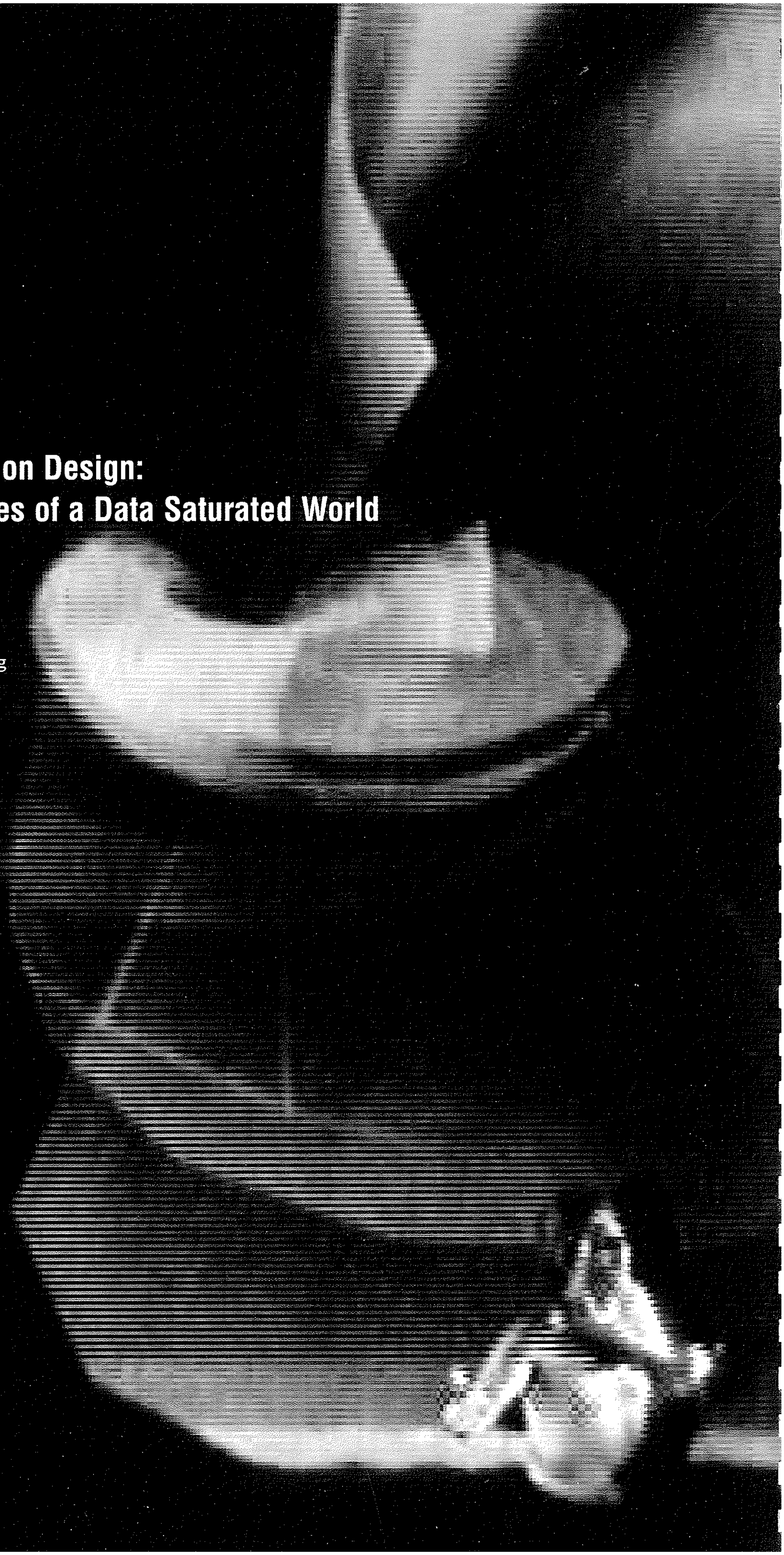


We are living in a world overflowing with information.[1]

Millions of labs, apparati and scientists across the planet are continuously conducting millions of experiments, observations, and analyses producing huge amounts of data. Our ordinary lives have become data traces too: the ATM transaction, the online registration of our new software, the credit card purchase at the mall, the cellular phone call, etc. The security concerns of late have only exacerbated this need for and accumulation of data. In this reality, the central issue has shifted from getting data to making sense of it.

Over 20 years of work in Scientific Visualization, Human Factors, and Semiotics indicates that there exists a direct correlation between how data is represented and the meaning we can extract from it. Better representations mean better understanding. In fact, *the way* that data is presented has an overwhelming weight in how a system or situation is perceived and what ultimately drives the decision making process.[2] Currently, there is wide agreement that *visualization* is the best representation method for turning complex data into information.[3]

Although there has been much work in the visualization design area, we are only beginning to tap the possibilities of communicating data visually. There have been many well documented examples of inappropriate decisions based upon information that was presented poorly (e.g., from the Harrisburg nuclear plant crisis in 1979 to the Challenger and Chernobyl disasters in 1985 to the breakdown in intelligence sharing leading to 9–11). Yet, more negative impacts may be found in less spectacular but more pervasive errors found in day-to-day information driven operations (e.g., medical services, process control management, network monitoring, business operations, and so forth).[4] The reason for this worrisome state of affairs is our persistence in using early twentieth century quantitative methods, naïve notion of human cognition, and simplistic representation spaces when battling data environments of twenty-first century complexity. We just cannot keep doing this any longer and expect good results. A good example of the prevailing and limited paradigm in information visualization is shown in Figure 1 on the following page.

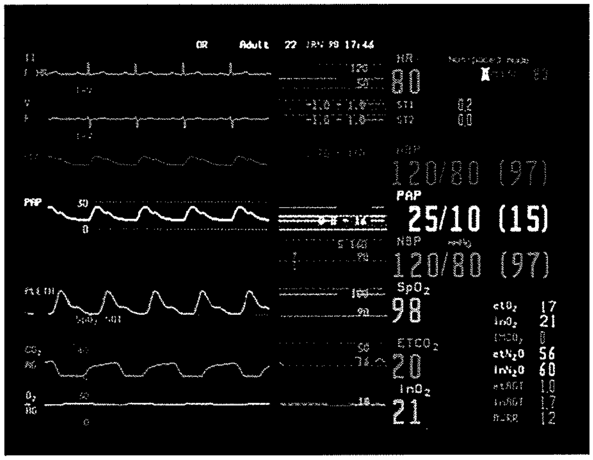


Figure 1: Current display of physiologic data in Anesthesiology (Datex-Ohmeda). Traditional representations are characterized by numerical-waveform (as opposed to geometrically graphic), discrete (as opposed to integrated), and non-interactive data representations. Shortcomings include (1) not grouping 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, (5) its unintuitive nature takes year of training to master; and as a result (6) experts (i.e., anesthesiologists) have the cognitively demanding and error-causing task of associating the variables in real time to correctly diagnose clinical scenarios

The present shortcomings of data representations can be traced back to the fact that most information visualizations have been produced by scientists and engineers, whom are trained in quantitative and not qualitative methods, in analytical and not integrative processes, in obtaining or using and not communicating knowledge. The data representation challenge confronting today's scientific and engineering communities may be summarized as follows:

> "Instead of concentrating on building more and more elaborated systems of rules, there must be an effort to accommodate the innate and vast human perceptual capability. The deficiency in many computer graphics presentation is not in the output volume, but in the display itself. More intelligent computer programs are not needed, but more intelligently-designed computer displays are"[5]

New approaches that enable data-based decision making to be *faster, more accurate*, take *less cognitive effort*, and require *less training* are needed. We need information visualization systems that *also* address the qualitative and symbolic dimensions intrinsic to all decision making process. It means to transform raw data into information through a refinement process called selected depiction. Pursuing this work demands the interdisciplinary collaboration among art, design, science, and technology.

On Data Representation Architecture & Interdisciplinary Collaboration

For over 8 years, our research group, CROMDI (Center for the Representation Of Multi-Dimensional Information, http://www.cromdi.utah.edu), has been working on the display of information in five domains: Anesthesiology, Finance, Process Control, Network Security and Monitoring, and Live Art Performances. Our goal has been the development of a new generation of *data representation architectures* that offer a better alternative to the existing status-quo in information visualization. We *define data representation* architecture as the organizational, functional, experiential, and media-technological order defining the interaction between data, representation, and user. Although our research group is composed of people from a variety of disciplines (e.g., Business, Computer Science, Mathematics, Medicine, Music, Psychology, and so forth), it is Architecture that has taken a decisive leadership role at the managerial, conceptual, and productive levels of the interdisciplinary effort.

Our experience has taught us that certain methods are more conducive than others in supporting interdisciplinary collaboration. Among them, three essential practices are at the heart of our approach and methodology:

(1) the pursuit of a committed and sustained *complete interdisciplinarity*,
(2) the utilization of the *design process* as the basic engine of its interdisciplinary methodology, and
(3) the application of *built-in evaluations* throughout the process as a quality control mechanism that feedbacks directly into the design development.

Architectural Relevancy & Interdisciplinary Collaboration

The relevance of *architectural research* to the design, construction and communication of data spaces has been supported by the leading minds in Architecture as a natural extension of designing and building functional forms and spaces.[6]

Our experience has taught us that there are four core architectural competencies that make our field especially relevant to information visualization:

(1) proficiency in representation, simulation, and communication;
(2) a developed knowledge base in formal semiotics;
(3) fluency in the management of multiple disciplines, technologies, and individuals toward achieving a goal, that is traceable to our design studio environment and master builder/ leadership training; and
(4) expertise in the employment of the design process as research methodology to solve ill-defined and difficult problems.

(1) Representation expertise

Architecture has a centuries-old expertise in the representation, simulation and communication of diverse and often complex types of information. There is also a long tradition of architects using depictions to conceive the not yet built and speculate about impossible architectures and utopian environments.[7] The recent full adoption of digital media (with its cross-disciplinary technological reach) gives architecture the potential to extend this expertise and visionary skills to other domains, notably in the creation of data environments wherein representation and imagination rule the day.

(2) Formal semiotics

Architects ordinarily deal with the syntax, semantics, and pragmatics of 2D and 3D form and space. As a result, the discipline has collected a comprehensive knowledge base of the nature, methods, and value of basic (i.e., abstract, geometrical) 2D and 3D design and their relationship to human collective and individual psychology and behavior (i.e., meaning and use). This knowledge base consists of basic principles (e.g., scale, shape, rhythm, color, structure), elements (e.g., line, figures, objects, space) and organizational rules (e.g., hierarchy, layering, symmetry)[8]

The architectural expertise in formal semiotics and representation lays the ground for developing graphic conventions (syntax) to successfully encode (and decode) data parameters into representations (semantics and pragmatics). They also prove resourceful when considering the economics of data processing, that is, the hardware and software inherent limitations in dealing with complex dynamic databases. It is natural for our discipline to take a leadership role in advancing the state-of-the-art of information visualization.

(3) The Studio Model & the Master Builder

Training Supporting Interdisciplinary Research Developing new data representation architectures demands responding to many intertwined issues. Not only must we have some cognitive model of the user's data-driven decision making process, but also determine the nature and behavior of the data (structure, process), the type of problem, needs and requirements, and the technology to deliver such depiction. Clearly, this cannot be done by architects alone. In fact, this task would overwhelm any single discipline by its sheer complexity, scale and multi-dimensionality. Nothing less than a well organized interdisciplinary approach will do. Bringing together the expertise of different disciplines provides the necessary tools to address this challenge.[9]

However, carrying out interdisciplinary collaboration is not easy. It requires a careful structuring of group dynamics, so that they are based on clear roles, respect, trust, values, shared goals, and a common language.[10] Here the tolerant yet critical and productive *architectural design studio* becomes remarkably useful. The *studio model* offers a real intellectual and physical environment for conducting inquiries engaging multiple viewpoints in cross fertilization, discussion, and production. Under such interdisciplinary collaborative conditions, we have discovered that architects are able to function as mediators and brokers of knowledge and ideas across domains with an ease and effectiveness not matched by others. This is due to the architects' master builder training that gives the ability to organize, communicate and coordinate disparate efforts into a coherent whole without loosing track of the goal. Not surprising, it is the architecture team, within our larger interdisciplinary group, leading the research efforts.

(4) The Design Process As Interdisciplinary Research Methodology

Our expertise in using the design process as a methodology for discovering, developing, and testing hypotheses is yet another reason behind the leadership and relevance of architecture in information visualization.

Adopting the design process as our interdisciplinary methodology naturally evolved during the first two years of research work. We determined that effective information visualization tools for decision making are better if developed with an iterative design process that permits simultaneous attention to multiple perspectives, skills and knowledge-bases. We also found that the *design process* allowed for a spontaneous and natural way of socially engaging a wide range of disciplines and individuals working in a very difficult problem. This is in line with existing knowledge that the *design studio model* in general and the design process in particular are a successful working laboratory and methodology for addressing open-ended, fuzzy, and multivariable problems.[11] Although this may not seem like a surprising finding for architects, it was indeed an important realization for those coming from other domains. We will describe the results of our data architecture work in three distinct areas: anesthesiology, computer network security, and live performance.

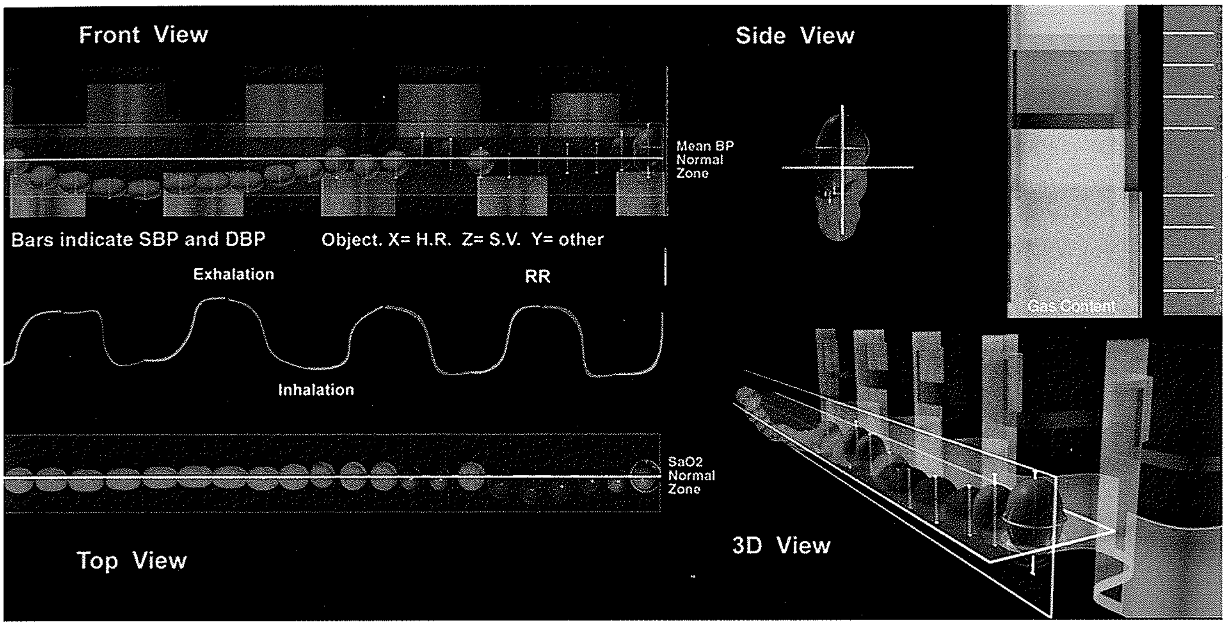


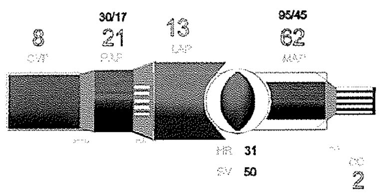
Figure 2: CROMDI's visualization system for displaying physiologic data in real time. (© copyright 2000 CROMDI, all rights reserved). Spherical object represents cardiac variables, Stroke Volume, Cardiac Output, and Heart Rate. Each ellipsoid shows the efficiency of a heart beat; deformations from normal 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. Compare to existing display shown in Figure 1.

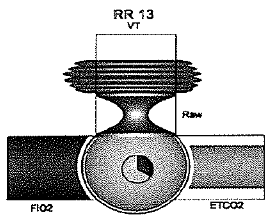
Project Description and Results

Anesthesiology

Anesthesiologists face unexpected incidents during 20 percent of all anesthetics. Human error is associated with more than 80 percent of the critical incidents and more than 50 percent of the deaths.[12] Many errors can be directly traced to erroneous or misleading information from monitors or in the physician's failure to recognize a pattern in the data that would have led to a correct diagnosis. The environment is stressful and the task is difficult because 30 variables need to be monitored and mentally integrated. Anesthesiology displays use a single-sensor single-indicator paradigm that is an addition to the strip chart recorder output Sir Thomas Lewis used in 1912 for the first ECG (Figure 1).

Clinicians must observe and integrate information generated by the independent sensors to observe significant changes. This process of sequential, piecemeal data gathering makes it difficult to develop a coherent understanding of the interrelationship between the presented information of physiological processes.[13] In order to address these matters, we worked for five years to develop displays for detecting, diagnosing and treating anesthesia related critical events that significantly reduce recognition times. Our data visualization solutions offer a fundamental departure from the way the medical field presently detects, diagnoses, and treats physiologic conditions. For example, Figure 2 shows our first completed data representation design attempting to offer a holistic view of the two major physiologic functions (cardiac and pulmonary) that need monitoring during anesthesia.





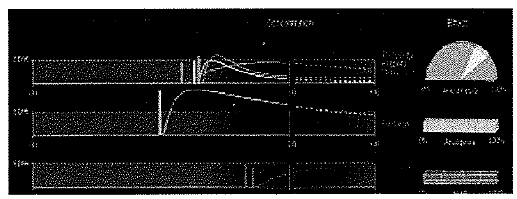


Figure 3 (left): Cardiovascular Data Display. Figure 4(Middle); Pulmonary Data Display. Figure 5 (right): Drug Data Display.

Figures 3 through 5 show our design efforts to develop physiologic data displays presently not available to physicians and anesthesiologists and which may result in significant improvement in high-risk medical services. Figure 3 shows our *Cardiovascular Data Display*. This design organizes measured and modeled cardiovascular information variables showing functional relationships and including concepts such as preload-afterload. Figure 4 presents our *Pulmonary Data Display*. This visualization design offers respiratory data about patient and ventilator while showing functional relationships and essential gas exchange information. Figure 5 portrays our *Drug Data Display* that delivers dynamic representations of pharmacokinetic behavior while offering prediction information and historical trending. These displays because of their holistic rather than isolated view of patient variables will have a positive impact in the current delivery of anesthesia.

Thorough scientific evaluations of CROMDI physiologic data displays have showed statistically significant improvements in performance in several critical scenarios when compared to performance utilizing traditional/existing data displays.[14] For example:

- Clinicians detected anesthesia-related critical events sooner (3.1 vs. 5.5 min),
- Abnormal events were diagnosed more accurately (error rate 1.1 percent vs. 4.1 percent),
- Problems were corrected in one-third the time (17 sec vs. 45 sec), and
- Drug delivery was better controlled (EC95 error 21 percent vs. 44 percent).

Computer Network Intrusion Detection

The goal of this research is to develop a new generation of cyber-security visual displays that integrate distinct advances in data representation design, cognitive psychology, computer visualization, with heuristic knowledge and statistical methods from cyber-security experts, to significantly improve network analysts' and decision makers' ability to discover, diagnose and rapidly respond to critical cyber situations.

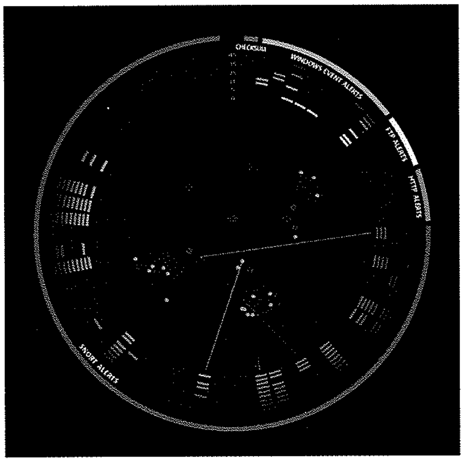
The state of the art in network monitoring is to present streams of abstract data (e.g. system logs, packet loss, intrusion alerts) with plots, pies, bars, maps, trees, and so forth (e.g. Fig. 2). Displays based on these centuries old metaphors do not reflect the relative importance of the variables and the evolution of the relationships; they do not capitalize on the power of modern computer graphics and on human natural perception; also, they have limited ability to convey insight from the increasing amount of data produced today. Sifting and integrating through screenfuls of such displays may produce information overload, which is a common complaint in this field and may not allow for analysts to see important patterns or trends. When faced with multi-variate information, decision makers develop their own heuristic rules and mental models for selecting and integrating information, which may take years of training or experience. In other situations, decision makers need intermediation by experts: this introduces layers of reliability loss and time delay, which interfere with mission criticality. In many cases, this results in suboptimal performance and human error. There is a need for tools that augment human ability to draw insight from abundant or complex data, in order to make decisions: *faster, more accurately*, with *less cognitive effort*, and with *less training*.

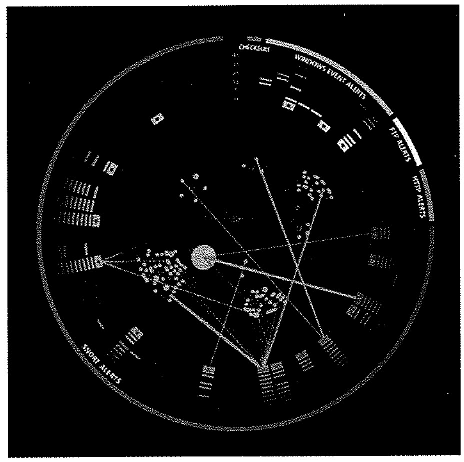
By delivering visual metaphors standing for assets, events, contexts, relationships, complexity levels, reliability, relevance, priority, and so forth in a dynamic reference to infrastructure, strategy, and tactical considerations, our design methodology fully exploits humans innate and vast cognitive abilities to recognize patterns and establish high situation awareness, resulting in substantially enhanced decision-making. Such an approach represents a radical shift from current network visualization using plots, graphs, bar charts.

left to right:

Figure 6: VisAlert Display left showing normal network traffic

Figure 7: VisAlert Display showing an intrusion attempt on machine with large circular node





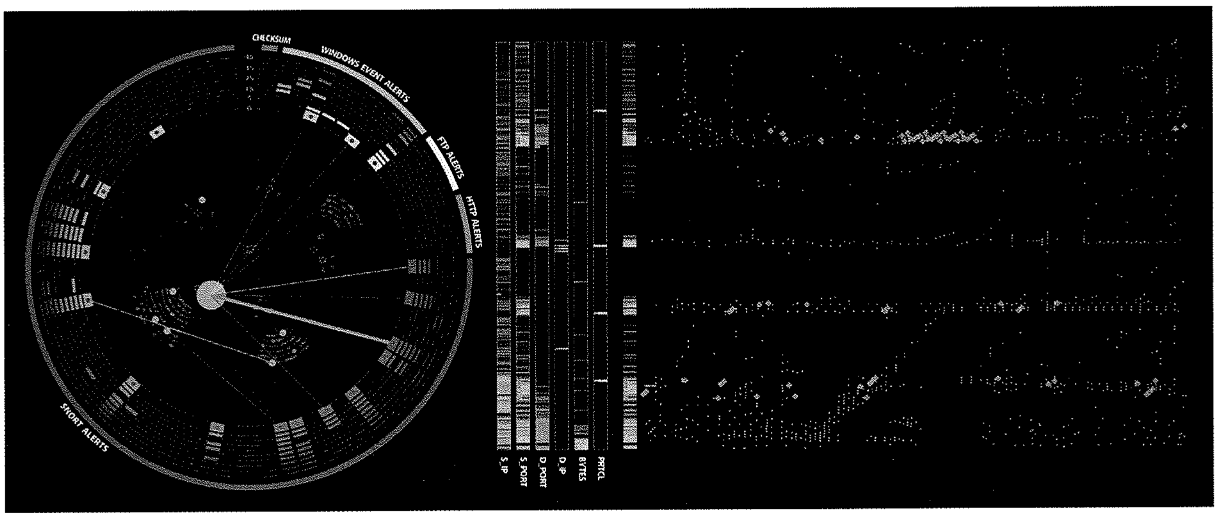


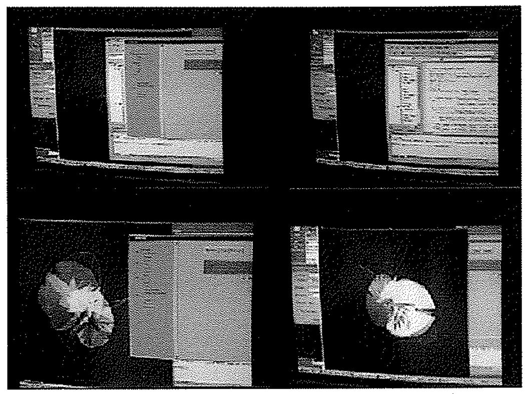
Figure 8: VisAlert Display showing 3 visualization modules. The leftmost display shows host and network based alerts around the ring and mapped to network topology. The waterfall display in the center shows a summarized view of network traffic associated with selected network nodes. The analysis view on the right shows a detailed view of the waterfall with time expanded in the X dimension. This work is © copyright 2003-05 by CROMDI, all rights reserved.

Visualization concepts

We developed three separate visualization modules that provide the user with different ways to view network related data. These visualization modules allow for the visual correlation of different logs from computer systems across an enterprise for the detection and diagnosis of complex intrusion attempts. These displays provide a view "at a glance" of the number of different types of alerts associated with machines across a network. This processed data (alert set) then provides the capability to drill down into particular aspects of the data to see patterns over a variable amount of time. The user then has the capability to interact with refined views of the data and configure different comparisons in the analysis. These views can then be saved and compared that may reveal attack signatures. The user also has the capability to enter notes about particular nodes that can be accessed by others as a way of sharing information. In summary, the visualization allows for the following benefits: data fusion of disparite data sources, data drill down, a holistic view of overall network activity, and pre-attentive design that takes advantage of innate human perceptual qualities.

Figure 9 (left). Choreographer Yacov Sharir (University of Texas at Austin) trying out the cyberPRINT technology.

Figure 10 (right). Screens of software running the project



Live Art Performance: The cyberPRINT

Our group has successfully developed the cyberPRINT, a live art production that has been performed more than 20 times nationally and internationally since May 2000. The cyberPRINT covers a wide and fertile territory that goes from the very technical and design/art oriented to the very theoretical and interdisciplinary.

The cyberPRINT is an electronic bio-feedback system driven by physiologic data drawn from a performer via special sensors attached to the body and transmitted wirelessly to computers which, in turn, generate and project a specially designed and programmed audio-visual 3D virtual reality in real time. Since the resulting virtual artifact represents the individual whose biological data generate and sustain it, it is a cyber-PRINT or personal signature of that individual in digital space. By enveloping its user through screen projection and/or virtual reality technologies, the cyberPRINT allows that individual to visualize, inhabit, and interact with themselves and others in unimaginable ways.

Great research effort was devoted at creating interfaces between biology and information technologies. Although we utilize existing technology to wirelessly obtain the data from the body, we had to develop our own hardware and software tools to be able to utilize those signals in the ways required by the project. The physiologic data is gathered from non-invasive medical sensors registering vital signs in real time in numerical data format (i.e., EEG, ECG, EMG, EOG, and PSG signals). The measured data is sent via radio signals directly to a PC where they are then pre-processed and immediately sent to another computer with special software to generate the cyberPRINT.

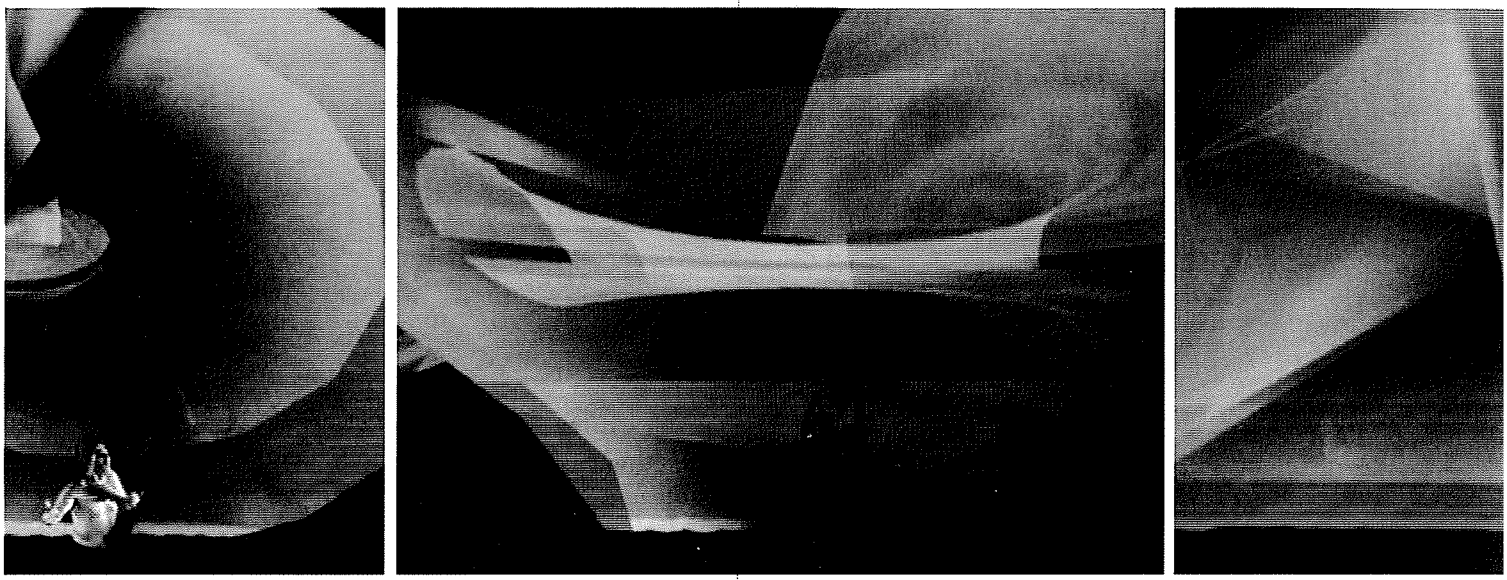


Figure 11-13 Three still video captures from live performances with Yacov Sharir (circa 2000-2002)

By making the body the hinge point where virtual and physical spaces meet and interact (i.e., the virtual is generated by the real, but the real is affected and changed by what the virtual does), the cyberPRINT casts new light into what has become ordinary for most individuals today, the coexistence of virtual and physical spaces at once. More intriguingly, it opens up the consideration of what may be called an "*architecture of being*" *that manifests anew the actual fluidity of the self in real time.* In doing so, this project offers a new understanding and expression to the ancient artistic quest of depicting the self and the body.

The cyberPRINT completely owes its existence to the interdisciplinary collaboration among architecture, bioengineering, medicine, computer science, choreography, modern dance, and music. In 'exchange' for this effort, the project has played an instrumental role in infusing impetus, creativity, and excitement to our overall research agenda. In fact, many new scientific, technological and design insights have been conceived and implemented *because of* the artistic development of the cyberPRINT. It is also clear that the research, design, and performance of the cyberPRINT have expanded the conceptual, aesthetic, and technological boundaries of architecture.

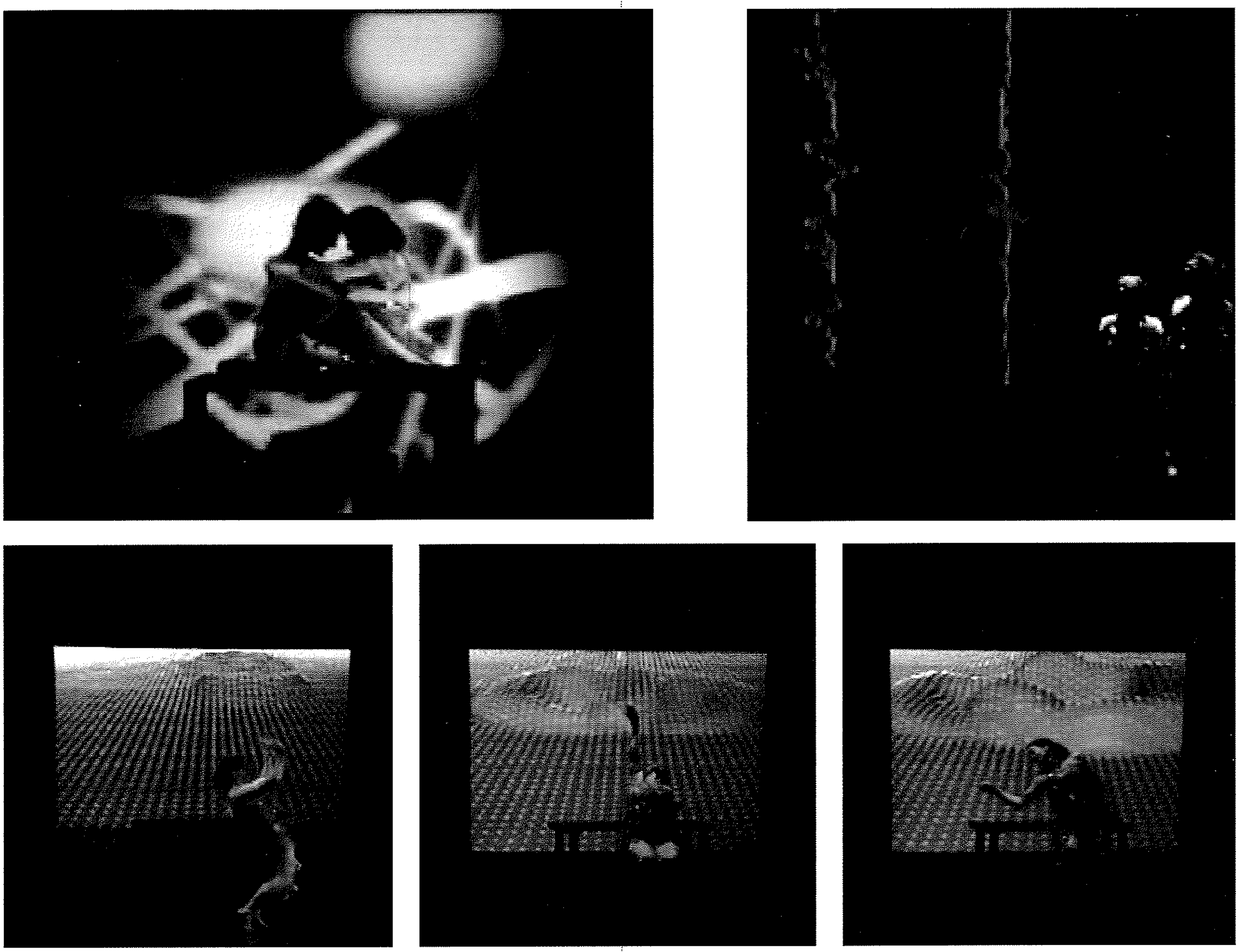


Figure 14 - 19: Five still video captures from last live performance at Oberlin College in May 2004. Collaboration with Oberlin College faculty Nusha Martynuk, Carter McAdams, Holly Handman and Tom Lopez

Conclusion

As our civilization dives deeper into the information age, making sense of ever more complex and larger amounts of data becomes critical. In order to respond to this challenge, we profess a new architecture made out of data, fluctuating with its rhythms, occupying digital space and aimed at improving the decision making of its users—who spend several hours a day dwelling in its midst. We call it data representation architecture. 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):

(a) Accommodating different methods, techniques, positions, interests, standards, languages, perspectives, knowledge, and so forth of our members' diverse disciplines.
(b) Working within a university structure that does not encourage interdisciplinary work because it doesn't fit traditional academic and administrative boundaries.
(c) Convincing funding agencies, peers, and journal publications of the value of interdisciplinary work in the face of a widespread attitude that working across fields is less scientifically rigorous (or suspect design-wise).
(d) Struggling through disparities in salary and academic recognition among the different disciplines.

Despite these challenges, we have been very successful at designing, building, and testing information visualizations supporting real time decision making in anesthesiology, finance, process control, live art performance, and network monitoring. These information spaces display data in a format that makes best use of human natural perceptual abilities. Rigorous scientific testing has demonstrated that 'dwelling' in such data representation architectures allows people (i.e., anesthesiologists, traders) to make more accurate, faster, and better decisions than with existing systems. Indeed, they can do so while with reducing their cognitive load, stress, and training time.

The success of this enterprise is proven by the longevity of our group (8+ year long), over $4.7M in grants (from the NIH, NASA, DARPA, ARDA, State Centers of Excellence, and private industry) and a very prolific productive record with over 50 articles published in 4 fields, several pending patents, a spin-off company, 3 commercial licenses and more than 20 public live art performances in 3 continents. The recent commercialization of our information visualization technology in Medicine means that our work will soon find its way into operating rooms, intensive care units, and other medical environments for the benefit of society at large.

Such accomplishments, as well as the role of architecture in leading this interdisciplinary effort, educate the university environment regarding the significant role that architecture may play in advancing the cause of science, technology, and academia at large. As important, it demonstrates the value of architectural education and inquiry to our own students, practitioners, scholars, and administrators. In doing so, this research work expands the existing boundaries of architectural research while offering a valid example of alternative architectural practice. It also shows the potential leadership role that architectural schools and faculty may play in interdisciplinary education and research on campus and beyond.

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