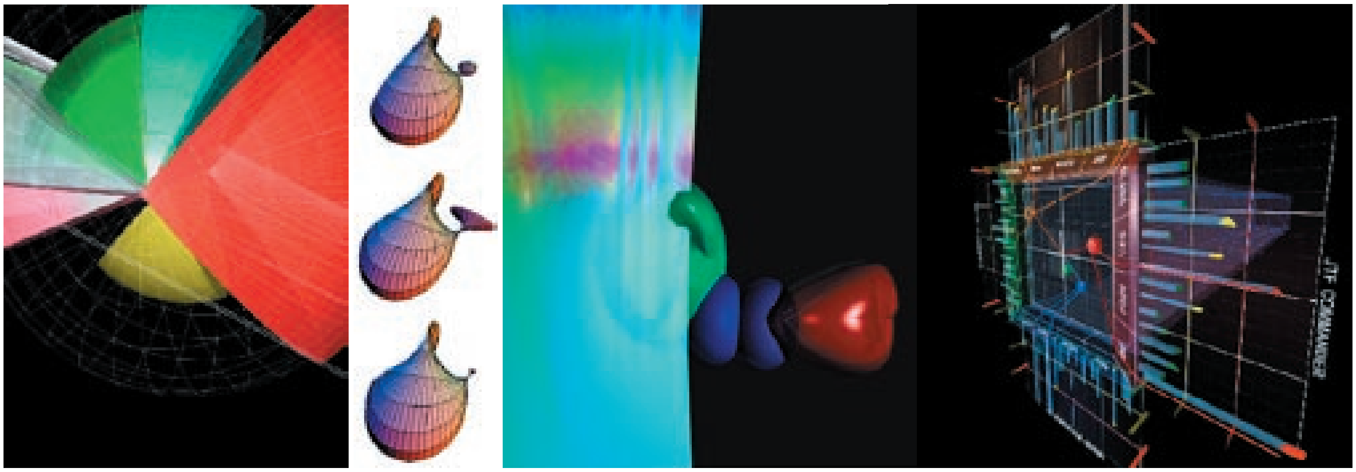
INTERDISCIPLINARY INFORMATION VISUALIZATION DESIGN
Toward A Data Representation Architecture



This nomination presents a broadly interdisciplinary, research and practice expanding, creative architectural work in the area of information visualization.

As our civilization continues to dive deeper into the information age, making sense of ever more complex and larger amounts of data becomes critical. This work takes on this challenge by using architectural expertise to solve information problems facing many fields. The result is the design, construction, testing, and deployment of data environments supporting real time decision making in Anesthesiology, Finance, Process Control, Live Art Performance, Nursing, and Network Monitoring. These information spaces display data in a format that makes best use of the vast and innate human perceptual abilities in pattern finding. Rigorous scientific testing have demonstrated that 'dwelling' in such data architectures allows people (i.e., anesthesiologists, traders, etc.) to make more accurate, faster, and better decisions while with reducing their cognitive load and stress. Furthermore, the intuitive nature of these information visualization designs imply less training time.

This work also demonstrates the natural leadership role that architecture may play in interdisciplinary endeavors. Using four core architectural competencies (i.e., representation, formal semiotics, design studio and organizational leadership, and the design process) architectecture faculty became the leading group within a collaborative assembly of 5 disciplinary teams with over 25 individuals.

The success of this research has been proven by the longevity of our group, over 4.7M in grants and a very productive record with over 50 articles published across 4 fields, several pending patents, a spin-off company, 3 commercial licenses, and over 20 live public performances in 3 continents. The recent commercialization of our visualization technology in anesthesiology means that our work will soon find its way in medical environments for the benefits of society at large.

Such accomplishments educate the university environment of the significant role that Architecture may play in advancing the cause of science, technology, interdisciplinarity, and academia. 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.

Background

The Growing Challenges of a Data Saturated World

We are living in a world overflowing with information.[1] Millions of labs, apparati and scientists across the planet are continually conducting millions of experiments, observations, and analyses producing ever growing amounts of information. 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 demand for and accumulation of data. In this reality, the 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 are many well documented examples of inappropriate decisions based upon poorly presented information and often leading to disastrous effects (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 effects may be found in the 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, etc.).[4] The reason for this worrisome state of affairs is our persistence in using early 20th century quantitative methods, naïve notion of human cognition, and simplistic representation spaces when battling data environments of 21st century complexity. A good example of the prevailing and limited paradigm in information visualization is shown below. We just cannot keep doing this any longer and expect good results.

Current display of physiologic data in Anesthesiology (Hewlett Packard). 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 years of training; and as a result (6) experts have the cognitively demanding and error-causing task of associating the variables in real time to correctly diagnose clinical scenarios

Toward Data Representation Architecture

The present shortcomings of data representations can be traced back to the fact that most information visualizations have been produced by scientists and engineers, who 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 elaborate 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, perceptual, and symbolic dimensions intrinsic to all decision making process. These systems must transform raw data into information through representation design. What appears difficult or impossible to accomplish from a hard-science perspective, is realizable from an architectural viewpoint.

For over eight years, our research group has been working on the visualization of information in five domains: Medicine, Finance, Live Art Performances, Process Control, and Network Monitoring. Our goal has been the development of new ***data representation architectures*** that offer a better alternative to the 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, Medicine, Music, Psychology), it is Architecture that has taken a decisive leadership role at the managerial, conceptual, and productive levels of the interdisciplinary effort.

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] Although there are excellent works in this area, [7] none covers the type or range of theoretical and practical issues of our research.

Our experience 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. [8] 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) [9]

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 thus natural for Architecture to take a leadership role in advancing the state-of-the-art of information visualization.

3. The Studio Model & 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, the technology to deliver such depiction, etc. Clearly, this cannot be done by architects alone. In fact, this task would overwhelm any single discipline by its sheer complexity, scale, multi-dimensionality, etc. 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. [10]

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. [11] 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 the one 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 evolved naturally 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 a simultaneous attention to multiple perspectives, skills, knowledge-bases, etc. 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. [12] Although this may not seem like a surprising finding for architects, it was indeed an important realization for those coming from other domains.

These four architectural competencies and their natural application to interdisciplinary work are particularly relevant to architectural programs because they speak of the potential capabilities of our discipline beyond the tradition bound conceptions of research and practice.

Following, we will show some of the results of our interdisciplinary work in four domains: Anesthesiology, Live Art Performance, Finance, and Network Monitoring.

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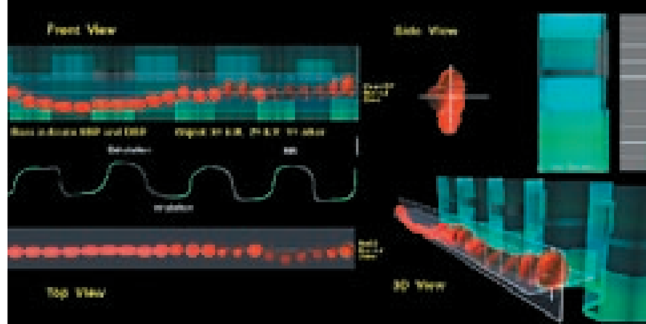
ANESTHESIOLOGY

Anesthesiologists face unexpected incidents during 20% of all anesthetics. Human error is associated with more than 80% of the critical incidents and more than 50% of the deaths. [13] 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 page 2).

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. [14] 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. We started by studying the visualization problem of having to represent 32 interrelated, non-spatial physiologic variables in real time *and* in a way that improved detection, diagnosis and treatment accuracy and speed over the existing data representation system. Presently, anesthesiologists watch all 32 parameters plotted separately as 2D waveform charts and numbers to determine if a patient is stable and in the desired physiologic state (see Figure in page 2).

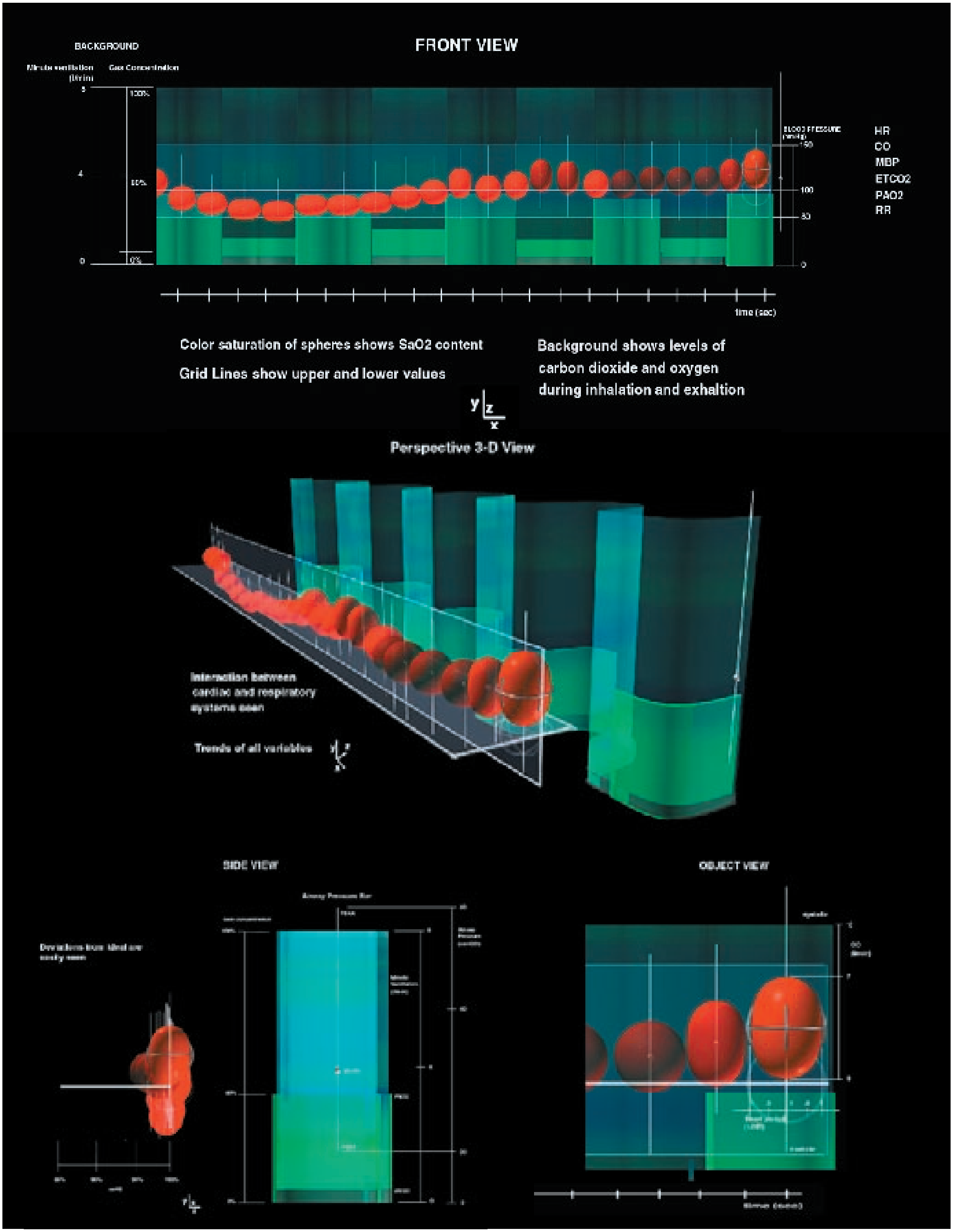
Our data visualization solutions offer a fundamental departure from the way the medical field presently detects, diagnoses, and treats physiologic conditions. Figure 2 shows our first completed data representation architecture displaying the same data in four interactive windows; each one designed to show certain information in detail and complementarily. Departure from "normal" reference grids, shapes, spacing, and colors helps the clinician ***discover change***. The display structure maps each variable to a clinician's mental model, to help ***diagnose problems***. Functional relationships link the elements of the display to help the clinicians ***treat problems***. The visualization design also offers a holistic view of the two major physiologic functions (cardiac and pulmonary) that need monitoring doing anesthesia.



Data modeling follows specified 3D configurations with time expressed in X. First, 13 measured variables are organized into data sets or "critical functions" that are then mapped to 3D objects and their behavior. These objects work as metaphors. The spherical object depicts cardiac variables: its height is proportional to the heart's Stroke Volume, its width is proportional to Heart Rate whereas its total volume is proportional to the heart's total Cardiac Output. Each 3D ellipsoid shows the efficiency of a heart beat: deformations from normal spherical shape show non-optimal functioning. Movements up and down allow the association of the state of that object (and its variable relationships) to Blood Pressure.

Critical respiratory function data are mapped to a bluish 'curtain' plane in the background. This object's ondulation back and forth in Z space plots Inhalation, Exhalation and Respiratory Rate information (Top View). Data relative to gas types and volumes are mapped in Y space. Variance of gray and green colors shows inspired and expired gases and their concentrations (Oxygen and Carbon Dioxide). The height of the "curtain" is proportional to Respiratory Tidal Volume. By establishing a figure-ground relationship between the "sphere" and the "curtain" and by incorporating color to depict Arterial Oxygen Saturation into the spherical object, there is an immediate perception of the health state of both essential physiologic functions.

A series of frameworks establishing normal values are offered to help detect departure from normalcy. Of the four views, the Side View *is critical in establishing the present physiologic state of the patient. It has been designed to work and look like a physiologic 'target' for the anesthesiologist to aim at. Top and Front Views show the "life space" or physiologic history of the patient. These two views allow for analysis and comparison. The 3-D View provides an uniquely comprehensive, integrated and interactive view of all physiological data at once.*


FRONT VIEW
BACKGROUND
HR
CO
MBP
ETCO2
PAO2
RR
time (sec)
Color saturation of spheres shows SaO2 content
Grid Lines show upper and lower values
Background shows levels of
carbon dioxide and oxygen
during inhalation and exhaltion
Perspective 3-D View
Interaction between
cardiac and respiratory
systems seen
Trends of all variables
SIDE VIEW
OBJECT VIEW

ANESTHESIOLOGY

The images on this spread show our design research efforts to develop physiologic data displays presently not available to physicians and anesthesiologists and which result in significant improvement in high-risk medical services.

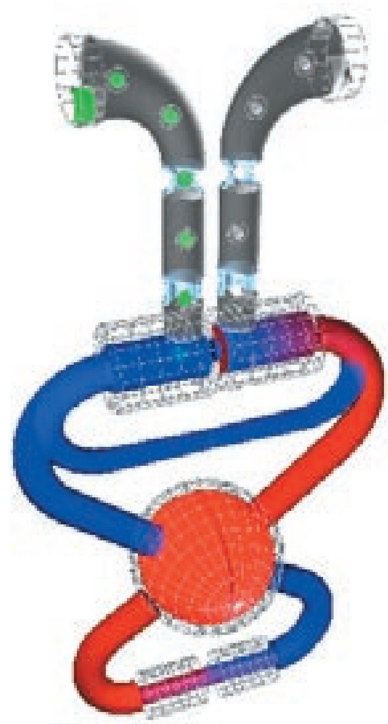
On the top half of both pages are sample screens of our *Cardiovascular Data Display***.** The design organizes measured and modeled cardiovascular information variables, showing functional relationships and including concepts such as preload-afterload. This visualization design also offers respiratory data displaying functional relationships and essential gas exchange information. Versions of both data representation architectures are being implemented in existing medical monitors..

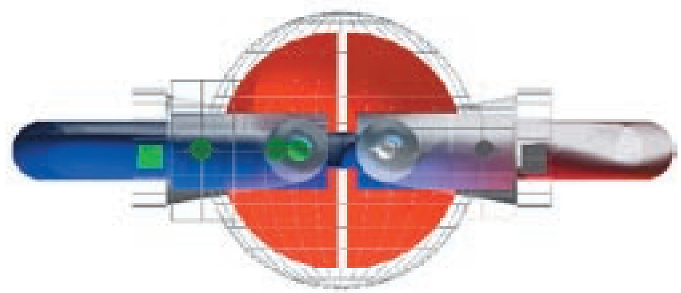
On the horizontal bottom of both pages are examples of our *Drug Data Display* that deliver dynamic representations of pharmacokinetic behavior while offering prediction information and historical trending. A version of this data representation architecture will soon be available for anesthesiologists in the market. Since no integrated visual display presently exists, our work is expected to have a positive impact in the current delivery of anesthesia.

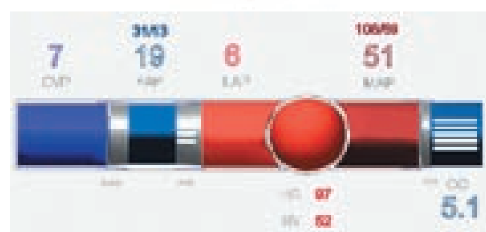
Thorough scientific evaluations of physiologic data displays have showed statistically significant improvements in performance in several critical scenarios when compared to performance utilizing traditional/existing data displays. [15]

For example:

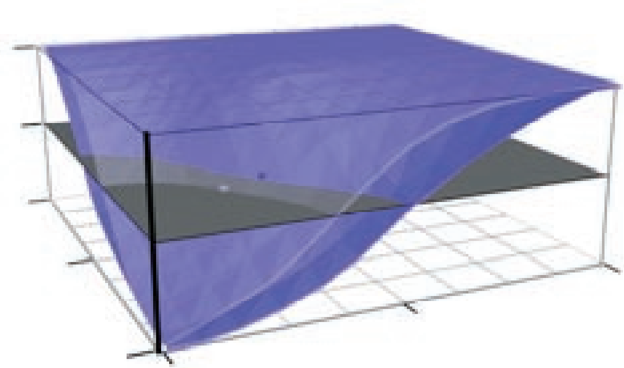
- Clinicians detected anesthesia-related critical events sooner (3.1 vs. 5.5 min),
- Abnormal events were diagnosed more accurately (error rate 1.1% vs. 4.1%),
- Problems were corrected in one-third the time (17 sec vs. 45 sec), and
- Drug delivery was better controlled (EC95 error 21% vs. 44%).

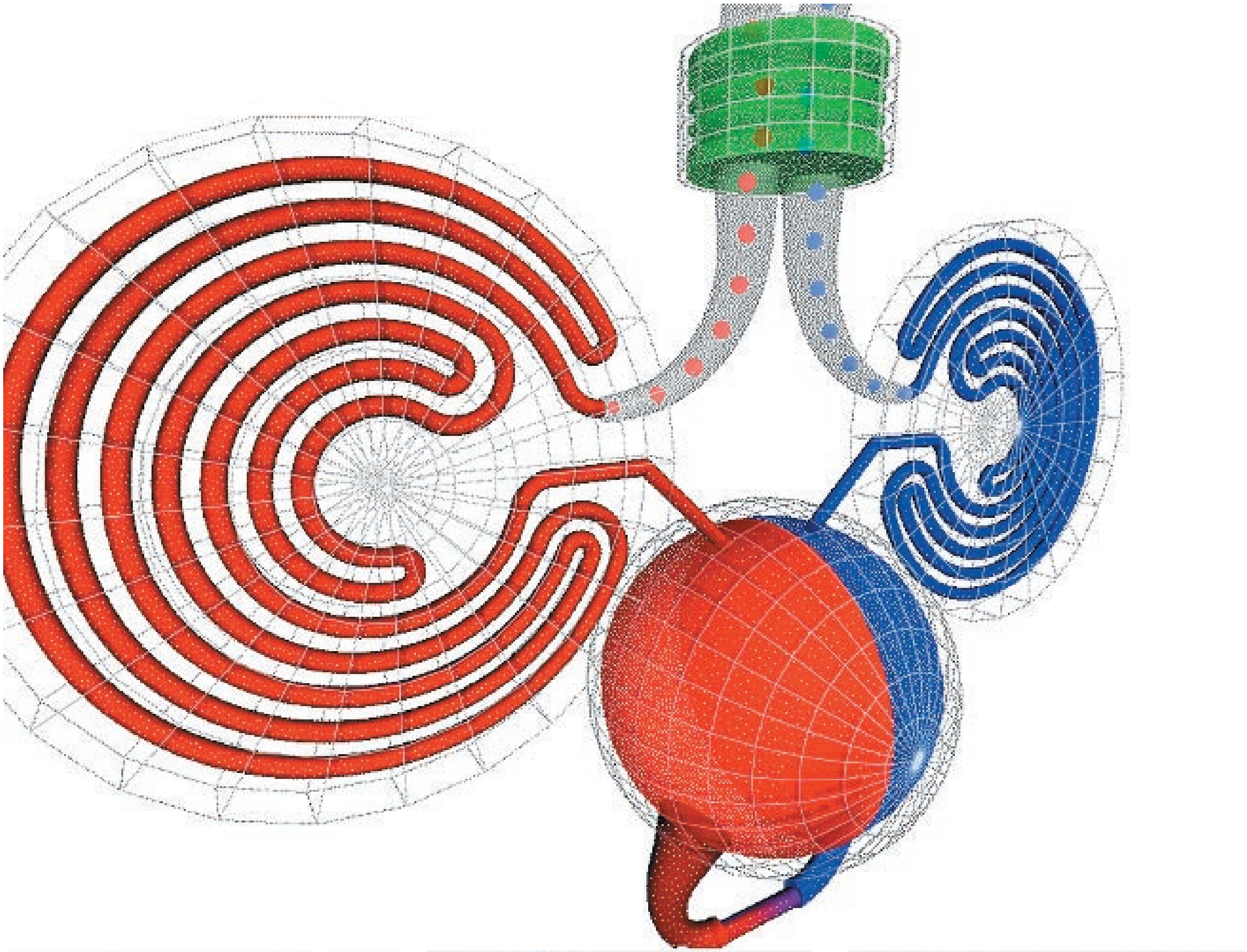


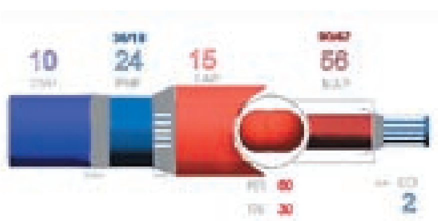




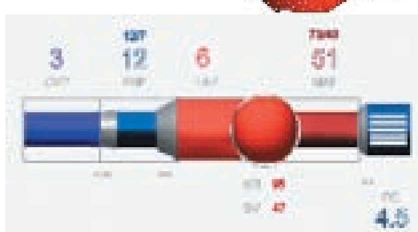
Normal Cardiovascular activity



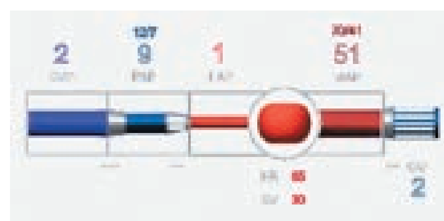




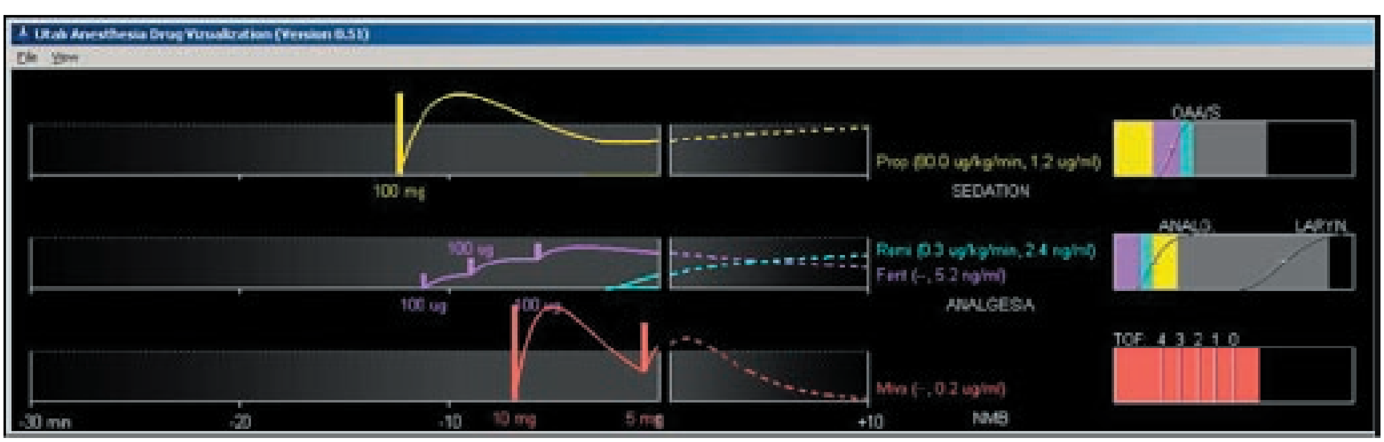
Ischemia



Anaphylaxis



Hypovolemia



FINANCE

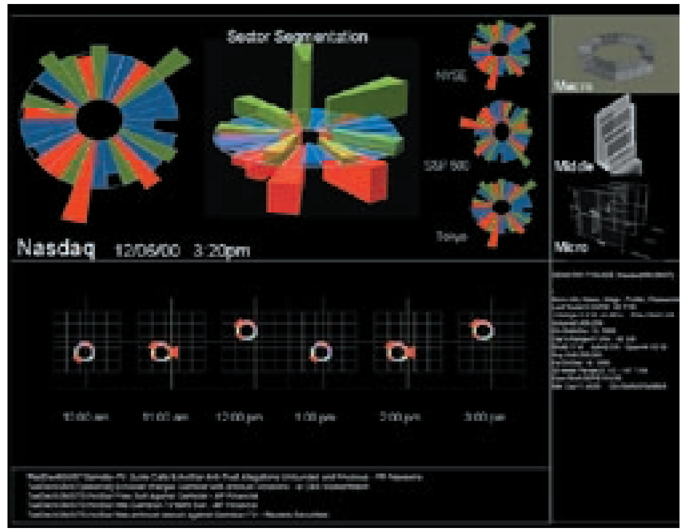
As in anesthesiology, the current paradigm for financial data representation uses alpha-numeric depictions or 2D graphs and bar charts. Little has been done to improve this situation, despite the increased amount of available real time, historical and computed market data. [16] The typical trader uses multiple monitors, and still complains of insufficient screen space and the difficulty to process the quantity of data displayed. Based on formal interviews with traders regarding their decision making strategies, data needs, usability expectations in combination with the equity trading expertise of our finance co-investigators, we developed an interactive prototype that organizes financial data according to use, scale, and trading tactics.

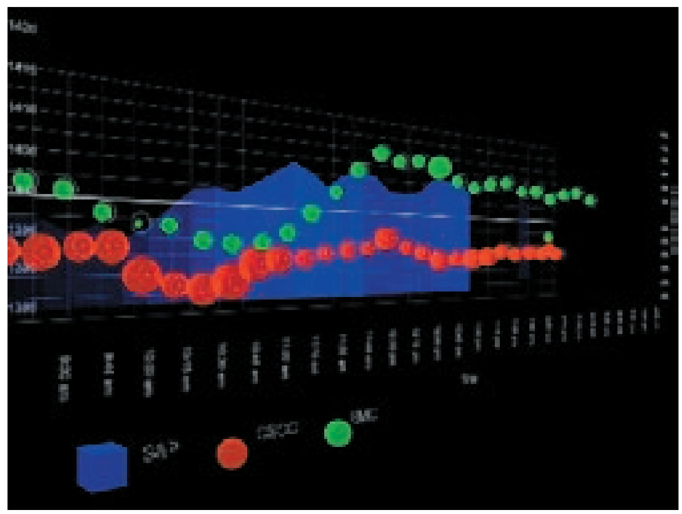
By integrating data following users' cognitive models, making full use of 3D objects and attributes for data mapping, layering and scaling data (from the whole stock market, to industrial sectors, to individual stocks), and permitting high levels of user interactivity, we were able to achieve a level of response to financial decision making not found in today's information visualizations.

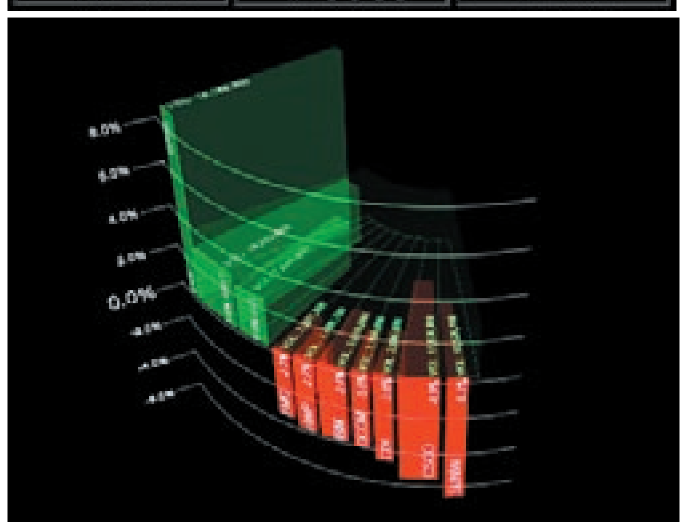
The resulting work was presented to 10 financial firms, including investment banks, data vendors and electronic exchanges companies. We received excellent feedback from all of the firms and three of them indicated an interest in collaborating with us to develop and refine our work. Based on this process and its results we are now working on an investment analysis visualization and moving toward a general data representation architecture for the equity trading market.

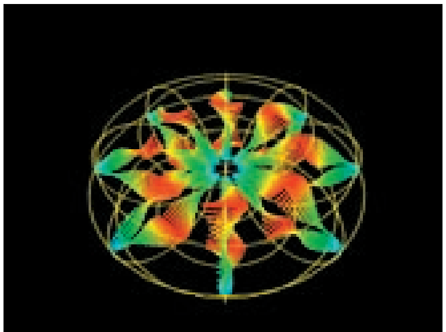
Note: Although the work of Asymptote on financial data may appear similar, there is a difference. Our work is grounded in wide interdisciplinary collaborations as well as substantial testing of the design work during and after development.

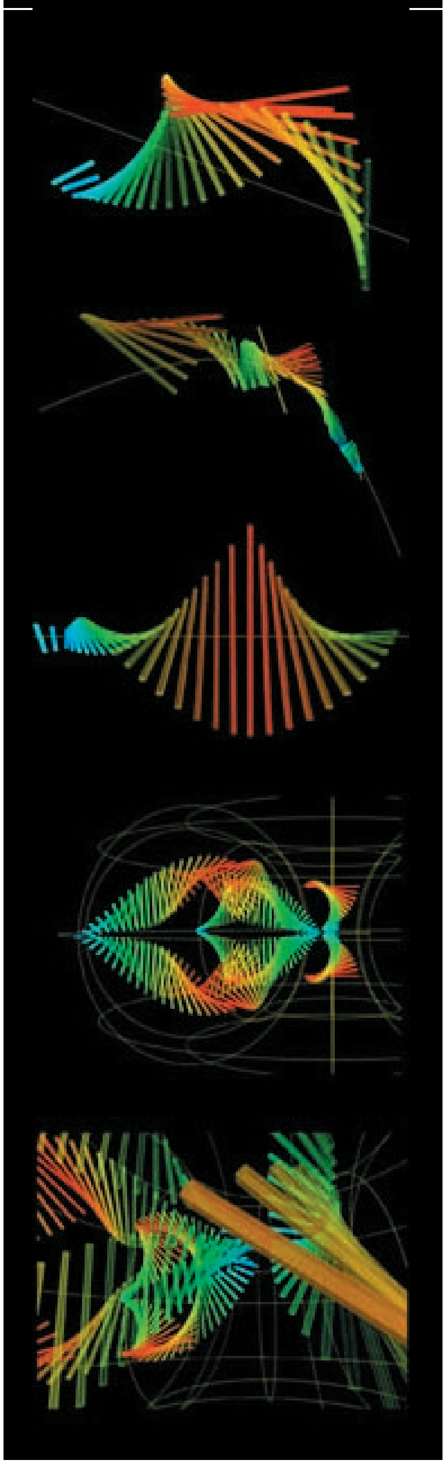
Right Column: Stock market visualization organized in multiple scales following data structure and user needs. Next page: Multiview of torus topological organization of financial data that is grounded on the cyclical nature of business transactions, market aggregation, sector and portfolio sectioning, and particular stock behavior.

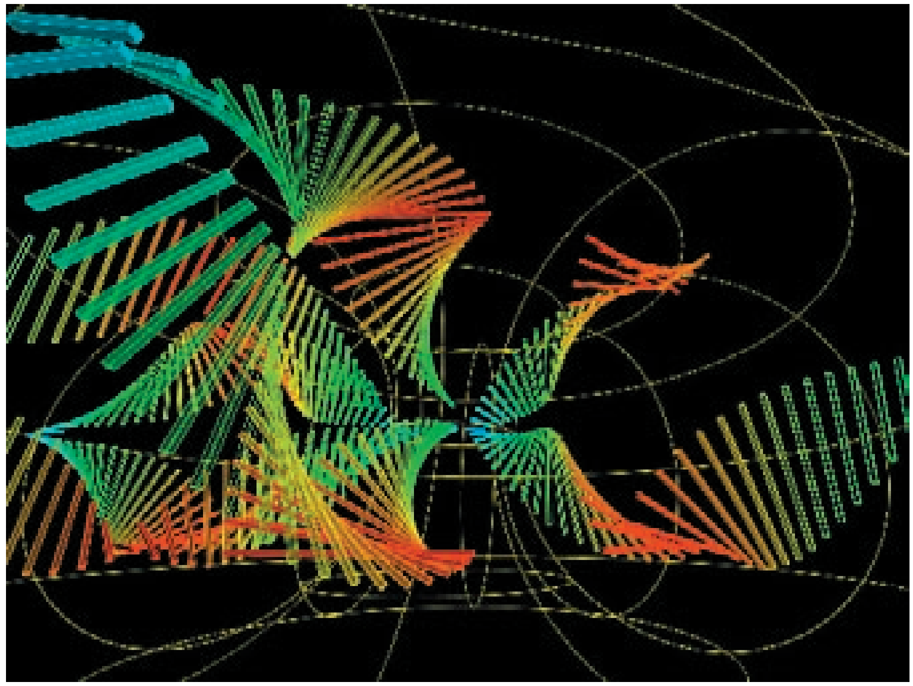


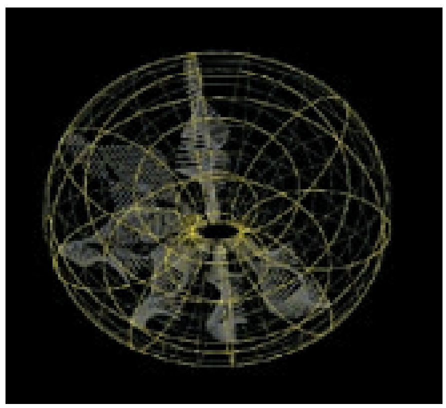


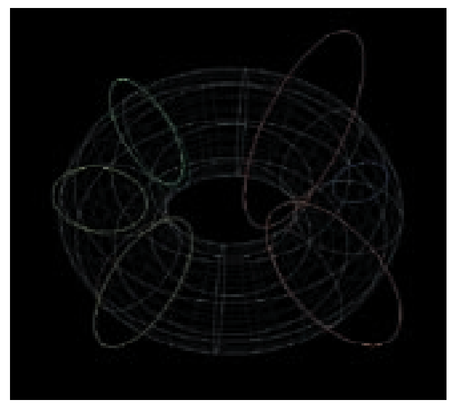


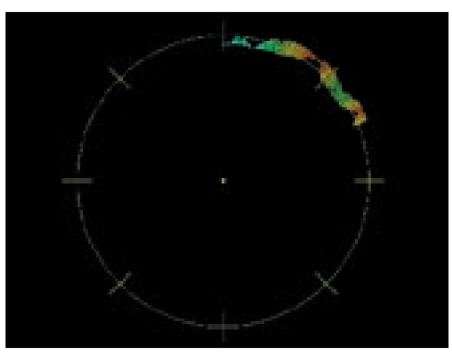


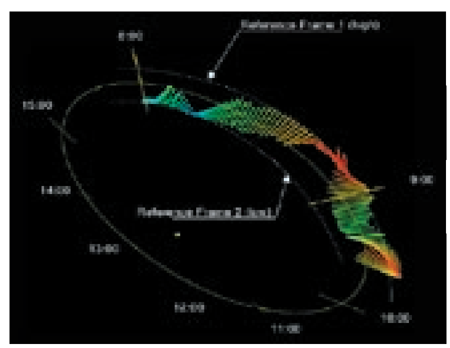


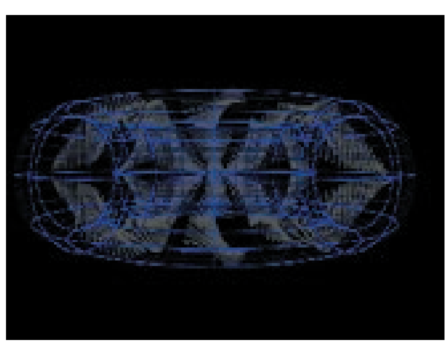


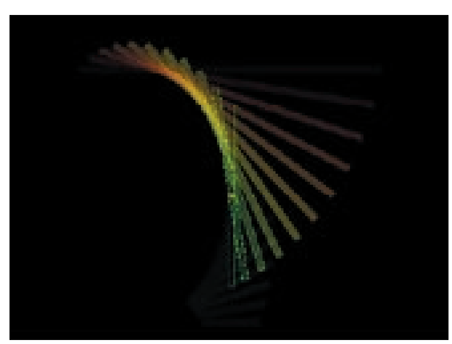




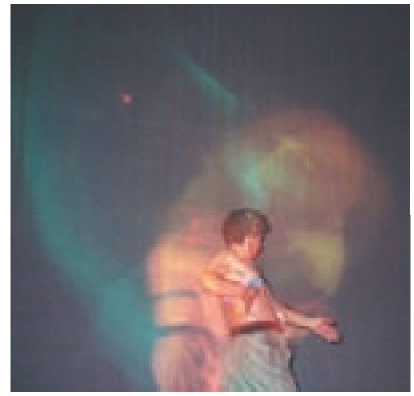


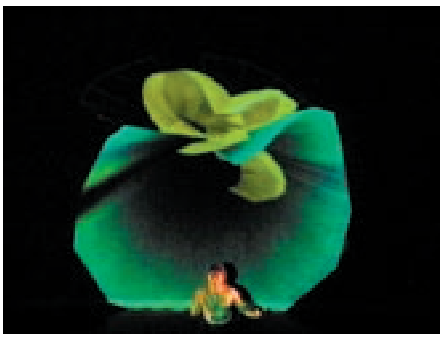


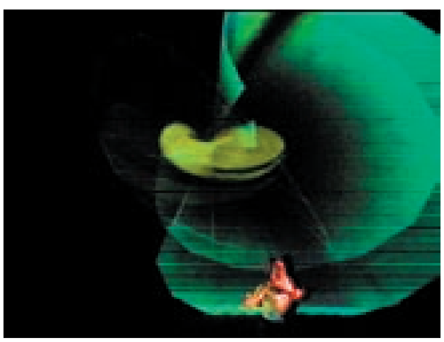


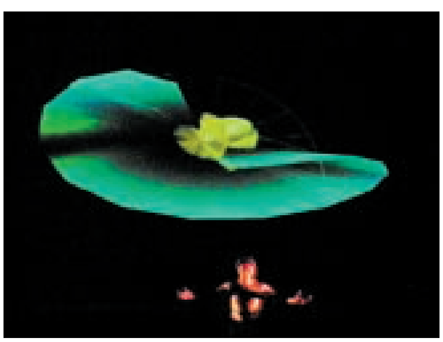


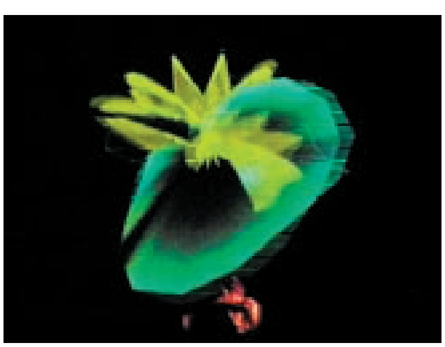
*cyber*PRINT: Live Art Performance

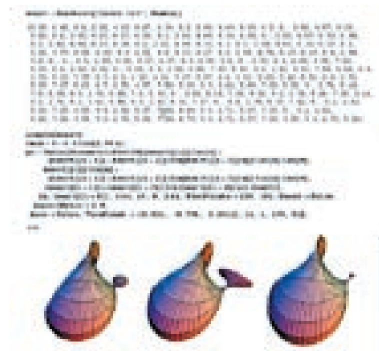


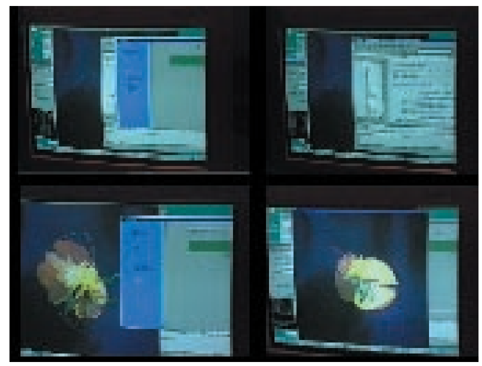




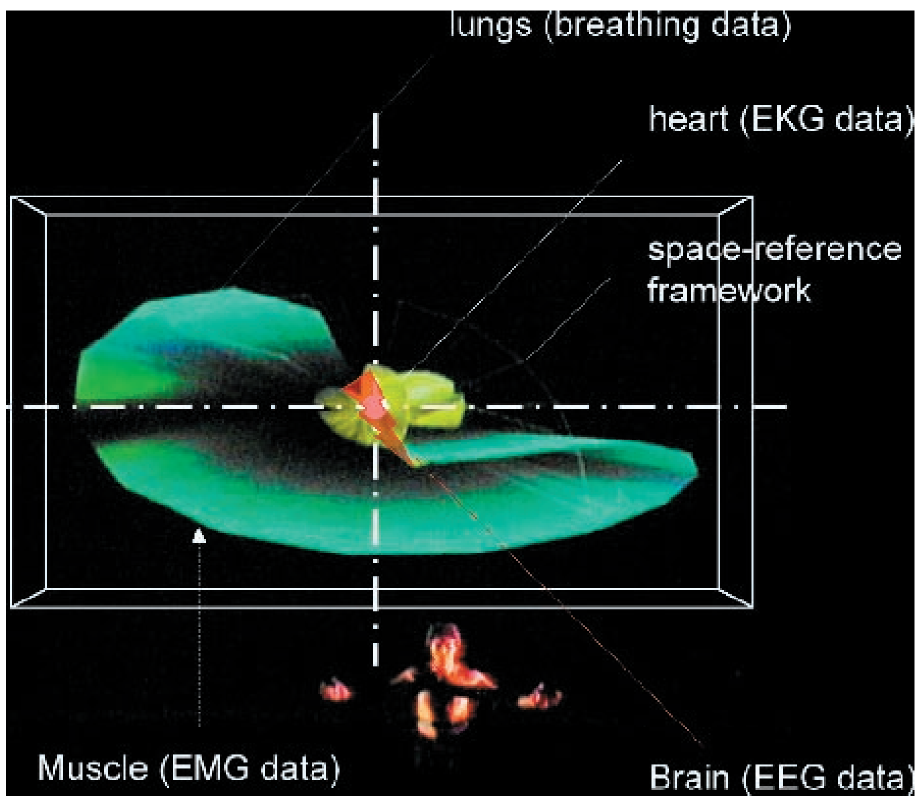


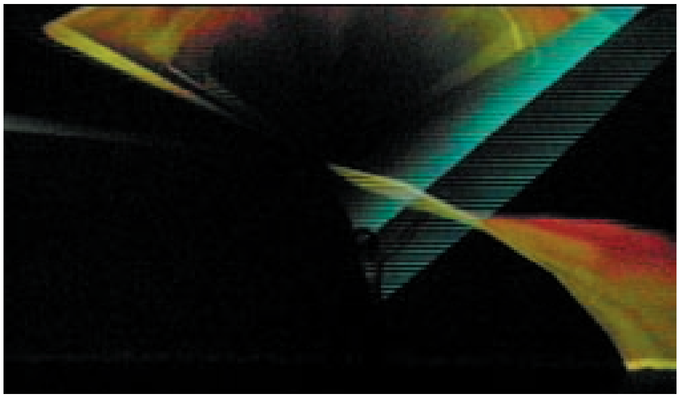


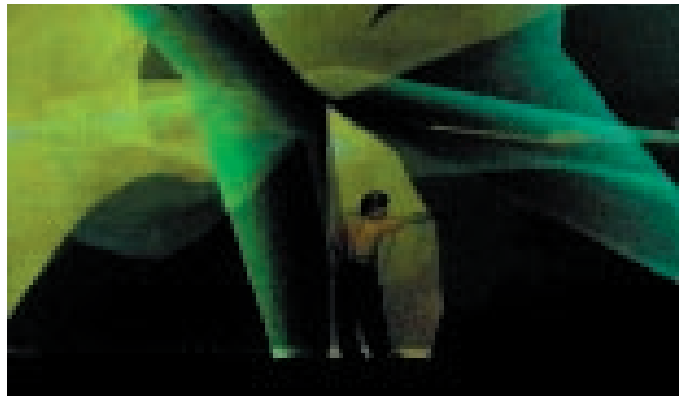




Top row: Performer trying out the cyber**PRINT** *technology. Abvove: Mathematical equations supporting architectural definitions (left) and screens of software specially written to run the project (right). Left column and next page: still video captures from live performances (circa 2000-2002). Below: diagram explaining the data mapping logic generating the virtual reality world in real time.*







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

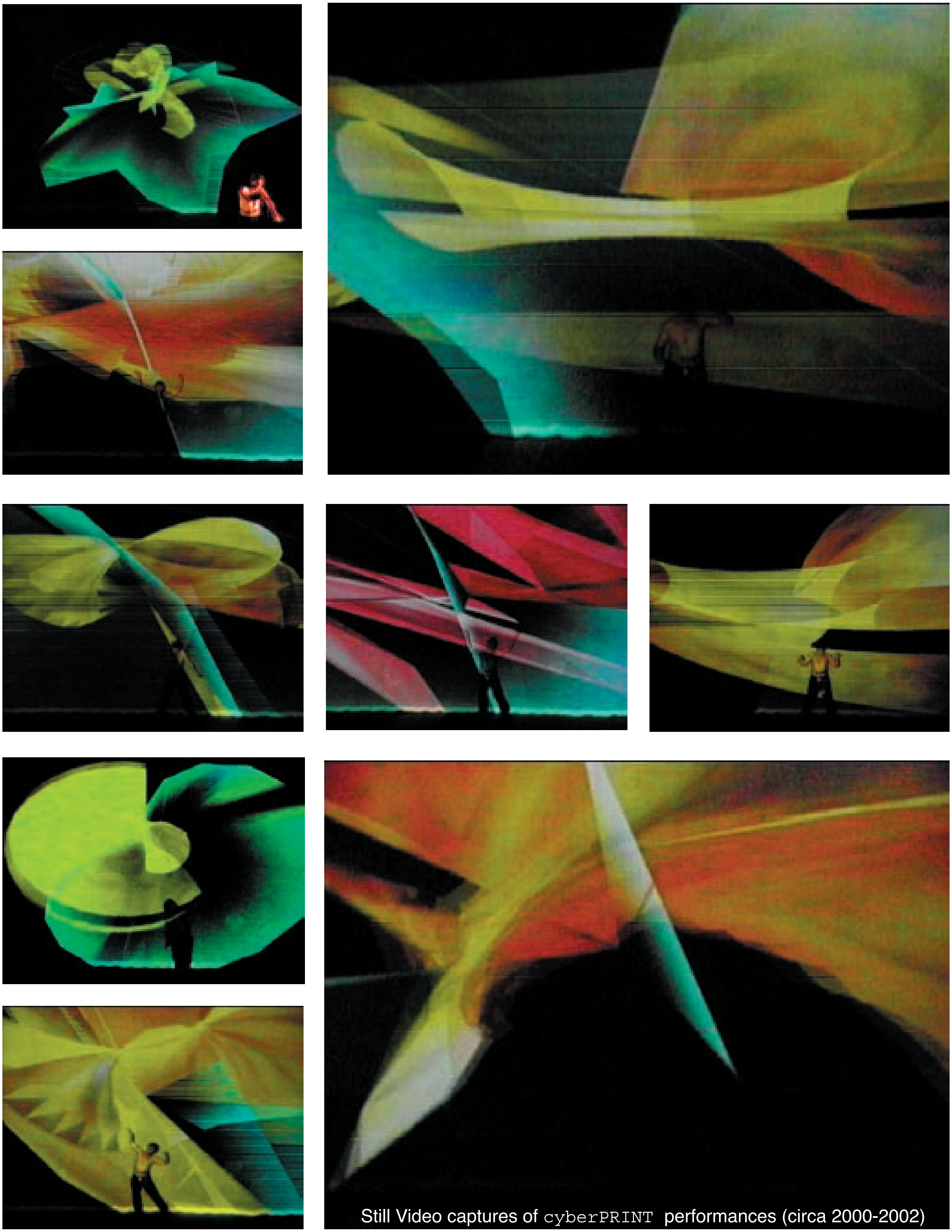
The *cyber***PRINT** is an electronic bio-feedback system driven by physiologic data drawn from a performer via special sensors attached to her body and transmitted wirelessly to computers which, in turn, generate and project a especially designed and programmed audio-visual 3D virtual reality in real time. Since the resulting virtual artifact *re*presents 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 *cyber***PRINT** allows that individual to visualize, inhabit, and interact with herself 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 *cyber***PRINT**.

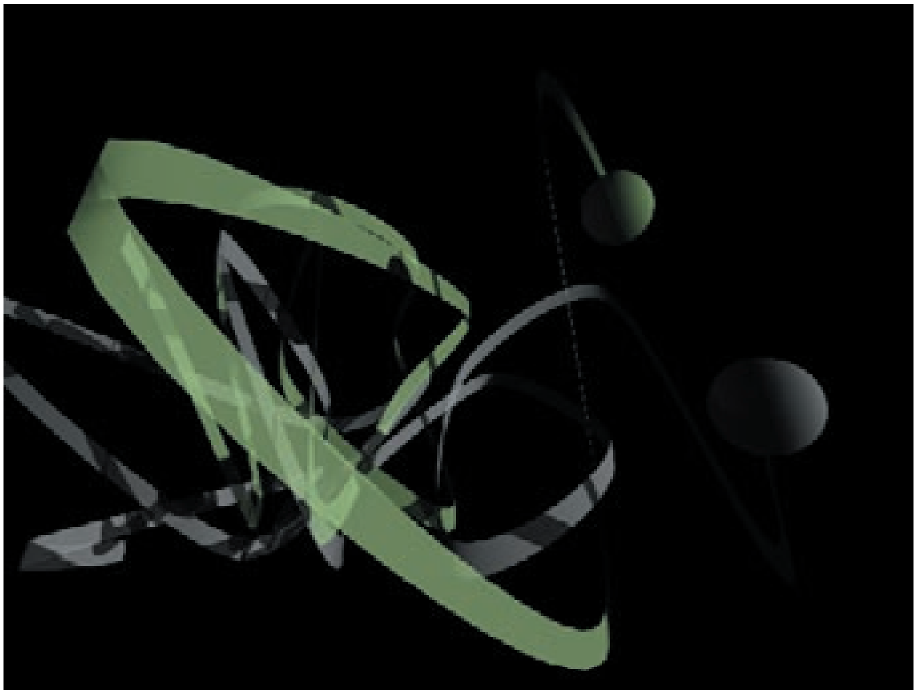
By making the body the hinge point where virtual and physical spaces meet and interact (i.e., the virtual is generated by the real but the real is affected and changed by what the virtual does), the *cyber***PRINT** casts new light into what has become ordinary for most individuals today: the coexistence 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.

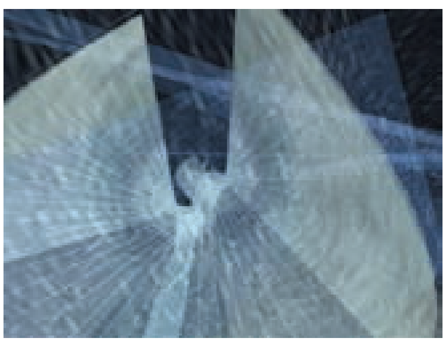
The *cyber***PRINT** completely owes its existence to the interdisciplinary collaboration among Architecture, Bioengineering, Medicine, Computer Science, Choreography, Modern Dance, and Music. In 'exchange' for this effort, the project has played an instrumental role in infusing impetus, creativity, 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 *cyber***PRINT** It is also clear that the research, design, and performance of the *cyber***PRINT** have expanded the conceptual, aesthetic, and technological boundaries of architecture. [17]

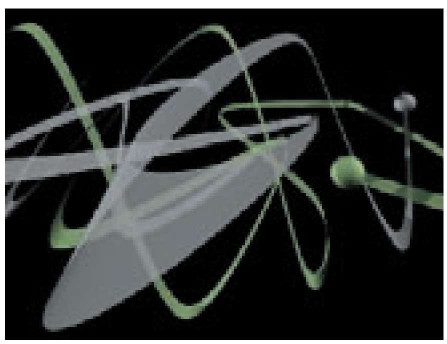
*cyber*PRINT

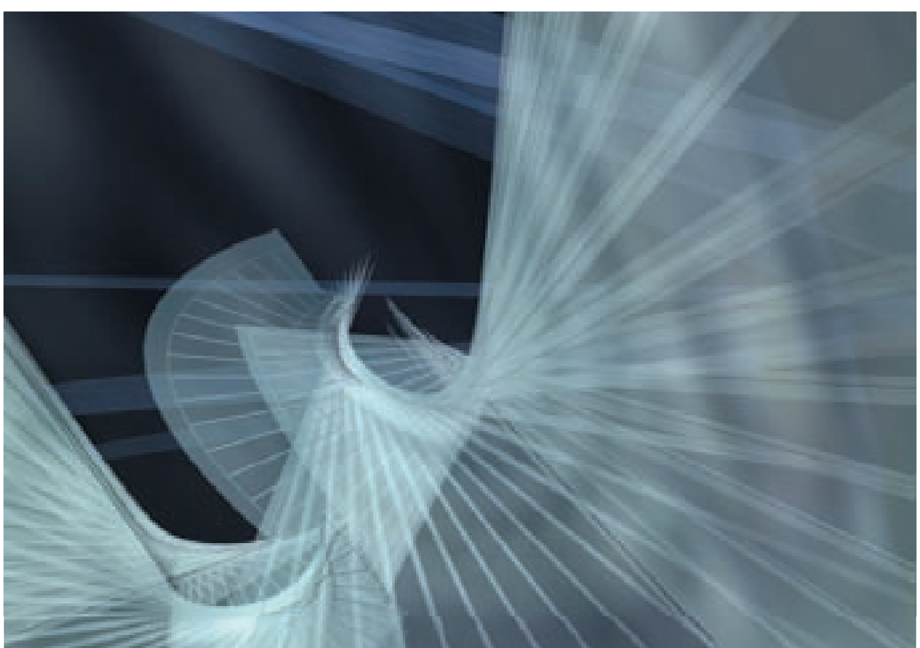


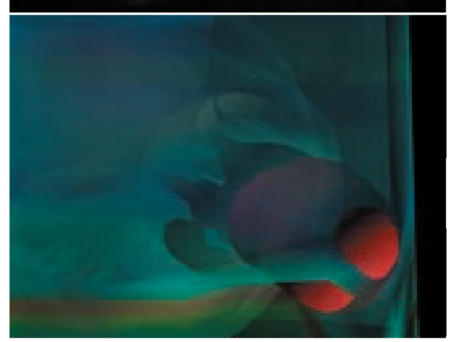
Still Video captures of cyberPRINT performances (circa 2000-2002)

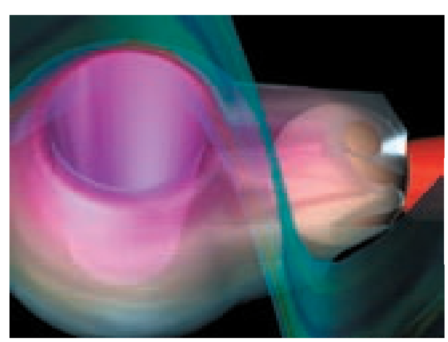












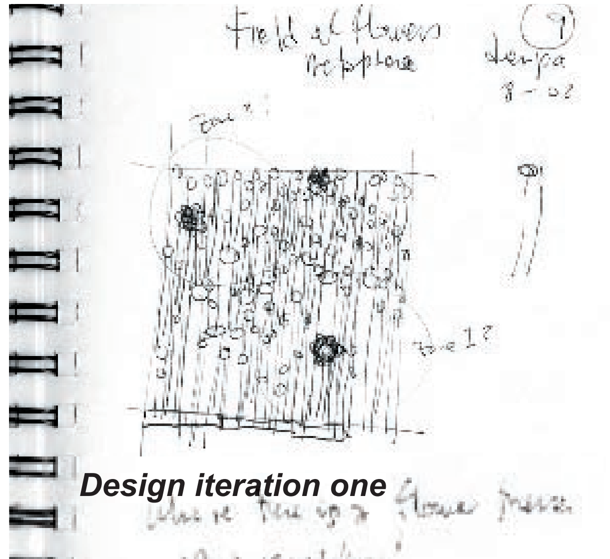
Virtual world details and still video captures of performances (May 2004)

NETWORK MONITORING

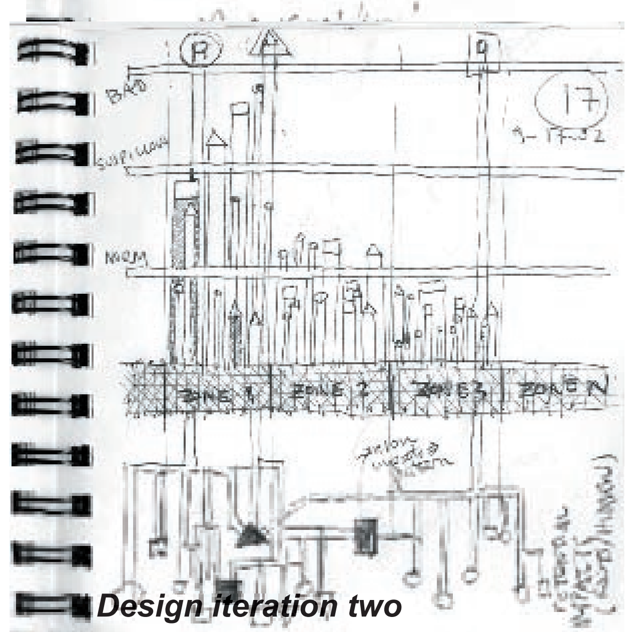
The health and security of information networks is a priority for science, engineering and society today. The Network Operations environment is not as regulated as Anesthesiology, and has not had as a large concentration or communication of operators as Finance. These facts have precluded the codification of heuristic knowledge, coherent analysis methodologies, and the standardization of monitoring tools. In a typical situation, a single engineer is responsible for a network, chooses among a plethora of software that substantially vary in purpose, complexity, and price, customizes a dashboard, and learns while working. Although countless tools have been developed to visualize the hierarchy of data structures, there is still no good information visualization model that adequately presents the extensive data volume that needs to be depicted while reducing its complexity without obscuring important data [18]

Our work takes on this challenge by a combination of synthetic reductions through spatial and temporal data scaling and layering, referential frameworks, and typological and topological data mapping design so that abnormal behavior may be detected. By offering a viewing device supporting both analytical and exploratory decision making, our data representation architecture presents critical events in ways that are easier to detect, diagnose and deal with. [19] Such visualization research effort may provide a complementary vision of network operations than the one coming out of many pure Computer Science Network Research efforts.

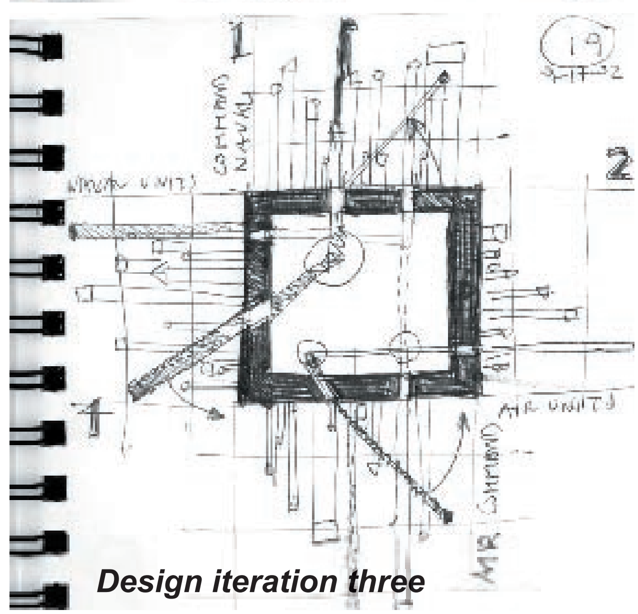
Another goal of this project is to develop data visualization that will consistently allow less experienced network operators detect early and diagnose accurately network abnormalities.



Design iteration one



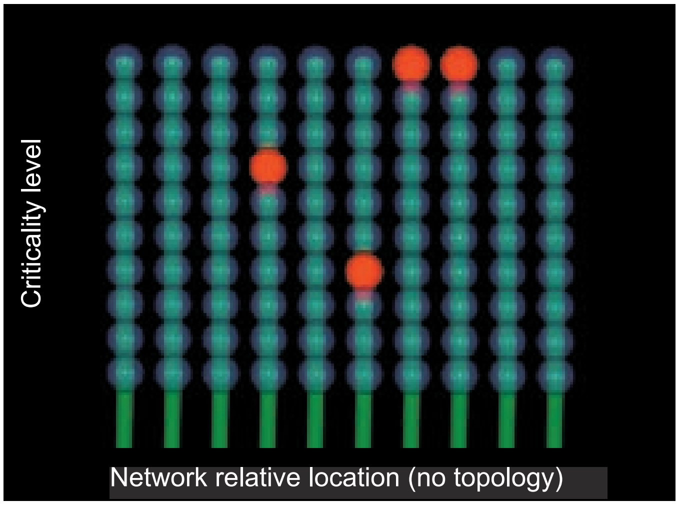
Design iteration two

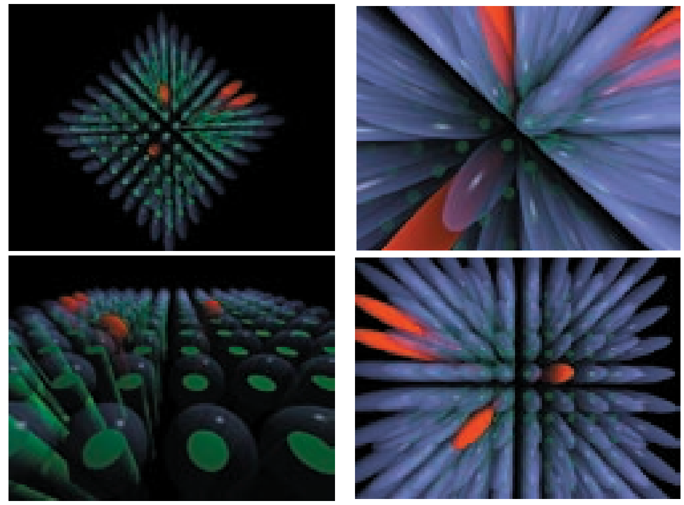


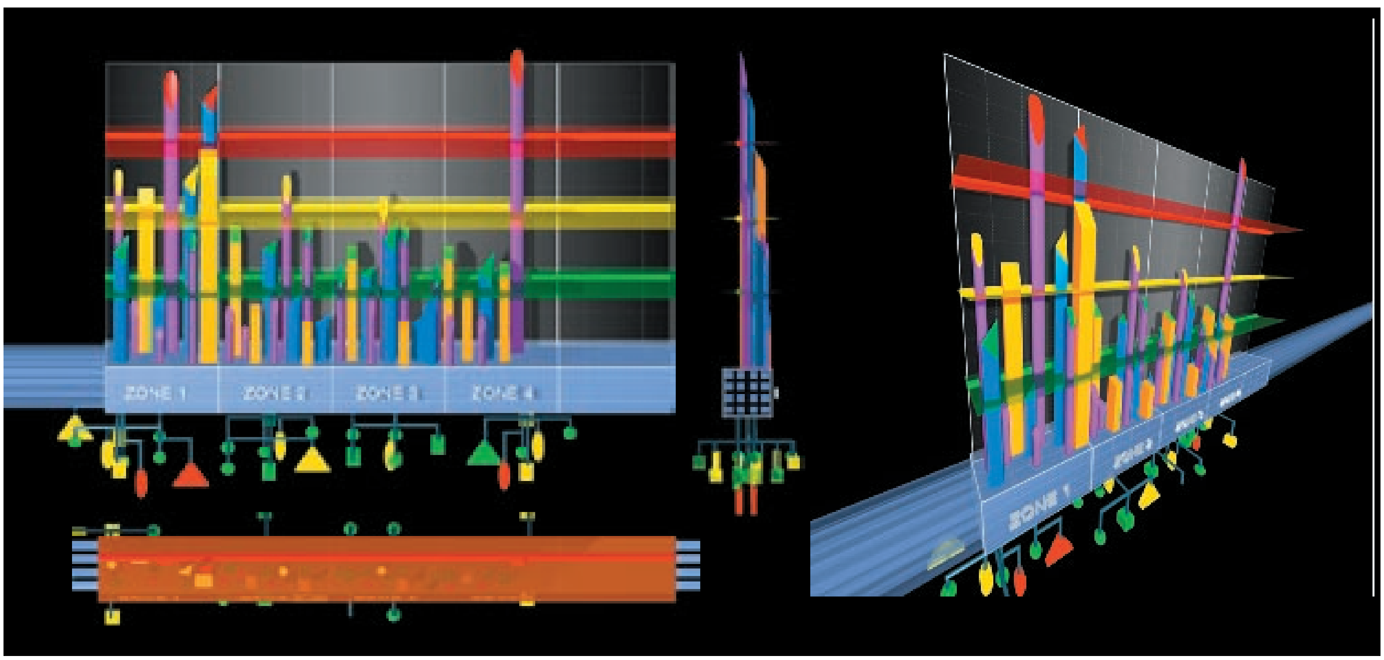
Design iteration three

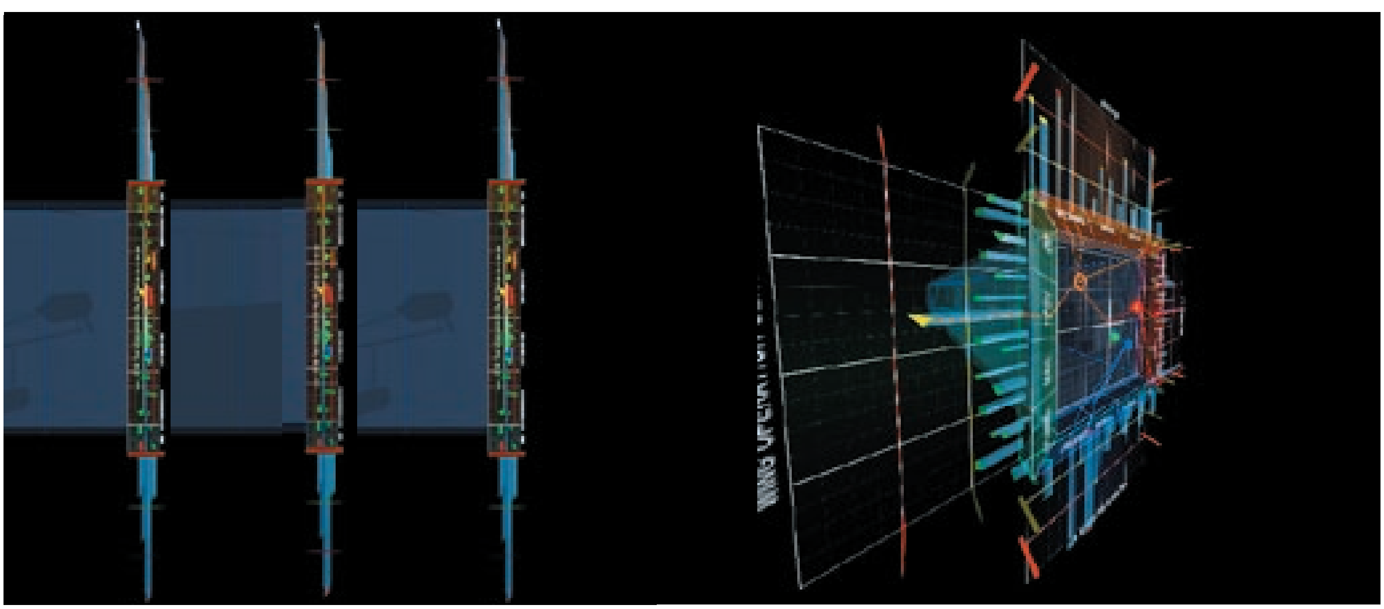
Top row (both pages): initial design scheme of network assets and zones based on a "field of flower" metaphor. Middle row (both pages): follow-up and trasnformation of the metaphor into an "urban section" concept. Bottom row (both pages and page 18): final "3D quadrant" scheme advancing earlier design ideas. Right column: freehand sketches starting each one of the three design iterations.
Page 19: Adaptation of quadrant scheme to address detailed and historicaln network data tracking needs.

NETWORK MONITORING

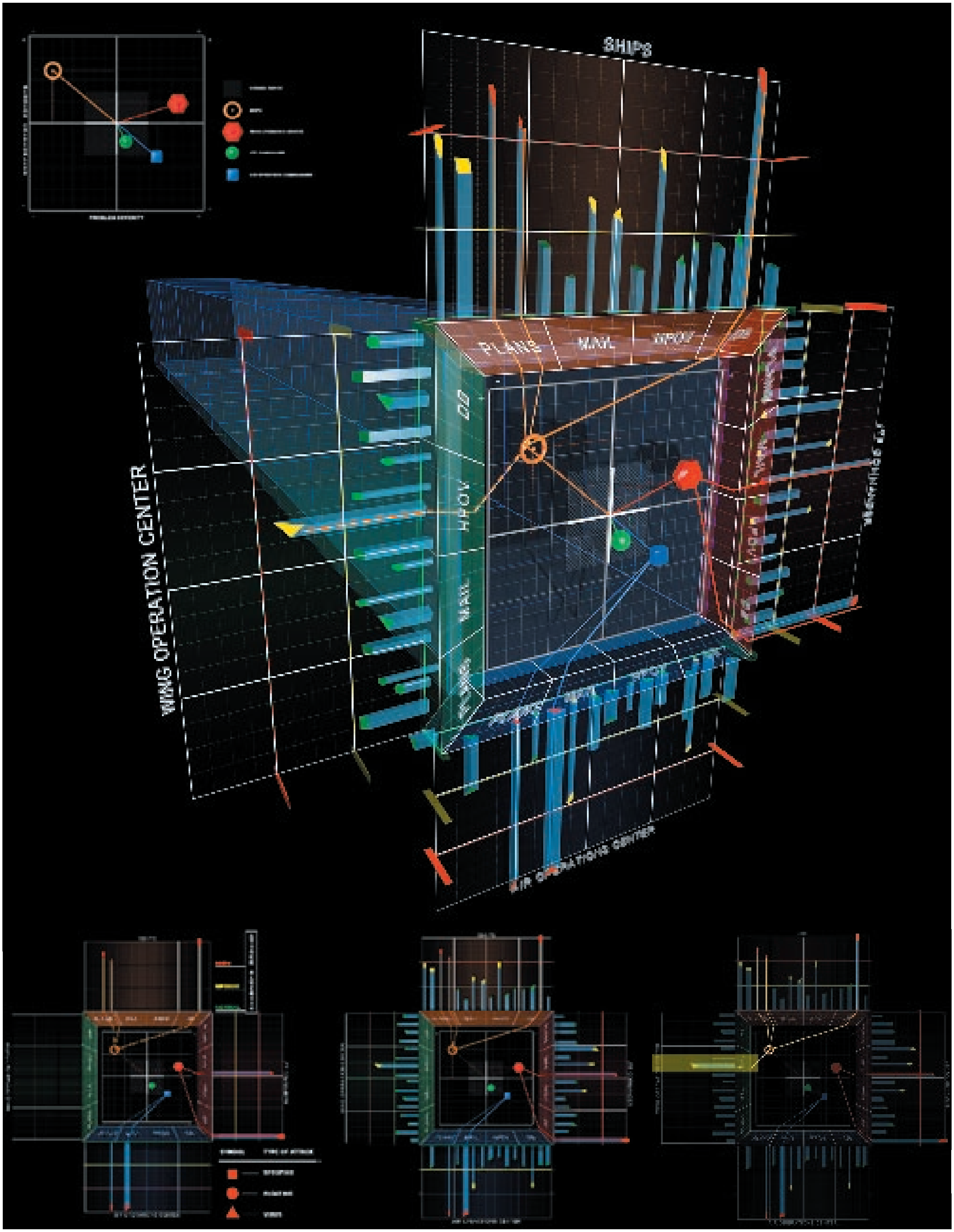




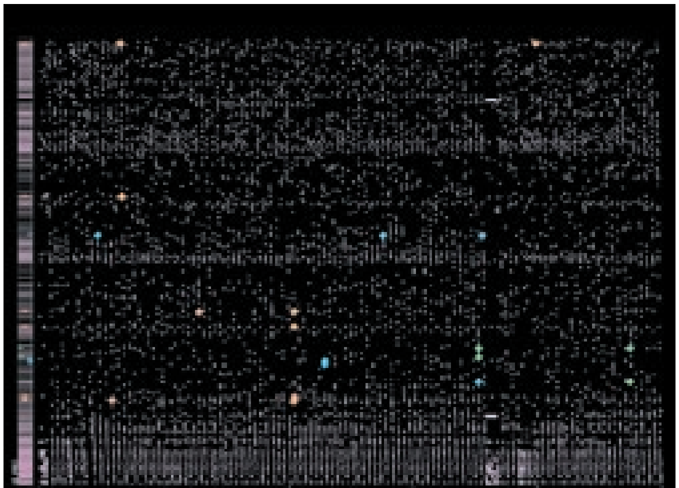




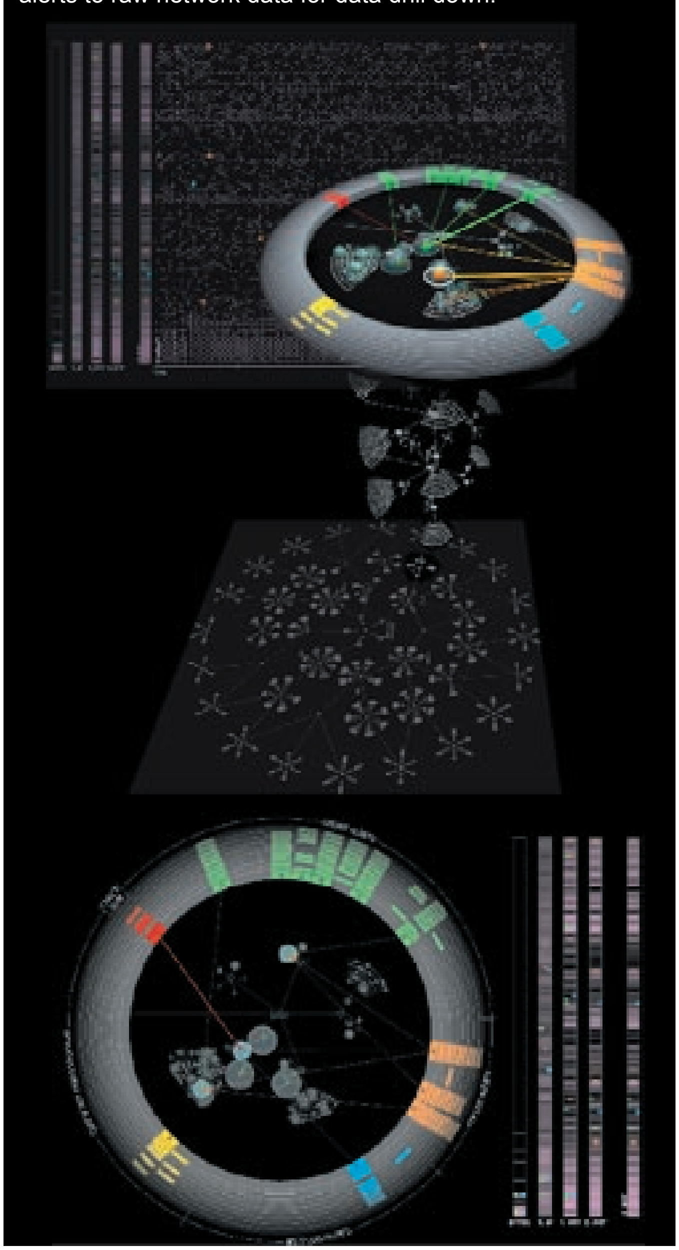
NETWORK MONITORING



CONCLUSION



Expanded view of waterfall display showing correlation of log alerts to raw network data for data drill down.



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 :

(a) Accommodating different methods, techniques, positions, interests, standards, languages, perspectives, knowledge, etc. 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, testing, and deploying 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, etc.) to make more accurate, faster, and better decisions than with existing systems. And they can do so while with reducing their cognitive load, stress, and training time.

CONCLUSION

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, the State Foundation and Centers of Excellence Program, and private industry), and a very 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 in operating rooms, intensive care units, and other medical environments for the benefits of society at large.

Such accomplishments as well as the role of Architecture in leading this whole interdisciplinary effort educate the university environment of 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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