

**Architectural Potential  
Of Data Representation:  
Modeling Physiologic Processes**

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**Abstract**

This inter-disciplinary project, seeks to develop new displays for visually representing physiologic variables, to enhance a clinician's ability to see and rapidly respond to critical events. A digital architectural visualization of an individual's physiologic data is created in real time. It is both a probing and representational system that brings together science and art through architectural design. Supported by a 5-year grant from the NIH, the project's goal is to create a coordinated and interactive hyper-representation that articulates physiologic data in a format that is easily and quickly understood. Raw data is obtained from existing medical equipment that measures human physiological signs using non-invasive techniques. Using this data 3-D objects are created in digital space that represent physiologic changes within the body and show functional relationships that aid in the detection, diagnosis, and treatment of critical event.

**Background**

Recent cognitive research studies have indicated that the human mind is better able to analyze and use complex data when it is presented in a graphic, real world type representation, rather than when it is presented in textual or numeric formats [I, II]. Additional research in thinking, imagination and learning has shown that visualization plays an intuitive and essential role in the association, correlation, manipulation and use of information. The more complex and more critical the information, the more imperative it is to communicate that information effectively. [III, IV]

Modern human factors theory suggests that effective data representation requires the presentation of information in a manner that is consistent with the perceptual, cognitive, and response-based mental representations of the user. [V, VI] For example, the application of perceptual grouping (using color, similarity, connectedness, motion, sound etc.) can facilitate the understanding of the relationships between individual pieces of data.

Proper presentation of information also affects the speed and accuracy of higher-level cognitive operations. For example, research on the “symbolic distance effect” suggests that there is a relationship between the nature of the cognitive decisions (i.e. is the data increasing or decreasing in magnitude?) and the way the information is presented (do the critical indices become larger or smaller? does the sound volume rise or fall?). Additionally, “population stereotypes” suggest that there are ways to present information that are compatible with mankind’s intuitive knowledge (i.e. an upwards movement indicates an increasing value, while a downwards movement indicates a decreasing value).

Where there is compatibility between the information presented to the user and the cognitive representations presented to the user, performance is often more rapid, accurate, and consistent. Conversely, a failure to use perceptual principles in the appropriate ways can lead to erroneous analysis of information. Therefore, it is imperative that information be presented to the user in a manner that facilitates the user’s ability to process the information and minimizes any mental transformations that must be applied to the data. [VII]

### Architectural Relevance

Architecture is a discipline that is concerned with many issues. One of the issues that architecture engages in is the design and planning of multidimensional environments that support human activities. In the context of this project, the environment is digital. Digital space can be seen as an information environment, which can be organized in a logical manner so that data is easily depicted, accessed, navigated, modified, stored, and retrieved. [VIII] This project utilizes the natural relationship between digital space and architecture and puts it to direct use in visualization design. The three Cartesian dimensions (x,y,z) of an object and that objects’ placement in space allows for a higher level of expression, a significant increase in the amount of data displayed, and a broader scope of application.

Second, architecture deals with the representation, simulation, and communication of complex information. This creates a knowledge base, consisting of basic principles (e.g., scale, shape, rhythm, balance, color, tectonics, structure, etc.), elements (e.g., line, figures, objects, space, etc.) and organizational rules (e.g., hierarchy, layering, typology, symmetry, etc.) which can be used to create a representation that organizes physiologic data in a clear and understandable way. [IX, X, XI]

### Project Description

While there is a clear understanding of how to represent anatomical aspects of the human body, the

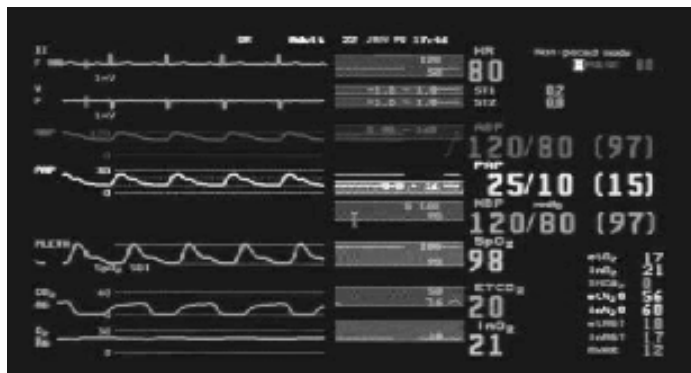


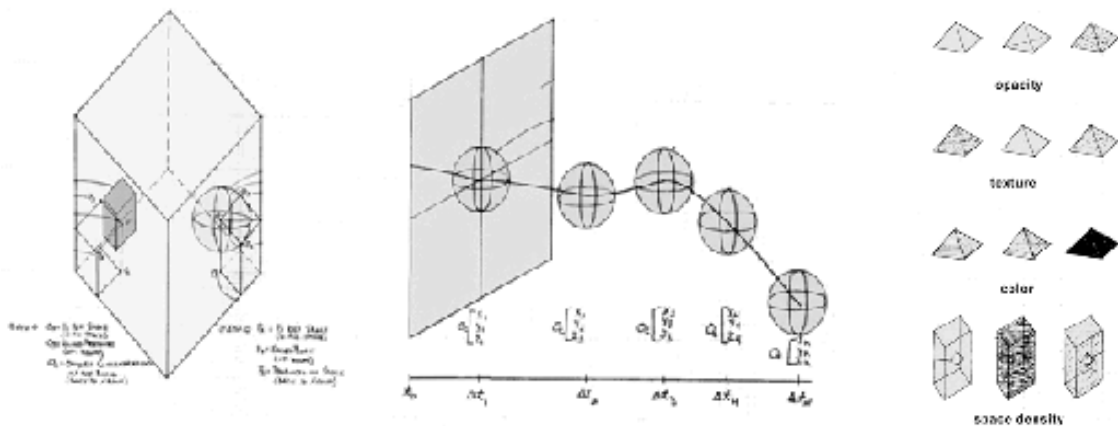
Fig. 1: Traditional monitoring system

representational language for body functions and physiology (processes and states) are not as well developed. During anesthesia, the anesthesiologist watches over 30 interrelated variables charted as 2D waveform data displays to determine if a patient is stable and in the desired physiologic state.

These variable are continuously monitored by the attending anesthesiologist: Pulmonary Function, updated each breath (Tidal Volume, Respiratory Rate, Nitrous Oxide, Oxygen, Carbon Dioxide, and Airway Pressure), Cardiac Output, updated each heart beat (Stroke Volume, Heart Rate, Systolic Blood Pressure, Diastolic Blood Pressure, and Arterial Oxygen Saturation), Predicted Plasma, Brain, and Muscle Concentrations, updated every 2 seconds (Fentanyl, Propofol, Isoflurane, and Vecuronium), Fluid Changes (Blood Loss and Blood Infused), Urine Output, and Body Temperature.

All of these variables are interrelated and constantly in flux. For example, when air is inhaled into the lungs, pressure is exerted on the heart due its close proximity. This pressure causes the volume of blood pumped by the heart to change with each beat. The 2D representation, which depicts each variable separately, does not show relationships between disparate data.

In a 3D display, measured or computed information can be organized into relevant data sets or critical functions. These data sets can then mapped as three-dimensional objects (e.g., cubes, spheres, pyramids, prisms) that work as metaphors of the critical functions of the system. The 3D objects' location and movement in space as well as their attributes (e.g., shape, texture, opacity, color, etc) correspond to pertinent data points. See *Fig II*



*Fig II:* Graphics showing basic visualization design concepts

Using the design techniques shown above this project creates a 3-D model of physiologic data displayed in four interactive windows; each one designed to show certain information in detail (Refer to *Fig III* below). Departure from “normal” reference grids, shapes 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*.

In the display created in this project, changes in the color, location, size and shape of the foreground spherical object (red sphere) communicate heart and blood physiologic information. A perfectly round object reflects normalcy whereas an oblong or squashed one reflects abnormality. If the object is centered on the horizontal and vertical grid mark, the patient is normal. If it is above or below the reference line, the patient’s blood pressure is abnormal. The front view shows a trend plot where the blood pressure fell, then returned to normal. In addition, the same view shows that the drop in the blood pressure was due to an inadequate stroke volume and decreased heart rate. Changes in the color, shape and size of the background plane (green and blue curtain) communicate respiratory activities. Specially designed lines and points establish referential data to detect abnormality. All of the objects and their placement in digital space help create a unique holistic view of the entire physiologic system as it fluctuates in time. As a result, this display is able to show the relationships that exist between discreet variables in human physiology.

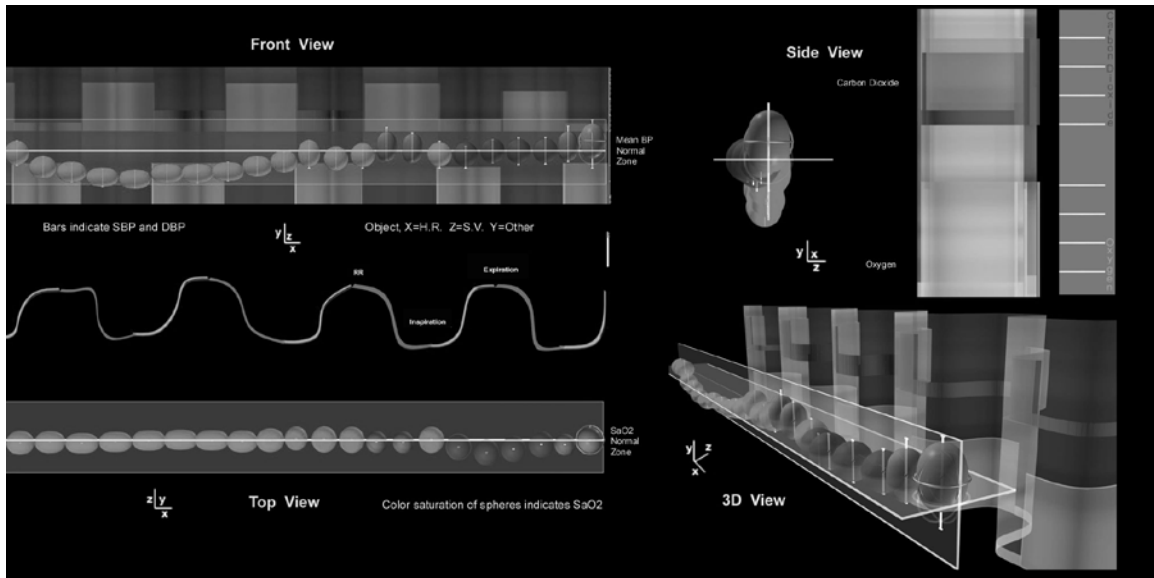


Fig. III Anesthesiology application. The prototype shows 13 variables on a single screen in real time (Heart Rate: HR; Diastolic, Systolic and Mean Blood Pressures: DBP-SBP-MBP; Arterial, SaO<sub>2</sub>, Respiratory Rate, Tidal Volume, Peak, Peep Respiratory Pressures, Stroke Volume, and Cardiac Output)

### Future Work

In initial testing of our prototype display we showed a statistically significant decrease in detection time in several critical scenarios when compared to traditional displays (Table 1).

CRITICAL EVENTS	HYPOVOLEMIA		ISCHEMIA		BRONCHOSPASM	
	TRADITIONAL	CROMDI	TRADITIONAL	CROMDI	TRADITIONAL	CROMDI
<b>Detection</b> (# of correct answers)	1.8	2.4	1.8	2.2	2.8	2.8
<b>Diagnosis</b> (# of correct answers)	1.4	2.2	2.8	2.2	2.8	3.4
<b>Recognition Time</b> (seconds)	96	48	138	126	180	120

Table I: Comparison testing between Traditional and Cromdi object display was done using 12 Bioengineering graduate students. Situation awareness questions were asked every 2.5 minutes and recognition time was measured when critical changes were seen (University of Utah, September 1999)

Based on the promising results of this informal study a more rigorous study is planned that will make use of eye-tracking equipment to determine where the anesthesiologist is focusing on the monitoring equipment when detecting a problem. In addition, rather than that using only students, anesthesiologists will be tested to determine the effective reduction of detection time using the graphic display compared to the traditional.

### Conclusion

There can be no denial that information is being produced today at an alarming rate. With the amount of information and the complexity of that information it is critical that display systems aid in reducing the cognitive loads placed on the individuals monitoring them. Through the use of 3D environments and digital technology architects can lead the design effort of innovative display systems with our knowledge of communication and representation techniques. Architects must take clues from the past and begin to look at other areas of investigation to help lead us into the future.

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