SCULPTING IN CYBERSPACE: PARALLEL PROCESSING THE DEVELOPMENT OF NEW SOFTWARE

Rob Fisher
Carnegie Mellon University
Pittsburgh, Pennsylvania

ABSTRACT

Stimulating creativity in problem solving, particularly where software development is involved, is applicable to many disciplines. "Metaphorical thinking keeps the problem in focus but in a different light, jarring people out of their mental ruts and sparking fresh insights. It forces the mind to stretch to find patterns between dissimilar concepts, in the hope of discovering unusual ideas in odd associations" (Technology Review January 1993, p. 37). With a background in Engineering and Visual Design from MIT, I have for the past 30 years pursued a career as a sculptor of interdisciplinary monumental artworks that bridge the fields of science, engineering and art. Since 1979 I have pioneered the application of computer simulation to solve the complex problems associated with these projects. A recent project for the roof of the Carnegie Science Center in Pittsburgh made particular use of the metaphoric creativity technique describe above. The problem-solving process led to the creation of hybrid software combining scientific, architectural and engineering visualization techniques. David Steich, a Doctoral Candidate in Electrical Engineering at Penn State, was commissioned to develop special software that enabled me to create innovative free-form sculpture. This paper explores the process of inventing the software through a detailed analysis of the interaction between an artist and a computer programmer.

INTRODUCTION

Since 1979 I have pioneered the application of computers to large-scale environmental sculpture, i.e. sculpture integrated into architectural spaces. This has taken many forms-- stereo three-dimensional dynamic imaging, CAD, engineering simulations, architectural-sculptural drawing, pattern design for silk-screening onto sculpture materials, animations for anticipating changing views, presentations, sketching and proposals, interactive video performances based on my sculpture--to name a few. In all instances I worked collaboratively with expert programmers to develop software that enabled me to create artworks that would be impossible without the use of the computer. My stated goal has been to demonstrate a symbiotic, synergistic approach to creating sculpture via computer technology, and to prove the efficacy of this approach by realizing these projects in realtime and realspace.

This paper focuses on the process for developing the original software whose express purpose was to facilitate the design of a huge exterior sculpture on the roof of the Carnegie Science Center in Pittsburgh. A full range of computer applications, from Scientific Visualization

to CAD and Architectural Simulation were brought to bear on a highly complex commissioned work of Art. The assignment, the conceptualization of the problem, the development and operation of the software, the emergence of the solution, and a discussion of the proposed use of interactive computer-controlled lasers and fibre-optics will be covered in this paper.

This paper has an unusual format in that it is written in two "voices", my own as the sculptor/end user and that of my associate, Dave Steich, expert programmer. At appropriate points in my text Dave's commentary is inserted in italics. It is our belief that this paper can provide valuable insights about how one artist went about communicating with a programmer regarding the development of highly unusual sculpture software and how the software was created to facilitate its usefulness to the artist during the sculpture process. This is an article about communication between disciplines and about the man/machine interface in which the user is a practising sculptor.

THE PROBLEM ASSIGNMENT

By far the most advanced project I have ever attempted was commissioned in 1991 by the Carnegie Science Center in Pittsburgh, Pennsylvania and is still under development. I was asked to create a work of art, monumental in scale, that would be a product of science and technology, that would be as much Science as Art. I was encouraged to investigate lasers and fibre-optics and to employ a space-frame system recommended by the architect.

The practical goal was to develop a realizable sculpture that would be placed on top of the Omni-max Theater at the Science Center. The prominent siting of the Science Center at the convergence of three rivers in Pittsburgh demanded a work that had impact both day and night and one that could be seen for miles. This presented the opportunity to also conceive of the work as public entertainment of almost unprecendent scope. It had to be understandable yet sophisticated, both scientifically and technologically, so that it would further the goals of the Science Center in terms of public education. And while it needed to utilize proven technologies of today, it had to look forward to a life well into the next millenium. Creating for the future had profound implications for the project resulting in a proposal for an open-architecture front-end to the highly interactive sculpture that would enable future generations to program the artwork with new tools and approaches as they evolved.

SCIENTIFIC ROOTS

Just as a tree grows organically from the earth, so did this project establish its roots in the field of Science, and more specifically, Scientific Visualization. As a result of a chance meeting with a prominent scientist, I was introduced to programs developed at Penn State University's internationally recognized Materials Research Lab. The artistic application of Voronoi Tesselation software, intended for scientific visualization of crystals, guaranteed that whatever form emerged would be a hybrid of Science and Art.

Dave Steich, a doctoral candidate in EE at Penn State, authored the poly-crystalline simulation program. During the next six months, Dave and I worked closely together pursuing the development of what became a new medium for sculpture using as a starting point his poly-crystalline simulation program. The software became more and more sophisticated and specialized and in the process, Dave wrote more than five thousand additional lines of code. The resulting unique hybrid software ultimately combined architectural, scientific and engineering programs. It introduced scale, dimension and engineering properties into scientific images where nothing of this sort was ever thought of previously.

The origin of the crystal simulation program was a scientific visualization program used to display polycrystalline topologies using 2D, 3D Voronoi tesselations. The visualization program displayed large groups of crystals, creating a surface similar to a close-up view of sand along the seashore. The computer simulations were "photorealistic" with lighting and shading of each facet of each crystal. These groups of amorphous crystals were rotated, scaled, translated, etc. in realtime on a computer and compared to actual images of real amorphous crystals under an electron microscope. The purpose of the visualization software was to show the striking similarity between actual amorphous crystals and present mathematical models used to simulate these crystals. The visualization software included the real time splitting apart of an amorphous material into two cleavage planes (each having the topological features of the actual polycrystalline ceramic).

My job was to modify and build on this original program, written on a Silicon Graphics 4D/220 GTXB computer, so that the software would allow the artist, Rob Fisher, to generate mathematically correct crystals to form a sculpture. It is difficult to envision the complexity of such a task.

First, the data set was enormously complicated. There were typically thousands of crystals each unique in shape, each with differing numbers of faces, edges, nodes, each uniquely related to other crystals. Displaying all the nodes and connections for a typical data set involves over 100,000 polygons and lines. Just displaying all the line segments of a volumetric data set would be so dense as to fill the screen. It would be like trying to see the bottom of a pot of boiling spaghetti, and that only consists of a few hundred strands, not thousands upon thousands of lines. Because these crystals simulated amorphous materials there was not periodicity in the data; everything was formed out of random distributions. Consequently the inter-relationships between each of the crystals was extremely complex.

On top of the data complexity was also the concern that the generated sculpture had to be built in relation to both the existing building and the trusses that would support the crystalline forms. The spatial relationship between sculpture, building and trusses was

essential for both aesthetic and practical reasons. It was possible in the simulation for a sculpture to cut through the building or intersect the trusses. Fisher had to be given enough visual information and control to avoid these collisions.

Another problem was that of input-output issues. The software to be developed had to receive input not only from the sculptor (via mouse) but also from HOK Architecture CAD software running on a Vax Main Frame. The output had to be compatible with the software of the space frame developer (Mero Structure) in order for the manufacturer to be able analyze and specify the engineering requirements of the sculpture. Mero's software ran on a older model DEC MicroVax.

Although the above issues were anticipated almost from the start of the project, the final complexity far exceeded the initial impression. In particular, not knowing what would be required of the software from the beginning of the project, the software had to be adaptable to as yet unknown requirements from the sculptor.

PROCESS AND METHODOLOGY

Studying Dave's software, I recognized a similarity between the wireframe images that outlined the three-dimensional crystalline shapes and space-frame structural systems used to create architectural structures of enormous scale. The space frame system, consisting of nodes and tubes, was a perfect metaphor of vector graphics with its end points and connecting lines. I intuitively sensed that here was an opportunity to generate poly-crystalline looking sculptural objects which could be replicated in the real world using standard architectural spaceframe components.

Discussions with engineers at MERO Structure focused on whether their usual production methods, used to create regular structures based on the Golden Mean, would apply to the highly irregular and organic shapes generated using the crystal-simulation program. A number of years ago they had changed over to CAM (Computer-aided manufacturing) which permitted great flexibility in the drilling of the forged steel nodes used in their system. Geodesic structures have areas of irregularity which could be readily accommodated by CAM since each node was specified individually in the data base. At least in theory, therefore, each node could be different and each connecting tube could have its own length. We obviously had to test this premise and see, as well, whether the resulting organic object would have any structural integrity. We produced data for a single crystal, assigned realworld dimensions and sent the data to MERO Structures computers for engineering analysis. Within six weeks MERO Structures produced a ten foot high prototype spaceframe crystal which clearly demonstrated the feasibilty of the process. We then proceeded on the development of the sculpture which would be more than 100 feet high and 120 feet in diameter!

The first and most basic issue to be resolved centered on an apparent anomoly. While the Scientific Visualization software could display the spatial location, angles and edges of every crystal, the image was

dimensionless, since scale was not a question, and the geometry of each crystal was buried inextricably in the program.

There were many limitations in the software that prevented its use in sculpture generation. Although the original visualization program could accomplish all of its intended purposes the software could not begin to be used as design tool. Often in visualization very little knowledge of the viewing object is required to adequately display the object. A CAD system typically requires much more information about an object so that it can be manipulated in many more ways.

For example, consider displaying a spider web on a computer screen. All that is needed to visualize the web is a series of line segments. Scaling, rotation, and translation of the web can easily be performed by multiplying the beginning and ending points of each line segment by a transformation matrix. The matrix would be identical for each node. But if a user desired to highlight a section of the spider web, or wanted to single out all the parts of the web that were in immediate contact with a given strand, or wanted to animate the order in which the web was created, much more information about the spider web is needed. Rather than a series of line segments, a program would need information about how each node was related to each other node. It is easy to see that designing and manipulating objects on a computer is in general more complicated than just visualizing the object.

Next, we had to merge the Scientific Visualization program with Architectural CAD software created on a completely different system for a totally different purpose. These two pieces of software were also written in different programming languages, C and Fortran, and were operating on a Silicon Graphics IRIS 4D-220GTX (for the crystal simulation located in a lab in EE) and an Evans and Sutherland Color MPS and a Tektronics system using HOK architectural software (located in the Department of Architecture at Penn State). While the networks were in place for these computers to talk to one another, there was no precedent for this interaction.

After discussions with MERO Structure, manufacturer of the spaceframe system, we discovered that they used an older but still useful computer system for their engineering analysis and design of their projects, a DEC MicroVax. We assumed it would not be a difficult matter to reformat the data to match their computer, once we had merged the Scientific and Architectural programs. Fortunately, I had been the recipient of a DEC MicroVax GPX many years before and the computer, used primarily by graduate students, was set up only a few feet from the Silicon Graphics Workstation. Once the SGI and the E & S could speak to each other, we could output any crystalline form in architectural terms, move and reformat the data onto the MicroVax, output to a floppy and send the disk to MERO for their use.

The software had to be written to implement the above tasks and

satisfy all of the constraints, i.e. environmental- building and trusses; sculptor - manipulation ability; mathematical - laws of physics; topology; geometry; etc.

In order to achieve the goals, a relational database was created. By using a relational database the above tasks could be accomplished without overwhelming the sculptor with many of the details of the mathematics of crystal formulation and yet provided maximum freedom to manipulate the data. The relational database would accept input from other computer systems (building and truss information) and from initial seed distributions (Voronoi tesselation output). The database would appear on the computer screen as a series of 3-D objects that could be manipulated by the sculptor using a mouse. Output of the created sculpture would be in a form that Mero Structure could readily accept. In this way the sculptor would be able to create his sculpture without having to deal with database details. He would only see the database in terms of 3-D objects with various spatial differences, colors, transparencies, etc.

All data that was not going to be manipulated in any detail could just be a series of lines and/or polygons. No interrelationships between the members would be required. In other words, any and all transformations like scaling, translating, rotating would be applied to "whole data sets". For example, there would be no reason to rotate a portion of the building in relation to the rest of the building. Also, there would be no reason to scale the top half of the trusses relative to the lower half of the trusses.

CONSTRUCTING THE BUILDING AS CONTEXT FOR THE SCULPTURE

Using methodology that had proven itself on many previous projects, I had an assistant (an architecture student) "build" an architectural computer model of the Science Center using existing programs designed for that purpose (HOK Software). I worked closely with the project architect, Tasso Katselas, on the development of an architectural spaceframe structure that complemented his building and provided the framework to support the yet to be created sculptural forms. We arrived at a series of trusses of varying length that were arranged almost like an open tepee. I envisioned the sculpture either floating within this structure or residing in the spaces between the trusses. The trusses were then added to the 3-D CAD image of the entire building giving me an interactive contextual image within which I could develop my sculpture concept. I could move around the image viewing it from any angle and distance, paralleling the experience of the real viewer. Concurrently, I visited the site and videotaped the building and site from every major location in the city, along the riverbanks and across the river from the cliff overlooking the site. These videoimages were to be later integrated into the computer program.

Dave and I decided to limit the amount of data brought over from the architectural CAD data to the immediate context of the truncated conical roof of the Omni-max theater and the seven trusses as this was

enough information for me to work within. His software automatically scaled the crystalline forms to realworld dimensions since they were created in the context of the scaled architectural images.

The building and trusses data, developed in the Architecture CAD lab from drawings provided by the architect, were read into the program and displayed on the screen. These objects could be rotated, scaled, and translated independently of the crystals. Although much of the building was brought into the program, it was decided that only the dome of the theater was needed in order to get a sense of sculpture in relation to the building. The trusses and dome were the immediate context for the sculpture.

The dome and truss data came from HOK architecture software. The dome data would not be changing because the building existed. The trusses were dimensionally designed in relation to the building. Although the crystals and dome-truss combination could be scaled, rotated etc. independently of each other, the sculpture output was always transformed to correspond with the initial building and truss data. In this way, the sculpture output (dimensions and geometry) that was generated would have accurate, realworld dimensions relative to the building.

GENERATING POLY-CRYSTALLINE SCULPTURE

The lengthy research and development just described brought me to the point where I could begin the long search for a dynamic sculptural solution. I first had to grasp how the Scientific Visualization program operated to see what parameters I could affect and what its limitations were.

DESCRIPTION OF VORONNOI TESSELATION

A starting set of random seed or "germination points" are chosen in a 3-dimensional unit cube space. Each of these seeds "grow" outward spherically until the spheres start to touch one another. Where two spheres first meet the growth stops at that point. However, at all other points both spheres continue to grow in a similar fashion. Two spheres meeting one another eventually produce a flat surface that is perpendicular to the direction of growth. The surface between the two spheres gets larger until a third sphere, equidistant to the first two spheres, produces an edge. The process continues and the edge length grows until there are four equidistant spheres (actually the spheres are distorted by this time) producing a point in 3D space called a vertex. By connecting the vertices together, polygons are formed. When the polygons are connected to other polygons closed surfaces are created. These closed surfaces (volumes), when in simple or elemental form, are called crystals. (Simple signifies that the closed surface contains no other closed volumes within itself).

For example, if the starting germination points were a periodic 3D array of points so that each point was equidistant to its nearest

neighbors in the x,y,z directions then the resulting Voronoi tesselation would be a 3D array of cubes. When the germination points are random in space, the case for amorphous materials, then the resulting crystals are random in shape and size.

Among other attributes, I realized that I could specify the arrangement (random or orderly) of the "seeds" or centers from which each crystal would grow. I could also vary the density of the seeds have the density itself vary throughout the unit cube. I began to feel like a botanist/gardener who could alter the composition of his garden by making determinations at the level of the seeds.

One of the first issues that had to be dealt with is what seed distribution(s) would be needed in order to have both a realistic crystal shape and an elegant sculpture.

After trying some trial data sets it was determined that a random data set with varying density in one direction would give the sculptor enough possible variations in crystal size and geometry to create a desireable sculpture. The data set was large with nearly 5000 germination points, 28,000 + vertices and over 100,000 edges.

MERGING THE CRYSTAL SIMULATOR WITH THE ARCHITECTURE: INTRODUCING THE CONCEPT OF THE "BOUNDING VOLUME"

The basic idea behind the software was to immerse the architectural dome and trusses into the seed bed. After scaling and rotating the dome and trusses in the seed bed as desired, the sculptor moved volumetric shapes within the seed bed. These volumetric shapes would capture all the germination points within the volume. Any crystal that had a germination point that was "captured" by one of these volumes was displayed on the screen. The idea was then to move the volumetric shapes around until a desired sculpture was created that would somehow fit into the spaces between the trusses.

We saw that the bounding box within which the seeds grew could be shaped anyway we desired. We first tried a concept whereby a triangular volume, similar to the space between the trusses, would serve as the limits to growth of the crystals. My thoughts at this point were to have the crystals "grow" into the space between the trusses. We tested this solution and Dave provided a program whereby the bounding triangular volume could be scaled, rotated and repositioned anywhere within the cube of seeds cum crystals.

The resulting objects were curious and sculptural. In their organic form they bore a resemblance to animals and even primative cave drawings. But they were quite arbitrary and the controls by which they were generated lacked the exactness I needed to precisely fit the objects into the architectural structure on the roof.

C-2

Although this procedure was successfully implemented it had some drawbacks. If the volumetric pie shape was moved even slightly it picked up several other crystals and the new sculptural shape was much different than what it was a moment before. Also due to the large number of line segments and nodes on the screen (typically thousands) it was difficult to get a feeling for the 3D aspect of the sculpture. Things became confusing not knowing which crystals were in front or behind others.

Dave and I then discussed a refinement in the process, which involved the creation of a rectangular bounding box, whose proportion and scale could be varied. The box could be scaled to encompass a single crystal or as many as I wished. With it I could move around in the virtual seed bed and generate a wide variety of sculptural forms, all of which could then be visually examined in the context of the architecture.

The "volumetric pie shape" idea was then refined to remove much of the difficulties being encountered. Rather than a "volumetric pie shape" a "rectangular bounding box" was used instead. This bounding box was semi-transparent and its proportions and dimensions could be scaled for differing aspect ratios. This bounding box could be translated and scaled within the seed bed. This new scheme gave the sculptor much greater control over which crystals would be selected and joined into a sculpture. He could isolate single crystals, save their location, and then search in all directions for adjacent crystals that might form a pleasing sculptural shape.

To summarize the process thus far:

First we created a unit volume (a cube) of seeds which represent the centers of growth of each crystal. The random composition of the seeds was mathematically determined in layers of decreasing density. Into these seeds I plunged an image of the entire roof of the theater and trusses to support the sculpture. This architectural object could be scaled, rotated and positioned anywhere I wished in the seeds.

The bounding box whose proportions I could vary, was then introduced into the image. When the box encircled a seed, the seed burst into life as a crystal. I moved the bounding box and the architectural structure around in this environment. In this manner I began to "grow" the crystals one by one immediately seeing them in the context of the sloped roof and trusses. Like a modern-day Michaelangelo extracting sculptures from stone, I witnessed forms emerging from the void of space, their existence governed by the virtual locations of the seeds.

A simple color system was developed to help the artist in his search for exciting sculpture solutions. When a seed lay within the volume of the bounding box, the crystal associated with the seed lit

up in the color green signifying growth. The sculptor could add this crystal to an existing sculpture or move on until other seeds were picked up. If the bounding box enclosed an existing part of the sculpture, it was illuminated in the color red, meaning that it was volatile, and could be deleted from the existing structure. When a crystal was part of the sculpture but lay outside the bounding box, it was colored blue, meaning safe. Crystals could be wire-frame structures or rendered as closed objects. These objects could be solid or semi-transparent. The multiple color scheme and transparency options were very useful when in the thick of a very complicated and dense area and allowed the artist to immediately get a depth perception of each crystal.

EMERGENCE OF THE "CYBERNAUTS"

Finally after months of sculptural exploration something magic occurred, an abstract form took shape that struck me as having the feeling of hieroglyphics. I called them glyphs. They were primative but they were communicating something from the past, something primal. (Several years ago, I visited a cave in southern France with some of the earliest examples of sculpture ever discovered, perhaps 15-20,000 years old. I felt a kinship with that prehistoric artist, the impulse to create a material form in space that communicates, however primatively, something about one's life and age.)

One night as I developed these primal forms, a strange figure suddenly appeared on the computer screen; first one leg grew, and then another. I laughed out loud at seeing this childlike figure. I asked this creature on the screen, "Now where in the world did you come from". But there it was, and I liked it. And I made another and then another, each different, each figure with its own quirky personality emerging from a virtual world. In the context of modern art history there is much precedent for these primative figures in the work of artist's I admire--Calder, Picasso, Braque, Oskar Schlemmer, Paul Klee, Dubuffet, and more recently Joel Shapiro and Keith Haring. Each of these artist's figurative work captures gesture, content, personality, and the child in us all.

I have titled these semi-abstract figures "Cybernauts". Born in a computer generated virtual world, these creatures of science and technology are like visitors from a parallel time and space. They look like crystals, like molecular structures, like enzymes, yet they look like us. They are happy, optimistic, dancing and marching to their own drummer. They suggest that we are all children of the Universe, but that the Universe is in all of us as well.

Here were unique sculptural forms, discovered in the laboratory of the computer from scientific principles; realworld sculpture determined by natural organic growth algorithms; a product of a symbiotic relationship between computer technology, art and programming skills and unattainable by any other means.

ARCHITECTURAL INTEGRATION

Placing these poly-crystalline figures in the architectural structure added layers of context from the history of sculpture and architecture, for we have only to turn to classical Greek and Roman buildings to see the introduction of the figure framed by columns and cornices. The process of intergrating these sculptures into the architectural structure also created some of the most challenging problems of programming. I wanted the figures to float in the triangular volume between each pair of trusses. This meant that each figure had to be precisely scaled and located so that they were a few feet from any truss and also a safe distance from the roof of the theater. They also had to be scaled relative to one another so that they appeared as a family of forms. The figures were each "grown" in the context of the architectural structure, but they were also each grown in the context of the seed bed which was their global universe. Each figure emerged from a separate sector of that seed bed universe. Thus the final composition of these Cybernauts appears as if they were all brought into being at once when in fact they all existed in parallel time but different spatial orientation.

At any time the artist could save his sculpture and retrieve it later. The sculptor's entire environment was saved so that he could immediately resume where he left off. By using the bounding box, transparency and realtime rotations, the sculptor could get a very good sense of each crystal's orientation with respect to the dome, trusses and other crystals. Hidden line/surface removal also helped, especially in determining when a crystal was cutting thorough the dome or trusses.

The artist could create and save the individual "cybernaut" sculptures. These individual figures would then be joined and become part of the truss data. Newly created sculpture would thus have some reference point and scaling relative to earlier decisions. The artist could move the truss system and saved sculptures as one unit within the seed bed. This allowed him to take advantage of the entire seed bed as he searched for and generated new sculptural forms.

While creating the sculpture, the sculptor would see a screen display presenting information about the polycrystalline sculpture indicating the number of edges, number of nodes, and total length of edges. This gave him a feeling of size/cost of his creation as he created it. This data was then sent to Mero Structure (the space frame manufacturer) to allow them to estimate cost and determine the structural soundness of the sculpture as it was being developed.

SIMULATING THE SCULPTURE ON TOP OF THE BUILDING

To create highly convincing simulations of the final sculpture, for presentation to the Carnegie Science Center Board of Directors some of the most difficult programming of the project was required. This involved taking images, framegrabbed from video of the site, and

inserting these two-dimensional images into the three-dimensional workspace used to develop the Cybernaut sculpture. The three-dimensional image of the trusses and figures was then manipulated so that its perspective and scale matched that of the building whereupon it was captured as a single image and subjected to extensive paint program modifications to eliminate hidden lines.

In order to simulate what the finished sculpture would look like in its surroundings, 2-D digitized video images consisting of various views were imported into the computer. These color images were digitized into arrays consisting of roughly 1000 x 1000 elements. Each element contained 24 bits of color information (8 bits red, 8 bits green, 8 bits blue). The elements were in 1-1 correspondance with the screen pixels.

Superimposing the 3-D sculpture onto the 2-D images posed some technical difficulties. Parts of every 2-D image were to be in front of the sculpture and trusses and other parts were to appear behind the sculpture. There was no easy way to have hidden line/surface removal between the 2-D video images and the 3-D sculpture. Edge detection algorithms that could pick out objects in the 2-D images could not, in general, be used because of the small contrast between colors of many of the objects.

To overcome the hidden line/surface difficulty a capture/paint function was developed. First it gave the artist the ability to capture any screen display he wanted. Second, the artist could change the screen to any other display. Third, the artist could use the mouse to create a composite between the captured and the currently displayed images. The composite image was produced as the artist used the mouse to erase part of the current display. As the current display was erased, the captured image lying beneath it was revealed. This new image could then be re-captured and the process repeated until the 3-D sculpture and trusses were successfully placed into the 2-D images with the correct hidden line/surface removal.

The procedure started with the 3-D image of the dome, sculpture and trusses appearing in front of the video images. The 3-D image was rotated, translated and scaled so that it matched the actual dome and perspective of the building in the 2-D image. Since the dome, trusses and sculpture were in 3-D, hidden line/surface removal could be performed on these components in the usual way and this modified image was then superimposed on the 2-D images and captured. The computer generated dome could then be erased revealing the actual dome beneath it, but now the portions of the 3-D sculpture and trusses that should be hidden from view were now missing.

Image processing of the 2-D imaages could be performed by the sculptor. By pushing buttons to increase or decrease contrast of the colors and total color density, the sculptor could change the clarity of the images (cloudiness or softness) and the time of day (dawn to dusk).

ILLUMINATION OF THE SCULPTURE

The last step in the software development for this sculpture was the simulation of possible lighting and animation effects. I envisioned a combination of lasers and fibre-optics which would take advantage of the current state of the art in these fields. This led to the development of a highly interactive scheme by which future generations of artists and programmers could plug into the system and create a continuuing series of lighting effects for the sculpture.

For the actual sculpture a metaphor of the telecommunications industry would be created. Each edge of each crystal would be outlined in special side-emitting fibre-optics. Each node would have a small illuminator in the form of a lens that would spread the small fibre-optic beam into a spot of light. Several thousand glass fibres would wend their way back from the nodes and edges of each crystal to a matrix panel where they would be cut and polished to receive laser light. The matrix panel would be aligned to face a computer-controlled full-color 25 watt laser.

Below the sculpture, in a small control room located within view of museum visitors (much like the Omnimax), would be an "instrument" which consists of a computer connected to various input devices. The interactive controls direct the laser beam across the matrix of fiber-optic ends. As the powerful beam strikes the end of each of the fibres, light is transmitted instantly to either a node or an edge of one of the crystals. Because the laser can scan the matrix at an extremely fast rate, the entire sculpture would have the appearance of being fully illuminated. By driving the laser beam across the fibre-ends, the sculpture could be animated in endless possiblities.

Both the computer and input devices are treated as modular and replaceable. The sculpture lighting is neither platform nor input-dependent. Instead I imagined that by special arrangement with the Carnegie Science Center, computer scientists and artists could develop new input devices, software and concepts that would take advantage of technology that is always on the move.

A typical scenario for one of these instruments is particularly exciting and utilizes currently available sonic input devices. A small scale model of the sculpture would sit next to the computer screen. The guest artist/composer would pick up a wand and touch one of the crystals on the scale model. Immediately that specific crystal lights up on the monitor. "What color do you wish the crystal to be?", asks the computer in a digital voice. "Do you want just the nodes to light up or the edges, or both?." The artist responds with yes or no answers and the image on the screen is changed accordingly. And so it goes, each crystal, each figure, all crystals, one figure at a time, only the nodes, only the edges, moving colors washing across the edges, the color spectrum. All decisions are encoded onto a tape for later playback or coordination with music. The animation can be previewed on the computer monitor so that the composer is satisfied that it is exactly what he or she wanted. Then the tape can drive the laser during an actual performance.

Other interactive approaches would permit real-time changes in the sculpture. The same wand could become the baton of the conductor of the Pittsburgh Symphony performing at Point Park across the river. As the conductor moves his baton the movement and rhythm of light across the surface of the sculpture would respond accordingly. Sound has been proposed as another driver for the sculpture, utilizing available sound such as airplanes passing overhead, car and traffic noises, or the cheers of the tens of thousands of spectators at the Three Rivers Stadium nearby. Similarly the sculpture could respond to weather conditions (it could be a barometer).

To present these effects to the Science Center board, Dave came up with a program of a limited number of animation routines which could be sequenced in a variety of ways. While these simulations didn't begin to touch on all of the possible lighting and animation opportunities, they gave an impression of what could be expected. Most importantly, the image of the sculpture superimposed on the video image of the building could be animated in full color giving a remarkable impression of the final effects.

These animation sequences were accomplished by cycling through the relational database used to create the sculpture. The relational database gave us the ability to create various sequences that were limited only by one's imagination. The finished 2-D images with the sculpture and trusses were animated to demonstrate what the actual light sculpture might look like. Dozens of animation sequences were chosen, some lighting randomly selected nodes with randomly selected colors, some lighting random line segments with random ordered colors, some lighting entire crystals in random fashion, some cycling through the figures in ordered fashion, some lighting the entire sculpture to simulate the apparent motion of the "Cybernauts" running around the dome.

THE DANCE OF THE CYBERNAUTS

Here is the vision of my sculpture as a performance work entitled "Dance of the Cybernauts". By day the brilliant reds and yellows of the organic sculpture create a focal point against the sky and the surrounding industrial buildings. The delicate truss work reminds one of earlier lacy steel monuments to technology like the Eiffel Tower. From every view the subtle differences in the figures emerge, or they coalesce into a new whole that suggests organic chemistry, molecular clouds, crystalline coral or the flames of a blast furnace.

But now it is evening; the sky has darkened. An audience of thousands, young and old, are tuned to a local FM stereo radio station which is about to broadcast a special electronic music concert simulcast with a lumia performance on the roof of the Carnegie Science Center. The audience waits in their boats floating on the river, in their cars parked along the banks, in the stadium parking lots, on blankets in Point Park. The floodlights dim on the figures as the performance begins.

For the next hour the sculpture comes to life in "The Dance of the

Cybernauts". They flicker like thousands of fireflies; they break apart chaotically into hundreds of darting lines like a cloud chamber; they burst and pop with electric energy like information coursing through the synapses of our brain; they march around the roof or chase each other in a game of cybertag; they sparkle like diamonds; they are awash with colors that change at the speed of light.

POSTSCRIPT

An interactive multi-media production, "Dance of the Cybernauts", is currently under development that would be projected onto the dome of the state-of-the-art planetarium at the Carnegie Science Center. In this production, artificial intelligence programs will be applied to each of the "Cybernaut" figures furthering the individuality and personality of each. Kinetic motion analysis will be applied to the poly-crystalline spaceframe figures as if the nodes were rotational
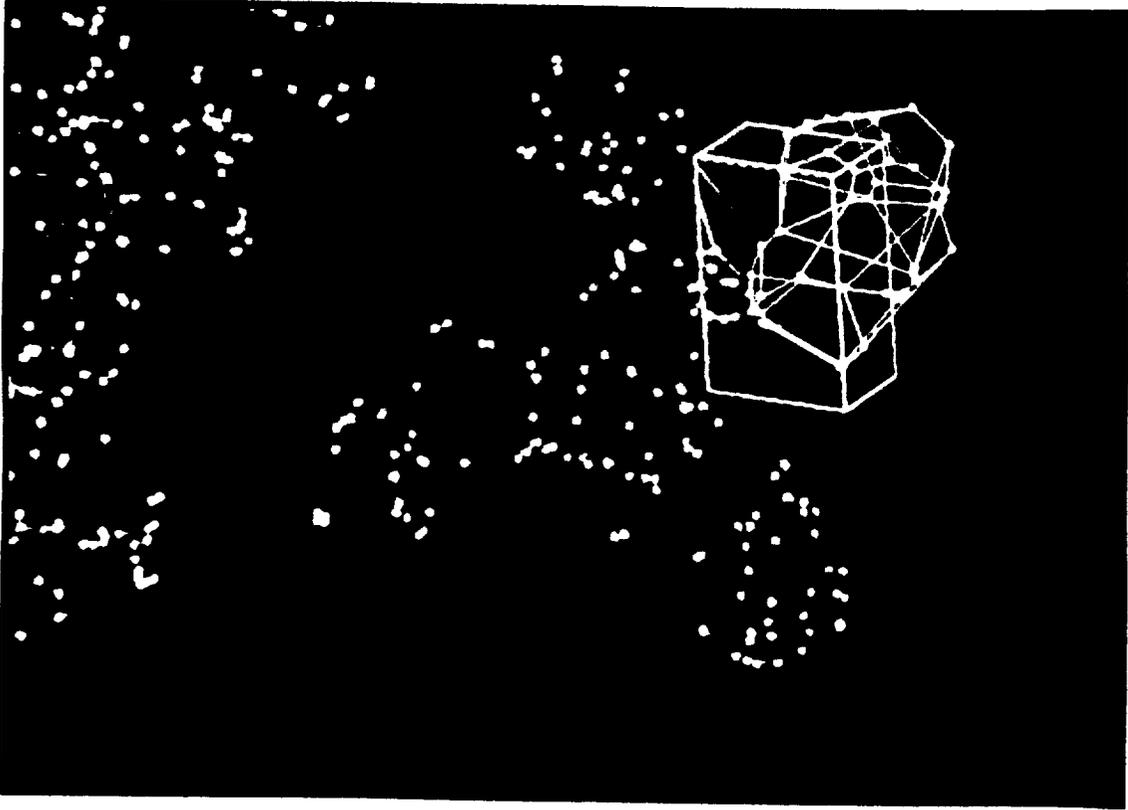
TOP- EMERGING "CYBERNAUT" WITH "BOUNDING BOX"
BOTTOM- "CYBERNAUT 1.0" FREE STANDING SCULPTURE
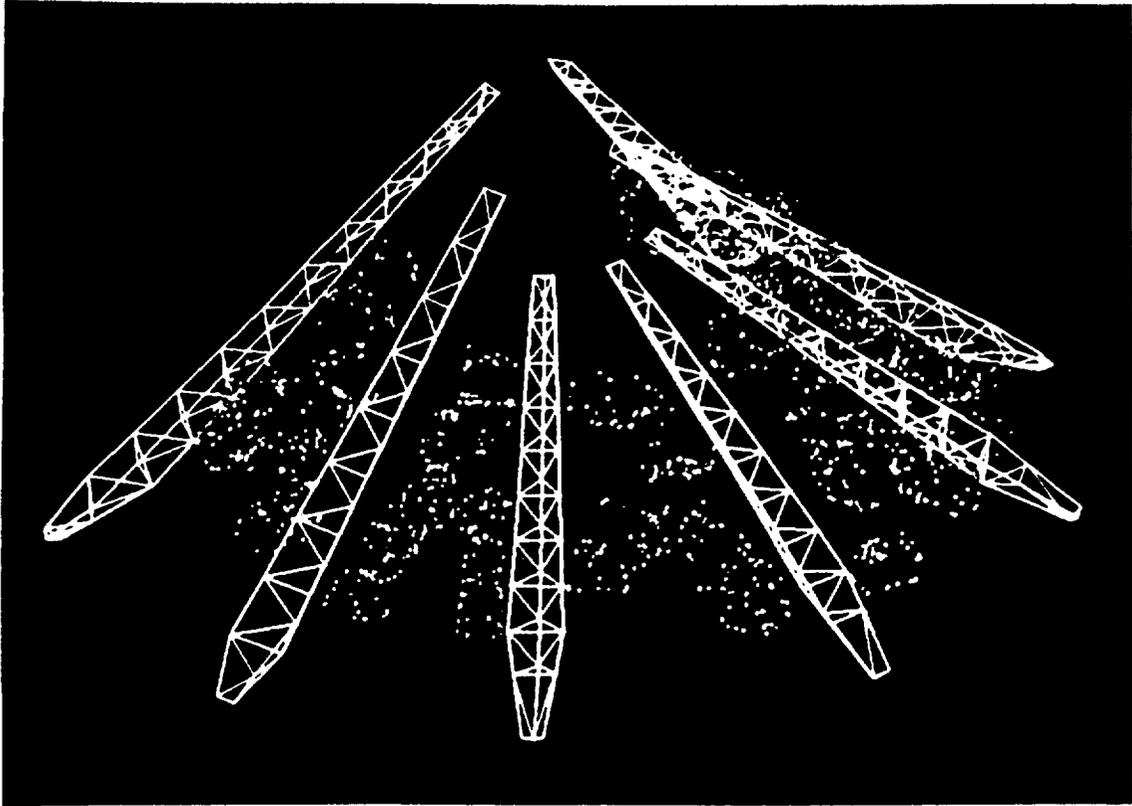
SIMULATION OF OMNIMAX DOME, TRUSSES, AND CYBERNAUTS