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GRAPHICAL MAN/MACHINE COMMUNICATIONS

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Salt Lake City, Utah

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GRAPHICAL MAN/MACHINE COMMUNICATIONS

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13. ABSTRACT

This document includes a summary of research activities and facilities at the University of Utah under Contract F30602-70-C-0300. Information conveys important research milestones attained during this period by each of the four major research activities:

1. Computer Graphics Techniques
2. Computing Systems
3. Digital Waveform Processing
4. Applications

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GRAPHICAL MAN/MACHINE COMMUNICATIONS

David C. Evans

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IC

PUBLICATION REVIEW

This technical report has been reviewed and is approved

Murray Kesselman

RADC Project Engineer

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PART I. SUMMARY OF RESEARCH ACTIVITIES

The objective of the graphical man/machine communication effort is the development of computers and computing techniques that people may use interactively in real time to extend their problem-solving capability, and to work cooperatively by means of improved communications via computer. This report summarizes the progress made in four major areas: 1) computer graphics techniques, 2) computing systems, 3) digital waveform processing, and 4) symbolic and algebraic manipulations.

A brief resume of the overall objective of each major research area is presented, along with highlights of the significant research findings that occurred during the period of 1 January 1972 to 30 June 1972.

A. COMPUTER GRAPHICS TECHNIQUES

The senior investigators in computer graphics techniques are David C. Evans (faculty), Ivan E. Sutherland (faculty), Ronald D. Resch (faculty), and Robert E. Stephenson (faculty). The primary goal of the research is the development of graphics techniques for the realistic dynamic display of three-dimensional objects.

Two aspects to this research are: (1) the techniques for picture generation from numerical models, and)2) development of languages, input devices, and other tools required to specify and manipulate models and pictures.

Our recent efforts have been concentrated on modeling representation, picture generating algorithms, and machinery. Although much work remains to be done in this area, the art has advanced sufficiently so that the most pressing work now is the graphic input and language problem. Emphasis is placed upon the capability of the user to interact with the structured data representation of the object being viewed by the graphic system, rather than emphasizing the graphic system as a picture generator by itself.

1. DISPLAY PROCESSOR

Watkins Processor

Work has proceeded on the Watkins Processor from January 1, 1972 until June 30, 1972 in the following areas:

a. The processor, capable of determining the visible surfaces, has been completely finished and reliability tests completed. The processor has been running without errors since May 19, 1972. A test program is used to compare the output of the hardware processor with a software program. Changing data structures are always used for checking the hardware (i.e. a rotating building.)

b. The shader which can store the visible segment output of the processor and create a faster scan of intensities has been completed. It needs some changes to decrease the clock period from 150 nano seconds to 110 nano seconds.

c. The digital to analog converter section had a prototype built last April, but it used a D/A converter for the X sweep. Along with other construction problems, it was found to have cross-over problems that caused visible glitches. A voltage controlled oscillator which is synchronized to a linear ramp is another approach that has since been designed. The construction is 40 percent complete, and all conditions look favorable for this method. Parts should arrive shortly and within three to four weeks it is hoped to attach the D/A section to the shader to test the complete system.

Computer display of solid objects has taken a leap forward with the implementation of the algorithm developed by Gary Watkins (1) to display solids composed of planar polygons. Watkins' algorithm efficiently clips, and eliminates hidden surfaces for objects defined in three dimensions. Associated with each polygon is an intensity for each of the primary colors: red, blue, and green. Each polygon is considered to be of a homogeneous color.

Exploration of the problem and possible advantages of associating more than one color definition with each polygon was conducted. This enabled one part of a polygon to be colored (or painted) differently from other parts of the same polygon.

There are two different uses for polygons with multiple color definitions. The first is a flat surface that has writing or different colored markings on it. An airport can be made with the flat ground as a polygon, and the runways and markings made with multiple color definitions.

The second usage involves polygons which are to be viewed only from a distance. In this case color can be used to approximate objects which need not be shown in detail. A mountain range can be given its general shape by a few polygons, and these polygons can be colored to approximate snow, erosion, and trees.

Both of these examples can be done with the restriction of single-colored polygons. For each marking that is of a different color than the background, it is necessary to define another polygon for that marking. Some scheme must then be used to assure that this marking polygon is visible and the background polygon is hidden in this area.

Adding extra polygons for markings complicates the hidden surface computations needlessly, since the marking polygons lie on the same plane and are bounded by the background polygon. A method was explored which allows the hidden surface computation to determine the area on which the background polygon is visible, and then it refers to a more elaborate color definition for that polygon to obtain the color or colors that are to be output for that area.

2. GRAPHIC LANGUAGES

Interactive Surface Design

A new breed of functions called B-splines were introduced at the University of Utah by Steve Coons of Syracuse University. These spline functions have several interesting properties that make them desirable for use in interactive surface design. Their most obvious advantages over other types of functions are: 1) they are local rather than global approximating functions, that is, each point in an array of points being approximated with the B-spline basis functions has influence on a fixed fraction of the surface rather than on the entire surface and 2) the surface generated from these functions is continuous to N-1 order where N is the order of the basis; moreover, the behavior of the surface is always predictable.

We have used these spline functions to generate some surfaces that illustrate some of their properties. Figure 1 is a surface described by the coordinates of 36 vertices. The vertices are arranged as successive squares of alternating size stacked along the vertical axis. The surface consists of 28 patches. Each patch joins the adjacent patch with continuity of the first derivative. The halftone picture was produced using Watkins' algorithm by dividing each patch into 16 planar polygrams.

Figure 2 is the same surface as in Figure 1 except that one of the vertices has been displaced outward. The interesting point here is that while the center portion of the "jar" is drastically modified in shape, the ends are exactly the same as before. This is an important property that an interactive surface design system must have. If the designer of a surface is satisfied with the design of a part of it, then he does not want that part modified while he works on another part.

Figure 3 is a halftone picture of a Klein bottle generated with a third order basis. The bottle was described by the coordinates of 28 vertices. The resulting surface consists of 28 patches (the two 28's are not necessarily related) that all join together with second order continuity. Each patch consists of 16 planar polygons.

The computation time required to produce each of the pictures described above was from one to three seconds on the PDP-10. The designer of a surface would like to have the ability to "sculpt" in real time. To accomplish this there must exist a faster means of computing the surface. Fortunately, B-splines are basis functions and are thus independent of the coordinates of the points being approximated. That is, linear combinations of the functions define the surface. The functions themselves can easily be built into hardware that will produce lines as fast as most line-drawing displays can handle them.

We hope to uncover more useful properties of these spline functions and plan to develop an interactive surface design system based on these and similar functions.

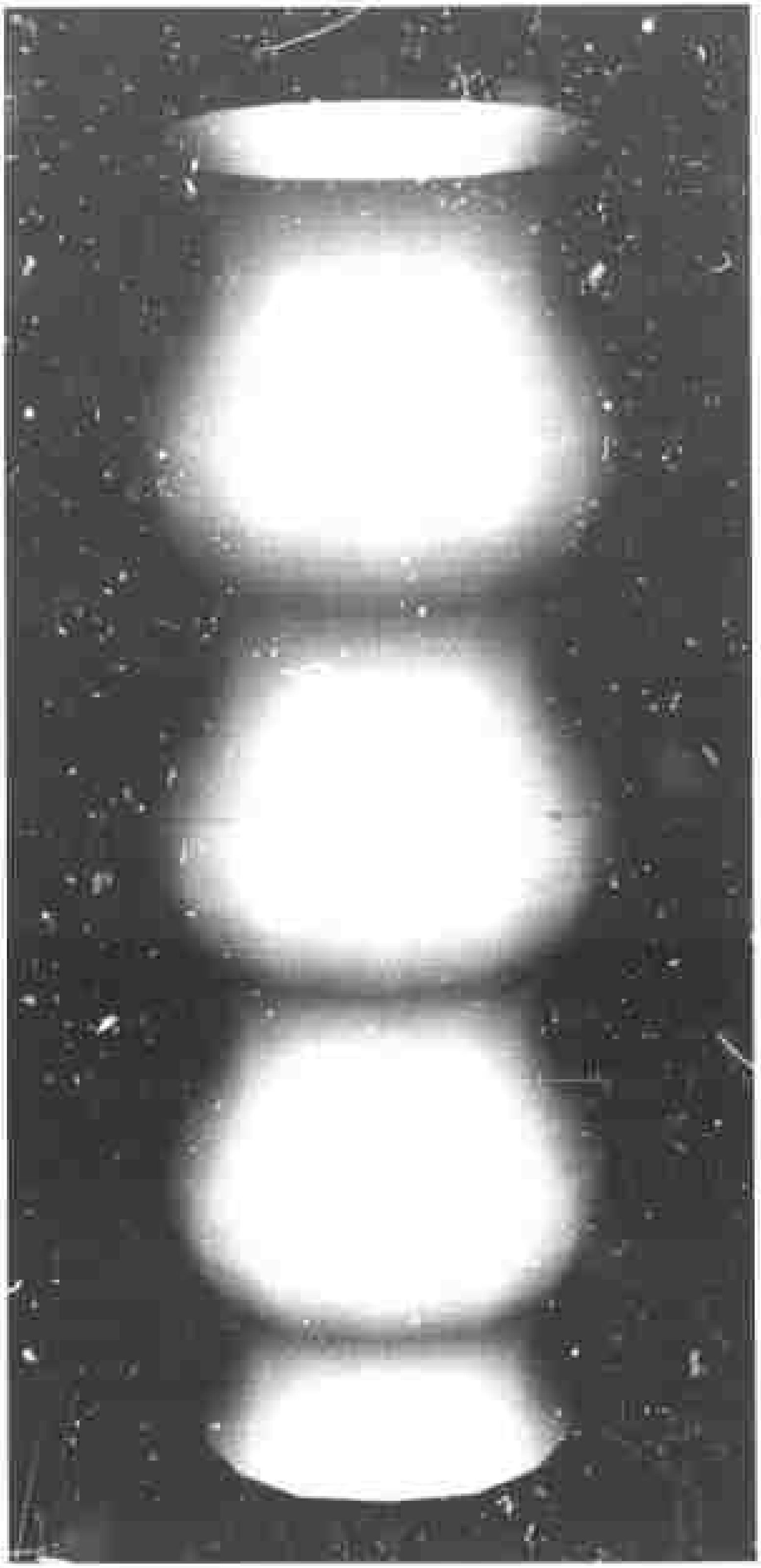


Figure 1

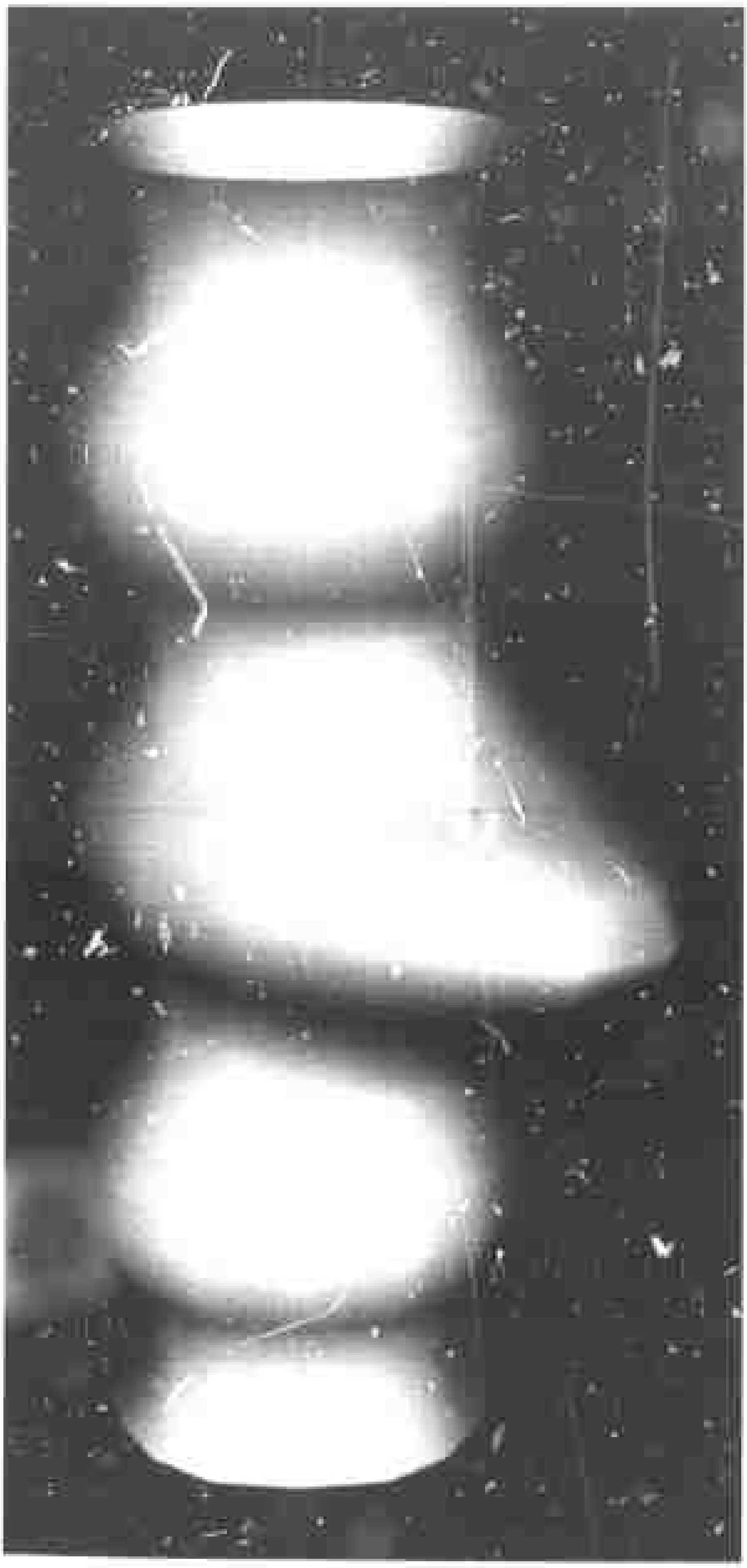


Figure 2

Figure 3

Halftone Systems

Due to the need for a great deal of computing and careful control over the CRT output device, the halftone picture work has traditionally been done on the single user PDP-10 system. As the system for generating halftones got more sophisticated and the objects being generated got more complex, (Figure 4) we found the single user memory was not large enough to hold all the programs and data. In addition the only file device on the single user system is DECTAPE which is both slow and inconvenient.

To correct these problems a system was built to allow communication between TENEX and the Single User System. The system was designed to: 1) require little or no software change in running programs; 2) use the TENEX virtual memory for active data storage; 3) use the TENEX file system for access to primary data; and 4) retain the bulk of the computation on the Single User. This goal was accomplished by creating a group of subroutine calls on TENEX that have the same names as the subroutines that call the Watkins routines, automatic movie camera, etc. Rather than doing the work directly these subroutines pass the call and the parameter information from TENEX to the Single User System. A program was created on the single user to accept the information and make the "real" calls. A side benefit of this system organization is that there is only one program for the single user system.

The system has been very successful and is widely used. One principal shortcoming of the system was that it required some (though little) processing by TENEX. Because of the extreme overload on our system the delays caused by the Time Sharing system have become untenable at times.

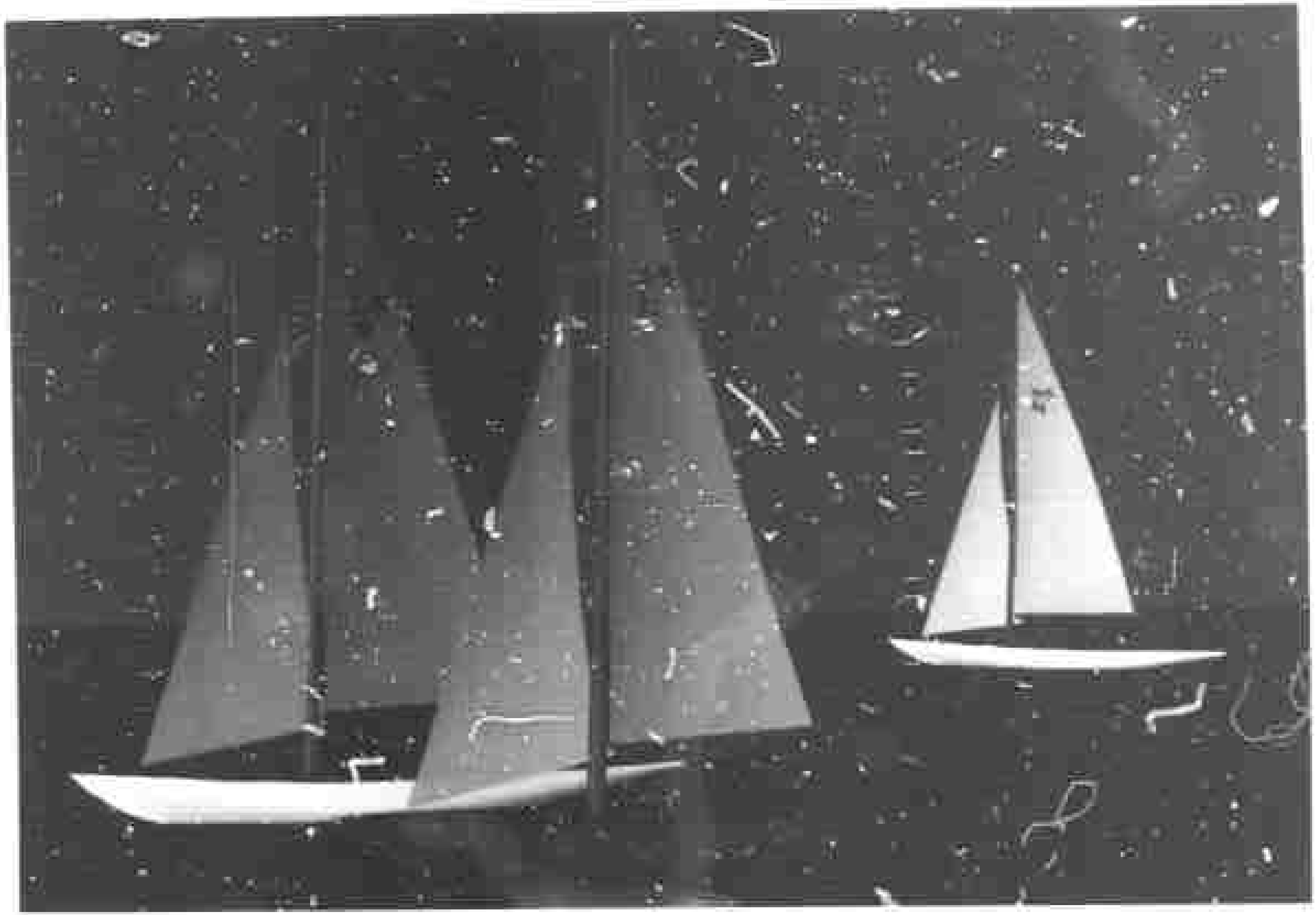


Figure 4 - Computer-generated Sailboats

A new group of subroutines was written to allow the Time Sharing part of the system to run at RAND TENEX. The data is transmitted through the Network to TENEX here which in turn gives the data unmodified to the Single User system.

Several pictures have already been made over the Network. The amount of computation required and the Network bandwidth is such that there is no noticeable reduction in performance due to the Network. In fact, due to the heavy load on our system, pictures can be generated in the afternoon two to five times faster using the Network.

Computer Animation

Several different software systems have been built to generate animated halftone movies. In this reporting period we have attempted to pool that experience and build a single new system that will encompass the known functions of the old systems through a single interface. The goal is not to provide a single system for everyone but rather for people who: 1) would like to generate animated films but have little or no programming skills; and 2) as a starting place for new researchers in the animation area.

The new system has three interfaces that the user sees: 1) Primitive object description; 2) Rigid object description; and 3) the Articulation description. The Primitive Object is the "Atom" of the system (indivisible element). It is composed of a description of one or more polygons which comprise the object, some properties of the polygons (color and priority), and some properties of the object (illumination control, etc.). The primitive object consists primarily of a description of the vertices in the object and the topolcgy of how those vertices are connected and ordered to define the polygons. Since they are atoms, the primitive object must be debugged or changed as a whole; therefore, the descriptions are kept to the smallest logical entity (the T37 airplane, for example, consists of five primitive objects; the fuselage, wing, canopy, insignia, and tail section).

To put these primitive objects together, a separate interface was built, called the Rigid Object description. This interface allows the user to assemble primitive objects and other rigid objects together. Once assembled a rigid object looks like a primitive object to all system operations. At the rigid object level, a U.S. T37 and a Japanese

T37 could be assembled by simply substituting the Rising Sun insignia for the U.S. insignia.

The Articulation description consists of commands for assembling rigid and primitive objects, placing them in the object space frame by frame (thus creating the illusion of motion), modifying the objects by scaling and rotation, deleting objects, transforming one object into another of similar topology, output of halftone pictures, and control of the automatic movie camera. The commands are stored in sequence in a file which may be generated manually or by program.

The system is currently in operation; user documentation is in preparation.

Computer Generated Animation of Faces

This research has been in three related areas; representation of the human face, animation of the face and three-dimensional data acquisition.

It was determined that the human face can be represented realistically by a polygonal skin containing about 300 polygons as shown in Figure 5.

Realistic animated sequences of a face changing expression (2) have been produced using a cosine interpolation scheme to fill in the intermediate frames between specified expressions.

A photogrammetric data collection method has been developed to extract three-dimensional position data from non-orthogonal pairs of photographs.

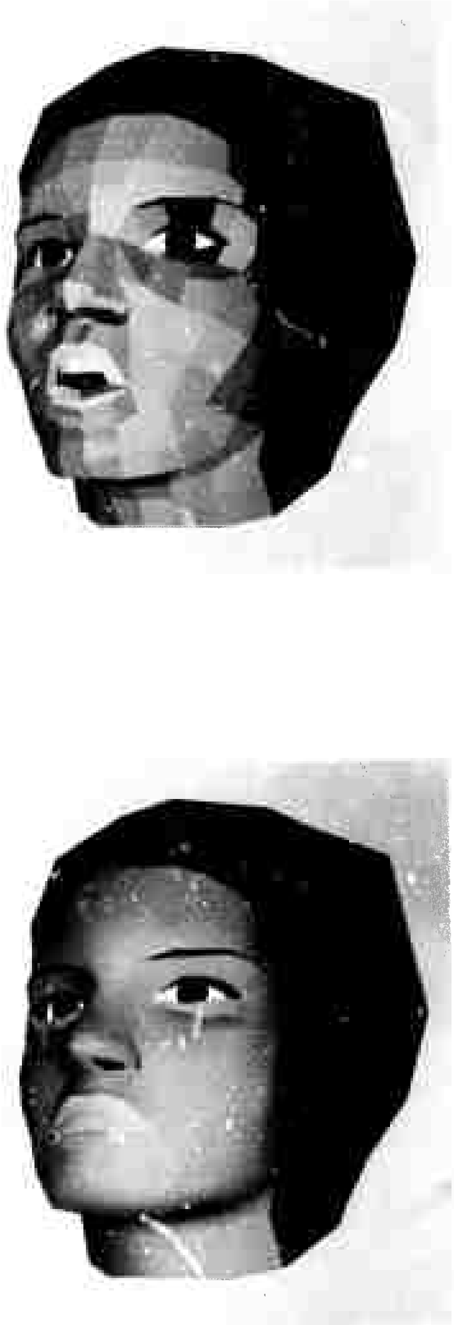


Figure 5. Human Face

Halftone Generation

During this reporting period an experiment was conducted between RADC and the University of Utah to test the possibility of using halftone pictures in photo interpretation. A stereo photograph of an unclassified subject was sent to Wright-Patterson AFB and was digitized by their experimental three-dimensional digitizer. The data was then input to our system from RADC via the ARPANET. The data was then debugged here and several halftone pictures were taken. A technique was devised to permit RADC to view the data as line drawings on their graphics equipment by transmitting the data back through the Network.

3. OUTPUT DEVICES

Head-Mounted Display System

In continuation of the research designed to locate an interactive 3-d environment with the head-mounted display and a 3-d wand, the following goals have been reached:

a. The 3-d wand using line and encoder tracking has been made operable.

b. All five buttons and a potentiometer on the wand are now usable.

c. A bank of 18 switches for communication to the computer is ready.

d. The data structure which allows real-time communication between room coordinate data and local coordinate data has been implemented.

e. The problem of tracking the 3-d wand in real time and checking to see if it is "touching" a computer-generated object in a minimal amount of time has been solved.

f. Difficulty with hardware reliability has been overcome by simulating the hardware with software--still real-time interaction is possible.

Future research will be oriented toward the final aspects of this project. These efforts will be aimed at implementing the already designed command language for communication from the 3-d wand to the computer and at evaluating the practicality of such a system for creating and modifying 3-d objects such as planes, boats, buildings, etc.

A Real-Time, Three-Dimensional, Precision Measurement and Communication System

A system is being built which will enable the dynamic determination of positions of objects in three-dimensional space. The points to be located are the positions in space of small intermittently activated light-emitting diodes which may be attached to the surface of a stationary or a moving object. The system will greatly aid in the description of such surfaces, the modification of objects represented in the computer, the reorientation of objects, the measurement of motion and the specification of motion.

Hardware consists of four sections and a special room:

1. Electromechanical scanners which make a one-dimensional scan of the environment and sense photons emitted by the light-emitting diodes.

   Special discs, special photomultiplier tubes, the associated electronics and other parts of the scanner are waiting to be mounted in housings currently being designed. Arrangements have been made for construction of the housings as soon as drawings are completed.

2. Two lamp packs:

   a. A lamp pack to be worn by moving objects consists of sixty-four light-emitting diodes which may be used in modules of eight. This lamp pack has been completely built.

   b. A second lamp pack is used to calibrate the equipment. The calibration stand has been built and is waiting for the attachment of the light-emitting diodes.

c. A digitizer and control section has been designed and assembled with the exception of a few components still to arrive from the manufacturer.

d. A computer interface has been built and tested with satisfactory results.

e. The equipment will be mounted in a room with the head-mounted display, since the two will be used together in the future. Braces for hanging the scanners are in place. Other modifications to the room are under way.

The basic system requires two software programs:

a. One software program is used in conjunction with the calibration lamp pack. It is currently in the final debugging stage.

b. A second program is used to determine three-dimensional positions, given the output of the scanners. It has been written, debugged to some extent, and should be running in the next few weeks.

Documentation which will form the basis for a technical report describing the system is well under way. It includes to date:

a. A survey of current methods and their limitations.

b. A discussion of the approach.

c. A discussion of a method for determining the equations of scanning planes.

d. A discussion of the calibration technique.

e. A discussion of the method by which three-dimensional positions are determined.

f. A discussion of data enhancement techniques.

g. A description of the lamp pack.

h. A description of the computer interface.

i. Some discussion of applications.

4. GRAPHICAL APPLICATIONS

The applications area includes a small set of carefully selected problem areas that will provide feedback to the researchers in the first three research categories, and will provide a mechanism for publication of newly learned techniques to people outside the relatively closed community of computer science researchers.

Involved in the applications activity are Henry N. Christiansen (faculty), and Harvey S. Greenfield (faculty). Applications are in the field of computer-aided design, the modeling of complex geometrical structures, and the modeling of a collection of fluid-flow problems (including the flow of blood in the human circulatory system). These problems are in the main supported jointly by the University of Utah and other agencies including the National Institutes of Health; hence this work does not represent an unreasonable fraction of the total resources.

KINEMATIC AND ELASTIC SYSTEMS

The period 1 January to 1 July of 1972 has seen the development to completion of two display programs. The first, displays distorted three dimensional structural frameworks and the second displays distorted plate, shell and/or solid structures.

Displays of Distorted Frameworks

A total scene consists of a group of distorted structural elements, loads (represented by computer generated arrows) and supports (models of rigid surfaces, etc.). Each structural element is represented by a large number of warped quadrilateral surfaces which define the cross-section of the element and trace the distorted shape. Beam segment lengths are controlled by the specification of the maximum allowable segment length and the minimum number of segments for any particular element. The computer generated arrows and supports are mosaics of planar elements.

As shown in Figure 6, five cartesian coordinate systems are utilized in the generation of the distorted beam geometry. All but the viewing coordinates are right-handed systems, and it is left-handed to accommodate existing graphics software programs.

By determining, in the viewing coordinate system, the location and orientation of two successive cross sections, one may define various warped cross-section beam segments. For example, an I-beam segment definition composed of three warped quadrilaterals is shown in Figure 7.

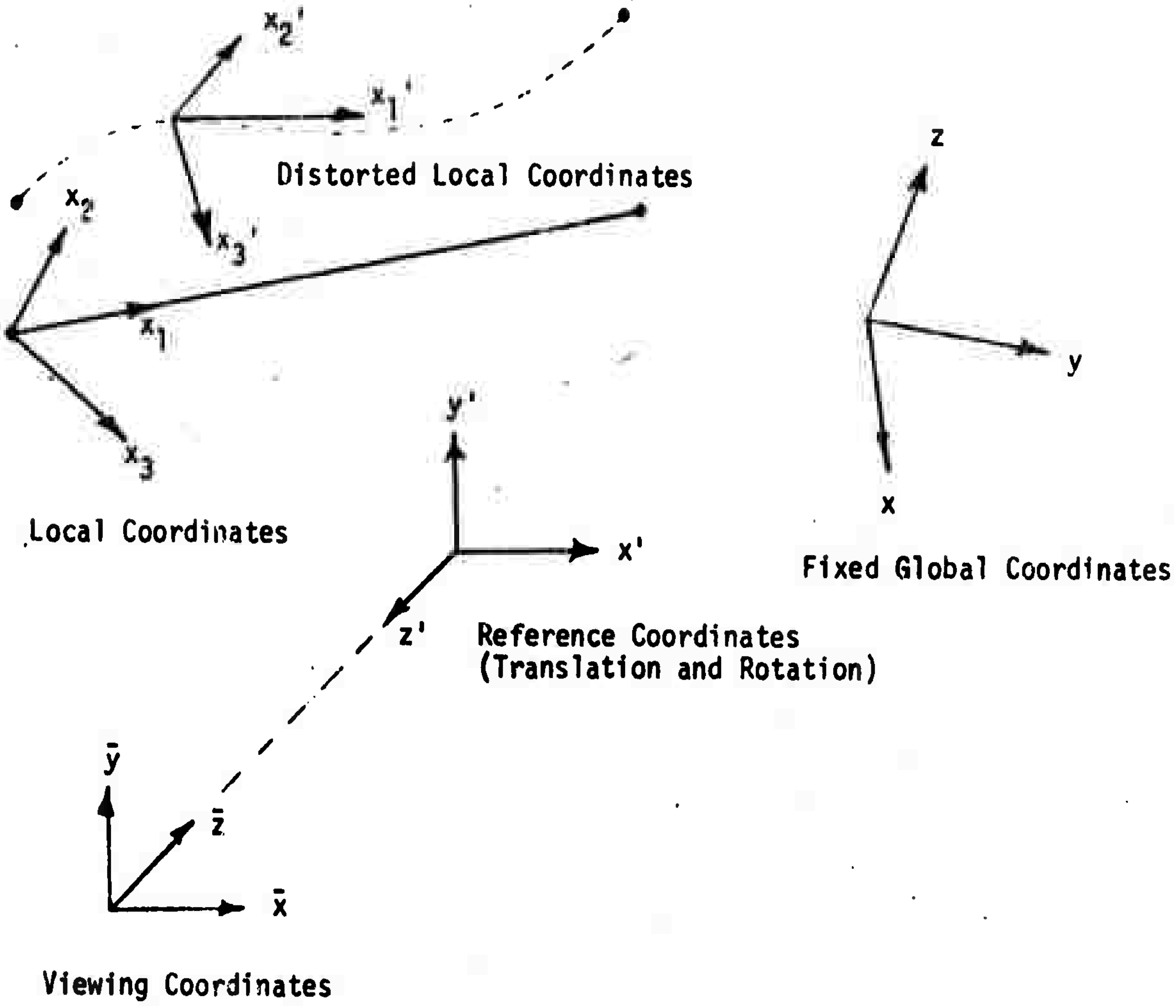


Figure 6. Coordinate Systems

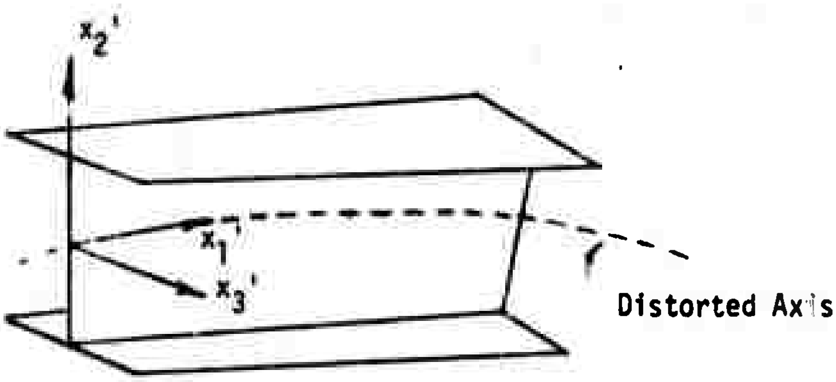


Figure 7. Distorted I-Beam Segment

To achieve, in the viewing coordinate system, the set of locations which define the cross-sectional shape at a specified location along the beam, one starts with the simple definition (two dimensional) of these locations in the distorted local coordinate system. The transformation to the local coordinate system is

$$\{X_{ij}\} = [A] \{X_{ij}'\} + \{B\} \tag{1}$$

where $\{X_{ij}\}$ are the coordinates of the cross-section points in the local coordinate system, $\{X_{ij}'\}$ are the same locations in the distorted local coordinated system, [A] is a direction cosine matrix, and {B} is the origin of the distorted local coordinate system.

Transformation to the fixed global system, then to the reference axes for rotation and translation (to accommodate different viewing angles), and finally to the viewing coordinate system are successively obtained using similar, linear transformations. These transformations are readily defined.

The coefficients of [A] and [B] are not so easily achieved. They are obtained by first, transforming the nodal displacement and rotation components in the fixed global coordinate system (as supplied by the frame analysis routine) to the local coordinate system. Since the axes of the local coordinate system coincide with the longitudinal and principal cross-section axes of the member, the displacement and rotation function (in this system) are simple polynomials in the axial coordinate and may be expressed in the form where u_i is the displacement function in the X_i direction and Θ_i is the rotation function for the X_i axis.

$$
\begin{array}{c} u_1 \\ u_2 \\ u_3 \\ \theta_1 \\ \theta_2 \\ \theta_3 \end{array}
\qquad
\begin{array}{ccccc}
c_{11} & c_{12} & c_{13} & 0 & 0 \\
c_{21} & c_{22} & c_{23} & c_{24} & c_{25} \\
c_{31} & c_{32} & c_{33} & c_{34} & c_{35} \\
c_{41} & c_{42} & 0 & 0 & 0 \\
c_{51} & c_{52} & c_{53} & c_{54} & 0 \\
c_{61} & c_{62} & c_{63} & c_{64} & 0
\end{array}
\qquad
\begin{array}{c} 1 \\ x_1 \\ x_1^2 \\ x_1^3 \\ x_1^4 \end{array}
$$

The coefficients, c_{ij}, are then written in terms of the uniform distributed loading (a particular solution to the governing differential equations), and the local coordinate system nodal displacement and rotation components (the solution to the homogeneous equations). Finally an evaluation of the displacement functions produces the coefficients of {B}, while an evaluation of the rotation functions yields the information necessary to calculate the coefficients of [A].

Figure 8 shows a beam in torsion (the double headed arrows represent moments) while Figure 9 illustrates the same beam under the combined loading of a shear force and a bending moment. Figure 10 shows a horizontal rectangular beam and two I-beam columns under a side-away loading as Figure 11 shows the same beam with a mid-span vertical loading.

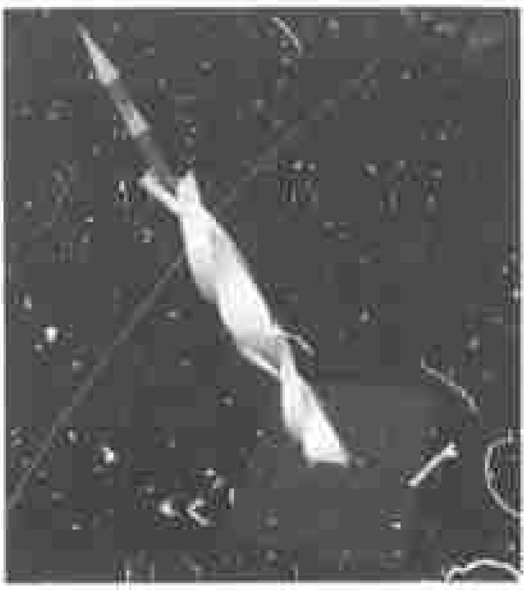


Figure 8

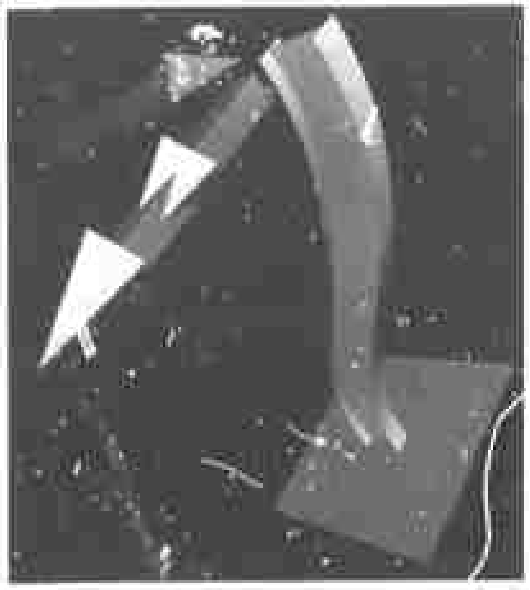


Figure 9

Figure 10

Figure 11

Display of Distorted Panel Systems

This is a straight forward display package which includes several special features which facilitate the display of structures which are modeled as mosaics of flat panels. Among these features is the ability to select a sub-set of parts for display and/or to "explode" the location of the parts. Displacement systems associated with static loadings or mode shapes resulting from vibration analysis may conveniently be brought into the computer and added to the undistorted coordinates to allow viewing of the structure in a distorted configuration. Also included is the capability to view the model with polygonal "flat" or curved "smooth" surface shading.

Figures 12 through 15 illustrate a math model of a sonar device. The unclassified data presented was supplied by the Naval Undersea Research and Development Center in San Diego, California. Figure 12 shows an undistorted view of the complete model with "flat" shading. Figure 13 is a "smooth" version of the complete model. Figure 14 shows a "flat" shaded view of the model vibrating in a particular mode shape. Figure 15 is an exploded view of several of the parts of the model in the same mode shape.

Figure 12

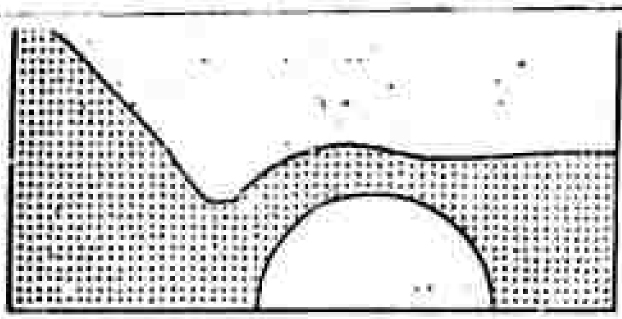
Figure 13

Figure 14

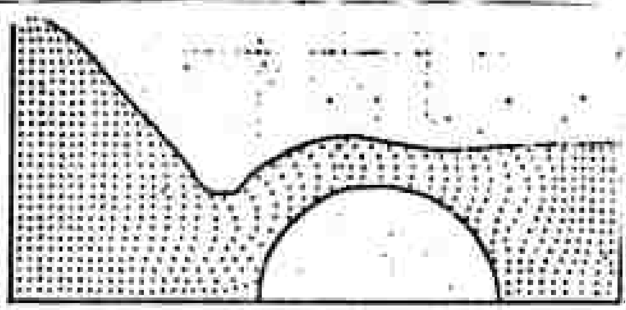
Figure 15

Large Scale Numerical Studies

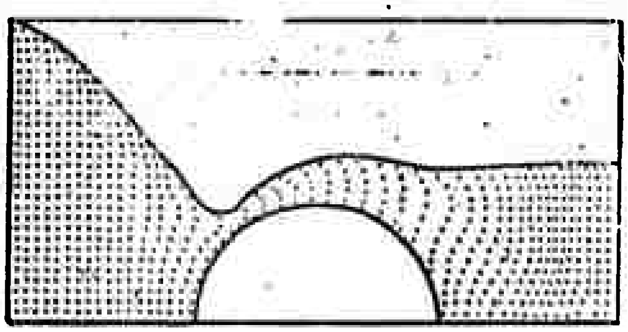
Numerical solutions to a particular system of nonlinear partial differential equations, common to certain studies in hydrodynamics, are being formed with the aid of computer graphics. Of particular interest is the duplication of flow over objects that undergo large deformations or move within the required computational mesh. One phase of the study is the involvement of free surface boundaries which occur in medical phenomena, such as the movement of a heart valve leaflet or in the pulsing of an arterial wall. The free surface boundary has been treated by use of the Arbitrary Boundary Marker and Cell method for the case of the movement of a prosthetic heart valve in the aortic position.[3] A computer generated picture of the investigated flow region was described by fluid marker particles as shown in Figure 16. Another capability within the algorithm and its resulting computer program was the formation of velocity vector plots



Enlarged section showing marker particles around ball for steady state form of solution.



Enlarged section showing change in marker particles as ball begins to move backwards.



Enlarged section showing change in marker particles as ball reaches closed position.

Figure 16

which allowed the inspection of numerical instability positions. Furthermore, for our special requirements it allows the pressure distribution and the stress distribution within the problem area to be formed and viewed upon the graphics display screen.

Stress distribution within arterial or heart valve flow is important since it can lead to red blood cell damage. A thesis was formed[4] which allowed graphics displays of the stress distribution about a heart valve disc occluder as it moved from full-closed to almost full-open position. The contributions of this study to the understanding of hemolysis and turbulence are unique in that the man-machine interaction present allowed information not to be gained by other approaches. For example, the development of an interactive curve plotting program allowed the investigator to examine stress distribution data along any selected cross-section position in the solution space, as shown in Figure 17, since all display programs were activated through keyboard

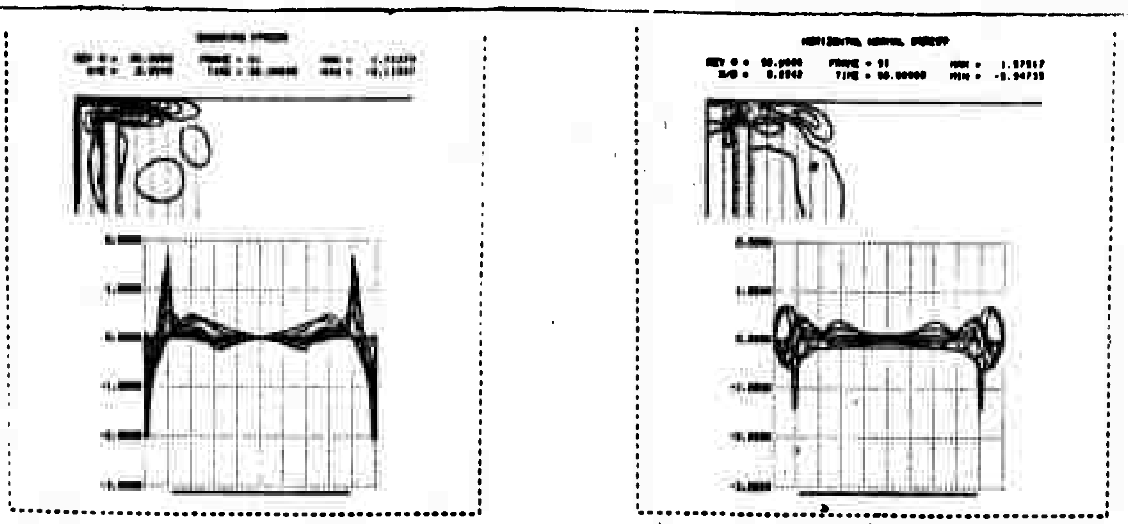


Fig. 17

Top view in each plot is one position of the valve occluder as it moves toward the wall. Bottom view in each plot is sum of all shear stress values as disc occluder has moved to that position. Each stress curve can be studied separately upon command.

interrupt, the simulation program was run on detached mode during production runs. In addition to providing a more efficient use of the available computing time, this action released the display unit for other uses. Throughout the study the resultant graphic displays pointed out various errors in boundary treatments and aided in locating programming errors.

The project previously mentioned in the last progress report concerned with steady flow through an abrupt expansion in a tube to an annular region, is continuing. Although the present application is of concern to determination of blood flow, in particular arterial channels, the algorithm developed is broad enough to pertain to any similar hydrodynamic study. The computer program for presenting different positions of a moving curved wall was completed and a sequence of views from the display screen has been obtained. This sequence will be employed to generate a movie of the flow pattern of blood in a pulsating arterial component; such a study to be incorporated into other circulatory studies. It is noted that the storage and speed of computation of our present computer equipment are inadequate for this project and recourse has been made to other equipment on the ARPA network.

A graduate student (E. Catmull) developed a computer graphics study of the motion of the human hand. The algorithms required are of interest to our investigations since they involve object representation, object manipulation, concurrent motion (flexible surface and parts that move relative to other parts), plus requirements for specifying sequential motion. The process requires the extraction of three-dimensional coordinates that define the surface (in our case) of the leaflets of a natural heart valve and the organizing of these coordinates into polygons that represent flexing parts of those leaflets. The polygons are now being refined in an interesting fashion. Polyurethane molds have been made of human heart valves in open position and closed position. These molds are to be sliced in extremely thin sections and each section is to be photographed with reference points allowing polygon representation of each surface section with care. The resulting surface coordinates will thus allow the true shadings upon the display screen as the algorithm employs all the sliced section values. The interim motion of the flexing leaflets between full-open and full-closed positions should then be displayed with required stress values for the required flexing investigated. Verification will be attempted by use of in vivo data from cadaver hearts. This is a rare combination of experimental procedure working in conjunction with a computer graphics analysis.

In conjunction with the head-mounted display system a "wand" has been developed by D. Vickers as a thesis project. We are attempting to apply this innovation to our studies. One can take a point in a stereoscopically viewed object (as formed in space by the head-mounted display system) and "pull" it out of shape by using the wand. The new shape at the particular point of interest in the object field is displayed via the head set or upon a CRT screen. This action, of course, will change the shape of the surface at one or more other positions because of the resulting constraints placed upon the other points. Assuming that the stress values involved are presented concurrently for perusal, a variant section in a heart valve can be studied. Too, one could attempt to form a surface view of an atherosclerotic lesion and form a computer simulation comparison. The observer would then change the surface shape by "pulling" to conform to some in vivo data of a blood-endothelial stress reaction as shown in Figure 18. If the surface conforms to the shape seen in autopsy or medical diagram, a resulting stress equation may be had for study. This equation or group of equations could improve our knowledge about lesion formation. This concept is presently in the preliminary stage as growing lesion shapes are being evaluated for display purposes and eventual reshaping.

B. COMPUTING SYSTEMS

This research group, directed by Charles Seitz, (faculty) has as its common interest real computing systems with radically improved characteristics for direct use by people, such as: communication devices, simulation and modeling devices, and computational instruments. Emphasis is not primarily on raw computational capacity, but rather on system problems of the direct use of these machines by people in a natural way, so that the procedures may be easily described and information may be simply represented.

Line-drawing Display

A microprogrammed control for the Harvard clipping divider has been designed. The microcode has been written and successfully simulated on the PDP-10. Rebuilding the clipper is in progress. The scope driver is built and operating correctly.

Acquisition of a new-style matrix multiplier has been delayed, but is still considered important to making this overall effort produce a useful research tool.

Printed-circuit Layout

A technical report (5) is being published which investigates a "dual" technique for printed circuit board design, in which the wires are treated all at once while using up area incrementally. The success of this technique depends heavily on the program deriving from an IC dictionary the logical and device commutivities in the net description.

Asynchronous Circuits

Substantial theoretical and experimental results have been achieved in this area, to be described shortly in a technical report. We are designing and testing a set of asynchronous modules which are based on a "four-phase" request-acknowledge link.

We have produced (and presented in a recent meeting in St. Louis) some experimental results to the effect that arbiters exit from their metastable "state" in a way approximating a Poisson process. The "Rate", ρ, is in the order of 350 MHZ for TTL, and HSTTL, but surprisingly is 0 for S-series TTL. (The "mesastable" region is in fact stable (!) for S-series arbiters.)

APL System

A paper has been submitted to the Communications of the ACM entitled "Data Structure Techniques in an Implementation of APL" covering research of ways to achieve net savings and controlled tradeoff in workspace size and CPU time in a practical APL operating system based on selective deferral of the evaluation of APL statements. Implementation of this APL system in the ARPA time-shared PDP-10 is progressing very well.

C. WAVEFORM PROCESSING

The senior investigators in Waveform Processing are: Thomas G. Stockham, Jr. (faculty), Ercolino Ferretti (faculty), and LaMar Timothy (faculty). The principal goal of this group is to pursue research involving the use of computers in processing signals with particular emphasis on processing pictures and sound.

The research embraces a broad spectrum of topics ranging from problems associated with digitizing and undigitizing image signals and audio signals to speculative inquiry requiring sophisticated and innovated processing methods as well as new fundamental knowledge concerning the psychophysics of human vision and hearing. Emphasis has been placed on obtaining very high performance quality, demonstrating the feasibility of processes which represent technological breakthroughs, the evolving of the computer as a basic tool for processing information in the form of signals, and emphasizing the importance of human observer characteristics in producing successful processes. The following work represents our continuing effort in these directions.

A-D and D-A Converters and Their Effect on Digital Signal Fidelity.

The eight identifiable forms of distortion associated with the use of analog-to-digital and digital-to-analog converters in processing signals are easily and frequently overlooked. Our attempt to make these problems explicitly clear, both theoretically and practically, have been continued successfully during this period. So far we have succeeded in producing demonstrations using computed spectra and/or recorded sounds for illustrating the phenomena of aliasing, quantization, imaging on playback, and high frequency amplitude distortion produced by the conventional zero order hold D-A converters. Similar demonstrations for distortions caused by aperature noise both random and line-frequency correlated are nearly complete. A report incorporating these results in a manner which will be simultaneously complete, vivid and easily understood is being prepared.

Automatic Image Deblurring when the Blur Is Unknown

Implementation of a general method for deconvolution of two-dimensional signals is continuing. This method is being used to deblur pictures which have been blurred by convolution with some arbitrary degrading function, as is the case with most motion-, focus-, and turbulence-blurred pictures.

The deblurring method uses the technique of generalized superposition, which involves mapping the blurred picture into a domain in which the picture and blur components are added. The blur can then be estimated by statistical averaging techniques and removed by linear filtering. The domain in which the picture and blur components are additive is the log Fourier transform domain.

At present any blur with zero phase can be estimated with very good accuracy. Research into estimation of blurs with phase reversals and arbitrary phase components is continuing. Several different phase recovery methods are under investigation.

Performance of the blur estimation technique in the presence of additive and multiplicative noise has been analyzed. Film grain noise can be characterized as multiplicative noise, while sensors and scanners often introduce additive noise into the process. Restoration filters estimated by the above method have been compared with other types of linear filters, including the Weiner filter, which has optimum least-squares error performance in the presence of additive noise.

Figures 19-22 demonstrates some of the progress made to date. Figure 19 shows an original scene, and Figure 20 shows the same scene after artificial blurring with a motion-type blur. Figure 21 shows the image of Figure 22 after linear filtering to remove the blur. The linear filter was estimated statistically as described above, and the statistical properties of an ensemble of pictures was used in the estimation process. In Figure 22 the image of Figure 20 has again been linearly filtered to remove the blur. In this case a closed-form curve which approximates some of the statistical properties of an ensemble of pictures was used in the filter estimation.

An unpleasant "ringing" effect can be seen in Figures 21 and 22. The "ringing" effect occurs because of truncation of the point spread function of the deblurring filter. The deblurring filter theoretically should be infinitely large in its spatial extent, but the estimation process and the use of digital computers constrains the filter to be truncated to a small size. The "ringing" effect appears worse in the dark areas. Effort is being made to find means of minimizing these effects in order to present a restored image with the best possible appearance to the human eye.

Figure 19

Figure 20

Figure 21

Figure 22

Vision Modeling and Image Processing

Following previous studies on computer modelling of vision and on its applications to digital image processing [6], progress has been made toward the extention of these notions to color vision and color images.

Our effort has first been devoted to a deeper investigation of the homomorphic model of achromatic vision and its implications. As previously mentioned, the early stage of the visual system can be modeled as a logarithm transformation, followed by a convolution process, investigated by several researchers [7,8,9,10], is in harmony with the established notion of lateral inhibition in neural networks[10]. As illustrated in Figure 23, this model predicts satisfactorily well-known perceptual phenomenons such as mach bands and brightness contrast.

Computing and displaying equipment is used to produce test patterns for psychophysical experiments: specific patterns are created and processed by computer programs, and displayed on a high quality CRT so as to obtain subjective cancellation of the contrast illusions. Through these experiments, better understanding has been gained about the fundamental quantitative and qualitative characteristics of the model and about its possible deficiencies. Experimental procedures have been developed, and special visual patterns have been studied for the establishment of these results. In particular, the effect and influence of edges and contours within the model have been investigated.

Concurrently, the problem of producing carefully calibrated color pictures has been studied. The output equipment is composed of a high resolution cathode-ray tube display, and a camera with a high quality

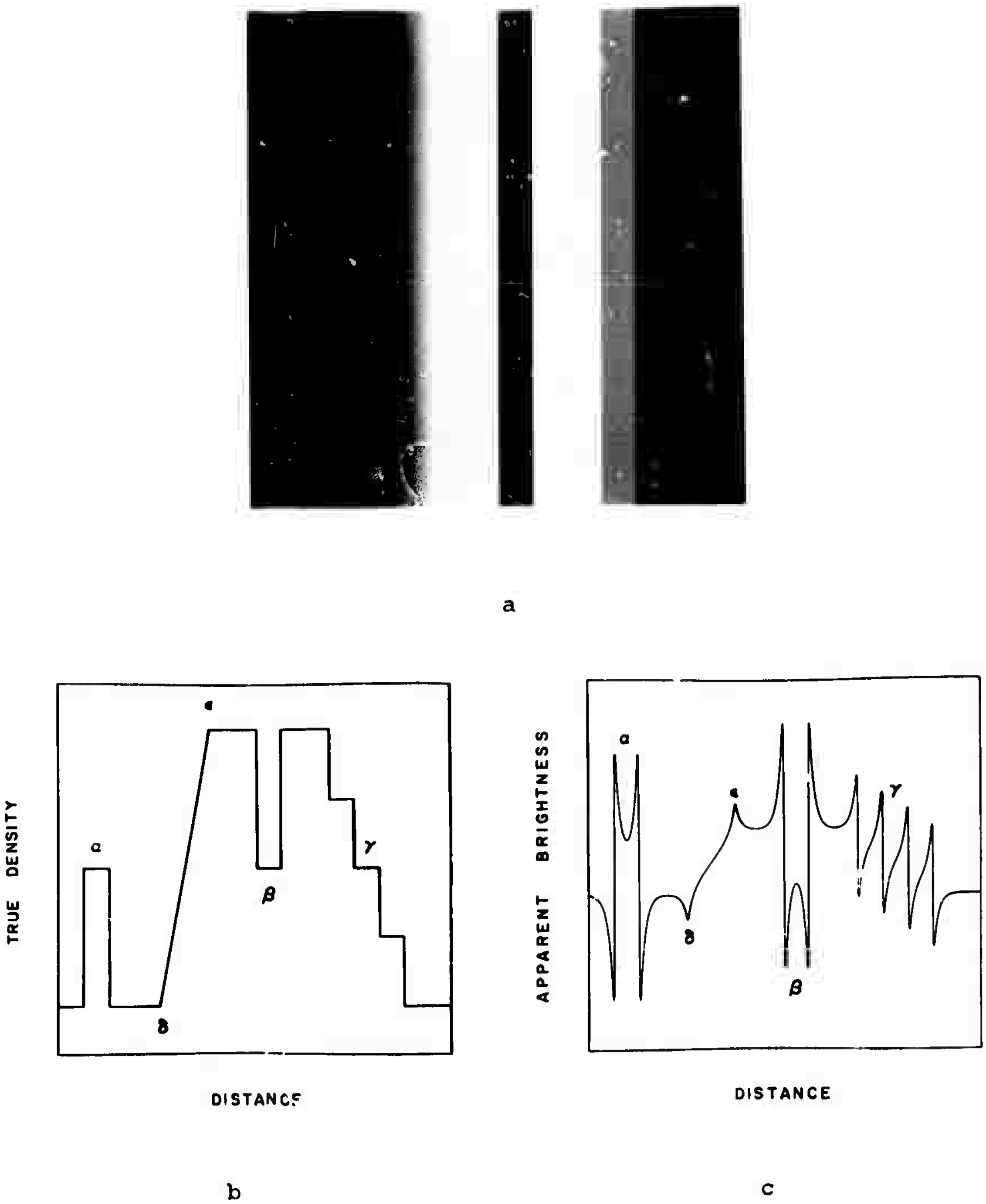
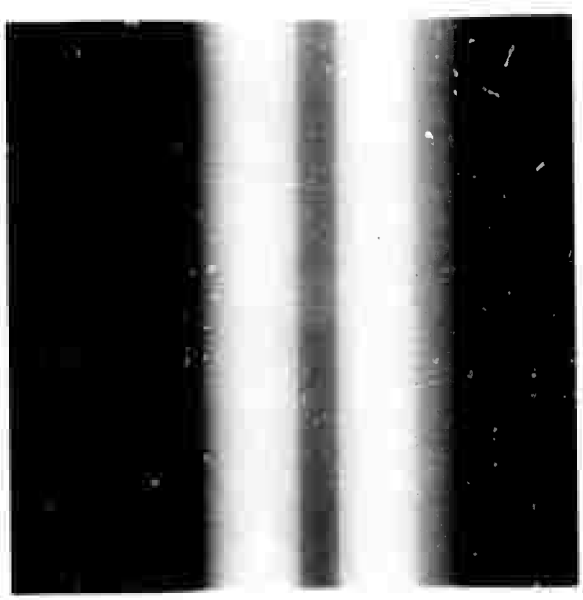
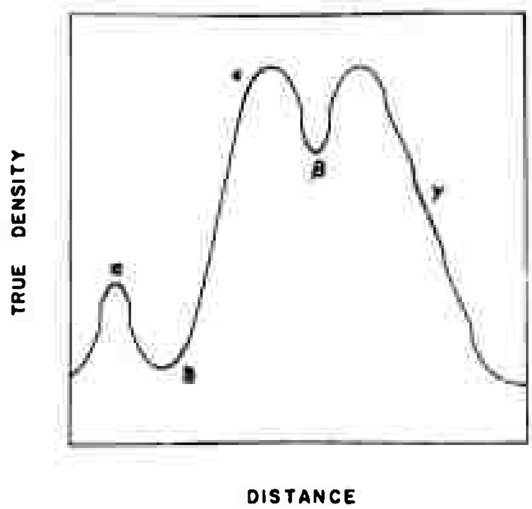


Figure 23

Patterns for use in testing and calibrating the visual model. (a) Observe the illusions of simultaneous contrast α, β, γ, and Mach bands δ, ε. (b) The true density representation of the image. (c) The approximate apparent brightness of the image.



d



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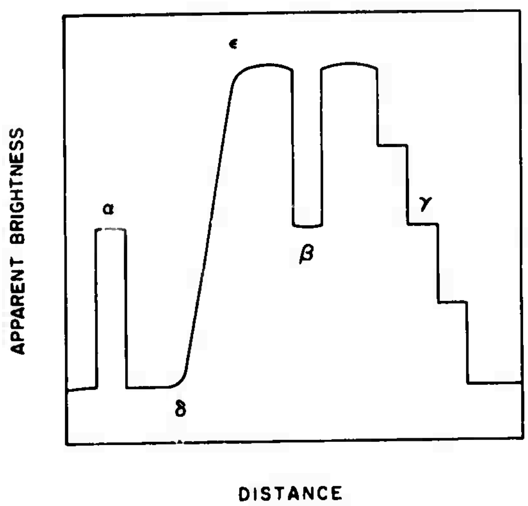


f

Figure 23

(d) The pattern of Fig. 23a processed in accordance with the model for the suppression of optical illusions. Compare with Fig. 23a. Appraise the amounts of remaining simultaneous contrast α, β, γ, and Mach bands δ, ε. (e) The true density representation of the processed image. (f) The approximate apparent brightness of the processed image as observed from a calibrated print. Curve taken as a subjective consensus from five knowledgeable observers.

lens. Color pictures are produced by three exposures, through blue, green and red filters, of polaroid or negative color films. At a first stage, color pictures will be compensated for global non-linearity of the film by table lookup (as is currently done for black and white pictures), combined with a matrix correction for the imperfection of the printing dyes.

The homomorphic model of color vision is currently being studied, as a three-dimensional extention of the achromatic model. Again, perceptual phenomenons such as color mach bands and color contrast will provide the experimental basis for this research.

Methods for Optical-to-Digital and Digital-to-Optical Scanning of Images

Our investigation into methods for producing digital images of the highest possible quality has progressed very well. We have successfully created a procedure for conveniently compensating the nonlinearity of photographic materials. This is accomplished by a computer program which fits an invertible-analytic-parametric function to the measured density vs log (digital intensity) characteristics of the composite digital-to-optical or optical-to-digital system being compensated. The function in question is related to the hyperbolic tangent and employs five parameters which adjust for the following system properties:

1) the whitest intensity obtainable
2) the dynamic range obtainable
3) the actual film speed
4) the gross contrast (i.e. gamma)
5) assymetrics in the saturation regions

The procedure is easy to use and so far has been capable of compensating our CRT digital to optical scanner to an accuracy of 0.06 density units of absolute accuracy across the entire dynamic range of several black and white print materials.

Reflectance Scanner

The process of converting a photographic image to numeric data generally requires some device for measuring the light intensity at each point in the image and converting that measurement to a number. One way to construct such a device is to fasten a photographic print to a rotating drum and move a lamp/photomultiplier assembly over the length of the drum. By means of rotating the drum and moving the lamp/photomultiplier, a measurement of the reflected light intensity may be made at each point on the print.

Such a device is being constructed and is in the process of being checked out on the computer. All indications are that a very high quality imagery can and will be attained by means of a convenient and inexpensive device. This device should be of interest to others involved in digital image processing research.

<u>The Removal of Background Sounds from Voice Signals</u>

During this period progress was made in the area of filtering of voice signals from background noise and signals. This filtering problem has been broken down into two general problem areas: the analysis of the noisy signal to obtain parameters describing the state of the vocal tract during a short interval, and the synthesis of the voice signal associated with the vocal tract over this interval.

The analysis problem was investigated both in terms of the accuracy of parameter estimation achieved automatically and achieved through interactive graphical presentation. The synthesis problem continued to be a fully automatic process.

Considerable time was spent in achieving long duration examples of the filtering process. Since problem recordings of noise speech of interest to the sponsor were not readily available, noisy recordings of singing with orchestral background were used. The goal was to remove the subjective presence of the noise and the instruments. The goal was reached with surprising success! The voice could be heard more clearly than in the original partially because of the suppression of distracting sounds and partially because multilated portions were reconstructed during the synthesis phase.

Results of the filtering process were presented at the 1972 International Conference held in Boston, Massachusetts in late April and were favorably received by the speech community.

Symmetry arguments indicate that the techniques described above are not likely to be able to separate one voice from another. The problem centers around the difficulty of detecting pitch for only one of the two voices. The use of cepstral pitch detection methods were shown to fail in this application during this research period. As a result an effort to discover pitch detection schemes which will work for double speakers was initiated.

The Automatic Removal of Resonances and Echos from Sounds

When a recorder sound is distorted by resonances and/or echos, the problem of removing these defects is complicated by the fact that their detailed mechanisms is in general unknown. Methods for overcoming this problem were disclosed by this group in 1971. The mathematical approaches now being used by the image deblurring research discussed above were a direct result of these methods. In its pure form the theoretical basis does not consider noise to be added to the distorted sounds. Considerable investigation has been made to determine best methods for removing resonances and echos from sound for that case in which noise has been added. These investigations are most important because in practice such noise cannot be avoided either in the case of sound or images. Means for evaluating the spectra of such noises from the contaminated record itself and for optimizing the restoration algorithms to reduce the auditory affect of such noise, is proceeding quite well and has already been demonstrated in a few cases.

Modeling Human Hearing

The human hearing system is a nonlinear filter. It is desired to model this system and to reconstruct the audio from the model output. This reconstructed audio will be used to make judgements about the quality of the model.

The outer and middle ear have been extensively studied and are well understood. The coclea and associated neural networks are less well understood. The coclea is a traveling wave chamber with a separating membrane. Different areas of this chamber resonate at different frequencies. The coclear membrane has various sensors which are acted upon by the resonant motion. Mechanically the coclea appears to be a time-varying-spectrum analyzer.

The neural networks attached to the coclear membrane sensors are not well understood physiologically. They respond approximately to the logarithm of the intensity of the stimulation and perform some sort of processing.

To understand the purpose of the processing performed by the neural networks, the psycophysical behavior of the human hearing system must be studied. Standard references point out several phenomena which result from this processing. They include tonal masking, tonal fatigue and automatic gain control. The system also appears to perform the function of a deconvolver to remove or at least reduce the effects of reverberant environments.

A promising model possessing similar properties is shown in the following block diagram.

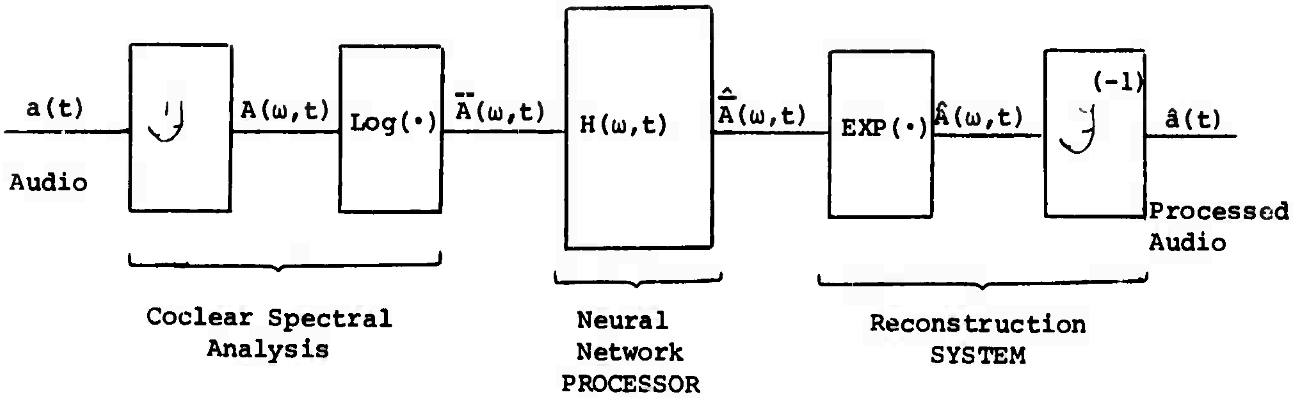


Figure 24

The coclear spectral analysis portion of this system has been implemented on a computer via a time varying fourier transform followed by a logarithm. The reconstruction system has also been created. These programs are in the process of being checked out. Without the neural network processor, the coclear spectral analyzer followed by the reconstruction system should be an identity system. This fact has been demonstrated subjectively by passing digital speech waves through that system. The neural processing program is in the early stages of development. Preliminary tests seem encouraging.

Predictive Coding of Speech

This section summarizes our recent research in predictive coding of speech waveforms. It describes briefly what predictive coding is, what algorithms were developed to analyze and synthesize speech, and what improvements we have made by incorporating a tool taken from modern control theory, recursive least squares (Kalman Filtering), in the estimation process.

In 1971 Atal and Hanauer[11], described a method of analyzing and synthesizing speech using predictive coding. Using this technique, the speech wave is analyzed directly by predicting any particular speech sample as a linear combination of the previous K samples. The K parameters which relate the previous speech samples to the present one are called the predictor coefficients. They are obtained by minimizing the mean squared error between the actual samples and the predicted values. This leads to a set of linear equations involving the unknown predictor coefficients and a covariance matrix. These coefficients are made to be the parameters of a time-varying digital filter which in turn is excited with synthetic pitch pulses to synthesize an approximation to the original speech wave.

As a starting point a "duplicate" of Atal's linear prediction system was developed. This system analyzes speech in terms of a set of parameters which are encoded and transmitted to the synthesizer. The speech wave is synthesized as the output of a linear recursive filter. The analysis parameters consist of the pitch period, K predictor coefficients for each pitch period, a binary parameter indicating whether the speech is voiced or unvoiced, and the RMS value of the speech computed over a short segment.

The specific routines written to estimate the analysis parameters include: (1) a matrix inversion routine to invert the covariance matrix; (2) a polynomial root finding program to compute the roots of the polynomial based on the estimated coefficients; and, (3) a program to estimate pitch information and the voiced/unvoiced decision.

The synthesized speech is generated as the output of a linear recursive filter excited by either a sequence of quasiperiodic pulses or a white noise source.

This vocoder system was then demonstrated to generate synthetic speech which has been judged comparable in quality to samples provided by Atal in his paper.

Subsequent research consisted of replacing Atal's method for finding the predictor coefficients by a recursive least squares algorithm. The advantages of this method are: (1) it incorporates information from the previous pitch period in estimating the predictor coefficients; (2) its estimate is insensitive to the effect of the glottal pulse; (3) it converges to an estimate using fewer speech samples per pitch period; and (4) it requires less memory. The overall effect from these advantages is higher quality synthesized speech requiring less computation and less memory than that using Atal's method.

Due to these advantages, present research efforts center on using the recursive least squares algorithm to further reduce transmission bandwidth requirements and to develop a real-time digital voice analyzer-synthesizer system.

A Catalogue of Window Functions

An important tool in digital signal processing is the use of so-called window functions. Windows are used to stabilize estimates of power spectra, to prevent the leakage of energies from one frequency band into another in the estimation of power spectra and in certain simple methods used to design digital filters employing impulse responses of finite length. We are producing a catalogue of all such windows known to us at this time. This catalogue will enable the reader to familiarize himself with these windows rapidly, to evaluate their relative performance values in various application situations, and to implement them readily in terms of his digital signal processing application.

To this end the catalogue will consist mainly of a large number of very high resolution plots representing the characteristics of these windows in both the time (space) and frequency domains. These presentations will be complete and their style uniform throughout the various window types.

Video Storage and Retrieval System

A system essential to a workable image processing facility was designed to allow a user easy reference to stored image data. This reference is by picture name, thus the user is required to remember only the name. Once a name has been recognized, complete information about a picture may be acquired under program control. Each picture file has space for a descriptive title, a format block containing the vital information concerning the structure of the image data, additional space for auxiliary information and the image data. Each disk to be used on this system is identified and equipped with a directory which contains the necessary information for locating each picture and directs the assignment of free disk space to new picture files. The basic system software has been developed and we are now gaining experience with this system.

D. Symbolic and Algebraic Manipulation

Many of the day to day problems which confront theoretical physicists, applied mathematicians, and engineers involve extensive algebraic or non-numerical calculation. Such problems may range from the evaluation of analytical solutions to complicated differential integral equations on the one hand, to the calculation of increasingly more complicated terms in a perturbative approximation to a physical theory on the other. The difference between these two classes of problems is obvious; in the former case no straight-forward algorithm exists which will guarantee a solution, and indeed an analytic form for the answer may not even be possible. On the other hand, algorithms do exist for the solution of problems such as series expansion and differentiation and so a correct answer may always be found provided the researcher possess sufficient time, perserverance and accuracy to carry the calculations through free of error. The appeal of using a computer for the latter class of calculations is obvious. Besides removing the tedium of doing complicated algebra, the result is guaranteed to be error free and can be obtained in a much shorter real time interval. A considerable degree of practical success in this field has now been obtained, and many computer algebraic calculations have been reported in the literature. The main research of this group is devoted to the development and application of the computer techniques necessary for the solution of such theoretical problems. This research is orientated toward both computer software development and the use of the developed programs in solving practical problems. The REDUCE (12 & 13) system, developed by Anthony C. Hearn, principal investigator, is used as a basis for this work. Originally, this began as a system for solving some particular problems which arise in high energy physics where much tedious repetitive calculation is involved. However, it was quickly recognized that the simplification processes being used were quite general, and in 1967 REDUCE was announced as a system for general purpose algebraic simplification and released for distribution. Over 50 installations in the USA and Europe now have REDUCE operating and over forty publications acknowledging its use have appeared in the literature.

The work during the last six months may be divided into three main areas and the progress in each area is discussed below.

1. System Development - The improvements in the REDUCE system which were discussed in the previous report have all been completed; the matrix routines are now an order of magnitude faster in many cases and a much wider range of substitution capabilities is possible in the system. We are presently boot-strapping this program from the Utah PDP-10 onto the IBM 360/91 at UCLA using the ARPA net, and the UNIVAC 1108 on this campus. Versions of REDUCE have previously been available on the IBM 360 machines but the 1108 implementation is new. We expect that this work will be completed during the next six months.

An improved version of the modular greatest common divisor algorithm has also been implemented and will be made available in the export version of REDUCE in the near future. Detailed timings were made in order to improve the efficiency of the polynomial arithmetic used by this algorithm. These timings have also helped us to improve the efficiency of several other parts of the REDUCE program.

2. Language Standardization - Our efforts at standardizing the REDUCE language are progressing. In order to facilitate this standardization a syntax directed META translator was adapted to use REDUCE as its source language. In order to make the translator as computer independent as possible several major modifications to the scanning and parsing facilities of REDUCE were necessary. However, we feel that this work will be justified by the ease with which REDUCE programs will be usable on a wide selection of computers.

3. Applications Research - We are considering two main applications problems at present. As part of our development of a system for the automatic calculation of processes in quantum electrodynamics (14), we are studying in detail the problem of computer renormalization of Feynman diagrams. We believe, on the basis of our present work, that a completely automatic program in this area will be possible within a year or two.

A second area of application has been to the automatic computation of a class of integrals which occur in quantum electrodynamics. It has been recognized by several people that in certain orders of quantum electrodynamics only well understood integrals of rational functions occur, and it has been possible for us to develop a program which will determine analytically all integrals which occur in Fourth order quantum electrodynamics. This again is a necessary part of our automatic Feynman diagram calculation system. This integration program is essentially complete and will be made available to interested persons working in this field.

PART II - FACILITIES

ARPA Network

The Network System software (NCP, etc.) was debugged and made operational during this reporting period after some initial problems associated with our IMP-TEN interface. Once operational, the benefits of the Network were advertised to the projects personnel. The results have been astounding! Driven to the Network mostly because of our own over-loaded machine, we currently run regularly on two Network Service Centers, the RAND TENEX SYSTEM and UCLA 360-91.

The use of the RAND TENEX system is a straight-forward hardware sharing application. Individuals with large or long running programs will move source files or core images and their data over the Network to RAND. For the past four months, we have received bills of $2-5K per month from RAND (these bills are for information purposes only). The users have found that their programs will run 2 to 10 times faster. This is due to the light load at RAND and the larger core size as contrasted with our system.

The use of the UCLA system has been much more interesting. We implemented a special program to access the 91 via NETRJS protocol developed by UCLA. Since that time we have opened several accounts at UCLA. The Symbolic Computation and the Graphics Application groups use the 91 on a daily basis. The Waveform Processing Group has not gotten under way as quickly because of the special problems created by the massive amount of input and output data associated with this application. We hope within the next reporting period to have some of the larger computing jobs in the Waveform Processing Area converted to run on the 91.

The problems of using the 91 are similar to the traditional problems of using a new machine, only compounded slightly. There were, of course, the difficult tasks of reprogramming and learning new operating procedures, command languages, etc. In addition, however, there was the difficulty of not having local user consulting services to help us when sticky problems arose. We were able to use the documentation, telephone services from UCLA, and some local expertise, but this was clearly not as efficient as personally taking the problem to a staff consultant. Some computer time and much user time was wasted in finding well-known answers (at least at UCLA) to some nebulous questions (e.g. finding the relative merits of the level G, H, and Watfive Fortran Compilers). There seems to be no easy solution to this problem until the local level of use of a particular Network Resource can justify the addition of a staff consultant for that machine.

There has been only occasional use of our machine by other Network sites. External use of our machine has been intentionally limited by us because of the severe overload of our system. Some uses that have gone on, however, are: the RADC use of the system described in the Graphics section of this report; BBN use for the NETPLANES experiment; and use by BBN system programmers in the debugging of parts of our TENEX system.

Our plans for the coming period involve further user support in getting a wider class of jobs done at UCLA and other Network Service Centers as they become available. In particular, we are looking forward to the entrance of the Berkeley Lab's CDC 7600. We also plan on implementing the recently specified (but not yet officially announced) file transfer protocol.

Quiet Room

Usefulness to the quiet room has been greatly enhanced by the addition of full computer input/output facilities, computer graphics, and audio input/output equipment during this last six month period. The normal Teletype I/O facility has been complemented by a high speed quiet terminal having graphics capability (a Tektronix 4010 Graphics Terminal). In addition, a Tektronixs 611 storage scope has been installed to facilitate audio waveform analysis. A switching system which allows easy selection of computers and operating band rates for the TTy and the 4010 terminal has been installed. Then to facilitate control of the single user computer system the computer console control switches used by all computer users have been duplicated in the quiet room and operate in parallel with the computer console itself.

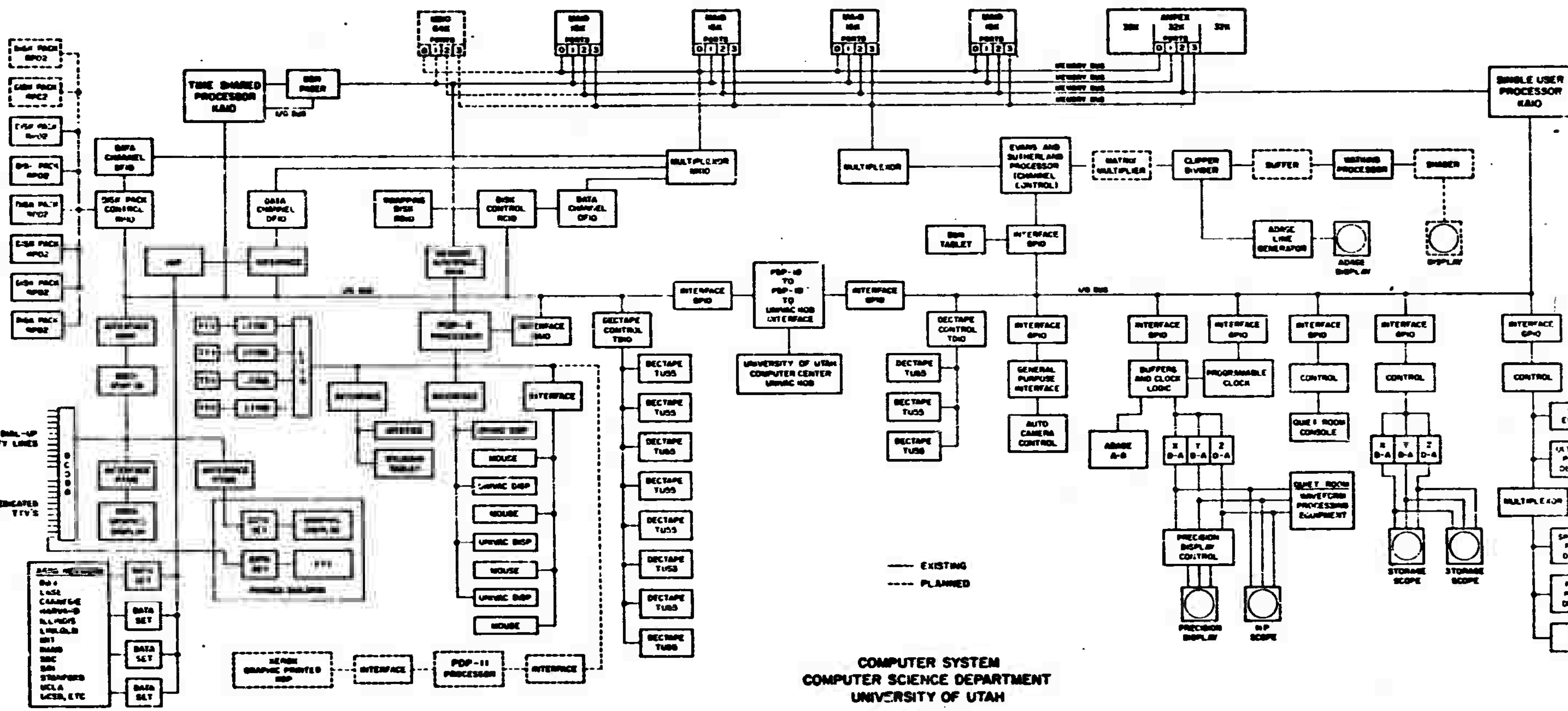
All of the above mentioned changes now make it possible for those doing research to operate entirely from the quiet room having full control of all computer facilities as well as having easy access to all audio input/output equipment. Thus the quiet room is now truly a fully implemented and quiet center for audio or acoustical research.

Computer Facilities

No major changes have been made in the computer hardware configuration. Figure 25 shows the present layout of the computing facilities and planned hardware additions that will increase the capabilities of this facility.

Adequate power distribution was a problem in the past and has been corrected by the addition of new main power cables and additional outlets.

Air conditioning distribution has also been a problem and efficiency has been increased by diverting the cold air under the computer room floor and into the bottom inlets to the equipment.



COMPUTER SYSTEM
COMPUTER SCIENCE DEPARTMENT
UNIVERSITY OF UTAH
JUNE 1972

Figure 25

PART III. PUBLICATIONS AND PRESENTATIONS

1 January 1972 to 30 June 1972

Following is a listing of presentations and publications made by Computer Science Department personnel during the reporting period related to ARPA sponsored projects and/or activities. This listing is included merely to indicate the scope of exposure our work has had during this period and not as a means of announcing new research discoveries made under the contract. All significant information contained in either the presentation or written articles has been previously reported on an individual basis.

Calmet, J. "A REDUCE Approach to the Calculation of Feynman Diagrams." First European Conference on Computational Physics. (Ern, Geneva, 1972. (To be published in Comp, Physics Comm.)

Greenfield, H. "Use of Computer Graphics in Studying Medical Phenomena." Trans. Amer. Soc. Artif. Int. Organs, 18: 607-612, 1972.

__________. and W. Kolff. "The Prosthetic Heart Valve and Computer Graphics." J. Amer. Med. Assoc., 219: 69-74 (3 Jan. 1972)

__________. "Large Scale Numerical Problems in Biomedical Studies." Computer Graphics in Medicine Symposium. Pittsburgh, 7-10 Mar. 1972. (To be published in Proceedings)

__________. "The Role of Computer Graphics in the Bio-Medical Area." 11th Annual meeting, Assoc. Computing Machinery. Chattanooga, 8-10 June 1972. (Special luncheon address)

__________. "The Artificial Heart and Computer Graphics." 11th Annual Mtg. Assoc, Computing Machinery. Chattanooga, 8-10 June 1972.

Greenfield, H. "Report on Research in Atherosclerosis." Cardiovascular Clinical Conf. Hotel Utah, Salt Lake City, 22-23 Mar. 1972

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