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Final Five-Year Summary Report

15 September 1986 through 30 September 1991

The Infrastructure of Command Information Systems

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Submitted to

Office of Naval Research
Arlington, VA 22217-5000

Submitted by

Department of Computer Science
The University of North Carolina at Chapel Hill
Campus Box 3175, Sitterson Hall
Chapel Hill, NC 27599-3175

Principal Investigators:

Frederick P. Brooks, Jr.
Donald F. Stanat
Stephen F. Weiss

Approved for release;
Distribution Unlimited

November 1991

Contract No. N00014-86-K-0680

91-16375

91 1122 101

THE UNIVERSITY OF NORTH CAROLINA
AT
CHAPEL HILL

Stephen F. Weiss
Professor and Chairman
Phone: (919) 962-1800
FAX: (919) 962-1799

Department of Computer Science
Campus Box 3175, Sitterson Hall
Chapel Hill, NC 27599-3175
Internet mail: weiss@cs.unc.edu

18 November 1991

Dr. Ralph F. Wachter
Scientific Officer
Office of Naval Research
800 North Quincy Street
Arlington, VA 22217-5000

Dear Ralph:

Ref: Contract #N00014-86-K-0680
The Infrastructure of Command Information Systems

Enclosed is a copy of the **Final Five-Year Summary Report** for the above-referenced contract. Copies are also being sent to those individuals listed in the distribution list, as noted below. If we can clarify or expand upon any area in the report, please let us know.

Our research efforts have been greatly enhanced as a direct result of this contract, and we have certainly enjoyed our association with the Office of Naval Research. On behalf of the members of the Executive Committee and all of our investigators, let me extend our sincere thanks to you, Ralph, for your help, unwavering support, and valued friendship during these five years. We hope that you will continue to come and see us whenever you can, and we look forward to working with you and your fine organization again in the future. Please stay in touch.

Sincerely,

Stephen F. Weiss
Chairman, ONR-URI Executive Committee

Enclosure

Distribution:

Christoph Hoffmann, Professor of Computer Science, Purdue
Stanley Wilson, Consultant, NRL
Elaine Cohen, Professor of Computer Science, University of Utah
Norman A. Meeks, Administrative Contracting Officer, ONR
R. Timothy Arnold, Contracting Officer, ONR
Defense Technical Information Center (12 copies)
Director, Naval Research Laboratory (6 copies)
Annette Crabtree, Contract Administrator, UNC–CH
Members, ONR-URI Executive Committee, UNC–CH
Investigators, UNC–CH

CONTENTS

SECTION 1: Productivity measures during contract period 1

SECTION 2: Executive Summary/highlights/accomplishments *(by project)* during contract period 2

Head-Mounted Display 2
Tracker 2
Pixel-Planes 5 3
Walkthrough 4
Artifact-Based Collaboration 4
Data-Parallel Execution 4
SoftLab 5

SECTION 3: Publications, reports, presentations, honors/prizes/awards during contract period 7

A. Publications, technical reports (appeared and to appear); books, chapters, videotapes 7
B. Refereed exhibitions 7
C. Refereed papers submitted (awaiting acceptance) 7
D. Presentations 8
E. Honors received 8
F. Prizes or awards received 8
G. Promotions obtained 8
H. Educational productivity 8

SECTION 4: Transitions and DoD Interactions *(by project);* follow-on research 9

APPENDICES

Appendix I	Participants
Appendix II	Educational productivity
Appendix III	Comprehensive bibliography
Appendix IV	Equipment Reports
Appendix V	Travel Reports
Appendix VI	ANNUAL REPORTS, for each of the five years

FINAL SUMMARY REPORT

Principal Investigators:	Frederick P. Brooks, Jr. Donald F. Stanat Stephen F. Weiss
PI Institution:	The University of North Carolina at Chapel Hill Department of Computer Science
PI Phone Numbers:	919/962-1931 919/962-1788 919/962-1888
PI E-mail Addresses:	brooks@cs.unc.edu stanat@cs.unc.edu weiss@cs.unc.edu

Contract Title:	The Infrastructure of Command Information Systems
Contract Number:	N00014-86-K-0680
Contract Period:	15 September 1986 through 30 September 1991

SECTION 1: Productivity measures during contract period

		ONR supported	Related
1.1	Refereed papers submitted *(awaiting acceptance)*	0	10
1.2	Refereed papers submitted *(to appear)*	2	2
1.3	Refereed papers published	41	54
1.4	Unrefereed reports and articles *(published or to appear)*	78	51
1.5	Books (or parts thereof) submitted (*to appear*)	0	0
1.6	Books (or parts thereof) published	1	9
1.7	Patents filed but not yet granted	0	0
1.8	Patents granted (includes software copyrights)	0	1

1.9 Educational productivity (see Appendix II for details)
Degrees earned by RAs supported by ONR ≥ 25% of full time during any year of contract period:
M.S. degree 29
Ph.D. degree 6

		Supported or Related
1.10	Presentations	85
1.11	Honors received	15
1.12	Prizes or awards received	3
1.13	Promotions obtained	5
1.14	Graduate students supported ≥ 25% of full time during any year of contract	47
1.15	Post-docs supported ≥ 25% of full time	1
1.16	Minorities supported ≥ 25% of full time during any year of contract period	4

SECTION 2: Executive Summary/highlights/accomplishments *(by project)* during contract period (including hardware/software prototypes developed)

Head-Mounted Display

Key words: Virtual reality; head-mounted displays; helmet-mounted displays; interactive 3D graphics; head-movement tracking.

Summary: of the head mounted display

Our primary objective is the exploration and development of dynamic interaction techniques between human users and computer-generated virtual worlds. This interaction depends upon the image of the virtual world responding to the user's movements in the same manner that the user's view of the real world does. A second objective is the dissemination of our research results to applications developers within our Department who wish to make use of virtual world technology.

The head-mounted display (HMD) project obtained ONR support during the 1987–88 project year (the second year of this contract). Our team had already been conducting research on the development and use of head-mounted display systems, but with ONR funding we were able to accelerate our effort. During that first year, we integrated our UNC-designed, head-mounted display prototype with the Pixel-Planes graphics engine, resulting in overall improvements in speed, image quality, and user control. The head-mounted display was also integrated with the Walkthrough prototype. The following year we obtained a fiberglass head-mounted display from the Air Force Institute of Technology and a VPL EyePhone, and began using those devices in our research. In addition, an effort to design and build a new real-time three-dimensional position and orientation-tracking device for head-mounted displays spun off the main head-mounted display research project that year.

In subsequent years, we have made significant progress in head-mounted display research, including the display of stereo images in the head-mounted display systems, user-controlled flying in virtual environments, the addition of sound triggered by events in a virtual environment, and the addition of a speech recognition capability. We began supporting multi-person shared virtual worlds. We also released Quatlib, Trackerlib, and Vlib standard software libraries, making the head-mounted display and other virtual world technology accessible by applications developers in the Department. Quatlib is a collection of quaternion-handling routines used by Trackerlib and Vlib. Trackerlib is a library of functions representing a level of abstraction between the applications programmer and the tracking device being used. Vlib enables the programmer to build, maintain, and interact with a virtual world. In the summer of 1991, we migrated the software and peripheral hardware to the newly developed Pixel-Planes 5 graphics engine and its attendant host. Pixel-Planes 5 is approximately 60 times faster and has greater generality than Pixel-Planes 4 and thus greatly enhances the image display for our HMDs.

Work with a novel display technology using lasers and moving mirrors was proposed and investigated. Upon further study, however, it was decided that none of these deflection methods could produce today a display device with resolution better than the current CRTs.

The idea of using a head-mounted display to superimpose real-time ultrasound images onto the tissue being imaged is also being investigated.

Jannick Rolland joined our team in June 1990, and has designed the custom optics for the planned new see-through head-mounted display for the medical "X-ray vision" and other applications.

Tracker

Key words: Optoelectronic tracker; lateral-effect photodiodes; head-mounted display; head tracker.

Summary: 0.080 in. 0.2 deg

An optical head tracking system has been developed that is easily scalable in size, has an update rate of 20-100 Hz with 20-100 milliseconds of lag, and resolves head motions of .080" and .2°. The system adopts an inside-out optical tracking paradigm first proposed by our research team and introduced in a paper by Gary Bishop and Henry Fuchs in 1984. A prototype was demonstrated at SIGGRAPH '91 with a 10 x12-foot working environment. The working environment is defined by a suspended ceiling of standard-sized, but custom 2 x 2-foot ceiling panels. Each ceiling panel precisely locates and controls 32 light emitting diodes (LEDs). Any LED in the ceiling can be addressed and then lighted with a programmable current level. With the 10 x 12-foot ceiling presently in place, 30 ceiling panels provide 960 LEDs as navigation beacons. In operation, four camera-like image sensors mounted on a head-mounted display measure—relative to the head—the photocoordinates of sequentially lighted LEDs. Given this two-dimensional information for three or more

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LEDs, as well as the known location of the LEDs in the environment, the position and orientation of the headset can be computed. We have extended a photogrammetric technique known as space-resection by collinearity to allow the photocoordinates emerging from a variable number of sensors to be used in the computation.

Pixel-Planes 5

Key words: 3D graphics; raster graphics; graphics architectures; VLSI, VLSI systems; multiprocessors; parallel processors; display algorithms.

Summary:

Our objective has been to design and to build multicomputer architecture (both hardware and software) for 3D interactive graphics that delivers in excess of one million polygons per second to real applications and that supports a wide variety of rendering algorithms.

The Pixel-Planes 4 raster graphics system was introduced at SIGGRAPH '86; design enhancements continued, and the three-year-long hardware development was essentially completed during 1987. At its introduction Pixel-Planes 4 was one of the fastest raster graphics machines and one of greater generality than most, capable of displaying rapidly not only polygons, but also spheres, shadows, Mandelbrot fractal images, and other types of imagery. Since 1986 the machine has been in daily service in our Graphics and Image Lab, where it is used by several research groups: in molecular modeling, in 3D medical imaging, and in building architecture previewing.

Work on algorithms and applications on Pixel-Planes 4 continued until 1991. A graphics library that implements a subset of the PHIGS+ standard was developed and is now in regular use.

The next generation graphics system, Pixel-Planes 5, was designed and built over a period of about three years: from late 1987 through 1991. (The hardware prototype became operational in July 1990, and the full three-rack system was completed during the summer of 1991.) This system is approximately 60 times faster than Pixel-Planes 4 and has greater generality (it can render some curved surfaces, textures, volume imagery) and greater modularity to allow various configurations and to upgrade components. Its architecture takes advantage of, and in some cases pioneers, several major trends in graphics algorithm and architecture research. In algorithms: rendering of curved surface primitives and more realistic lighting models. In architecture: virtual pixel maps; virtual pixel processors; composite parallel processing, combining fine-grained SIMD parallelism with large-grained MIMD parallelism, interconnected with a 5Gbit ring network, using a message-passing distributed operating system.

Work continues on refining software to use the hardware more efficiently, and developing algorithms, applications, and system software.

We transported a Pixel-Planes 5 three-rack system and exhibited it in the Tomorrow's Realities Gallery at the SIGGRAPH '91 conference, July 28–August 2, 1991. Of all the applicants, UNC–CH had the largest number of demonstrations accepted for this juried exhibit and had the largest booth (29 x 43 feet). We showed a number of applications running on Pixel-Planes 5, including the head-mounted display, volume rendering, and polygon and sphere rendering at over two million polygons/sec. The demonstrations were: 3dm—A Two-Person Modeling System, Interactive Building Walkthrough Using a Steerable Treadmill, Interactive Building Walkthrough Using the Optical Tracker, Flying Through Molecules, A Mountain Bike with Force Feedback Pedals, Radiation Therapy Treatment Planning, and the Virtual Pilot. All of our demonstrations at the exhibit were single-user, "hands-on" experiences. Because each demonstration takes about five minutes, we were able to show demos to a relatively limited number of people. During the five days that the exhibit was open, approximately 600 people were able to experience our virtual reality demos. Crowds were able to experience demos second-hand by observing monitors that showed the same images that were being fed to the head-mounted display and being seen by the single interactive user.

In 1991, we granted a limited license of our two patents to IVEX Corporation (Norcross, Georgia) for use in vehicle and flight simulation and training. One of our former senior staff members, Thomas "Trey" Greer, has joined IVEX's staff but continues to work part-time in our laboratory developing algorithms (that remain in the public domain) for future IVEX products based on our technology (IVEX pays UNC–CH for Greer's use of the facilities). In February 1992 IVEX plans to ship the first product incorporating the Pixel-Planes technology. These are enhancements to current products—visual systems for flight simulators. IVEX expects FAA Phase 2 certification, based in part on the anti-aliased, polygon-generation capabilities provided by the Pixel-Planes technology.

The major funding for Pixel-Planes research during the past decade has come from DARPA and NSF. Support by ONR has accelerated our research efforts.

Walkthrough

Key words: Computer graphics.

Summary:

We developed and refined a prototype software system enabling a user to walk through a virtual building in real time and to get rather good visual and aural impressions of how the spaces will feel. 1991 user studies confirm this adequacy.

Accomplishing this required us to make advances in four areas:

- Faster—During the five years, we improved our image generation rate 200 times, from one image each four seconds to 56 images per second. This was done by hardware and algorithm advances.
- Prettier—During the five years, we went from monocular views to stereo, and from flat-shaded polygons lighted uniformly to
  - –Phong-shaded polygons
  - –quite realistic radiosity lighting
  - –textured polygons

  The user also hears sounds appropriate to the virtual space he is in.
- Handier—We developed, in conjunction with other projects, a very natural interface that allows the viewer to freely roam a 10 x 12-foot space and to translate that space through building models. The interface also allows the user to turn individual lights on and off almost instantaneously.
- Realer—We developed better modeling techniques for highly detailed, substantial buildings and produced three models that are extensively used in the virtual worlds research community.

Artifact-Based Collaboration

Key words: Collaboration strategies; machine-recorded protocols; automated analysis; cognitive grammars; visualization tools.

Summary:

During the last five years, ONR has supported our work toward two major goals. First, we have developed new tools and methodology for studying how people work with computers. By understanding users' strategies and behaviors better, we can, in turn, build computer systems that more closely match the way they think and work. Toward that end, we have developed tools that automatically record users' actions, replay sessions for study and analysis, tools to analyze these data automatically, and tools to display the data in ways that make it easier to understand and characterize. Second, we have extended our work in this area from single users to groups of users working collaboratively. In this latest project—which is supported primarily by NSF and IBM with additional support from ONR—we are studying the process of collaboration, building an advanced hypermedia system to support collaboration on software development and other similar design projects, and studying users working with our system. ONR has helped us explore tools for recording and analyzing the actions of groups, analogous to the earlier tools we built to study individual users.

Data-Parallel Execution

Key words: Highly parallel computing; data-parallel programming languages; MasPar MP-1; dynamic load-balancing.

Summary:

Programming Highly parallel computers

While highly parallel computers now offer the highest computing performance available, the principal impediment to their general use lies in the difficulty of programming them. A portion of this contract has sponsored work aimed at the understanding, simplification, and application of data-parallel programming techniques to program these machines. To yield *efficient* programs, we have identified an expressive class of data-parallel expressions and a compilation technique to make direct use of mesh and hypercube connectivity in target machines. To yield *portable* programs, we target CVL, a data-parallel intermediate language developed at CMU, which has implementations on a wide class of machines.

MasPar MP-1 acquisition

The first MasPar MP-1 massively parallel computer to be placed in a University was installed in our Department in January of 1990. Acquisition of the 4,096-processor MP-1 was jointly funded by ONR (this contract), The University of North Carolina at Chapel Hill, and NIH. This machine has enabled the data-parallel execution work to expand from theory into practice. In the 18 months since its installation, we have designed and implemented new sorting and graphics algorithms, implemented the CVL data-parallel intermediate language, and demonstrated a variety of applications, including real-time force calculation and feedback for the molecular docking experiment in the GRIP project, applications in image processing, neural-network computations, and physical system simulations.

A new course on programming highly parallel computers was developed to use the MP-1 as its practicum. More than 60 students undertook projects on the machine through this course.

Scan-directed load balancing

A dynamic technique for equalizing the computational work without sacrificing the locality properties of a parallel computation was developed and is the subject of ONR fellow Ed Biagioni's Ph.D. thesis (expected Nov 1991). Extensive experiments with its application were run on the MP-1.

SoftLab (Infrastructure)

Key words: Software engineering; technology transfer; software capitalization; software development environments; software tools.

Summary:

SoftLab Software Systems Laboratory is an infrastructure organization that provides the UNC–CH Computer Science Department with software systems and software packaging and distribution services analogous to those typically found in industry. As such, SoftLab serves as a software development resource for the Department and as an agent of technology transfer to other universities and to industry.

Since it was established in 1989, SoftLab has supported the rapid prototyping of experimental VLSI architectures and distributed systems by developing simulators, drivers, compilers, interfaces, and communications software. During this three year period, SoftLab completed microcode preprocessors for two custom-built graphics engines, one partly based on the Weitek XL chip and the other partly based on the Intel i860 chips. Both preprocessors facilitate hand optimization of assembler and are heavily used by Department software developers to code graphics applications programs that require high-speed performance.

IDL (Interface Description Language), a programming environment for rapid prototyping of compilers, designed by Richard Snodgrass, was an early SoftLab project. IDL has been widely distributed and is regularly used by SoftLab to develop other software, including the preprocessors described above. In addition, SoftLab also developed a preliminary version of a C optimizer for the i860. Other prototyping support tool work during this period included major enhancements to an architectural simulator, drivers for downloading program and text from a UNIX workstation to BLITZEN, a custom SIMD machine developed jointly by Duke, UNC–CH, and MCNC, and a driver to integrate our Department's network of UNIX workstations with our telephone switch.

One very important SoftLab function is the capitalization of its own software and the software developed by other research groups within the Department. To this end, SoftLab has defined and implemented a software packaging, distribution, and support methodology that serves a customer base of almost 200 domestic and foreign academic and commercial institutions. This methodology includes code and documentation review and revision, configuration control, versioning, preparing for remote installation, porting to various hardware platforms, testing, advertising, licensing, acquiring copyright protection, assembling distribution, customer interfacing, and, in some cases, making future enhancements. This centralizes the Department's software distribution function achieving economy of scale and freeing individual researchers from associated administrative burdens.

Finally, SoftLab has served as a software engineering practicum for students. Work on SoftLab software capitalization projects provides graduate student research assistants with exposure to issues, methods, and solutions needed for software development in the large. In addition, SoftLab has been a client for Software Engineering course programming teams. This has given course students the opportunity to experience work for a real client on real projects. Finally, SoftLab has served as a consultant on software engineering issues arising in the development of research software in the Department. It has participated in the design of the build mechanisms for several major software systems in the Department and has developed guidelines for documentation and configuration management.

PROTOTYPES:

IDL

The IDL Toolkit is a programming environment for rapid prototyping of compilers designed and implemented by Richard Snodgrass and his students. IDL was originally packaged and distributed by SoftLab, but distribution and support were later assumed by a commercial software distributor, UniPress Software, Inc.

MAXL 2.0

Pixel-Planes 4 is a high-performance, 3D raster display system that harnesses the power of custom VLSI circuits. Pixel-Planes 4 architecture is partly based on the Weitek XL chip, and many application programs are written in Weitek assembler for performance reasons. SoftLab, working in conjunction with Pixel-Planes application programmers, developed a microcode preprocessor that automated register allocation, pipeline analysis and other machine details. This preprocessor has significantly improved Pixel-Planes 4 programmer productivity. Weitek has a copy of the code, and there was discussion about commercialization. However, commercialization is unlikely since the chip is becoming obsolete.

MAST860

MAST860 is a microcode preprocessor for the Intel i860 floating point chip. It facilitates hand optimization of i860 assembler by automating register allocation and other machine details and by performing pipeline analysis. MAST860 is currently used by Pixel-Planes 5 applications programmers who code in-hand optimized assembler for performance reasons. We have advertised this prototype on various bulletin boards and have also sent a preliminary copy to Intel for review. Future commercialization is a possibility.

UNIX-PHONE SWITCH INTERFACE AND APPLICATIONS

Last year, SoftLab implemented a UNIX driver that allows telephone switch functions such as phone calls and networking operations to be controlled from Department workstations. This driver communicates with our InteCom switch via the InteCom Open Applications Interface (OAI) feature on the switch. Our UNIX driver software was made available to InteCom, which is starting up a UNIX application development effort. In addition, we also implemented two UNIX applications on top of the driver software. The first was a voice mail application that stored and manipulated voice messages as UNIX files; and the second was a power dialer that allowed phone calls to be placed by UNIX workstation commands using online databases of numbers and speed-calling lists. This work was an initial step in setting up an integrated voice and electronic messaging system that would form a test bed for Department research in distributed computing. InteCom included a description of our applications in its advertising literature, and we have been contacted by DataTrac, Inc. about a possible joint venture for further application development.

MOSEL

MOSEL (Modular Operating System Experimentation Laboratory) is a family of architecture and operating system experimentation tools that will include a hardware simulator for M-code architectures with the ability to simulate execution of both Modula-2 and C programs, some extensible operating systems for two basic machine simulations, and various tools for monitoring and analyzing architectures and operating systems. MOSEL is intended for both classroom and rapid prototyping use. At this time, the simulator is largely complete and execution of modula-2 programs can be simulated. We are currently working on the C program simulation tools. We also have a single process operating system, and the beginnings of the multi-process version in place. Work continues.

Refer to Appendix VI for information about projects supported by ONR during only the first 2–3 years of the contract.

SECTION 3: Publications, reports, presentations, honors/prizes/awards during contract period

A. Publications, technical reports (appeared and to appear); books, book chapters; videotapes

See Appendix III—Comprehensive Bibliography—for a complete categorized list, to date.

B. Refereed exhibitions

The UNC–CH Computer Science Department provided a major exhibit in the "Tomorrow's Realities" Gallery at the SIGGRAPH '91 Conference, Las Vegas, NV, 28 July-2 August, 1991. Demonstrations included:

A. Pixel-Planes 5 three rack system.

B. 10 x 12-foot Optical "Ceiling" Tracker.

C. 3dm—A Two-Person Modeling System.

D. Interactive Building Walkthrough Using a Steerable Treadmill.

E. Interactive Building Walkthrough Using the Optical Tracker.

F. Flying Through Molecules.

G. A Mountain Bike with Force Feedback Pedals.

H. Radiation Therapy Treatment Planning.

I. Virtual Pilot.

C. Refereed papers submitted *(awaiting acceptance)*

Banks, David. "Interactive Manipulation and Display of Surfaces in Four Dimensions," submitted to *1992 Symposium on Interactive 3D Graphics*, Cambridge, MA, 29 March–1 April 1992.

Butterworth, Jeff, Andrew Davidson, Stephen Hen h, and T. Marc Olano. "3DM: A Three Dimensional Modeler Using a Head-Mounted Display," submitted to *1992 Symposium on Interactive 3D Graphics*, Cambridge, MA, 29 March–1 April 1992.

Chung, James C. "A Comparison of Head-Tracked and Non-Head-Tracked Steering Modes in the Targeting of Radiotherapy Treatment Beams," submitted to *1992 Symposium on Interactive 3D Graphics*, Cambridge, MA, 29 March–1 April 1992.

Jeffay, Kevin. "Scheduling Sporadic Tasks with Shared Resources in Hard-Real-Time Systems," submitted to *IEEE Trans. on Computers*, TR90-039, Department of Computer Science, UNC at Chapel Hill, Nov. 1990.

Neumann, Ulrich. "Interactive Volume Rendering on a Multicomputer," submitted to *1992 Symposium on Interactive 3D Graphics*, Cambridge, MA, 29 March–1 April 1992.

Rhoades, John, Greg Turk, Andrew Bell, Andrei State, Ulrich Neumann, and Amitabh Varshney. "Real-Time Procedural Textures," submitted to *1992 Symposium on Interactive 3D Graphics*, Cambridge, MA, 29 March–1 April 1992.

Robinett, Warren, and Richard Holloway. "Implementation of Flying, Scaling and Grabbing in Virtual Reality," submitted to *1992 Symposium on Interactive 3D Graphics*, Cambridge, MA, 29 March–1 April 1992.

Smith, John. B., and Dana K Smith. "Automated Protocol Analysis," submitted to *Human-Computer Interaction*, TR91-034, Department of Computer Science, UNC at Chapel Hill, Aug. 1991

Surles, Mark C. "Interactive Modeling Enhanced with Constraints and Physics—with Applications in Molecular Modeling," submitted to *1992 Symposium on Interactive 3D Graphics*, Cambridge, MA, 29 March–1 April 1992.

Ward, Mark, Ronald Azuma, Robert Bennett, Stefan Gottschalk, and Henry Fuchs. "A Demonstrated Optical Tracker with Scalable Work Area for Head-Mounted Display Systems," submitted to *1992 Symposium on Interactive 3D Graphics*, Cambridge, MA, 29 March–1 April 1992.

D. Presentations

See individual Annual Reports, included as Appendix VI. See also Section I, Productivity Measures.

E. Honors received

Frederick P. Brooks, Jr.:

- elected Foreign Member of the Royal Netherlands Academy of Arts and Sciences (Science Division), April 1991.
- has served on the National Science Board since 1987.
- has served on the IBM Science Advisory Committee since 1979.

John Eyles served on the Program Committee of the Third Workshop on Graphics Hardware, sponsored by Eurographics, September 1988.

Henry Fuchs:

- co-director (with Karl Heinz Höhne and Stephen M. Pizer) of the NATO Advanced Research Workshop on 3D Imaging in Medicine, Travemünde, Germany, June 1990.
- served on the following conference program committees: Symposium on Interactive 3D Graphics, 1990; Chapel Hill Workshop on Volume Visualization, 1989, Conference on Advanced Research in VLSI, 1986–1990; Computer Graphics International, 1987 & 1988.
- served on the following conference papers committees: ACM SIGGRAPH, 1986–1991; Conference on Advanced Research in VLSI, 1986–1990; Eurographics, 1986; International Electronic Image Week (CESTA, SIGGRAPH), 1986 & 1987; Computer Graphics International, 1987 & 1988.
- chaired the 1986 Workshop on Interactive 3D Graphics, held at UNC–Chapel Hill, October 22-24, 1986.
- served as associate editor of ACM's *Transactions on Graphics*, 1983–1988.

John Poulton became a Senior Member of IEEE in 1990.

F. Prizes or awards received

Frederick P. Brooks, Jr.:

- Harry Goode Memorial Award, American Federation of Information Processing Societies, 1989
- Distinguished Service Award, ACM, 1987
- Thomas Jefferson Award, University of North Carolina at Chapel Hill, 1986

G. Promotions obtained

Gary Bishop joined our faculty as Research Associate Professor in May 1991.

John Eyles was promoted from Senior Research Associate to Research Assistant Professor in 1988.

Henry Fuchs:

- was named Federico Gil Professor of Computer Science in 1988.
- was appointed Adjunct Professor of Radiation Oncology in 1988.

John Poulton was promoted to Research Associate Professor in 1988.

H. Educational productivity

See Appendix II.

SECTION 4: Transitions and DoD interactions *(by project);* follow-on research

A. Transitions of results and DoD interactions

For years 4 and 5, please also see Section 4 of FY89-90 and 90-91 Annual Reports, included with this report as Appendix VI. Please also see "Presentations," included in each annual report.

ONR site visitors, years 1 through 5:

27 May 1987:

A. F. Tony Norcio, Computer Scientist, NRL
Andre van Tilborg, Computer Scientist, ONR
Ralph F. Wachter, Program Manager, Computer Science Division, ONR
Stanley H. Wilson, Chief Scientist for Computation, Information Technology Division, NRL

8 July 1987:

Charles Holland, Scientific Officer, ONR

4-5 April 1988:

Charles Holland, Scientific Officer, ONR
Andre van Tilborg, Computer Scientist, ONR
Ralph F. Wachter, Program Manager, Computer Science Division, ONR
Stanley H. Wilson, Chief Scientist for Computation, Information Technology Division, NRL

31 August–1 September 1989

Peter Brown, Mechanical Engineer, National Institute of Standards and Technology (NIST)
Christoph M. Hoffmann, Professor, Computer Science, Purdue University
Cmdr. John Sheridan, Deputy Director, Engineering Sciences Directorate, ONR
Andre van Tilborg, Director, Computer Science Division, ONR
Ralph F. Wachter, Scientific Officer, ONR
Stanley H. Wilson, Chief Scientist for Computation, Information Technology Division, NRL

25-26 September 1990

Peter Brown, Mechanical Engineer, National Institute of Standards and Technology (NIST)
Susan Chipman, Program Manager for Cognitive Science, ONR
Christoph M. Hoffmann, Professor, Computer Science, Purdue University
William E. Isler, Assistant Dean for Research, College of Engineering, NC State University
Richard Miller, Chief Scientist, Mechanics Division, ONR
Ralph F. Wachter, Scientific Officer, ONR
Stanley H. Wilson, Consultant, Information Technology Division, NRL

Agendas for each site visit were appended to each Annual Report (see Appendix VI of this report).

Pixel-Planes 5

In summary: Ideas from Pixel-Planes 4 and some of its predecessors have been adopted by several commercial high-performance systems, among them the Stellar GS-1000, the Silicon Graphics IRIS VGX, and the AT&T Pixel Machine.

From October 1988 to May 1990, we conducted a study for the U.S. Air Force (monitoring organization was the Cockpit Integration Directorate at Wright-Patterson Air Force Base) entitled "An Architecture for Advanced Avionics Displays." In this study we investigated several existing and emerging high-performance graphics architectures. We also performed an analysis of the specific requirements for airborne graphics systems in order to identify the most critical requirements. The graphics architectures were evaluated with regard to their applicability to an airborne system, and a candidate architecture was selected. A high-level design of an airborne system meeting the requirements and based on the candidate architecture was performed, with detailed analysis of the actual implementation of features identified as critical, including the algorithms to be used.

SoftLab (Infrastructure)

Products distributed by SoftLab:

These numbers reflect distributions made between January 1989 and August 1991.

Volume Rendering Data Sets (numbers for Volumes I and II combined)

The Volume Rendering Data Sets Volume I and II contain medical and other images as shown at the 1990 Volume Visualization Workshop. These are the first items in a planned "visual data set" product line.

37 academic distributions
34 industry distributions

COOL 1.0

COOL is a software library developed by James Coggins. COOL, written in the object-oriented language C++, contains class definitions relevant to research in computer vision, image pattern recognition, and computer graphics. We are currently working on the packaging of COOL 2.0.

6 industry distributions

RSpace 1.3

RSpace is an interactive program, developed in the Computer Science Department by Mark Harris in 1988, which is designed to help crystallographers plan data collection strategies when using diffractometers equipped with area detectors. SoftLab is currently developing RSpace 2.0, which will include some significant new user interface features. These are expected to broaden the RSpace customer base further.

36 academic distributions
19 industry distributions

IDL ToolKit

The IDL (Interface Description Language) ToolKit was implemented by Richard Snodgrass and his students. IDL essentially a programming environment for rapid prototyping of compilers, although it has more extensive application than this. IDL was originally packaged and distributed by SoftLab, but distribution and support responsibilities were later assumed by a commercial software distributor, UniPress Software, Inc.

The numbers below include only SoftLab distributions.

33 academic distributions
24 industry distributions

WE

WE (Writing Environment) is a hypertext, graphic-based system, written in Smalltalk, designed to help professionals write more effectively and efficiently. Unlike many conventional documentation systems, WE is much more than a word processor; it carries the user through all phases of the writing process, from organizing ideas to editing text.

New Product

B. Follow-on research

Head-Mounted Display and Tracker

During this reporting period, we received funding for a proposal entitled, "Advanced Technology for Portable Personal Visualization." Funded by DARPA/ISTO (order no. 7508), this effort will accelerate dramatically our ongoing work in head-mounted display systems by developing four technological thrusts crucial to the realization of portable personal visualization computer systems: portable image generation, optical and inertial head tracking, optical hand tracking, and improved design of headgear optics.

In conjunction with four other institutions (Brown University, California Institute of Technology, Cornell University, and University of Utah), we received a grant from the National Science Foundation (cooperative agreement no. ASC-8920219) to create a Science and Technology Center in Computer Graphics and Scientific Visualization. The funding of this grant will offer the opportunity for collaborative efforts among researchers and graduate students at the five participating institutions.

UNC–CH points of contact for additional information: Frederick P. Brooks, Jr. and Henry Fuchs.

Pixel-Planes 5

Several closely related projects have been launched at UNC–CH during this reporting period:

VISTAnet: A Very High Bandwidth Prototype Network for Interactive 3D Medical Imaging Research. This prototype network is one of five nationwide, funded by NSF and DARPA through the Corporation for National Research Initiatives, and by BellSouth and GTE. It will link researchers in the UNC–CH Department of Radiation Oncology with the North Carolina Supercomputing Center's Cray Y-MP and UNC–CH Computer Science Department's Pixel-Planes 5 graphics engine. The network will deliver powerful computing and visualization capabilities for real-time 3D radiation treatment planning.

Advanced Technology for Portable Personal Visualization. Funded by DARPA ISTO (Order No 7508), this effort will accelerate dramatically our ongoing work in head-mounted display systems by developing four technological thrusts crucial to the realization of portable personal visualization computer systems: portable image generation; optical and inertial head tracking; optical hand tracking; improved design of headgear optics.

Three-Dimensional Display for Read-Time 3D Ultrasound Imaging. Part of Duke University's NSF-sponsored Engineering Research Center for Emerging Cardiovascular Technologies, this project seeks to provide real-time display of 3D ultrasound data to be acquired in real time by a new ultrasound imaging system under development at Duke. Started several years ago, significant hardware construction has waited for the availability of Pixel-Planes 5. We plan to build a prototype system based on Pixel-Planes 5 that will interactively generate volume imagery incrementally built up from multiple image slices as they are acquired by a conventional 2D ultrasound scanner.

Science and Technology Center in Computer Graphics and Scientific Visualization. In conjunction with four other institutions (Brown University, California Institute of Technology, Cornell University, and University of Utah), we received a grant from NSF and DARPA to create a Science and Technology Center in Computer Graphics and Scientific Visualization. Collaboration with researchers at these four institutions has now begun. We anticipate that the earliest results relating to Pixel-Planes may be more rapid interaction in images with global lighting effects. This would be a result of collaboration with our Cornell colleagues, who have pioneered these "radiosity" lighting techniques.

UNC–CH point of contact for additional information: Henry Fuchs.

Walkthrough

The follow-on research is jointly funded by DARPA and NSF in a five-year grant The scope of the grant includes developing technology and applications for personal portable virtual reality systems. Lance Glasser at DARPA is one of the contract officers.

UNC–CH points of contact for additional information: Frederick P. Brooks, Jr., and Henry Fuchs.

Artifact-Based Collaboration

Follow-on grants for collaboratory research include:

"Building and Using a Collaboratory: A Foundation for Supporting and Studying Group Collaborations," grant from the National Science Foundation (IRI-9015443), for the period 09/01/90 through 08/31/93.

"A Hypermedia Environment for Software Development," grant from IBM Corporation (#866), for the period 09/01/89 through 08/31/92.

UNC–CH point of contact for additional information: John B. Smith.

Data-Parallel Execution

Initial research undertaken as part of the URI contract led to a separate ONR proposal entitled, "Compiling Data-Parallel Programming Languages for SIMD Execution," (Contract #N00014-89-J-1873), for the period 03/15/89 through 06/30/90.

Complementary interests between our data-parallel programming languages group and a group led by John Reif at Duke University studying parallel algorithms led to the formation of a joint research group on high-level, data-parallel programming languages. In conjunction with Kestrel Institute, we proposed to DARPA that we design a high-level language for prototyping parallel and distributed applications. This effort was funded by DARPA (monitored by ONR under contracts N00014-90-K-0004 and N00014-91-C-0114) from 05/01/90 to 05/01/92 at approximately a $1.2 million funding level, of which currently one-third comes to our group at UNC–CH. Further work in the implementation of the language has been proposed to start in the summer of 1992.

UNC–CH point of contact for additional information: Jan Prins.

APPENDIX I

Personnel By Project, FY90-91

(during full or partial year)

ONR Executive Committee:

Frederick P. Brooks, Jr.
Henry Fuchs
Ralph A. Mason
Donald F. Stanat
Stephen F. Weiss, chairman
Warren Robinett, technical liaison
Jeannie M. Walsh, administrative coordinator

PIXEL-PLANES 5

Coordinators:

Henry Fuchs, PI
John Poulton, PI and project manager

Staff:

Laura Weaver (research engineer)
Edward Hill (applications programmer)

RAs:

Mike Bajura (MCNC fellow)
Andrew Bell
Jeff Butterworth
David Ellsworth (ONR fellow, FY89-90, 90-91)
Howard Good
Victoria Interrante
Jonathan Leech
Steve Molnar (IBM Mfg. Research fellow, FY89-90, 90-91)

Other Faculty:

John Eyles (senior engineer)
Anselmo Lastra

Carl Mueller
Ulrich Neumann
Marc Olano
Mark Parris
John Rhoades
Andrei State
Greg Turk (IBM fellow, FY89-90, 90-91)

WALKTHROUGH

Coordinator:

Frederick P. Brooks, Jr.

Staff:

John Hughes (research associate)
Deep Jawa (research associate)
David Lines (editorial assistant)

RAs:

John Alspaugh
Randall Brown
Curtis Hill

Amitabh Varshney
Yulan Wang
Xialin Yuan

HEAD-MOUNTED DISPLAY

Coordinators:
Frederick P. Brooks, Jr.
Henry Fuchs

Other Faculty:
Stephen M. Pizer
Vernon L. Chi (director of MSL)

Staff:
Warren Robinett (project leader)
Jannick Rolland (optical engineer)
John Hughes (research associate)

RAs:
Ron Azuma
William Brown
James Chung
Andrew Davidson
Erik Erikson
Richard Holloway

Other:
Michael Pique (collaborator, Scripps Institute)

TRACKER

Coordinator:
Henry Fuchs

Other Faculty:
Vernon L. Chi
Gary Bishop
John Eyles

Staff:
Brad Bennett (electronic technician)
Stefan Gottschalk (programmer)
Jack Kite (research engineer)
Mark Ward (research engineer)

RAs:
Ron Azuma
Carney Clegg
Phil Jacobsen

ARTIFACT-BASED COLLABORATION

Coordinators:
John B. Smith and Stephen F. Weiss

Other Faculty:
Peter Calingaert
Kevin Jeffay
Marcy Lansman
Dana Kay Smith
F. Donelson Smith

RAs:
Murray Anderegg
Eileen Kupstas

DATA-PARALLEL EXECUTION

Coordinator:
Jan Prins

RAs:
Ed Biagioni (ONR fellow, FY90-91)
Quan Zhou

SOFTLAB (infrastructure)

Coordinator:
Susanna Schwab (director of SoftLab)

RAs:
David Becker
Charles Clark
Heng Chu
Steve Tell

Staff:
Arie Trinker (research associate)
Madelyn Mann (secretary and SoftLab coord.)

30 September 1991
jmw

All participants during FY90-91
(includes infrastructure)

ONR-URI Executive Committee:

Frederick P. Brooks, Jr.
Henry Fuchs
Ralph A. Mason, Jr.
Donald F. Stanat
Stephen F. Weiss (Chairman)

Other Faculty:

Gary Bishop
Peter Calingaert
Vernon L. Chi
John G. Eyles
Kevin Jeffay
Marcy Lansman
Anselmo Lastra
Stephen M. Pizer
John W. Poulton
Jan F. Prins *
Susanna Schwab *
Dana Kay Smith
F. Donelson Smith
John B. Smith

Staff:

Wanda Andrews *	Secretary (half-time)
Brad Bennett	Electronic technician
Coldwell/Christensen/Folda *	Secretaries (part-time)
Lynne Cohen Duncan *	Systems software manager
Stefan Gottschalk	Programmer
Edward Hill	Applications programmer
John Hughes	Research associate
Deep Jawa	Research associate
Frederick Jordan *	Lead computing services technician
Jack Kite	Research engineer
David Lines	Editorial assistant
Ransom Murphy *	Systems programmer (temporary)
Steven Ornat *	Televideo communications technician
Madelyn Mann	Secretary and SoftLab coordinator
Warren Robinett (technical liaison to ONR)	Research associate and project leader, Head-Mounted Display project
Jannick Rolland	Visiting optical engineer (see-through optics)
Arie Trinker	Research associate
Norman A. Vogel *	Director of communications research (Research engineer, Head-Mounted Display project, effective 3 April 1991)
Jeannie M. Walsh *	Research assoc. and admin. coordinator, ONR Contract
Mark Ward	Mechanical engineer (optical tracker)
Laura (Israel) Weaver	Research engineer

Research Assistants:

John Alspaugh *
Murray Anderegg *mp* *
Ron Azuma *
Mike Bajura *mp* *
David Becker
Andrew Bell *mp*
Ed Biagioni * ..... ONR Fellow
Randall Brown *m* *
William Brown *m* *
Jeff Butterworth
Jijun Chen
Heng Chu
James Chung *
Carney Clegg
Andrew Davidson
David Ellsworth * ..... ONR Fellow
Erik Erikson
Howard Good *
Curtis Hill *
Richard Holloway *
Victoria Interrante
Phil Jacobsen *
Eileen Kupstas *
John Lusk *
Jonathan Leech *
Peter Mills *
Steven Molnar
Carl Mueller *
Ulrich Neumann
Marc Olano
Mark Parris
John Rhoades
Andrei State *m*
Steve Tell
Greg Turk
Amitabh Varshney *mp*
Yulan Wang
Xialin Yuan
Quan Zhou

Undergraduate assistants (facilities):

Doug Corbett *

Other:

Michael Pique (collaborator, Scripps Institute)

* *Salary support provided in full or in part by ONR during this reporting period (RAs: ≥ 25%)*
m *M.S. Degree granted during this reporting period*
mp *M.S. Degree granted during this reporting period; on to Ph.D.*

PERSONNEL BY PROJECT, FY89-90

* *Salary partially or fully supported by ONR* (Degree listed if participant left UNC.)

ONR Executive Committee:

Stephen F. Weiss, chairman
Frederick P. Brooks, Jr.
Henry Fuchs
Ralph A. Mason
Donald F. Stanat

*Warren Robinett, technical liaison
*Jeannie M. Walsh, administrative coordinator

PIXEL-PLANES

Coordinators:
Henry Fuchs, PI
John Poulton, PI and project manager

Staff:
Trey Greer (research engineer)
Laura Weaver (research engineer)
Edward Hill (applications programmer)

Other Faculty:
John Eyles (senior engineer)

RAs:
Mike Bajura (MCNC fellow)
*Andrew Bell
*David Ellsworth (ONR fellow, FY89-90, 90-91)
*Howard Good
Victoria Interrante
*Jonathan Leech
*Steve Molnar (IBM Mfg. Research fellow, FY89-90, 90-91), *summer 1990
Carl Mueller (fall 90)
*Ulrich Neumann
Marc Olano (fall 90)
*John Rhoades
Andrei State (fall 90)
*Brice Tebbs
Russ Tuck (Ph.D.—Duke, May 90)
Greg Turk (IBM fellow, FY89-90, 90-91)

WALKTHROUGH

Coordinator:
Frederick P. Brooks, Jr.

Staff:
John Hughes (research associate)
David Lines (editorial assistant)

Visiting Faculty:
Jane Richardson, Duke (starting fall 90)
David Richardson, Duke (FY89-90)
William Wright (Director of GRIP)

RAs:
John Alspaugh
John Airey (Ph.D. Aug 90)
Randall Brown
Curtis Hill
Penny Rheingans
John Rohlf (M.S. May 90)

HEAD-MOUNTED DISPLAY

Coordinators:
Frederick P. Brooks, Jr.
Henry Fuchs

Other Faculty:
Stephen M. Pizer
Vernon L. Chi (director of MSL)

Staff:
*Warren Robinett (project manager)
*Jannick Rolland (optical engineer)
John Hughes (research associate)

RAs:
Ron Azuma
*William Brown
*James Chung
*Richard Holloway
*Michael T. Kelley (M.S. Dec 89)
*Phil Jacobsen
Jih-Fang Wang (Ph.D. May 1990)

Other:
Michael Pique (collaborator, Scripps Institute)

TRACKER

Coordinator:
Henry Fuchs

Other Faculty:
Vernon L. Chi
Gary Bishop
John Eyles

Staff:
*Mark Ward (research engineer)

RAs:
*Ron Azuma
Phil Jacobsen (since June 1990)
Jih-Fang Wang (Ph.D. May 1990)

PROTOCOL ANALYSIS TOOLS/COLLABORATORY

Coordinators:
John B. Smith
F. Donelson Smith

Other Faculty:
Stephen F. Weiss
*Marcy Lansman, Psychology

Staff:
Gordon Ferguson (research associate), through Feb. 1990

RAs:
*Murray Anderegg
Barry Elledge (M.S. May 90)
*Richard Hawkes (M.S. May 90)
*Eileen Kupstas
Doug Shackelford

DATA-PARALLEL EXECUTION

Coordinator:
*Jan Prins

RAs:
*Ed Biagioni (ONR fellow, FY90-91), *fall 90
*Dan Poirier
*John A. Smith

CLOCS (ONR Fellow)

Coordinator:
Donald F. Stanat

RA:
*Mark Davis (ONR fellow, FY87-88, 88-89, 89-90 thru March '90) (Ph.D. May 90)

INFRASTRUCTURE

Coordinator:
Ralph A. Mason (assoc. chairman for admin.)

Staff: (technical)
*Lynne C. Duncan (systems software manager)
*Frederick Jordan (computing services hdw tech)
*Ransom Murphy (systems programmer)
*Steve Ornat (communications hardware tech)
*Norman Vogel (director of comm. research)

(administrative)
*Jeannie M. Walsh (admin. coordinator)
*Wanda Andrews (secretary)

Students (facilities):
*Jeff Lewis
*Jonathan Whaley

SOFTLAB

Coordinator:
*Susanna Schwab (director of SoftLab)

RAs:
David Becker
Charles Clark

Staff:
Arie Trinker (research associate)
Pam Payne (secretary and SoftLab coord.)

Heng Chu
Steve Tell

21 September 1990
jmw

Participants During FY88-89

ONR-URI Executive Committee:

Donald F. Stanat (Chairman FY88-89)
Frederick P. Brooks, Jr.
Henry Fuchs
Ralph A. Mason
Stephen F. Weiss (Chairman FY89-90)

Other Faculty:

Gary Bishop
Vernon L. Chi
John G. Eyles
John Halton
Marcy Lansman
John W. Poulton
Jan F. Prins (separate contract)
Susanna Schwab*
John B. Smith
Richard Snodgrass*

Staff:

Andrew Certain*	temporary (student)
Lynne Cohen Duncan*	systems software manager
Gordon Ferguson	research associate
Trey Greer	research engineer
Willard Hewitt*	temporary (student)
Edward Hill	applications programmer
John Hughes	research associate
Frederick Jordan*	lead computing services technician
David Lines	editorial assistant
Steven Molnar	research engineer
Steven Ornat*	televideo communications technician
Pamela Payne	secretary and SoftLab coordinator
Warren Robinett*	research associate and project leader, GRIP and Head-Mounted Display projects
Raj Singh*	project management engineer
Arie Trinker	research associate
Norman A. Vogel*	director of communications research
Jeannie M. Walsh*	research associate and administrative coordinator, ONR Contract
Sharon Walters*	secretary (half-time)
Laura (Israel) Weaver	research engineer
Jonathan Whaley*	temporary (student)

Research Assistants:

John Airey*
John Alspaugh
Murray Anderegg*
Ron Azuma*
Mike Bajura*
David Becker
Andrew Bell
Gregory Bollella*
Randall Brown*
William Brown*
Debashish Chatterjee
Heng Chu
James Chung*
Charles Clark
Mark Davis* (Fellow, FY88, 89, 90)
Barry Elledge*
David Ellsworth* (Fellow, spring '89; FY90)
Susan Gauch* (Fellow, fall '88)
Howard Good
Richard Hawkes
Curtis Hill
Victoria Interrante
Robert Katz*
Michael T. Kelley*
Mike Kotliar*
Jonathan Leech
John Menges
Ulrich Neumann
Daniel Palmer*
Dan Poirier
Penny Rheingans*#
John Rhoades
John Rohlf%
Frank Silbermann*
John A. Smith
Robert Stam*#
Brice Tebbs#
Steve Tell
Russ Tuck
Greg Turk#
Jih-Fang Wang
Chin Ho Yeh

* *Salary support provided in full or in part by ONR during this reporting period*
% *M.S. Degree granted during FY88-89*
\# *M.S. Degree granted during FY88-89; on to Ph.D.*

Participants during FY 87-88

ONR-URI Executive Committee:

Frederick P. Brooks*, Jr., Committee Chairman
Donald F. Stanat*^, Technical Director
Jay Nievergelt*
Ralph Mason*

Other Faculty:

J. Dean Brock
Vernon L. Chi*
Peter Calingaert
James Coggins
Henry Fuchs*
Bharat Jayaraman
Gyula A. Mago'
David A. Plaisted
John Poulton*
Jan Prins* ^
John B. Smith
Richard T. Snodgrass* ^
Yuki Watanabe
Stephen F. Weiss

Vis. Faculty:

Hussein Abdel-Wahab
Tony Marsland^

Staff^:

Graham Gash, Software Manager
Lynne C. Duncan*, Software Research Manager
Fred Jordan*, Electronics Technician
John Menges*, Communications Software Engineer (through 16 Aug 88/RA)
Steven Ornat*, Communications Hardware Technician
Raj Singh*, Project Management Engineer
Norman A. Vogel*, Director of Communications Research
Jeannie M. Walsh*, Administrative Coordinator
Sharon Walters*, Secretary (half-time)

RAs^:

John Airey*
Edoardo Biagioni
Paulette Bush+
James Chung*+
Mark Davis* (Fellow FY88, FY89)
William Gallmeister+
Susan Gauch* (Fellow FY89)
William Gibson+
Michael Kelley*
Marc Levoy (Fellow FY88)
Richard Potter+
Penny Rheingans*
Frank Silbermann*
Robert Stam*
Mark Surles
James Symon
Douglass Turner+

* *currently participating during FY 88-89*
\+ *M.S. Degree granted during FY 87-88*
^ *Salary support provided in full or in part by ONR during FY 87-88*

Participants, FY86-87

ONR-URI Executive Committee:

Frederick P. Brooks, Jr.
Ralph A. Mason, Jr.
Jay Nievergelt (Chairman)
Donald F. Stanat

Other Faculty:

Hussein Abdel-Wahab, David Beard, Dean Brock, Peter Calingaert, Vern Chi, James Coggins, Henry Fuchs, John Halton, Kye Hedlund, Bharat Jayaraman, Gyula Mago, Tony Marsland, Daniel Pitt, David Plaisted, John Poulton, Jan Prins, Stephen Pizer, John Smith, Richard Snodgrass, Akhilesh Tyagi, Yuki Watanabe, Steve Weiss, Turner Whitted

Staff:

Sharon Core, John Eyles, Graham Gash, William Howell, David Kuzminski, John Menges, Steve Ornat, Raj Singh, Norm Vogel, Jeannie Walsh

Research Assistants:

John Airey
Edoardo Biagioni
Vikram Biyani
Paulette Bush
Jim Chung
Sailesh Chutani
Mark Davis
William Gallmeister
William Gibson
Sheng-uei Guan
Gopal Gupta
Tai-Sook Han
Curtis Hill
Ming Ouh-Young
Amos Omondi
Muru Palaniappan
Penny Rheingans
John Rohlf
Robert Stam
Bryce Tebbs
Russell Tuck
Douglas Turner
Yen-Ping Shan
Will Partain
James Symon
Frank Silbermann

APPENDIX II

Educational Productivity

Degrees Received by Year 1986–1991

RAs who received full or partial ONR salary support

M.S.

1986

Shannon, Karen
Westover, Lee

1987

Clapp, Katherine
Davis, Mark
White, Brian

1988

Bush, Paulette
Ellsworth, David
Gallmeister, Bill
Gibson, William
Potter, Richard
Rheingans, Penny
Stam, Robert
Surles, Mark
Symon, James
Turner, Doug

1989

Jacobsen, Phil
Kelley, Michael T.
Neumann, Ulrich
Rhoades, Johnny

1990

Azuma, Ron
Bajura, Mike
Bollella, Greg
Brown, Randy
Brown, William
Good, Howard
Hawkes, Richard
Palmer, Dan

1991

Anderegg, Murray
Bell, Andrew

Ph.D.

1989

Levoy, Marc
Silbermann, Frank

1990

Airey, John
Davis, Mark
Gauch, Susan

1991

Westover, Lee

Note: ONR fellow Ed Biagioni defends his Ph.D dissertation on 19 November 1991. A copy of his dissertation will be forwarded to Ralph Wachter as soon as it is available.

RAs SUPPORTED by ONR

(RAs who received full or partial ONR salary support)

Name	minority	86-87	87-88	88-89	89-90	90-91
Airey, John				X		
Alspaugh, John					X	X
Anderegg, Murray					X	X
Azuma, Ron	m				X	
Bajura, Mike						X
Bell, Andrew					X	
Biagioni, Edoardo		X	X		X	X*
Bollella, Greg				X		
Brown, Randy				X	X	X
Brown, William				X	X	X
Bush, Paulette			X			
Clapp, Katie		X				
Chung, Jim	m			X	X	X
Davis, Mark		X	X*	X*	X*	
Ellsworth, David		X		X*	X*	X*
Gallmeister, Bill			X			
Gauch, Susan				X*		
Gibson, William		X	X			
Good, Howard					X	X
Hawkes, Richard					X	
Hill, Curtis					X	X
Holloway, Rich					X	X
Jacobsen, Phil					X	X
Kelley, Michael T.			X	X	X	
Kupstas, Eileen					X	X
Leech, Jonathan					X	X
Levoy, Marc		X	X*			
Lewis, Jeff					X	
Lusk, John						X
Mills, Peter						X
Molnar, Steve					X	
Murphy, Ransom						X
Neumann, Ulrich					X	
Palmer, Dan				X		
Potter, Richard		X	X			
Rheingans, Penny			X	X		
Rhoades, Johnny					X	
Shannon, Karen		X				
Silbermann, Frank		X	X	X		
Stahl, David						X
Stam, Robert		X	X	X		
Surles, Mark		X	X			
Symon, Jim		X	X			
Tebbs, Brice					X	
Turner, Doug	m	X	X			
Westover, Lee		X				
White, Brian		X				
TOTALS:	3	15	14	13	23	17
Approx FTE:		14	11	11	11	11

**ONR fellows*

APPENDIX III

COMPREHENSIVE BIBLIOGRAPHY

Through September 1991

Publications supported by ONR, or related to ONR-supported research projects on Command Information Systems

Contract No. N00014-86-K-0680

**(ONR-supported)*

Refereed Journal Articles (Invited)

*Jayaraman, Bharat. "Semantics of EqL," invited paper for a special issue of *IEEE Transactions on Software Engineering*, 14(4), April 1988, 472-480.

*Watanabe, Hiroyuki. "VLSI Realization of Fuzzy Inference Mechanism," *Trans. (Section A) of Institute of Electronics, Information, and Communication Engineers*, J72A(2), Feb. 1989, 179-187.

Refereed Journal Articles

*Abdel-Wahab, Hussein M., Sheng-Uei Guan, and J. Nievergelt. "Shared Workspaces for Group Collaboration: An Experiment using Internet and Unix Interprocess Communications," *IEEE Communications Magazine*, 26(11), Nov. 1988, 10-16.

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*Ahn, Ilsoo and Richard Snodgrass. "Partitioned Storage Structures for Temporal Databases," *Information Systems*, 13(4), 1988, 369-391. (See TempIS Doc. No. 19.)

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*Levoy, Marc. "Volume Rendering by Adaptive Refinement," *The Visual Computer*, 6(1), Jan. 1990. (See TR88-030.)

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*Levoy, Marc. "Direct Visualization of Surfaces from Computed Tomography Data," *Medical Imaging II, Proc. SPIE*, 914, 1988, 828-841. (See TR88-008.)

Losee, B. "Information in a Data Collection: Models of Database and Library Quality," *Journal of the American Society for Information Science*, 41(5), 1990, 359-367.

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Nie, Xumin and David Plaisted. "Experimental Results on Dynamic Subgoal Reordering," *IEEE Transactions on Computers*, 1989. (See TR87-027.)

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*Plaisted, David A. "Non-Horn Clause Logic Programming without Contrapositives," *Journal of Automated Reasoning*, 4 1988, 287-325.

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(ONR-supported)

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Contract No. N00014-86-K-0680

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ONR-SUPPPORTED PROJECTS: Asterisk next to the entry indicates research has received (or continues to receive) ONR support; technical reports lists are split (supported/not supported). Other papers are considered *related* to ONR research.

Copies of papers/tech reports (*related* to currently-funded projects) were forwarded to Ralph Wachter, Scientific Officer, as soon as they were available; copies were sent to ONR personnel listed on the Contract continuation sheet (for Block 25 DD Form 2222) every six months during semi-annual and annual report distribution.

Abstracts (ONR-supported research only) were mailed electronically to ONR (baux) upon receipt.

NOTE: Copies of <u>new</u> papers/reports that will be completed up to six months AFTER the contract period ends will be provided to Ralph Wachter as soon as they are available. Copies of papers/reports created after that time will be provided upon request.

APPENDIX IV

ONR 35740-5211

Revised
1-Nov-91

EQUIPMENT
SUMMARY REPORT

For Contract Years FY87 through FY91

ONR-URI CONTRACT #N00014-86-K-0680

ITEM	NUMBER OF UNITS (equivalent)						TOTAL ONR
	86-87	87-88	88-89	89-90	90-91	TOT	$ Contrib.
DEC workstations, systems	1	1	0	0	5	7	94,325
SUN workstations, systems	17	1	1	1	0	20	174,928
SUN servers w/disks	2	1	0	1	0	4	181,487
Macintosh systems	4	7	8	1	2	22	94,361
Other workstations	0	2	0	0	0	2	17,129
Terminals	5	0	0	0	0	5	2,141
Parallel processor	0	0	1	0	0	1	98,430
Printers, plotters	0	3	11	0	0	14	18,211
Other monitors (& periph)	0	9	8	0	0	17	17,721
Other disks/drives/tape sys	6	11	0	0	29	47	141,192
Miscellaneous							88,205
TOTAL							928,130

ONR Contract
5-35740-5211

ANNUAL EQUIP. REPORT, Y5

Encumb/expen 15 Sept. '90–30 Sept. '91

FY90-91

as of:
1-Nov-91

QTY	% FROM ONR	VENDOR	DESCRIPTION	ONR CONTRIB.	REQ. NO.
WORKSTATIONS/MINIS/MICROS:					
4	100%	Digital Equip.	PM339-BY DECstation 5000/120, 16mb, LK401-AA Keyboard; PMAG-BB 8-plane color frame buffer; VR297-DA 16" color Trinitron monitor; RZ24-FF 209 MB disk dr.	59,307.85	180937
1	100%	Digital Equip.	PM339-BY DECstation 5000/120, 16mb, LK401-AA Keyboard; PMAG-BB CX color framebuffer; VR297-DA 16" color trin. mon.; RZ24-FF 209 MB disk drive.	12,814.57	180941
2 ea	100%	Apple Computer	M5722LL/A Mac IIsi 5MB Disk; M0404 Apple Mac Portrait Display	7,218.00	344955
TAPE SYSTEMS, DISKS, DRIVES, PLAYERS:					
3	100%	Aviv Corp.	ACT840DS-SB Exabyte 8500 8mm tape subsys	10,801.19	14222
25	100%	Digital Equip.	RZ24-FF 209 MB disk drives	15,701.72	180952
1	100%	Digital Equip.	Rz24-FL 209 MB disk internal for 5000/120	1,075.83	14214
MISCELLANEOUS:					
1	83%	Circuit City	Sony ccdf55 8mm camera, sonnp77h battery, tripod, camera bag.	1,120.50	344543
	100%	Cary Machine Co	Modify XY sliding table	1,260.00	180674
1	100%	Total A/V Svcs.	Electrohome ECP-4101 Model 38-B09980-AC Projector	20,343.65	14205
1	100%	Total A/V Svcs.	ECP ceiling mount, Sun Sparc Harness, IR remote video/data switcher and rack mount brackets, splitter, input module, & decoder	3,032.90	344900
1 ea	100%	Heurikon Corp	68030 processor board; ROM for VX Works OS	3,908.22	180993
TOTAL:				136,584.43	

ONR Contract
5-35740-5211

ANNUAL EQUIP. REPORT, Y4

Encumb/expen since 15 Sept. '89

FY89-90

as of: 20-Sep-91

QTY	% FROM ONR	VENDOR	DESCRIPTION	ONR CONTRIB.	REQ. NO.
WORKSTATIONS/MINIS/MICROS:					
1	100%	Apple Computer	MacII system: M5740LL/A MacIIci w/80 HDisk & 4MB, M0116 keybd, M0410LL/A ethertalk card, M0401 monitor, M0324 video card, stand, M0402 monitor, M0260 video card, M0213 expansion kit.	10,090.21	180305
1	25%	Computerland	POQET Computer, #POQT-AO164	853.12	181589
1	58%	Sun	SPARC station w/16" color monitor, 8bm, 104MB SCSI internal disk, 4/65FC-8-Pe	4,283.28	180429
1	85%	Sun	4/280S-P14 Sun file server	31,250.44	180427
OTHER COMPUTERS:					
1	87%	MasPar Corp.	Parallel processor	53,132.97	344476
DISKS, DRIVES, PLAYERS:					
1	22%	Camera Corner	Pioneer laser disc player LD-V2200	168.41	180474
MISCELLANEOUS:					
1	100%	Clark-Powell	Sony VPH-1270Q video projector	12,315.45	180204
1	100%	Midwest Comm.	Broadcast video encoder #EN-300 & rack	1,796.40	014385
1	100%	Hamamatsu	Passive position sensor #C2399-01H	2,039.46	181294
1	100%	Apple Computer	M0401 monitor, M0324 video card, stand	1,331.40	180305
1	100%	Currie-Peak-Fr	AD9003 KM A/D Converter	2,024.33	014400
	100%	Newport Corp	Breadboards, posts, clamps for trkr system	2,586.93	180709
	100%	Newport Corp	Breadboards, posts, clamps for HMD system	2,641.53	180710
4	100%	MPCS Video	JVC Tk-870u color video CCD camera with RGB & composite outputs; JVC Hz-C611AFU power zoom lens w/C mount; power supply and cable.	6,594.26	180484
1	100%	Circuit City and Camera Corner	Panasonic WJ450 digital color quad system; Sony KU-13TR20 Trinitron color monitors (4 ea) w/RF tuner, baseband video & audio	2,378.28	180713
TOTAL:				133,486.47	

ONR Contract
5-35740-5211

ANNUAL EQUIP. REPORT, Y3 FY88-89

Expenditures 15 Sept. '88 - 14 Sept. '89 1-Dec-89 revised

QTY	% FROM ONR	VENDOR	DESCRIPTION	ONR CONTRIB.	REQ. NO.
WORKSTATIONS/MINIS/MICROS:					
5	97%	Apple Computer	M5680 MacIICX w/4 mb and 80 mb disk	20,978.15	013554
1	100%	Apple Computer	M5680 MacIICX w/4 mb, 80mb disk, keyboard	4,855.05	014373
2	100%	Apple Computer	MacII systems: M5680 MacIICS w/4 mb and 80 mb disk; M0115 keyboard; M0402 mono monitors; M0260 video cards; M0404 portr. displays; M0119 display video cards; M0213 expns. kit	14,317.32	014371
OTHER COMPUTERS:					
1	53%	Sun Microsystems	4/60M1-8 SPARC station w/8 mb, 19" mon.	2,779.00	013382
1	100%	MasPar Corp.	Parallel processor	45,296.45	344476
MONITORS and THEIR PERIPHERALS:					
4 ea	100%	Apple Computer	M0402 mono monitors and M0250 videocards	7,000.00	014371
4 ea	100%	Apple Computer	M0404 portrait displays and M0119 display video cards	4,356.00	014371
20	100%	Apple Computer	M0213 video card expansn. kits	1,742.72	014371
16	100%	Apple Computer	M0403 monitor stands	1,051.00	014371
PRINTERS/PLOTTERS:					
2	100%	Apple Computer	A9P0500 ImageWriter LQ	2,010.00	014371
8	100%	Apple Computer	A9P0329 ImageWriter II	3,525.00	014371
11	100%	Apple Computer	A9B0314 ImageWriter LQ/LocalTalk option	1,042.00	014371
1	100%	Apple Computer	M6215 Laserwriter II NTX w/M6006 4MB exp	5,904.26	181124
MISCELLANEOUS:					
1	100%	Hamamatsu	C2399-01H Photodiode Sensor Head	2,050.13	013143
2	100%	Hamamatsu	C2399-01H Photodiode Sensor Head	4,076.43	013031
1	100%	UNC Instrumt.	Alum. Mount for 3-camera tracking system	890.95	OR-749
TOTAL:				121,874.46	

ONR Contract
5-35740-5211

ANNUAL EQUIP. REPORT, Y2

Expenditures 15 Sept. '87 - 14 Sept. '88

FY87-88

1-Jul-89 revised

QTY	% FROM ONR	VENDOR	DESCRIPTION	ONR CONTRIB.	REQ. NO.
WORKSTATIONS/MINIS/MICROS:					
1	37%	Sun Microsystems	Sun-4 workstation	27,564.05	012920
2	100%	IBM Corp.	PS/2 Model 80/071 with drive, mouse interfaces, coprocessor, display adapter, 16" high res. color monitor	16,276.05	617383
1	100%	Digital Equip.	Workstation VS450-GA VS2000, 6MB, 19", mono., keyboard, mouse, 159MB disk, base	6,707.28	565306
4	100%	Apple Computer	M5333 Macintosh II CPU	9,181.20	683647
3	100%	Apple Computer	M5300/A Macintosh II CPU	6,885.90	617389
FILE SERVERS:					
1	100%	Sun Microsystems	4/280S-P14 data center server	68,355.00	617393
DISKS/DRIVES/TAPE DRIVES:					
7	100%	Apple Computer	M0233 internal 80SC hard disks	13,090.35	617389
1	100%	Sun Microsystems	631FR1 2X892 MB formatted disk subsystem	26,964.00	617393
1	26%	Sun Microsystems	X675A 6250/1600 bpi 1/2" tape drive subsys.	2,820.60	617393
3	100%	Apple Computer	M0233/A Macintosh internal 80SC hard disks	5,817.00	683647
PRINTERS/PLOTTERS:					
1	53%	Hewlett-Packard	HP7596A Draftmaster II plotter	4,062.90	617396
2	100%	Apple Computer	M6006 LaserWriter IINTX, 4MB memry exp kit	1,661.10	617389
MONITORS:					
6	100%	UNC Student Stores	M0400 Apple high-res. monochrome monitors	1,668.70	683584
1	100%	UNC Student Stores	M0401 Apple high-res. color RGB monitor	687.75	683584
2	96%	Apple Computer	M0401 Apple high-res. color RGB monitor	1,215.80	683647
MISCELLANEOUS:					
1	18%	Internat'l Scient.	Demonstrator SS-40 E-Beam probing system	8,291.96	683691
7	100%	UNC Student Stores	M0211 Macintosh II video cards	2,534.45	683584
4	100%	UNC Student Stores	M0213 Macintosh II video expansion kits	102.90	683584
2	100%	Apple Computer	M0405 Ethertalk interface cards	1,073.77	
TOTAL:				204,960.76	

ONR Contract 5-35740-5211

ANNUAL EQUIP. REPORT, Y1

Expenditures 15 Sept. '86 - 14 Sept. '87

FY86-87

1-Jul-89 revised

QTY	% FROM ONR	VENDOR	DESCRIPTION	ONR CONTRIB.	REQ NO.
WORKSTATIONS/MINIS/MICROS:					
14	100%	Sun Microsystems	Model #3/60M-8, Sun 3/60M 8MB monoch.	90,847.90	571090
1	100%	Sun Microsystems	Model #3/60FC-8, Sun 3/60FC 8MB w/16" mon.	7,372.05	571090
1	100%	Sun Microsystems	Model #3/60C-20, Sun 3/60C 20MB w/19" mon	12,947.55	571090
1	50%	Sun Microsystems	Model #3/110C-8, Sun 8MB w/19" color mon.	10,639.64	339248
1	100%	Sun Microsystems	Model #3/110C-4, Sun 3/110 4MB w/19" mon. 150A FPA, RTU license	18,495.13	472504
4	100%	Apple Computer	M5300 MACIIs w/keyboard, 80SC hard disk, 1MB expansion kit, Apple Ethertalk card, monochr. monitor, video card; Imagewriter	10,699.83 10,136.04	565241 276019
1	25%	Digital Equipment	Model #SU-LV55U-EK MVII/GPX Workstation	4,987.12	339193
4	10%	Digital Equipment	3 of Model #SU-LV55U-EK MVII/GPX Work-stations, disks, interface, cable kit; 1 Model #SU-LV598-EK MVII/GPX Workstation, disks, cables, controllers, memory, cable kits	10,509.59	276101
FILE SERVERS:					
1	100%	Sun Microsystems	Model #4/280S-P2, Sun 4/280S Data Center Server w/ cabinet, disk subsystem, expansion disk, tape subsystem	64,985.55	571090
1	100%	Sun Microsystems	Model #3/180S-8, Sun 3/180 Server w/8MB	16,896.42	339251
TERMINALS:					
5	100%	Data Term	WYSE 60 Terminals w/ambr screen, ASCII keybd	2,140.95	565327
DISKS/DRIVES:					
2	100%	Sun Microsystems	Model #626A, 575 MB formatted expan. disks	24,656.10	571090
4	83%	Systems Industr.	Fujitsu Super Eagle Disk Drives w/cables, terminator, rack slides, documentation	9,555.00 19,110.00 3,415.20	339204 276022 339174
1	100%	Systems Industr.	Eagle Disk Drive w/cables, termin., slide, docum.	8,015.70	276163
MISCELLANEOUS:					
2	100%	Helios Systems	MSV-8 Sun 3/110 Add-On Memory, 8MB	4,972.80	472508
1	100%	Newark Electr.	Stock #99F1070, 79" rack w/4 #91F094 castrs	841.09	276001
TOTAL:				331,223.66	

APPENDIX V

Travel Report

FY90-91

ONR-Supported (full or partial)

Traveler	Title	Place/Date	Purpose
Ed Biagioni	Research Assistant	Nags Head, NC 10/28/90–10/31/90	Present paper at Workshop on Unstructured Scientific Computation on Scalable Multiprocessors
Vernon Chi	Director, MSL	San Jose, CA	Attend Microelectron. System Education Conference & Expo
		Las Vegas, NV 07/21/91–08/04/91	Attend SIGGRAPH '91 Conference
Lynne Cohen Duncan	Systems Software Manager	Raleigh, NC 08/12/91–08/15/91	Technical training, ULTRIX (run by Digital)
Henry Fuchs	Federico Gil Professor	Las Vegas, NV 07/25/91-08/04/91	Chair session, serve on panel, supervise virtual reality exhibit, SIGGRAPH '91
John Hughes	Research Associate	Las Vegas, NV 07/25/91–08/03/91	Technical support, SIGGRAPH '91 Conference
		Bethesda, MD 12/02/90–12/14/90	Technical training, Silicon Graphics
David Plaisted	Professor	Palo Alto, CA 06/02/91–06/09/91	Attend committee meeting of International Logic Programming Symposium
John Poulton	Research Assoc. Prof.	Las Vegas, NV 07/25/91–08/03/91	Attend SIGGRAPH '91 Conference
Jan Prins	Assistant Professor	Hilton Head, SC 07/20/91–07/24/91	Attend SPAA 1991 Conference
Jannick Rolland	Visiting Res. Associate	Las Vegas, NV 07/27/91–08/03/91	Attend SIGGRAPH '91 Conference
John Smith	Associate Professor	Washington, DC 06/23/91–06/26/91	Speaker at BRG C2 Research Symposium

Travel Report
FY89-90
ONR-Supported (full or partial)

Traveler	Title	Place/Date	Purpose
Ronald Azuma	Research Associate	Orlando, FL 18-22 April 1990	Present paper at Technical Symposium on Optical Engr. & Photonics in Aerospace Sensing
		Dallas, TX 4-10 August 1990	Attend SIGGRAPH '90
		Atlanta, GA 13 June 1990	Attend Architectural/Engr/Construc-tions '90 Conf. & Exposition
Frederick P. Brooks, Jr.	Kenan Professor	Santa Barbara, CA 3-8 March 1990	Present paper at MIT Foundation Conference
		Salt Lake City and Snowbird, UT 21-28 March 1990	Attend pre-site visit at U of UT; and Symposium on Interactive 3D Graphics
William Brown	Research Associate	Snowbird, UT and Seattle, WA 22 March - 8 April 1990	Attend Symposium on Interactive 3D Graphics; and SIGCHI Conference on Human Factors & Computing Systems
		Dallas, TX 4-10 August 1990	Attend SIGGRAPH '90
David Ellsworth	Research Assistant	Snowbird, UT 25-28 March 1990	Present paper at Symposium on Interactive 3D Graphics
Henry Fuchs	Federico Gil Professor	Snowbird, UT 25-28 March 1990	On Program Committee and panel moderator, Symposium on Interactive 3D Graphics
Curtis Hill	Research Associate	Monterey, CA 12-14 June 1990	Present paper (if accepted) at 1990 Symposium on Command and Control Research
Rich Holloway	Research Associate	Atlanta, GA 21-26 May 1990	Attend conference on visualiza-tion in biomedical computing
		Dallas, TX 4-10 August 1990	Attend SIGGRAPH '90
Ralph A. Mason, Jr.	Assoc. Chairman	Monterey, CA 12-14 June 1990	Attend 1990 Symposium on Command and Control Research
David Richardson	Visiting Assoc. Professor	Arlington, VA	Met with R. Wachter re: ARM and molecular visualization
Warren Robinett	Project Leader, HMD	Snowbird, UT 24-29 March 1990	Attend Symposium on Interactive 3D Graphics

Traveler	Title	Place/Date	Purpose
		Santa Clara, CA 11-21 February 1990	Attend SPIE Conference
		Dallas, TX 6-10 August 1990	Attend SIGGRAPH '90
		Boston, MA 28-30 July 1990	Partic. in 8th National Conference on AI
Jeannie M. Walsh	Administrative Coord.	Research Triangle Park, NC 27 February 1990	Attend EXCEL macros workshop
		Raleigh, NC 22 March 1990	Attend workshop on document editing, design, and production

Travel Report, FY88-89

ONR-Supported (fully or partially)

Traveller	Title	Place/Date	Purpose
Peter Calingaert	Professor and Assoc. Chairman for Academics	Ithaca, NY 07/08/89-07/21/89	Attend course on distributed systems
James Chung	Research Assistant	Los Angeles, CA 01/16/89-01/21/89	Present paper, SPIE OE/LASE '89 Conference
Susan Gauch	ONR Fellow, fall '88	Washington, DC 03/29/89	Present paper at AI System in Government conference
Richard Snodgrass	Associate Professor	to UNC-CH from Tuscon, AZ	Present at 1989 ONR Site Visit
Donald Stanat	Professor	CMU, Pittsburgh, PA	Attend ONR-SEI Computer Science Workshop
Steve Weiss	Prof. & Chairman	Washington, DC 06/27/89-06/29/89	Attend C^3 Symposium
RAs to SIGGRAPH: John Airey, Ron Azuma, Mike Bajura, William Brown, James Chung, David Ellsworth, Michael Kelley, Dan Palmer	Research Assistants	Boston, MA 07/30/89-08/04/89	Attend SIGGRAPH '89

TRAVEL REPORT--FY 87-88

ONR Supported (fully or partially)

TRAVELLER	TITLE	PLACE/DATE:	PURPOSE
J. Dean Brock	Assistant Professor	Sydney, BC, Canada 04/06-04/08/88	present paper at Internat'l Symposium on Lucid and Intentional Programming
Frederick P. Brooks, Jr.	Kenan Professor	San Diego, CA 05/09/88	to NOSC for information exchange
Peter Calingaert	Professor	Chicago, IL 09/28-09/30/87	attend National Communications Forum
Vernon Chi*	Director, MSL	Portland, OR 09/13-09/20/87	attend FPCA '87 Conference and meeting at ESI
James Chung	Research Asst.	Atlanta, GA 07/31-08/05/88	attend SIGGRAPH '88 Conference
Bharat Jayaraman*	Assistant Professor	Portland, OR 09/12-09/17/87	present paper at FPL&CA '87 Conference
Marc Levoy	Research Asst.	Atlanta, GA 07/31-08/05/88	attend SIGGRAPH '88 Conference
Ralph Mason	Assoc. Chairman for Adminis.	Washington, DC 04/19-04/20/88	attend National Net 88 Telecom. Conf. and meeting with Aegis Project Mgr.
Jay Nievergelt	Chairman and Kenan Professor	Monterey, CA 06/07-06/09/88	attend Communications and Controi Symposium
Steven Ornat	Communications Technician	Washington, DC 01/26-01/27/88	attend Communications Network Conference
		Plano, TX 07/19-07/29/88	attend InteCom communications classes
David Plaisted	Professor	Argonne, IL 05/23-05/26/88	attend 9th International Conference on Automated Deduction
Jan Prins	Assistant Professor	Atlanta, GA 06/21-06/24/88	attend SIGPLAN '88 Conference
Richard Snodgrass	Assistant Professor	Chicago, IL 05/31-06/03/88	attend ACM SIGMod '88 Internat'l Conference on Mgmt. of Data

TRAVELLER	TITLE	PLACE/DATE:	PURPOSE
Donald F. Stanat	Professor and Assoc. Chairman for Academic Affairs	San Diego, CA 05/09-05/10/88	to NOSC for information exchange
Russ Tuck	Research Asst.	Shelton, CT 10/05-10/07/87	attend Pegasus Users Group meeting
Norman Vogel	Director of Communications Research	Napa Valley, CA 10/03-10/08/87	participate in 10th Annual Data Communications Symposium
		Washington, DC 01/27/88	attend Communications Network Conference
		Washington, DC 03/06-03/09/88	attend TeleStrategies Conference
		Washington, DC 04/18-04/20/88	attend National Net '88 Telecom. Conference

**also listed in Year 1 Annual Report*

Travel Report FY 86-87

September 15, 1986 through September 14, 1987

TRAVELLER	TITLE	PLACE/DATE	PURPOSE
Vernon Chi	Director of MSL	San Diego, CA 11/02-11/03/86	visit the Dynair Co.
Vernon Chi	Director of MSL	Washington, DC 06/18/87	attend meeting at DARPA
Vernon Chi	Director of MSL	Portland, OR 09/13-09/20/87	attend FPCA '87 Conference and meeting at ESI
James Coggins	Assistant Professor	Shelton, CT 07/06-07/07/87	discuss PIXAR project
Bharat Jayaraman	Assistant Professor	Portland, OR 09/12-09/17/87	present paper at FPL& CA '87 Conference
Gyula Mago	Professor	Washington, DC 06/18/87	attend meeting at DARPA
John Menges	Communications Sftwre Engineer	Dallas, TX 03/14-04/05/87	training at InteCom (IBX database design)
John Menges	Communications Sftwre Engineer	Washington, DC 06/26-06/27/87	investigate InteCom IBX switch
Jay Nievergelt	Professor and Chairman	Washington, DC 10/20-10/22/86	attend ONR workshop and meeting
Jay Nievergelt	Professor and Chairman	Washington, DC 05/29-06/19/87	meeting of URI P.I.'s
Steve Ornat	Communications Technician	Washington, DC 02/10/87	attend Communications Networks '87 Conference

TRAVELLER	TITLE	PLACE/DATE	PURPOSE
Steve Ornat	Communications Technician	Dallas, TX 04/06-05/01/87 05/26-06/19/87	training at InteCom
David Plaisted	Professor	Bordeaux, France 05/21-05/28/87	attend 2nd Internat'l Conf. on Rewriting Techniques & Applications
Rick Snodgrass	Assistant Professor	San Francisco, CA 05/26-05/29/87	present paper to '87 SIGMod Conference
Donald Stanat	Professor and Assoc. Chairman, Academic Affairs	Austin, TX 06/06-06/13/87	participate in Institute on Logical Foundations of Functional Progrmg.
Donald Stanat	Professor and Assoc. Chairman, Academic Affairs	Austin, TX 08/22-08/29/87	participate in Institute of Declarative Programming
Norman Vogel	Director of Communications Research	Dallas, TX 05/06-05/08/87	attend InteCom IBX University Users meeting

APPENDIX VI:

Annual Reports and Summaries
FY87 through FY91

Note: To assist the reader in finding information, pertinent parts of each Annual Report appendix were extracted and are currently included as Appendix I through V of this Final Five-Year Summary report.

ANNUAL REPORT

15 September 1990 through 30 September 1991

Y5

The Infrastructure of Command Information Systems

Submitted to

Office of Naval Research
Arlington, VA 22217-5000

Submitted by

Department of Computer Science
The University of North Carolina at Chapel Hill
Campus Box 3175, Sitterson Hall
Chapel Hill, NC 27599-3175

Principal Investigators:

Frederick P. Brooks, Jr.
Donald F. Stanat
Stephen F. Weiss

1 October 1991

Contract No. N00014-86-K-0680

CONTENTS

SECTION 1: Productivity measures during this reporting period 1

SECTION 2: Detailed Summary of Technical Results *(by project)* during this reporting period 2

Pixel-Planes 5 2

Walkthrough 3

Head-Mounted Display 4

Tracker 5

Artifact-Based Collaboration 6

Data-Parallel Execution 6

SoftLab 7

SECTION 3: Lists of publications, presentations, reports, awards/honors/prizes during this reporting period 9

A. Refereed papers (to appear) 9
B. Refereed papers published 9
C. Refereed exhibitions 10
D. Refereed papers submitted (awaiting acceptance) 10
E. Unrefereed reports and articles 11
F. Books (or parts thereof) published (and to appear) 12
G. Videotapes 12
H. Invited presentations 12
I. Contributed presentations 14
J. Honors 15
K. Prizes or awards 15
L. Promotions obtained 15
M. Educational productivity 15

SECTION 4: Transitions and DoD Interactions during this reporting period *(by project)* 16

SECTION 5: Software and Hardware Prototypes during this reporting period *(by project)* 20

APPENDICES

Appendix I Comprehensive Bibliography

Appendix II Personnel by Project, FY90–91

Appendix III Travel Report, FY90-91

Appendix IV Equipment Report

ANNUAL REPORT for FY90-91

SECTION 1: Productivity measures during this reporting period

Principal Investigators:	Frederick P. Brooks, Jr. Donald F. Stanat Stephen F. Weiss
PI Institution:	The University of North Carolina at Chapel Hill Department of Computer Science
PI Phone Numbers:	919/962-1931 919/962-1788 919/962-1888
PI E-mail Addresses:	brooks@cs.unc.edu stanat@cs.unc.edu weiss@cs.unc.edu

Contract Title:	The Infrastructure of Command Information Systems		
Contract Number:	N00014-86-K-0680		
Reporting Period:	15 September 1990 through 30 September 1991		

		ONR supported	Related
1.1	Refereed papers submitted *(awaiting acceptance)*	0	10
1.2	Refereed papers *(to appear)*	3	2
1.3	Refereed papers published	2	4
1.4	Unrefereed reports and articles *(published or to appear)*	16	8
1.5	Books (or parts thereof) submitted (*to appear*)	0	0
1.6	Books (or parts thereof) published	2	1
1.7	Patents filed but not yet granted	0	0
1.8	Patents granted (includes software copyrights)	0	0

		Supported or Related
1.9	Invited Presentations	22
1.10	Contributed Presentations	12
1.11	Honors received	9
1.12	Prizes or awards received	0
1.13	Promotions obtained	0
1.14	Educational productivity	
	degrees received during FY by those supported ≥ 25% of full time during FY	4
	degrees received during FY by those not ONR supported during FY but working on project	3
1.15	Graduate students supported ≥ 25% of full time	19
1.16	Post-docs supported ≥ 25% of full time	0
1.17	Minorities supported ≥ 25% of full time	8

SECTION 2: Detailed Summary of Technical Results *(by project)* during this reporting period

Principal Investigators:	Frederick P. Brooks, Jr. Donald F. Stanat Stephen F. Weiss
PI Institution:	The University of North Carolina at Chapel Hill Department of Computer Science
PI Phone Numbers:	919/962-1931 919/962-1788 919/962-1888
PI E-mail Addresses:	brooks@cs.unc.edu stanat@cs.unc.edu weiss@cs.unc.edu

Contract Title:	The Infrastructure of Command Information Systems
Contract Number:	N00014-86-K-0680
Reporting Period:	15 September 1990 through 30 September 1991

Pixel-Planes 5

Our objective is to design and build multicomputer architecture (both hardware and software) for 3D interactive graphics that delivers in excess of one million polygons/sec. to real applications and that supports a wide variety of rendering algorithms.

In the past fiscal year, we have made significant progress in our research on the Pixel-Planes 5 system, described below.

We have built and installed a third rack of boards for Pixel-Planes 5. We will continue to configure the system as one large machine when top performance is desired or as two independent machines to better support multiple developers and users.

The polygon rendering speed of the Pixel-Planes 5 prototype has now exceeded our performance goal of 1 million polygons/sec. In fact, with one detailed model of terrain of the Sierra Nevada Mountains we sustain more than 2 million on-screen triangles per second (full-color, Phong-shaded, with specular highlights). The data set consists of approximately 166,000 triangles and is rendered at 12 frames per second, a rate that allows quite reasonable user interaction. This 2.3 million triangles per second is, to our knowledge, the highest polygon-rendering rate achieved anywhere to date. This rate is achieved on a three-rack system with 45 GPs and 24 Renderers (each Graphics Processor (GP) is an i860 with 8 megabytes of memory, each Renderer is an SIMD array of 16,384 1-bit processors and custom parallel polynomial evaluation circuitry). Besides the hardware additions made during the last six months, several factors have contributed to these improvements: a more stable, faster Ring Operating System (ROS), i860 assembly language coding of a few critical routines, and extensive event tracing to determine where the bottlenecks are.

We developed an NTSC frame buffer and modified ROS and Rendering Control System (RCS) to support it. We have completed the PPHIGS work needed to support the NTSC frame buffer in stereo mode and interface the head-mounted display to the system.

Trey Greer (now with IVEX Corp.) developed a tiny system of only one GP and one Renderer that renders anti-aliased triangles at a rate of 50,000 per second.

The VISTAnet project successfully connected a Cray Y-MP computer located in Research Triangle Park to the Pixel-Planes Ring via a dedicated T3 fiber line potentially operating at 45 Mbits/sec. (only about 5 Mbits/sec. achieved application-to-application so far). The Cray computes radiation dose levels based on user input at a workstation in UNC-CH Department of Radiation Oncology, and transmits the dose to Pixel-Planes for interactive display.

Significant progress was made in doing volume rendering on Pixel-Planes 5. Tim Cullip developed an all-GP algorithm that can render coarse images of a 128-cubed voxel data set at better than 10 frames/sec. Ulrich Neumann developed a volume renderer based on using the Renderers to do splat buffering that produces up to five frames/sec. for a 128-cubed

voxel data set. Neumann is now preparing a volume rendering animation sequence for Apple Computer. Apple will distribute this on their "Multimedia" CD ROM.

We are now implementing a new volume renderer on Pixel-Planes based on Tim Cullip's design concept, but which will permit the use of larger (up to 27,000,000 voxels) data sets and provide at least the full function of the existing *vrn* program.

The performance of Pixel-Planes 5 with large numbers of procedural textures is being optimized. Our local colleagues on the Walkthrough project built a radiosity model of a house that now uses about 20 procedural textures (such as brick, kitchen tile, ceilings) to create a complex and interesting visual environment. The current frame rates are up to around 25 frames/sec on a "low resolution" 640- x 480-pixel monitor, and the textures are now anti-aliased.

A high-level design for a new graphics system based on image-composition was developed and reviewed. Because the system looks so promising, we decided to undertake a full, detailed design of the hardware and are now in the beginning stages of this.

We transported a Pixel-Planes 5 three-rack system and exhibited it in the Tomorrow's Realities Gallery at the SIGGRAPH '91 conference, July 28-August 2, 1991. Of all the applicants, UNC had the largest number of demonstrations accepted for this juried exhibit and had the largest booth (29' x 43'). We showed a number of applications, including the head-mounted display, volume rendering, and polygon and sphere rendering at over 2 million polygons/sec. The demonstrations were: 3dm—A Two-Person Modeling System, Interactive Building Walkthrough Using a Steerable Treadmill, Interactive Building Walkthrough Using the Optical Tracker, Flying Through Molecules, A Mountain Bike with Force Feedback Pedals, Radiation Therapy Treatment Planning, and the Virtual Pilot. All of our demonstrations at the exhibit were single-user, "hands-on" experiences. Because each demonstration takes about five minutes, we were able to show demos to a relatively limited number of people. During the five days that the exhibit was open, approximately 600 people were able to experience our virtual reality demos.

Walkthrough

Major Milestone Reached

The Walkthrough Project reached a major milestone with the demonstration in July at SIGGRAPH '91 of two Walkthrough systems, each at a new level of performance. These systems were part of the UNC Exhibit in the Virtual Reality Gallery.

The scenes are shown with radiosity illumination, lights that can be switched on or off with only 100 msec. delays, textured surfaces, and near-real-time display from changing viewpoints. Update rates realized by the Pixel-Planes 5 graphics scene generator are 30-40 updates/second (15-20 stereo images/second) on scenes consisting of thousands of polygons, many textured.

One system uses a head-mounted display and the new UNC Ceiling Tracker to allow the viewer literally to walk freely about a 10' x 12' living room in an imaginary apartment. Both systems include the display of scene-appropriate sounds.

The second system uses our UNC steerable treadmill and a head-mounted display to allow viewers to virtually walk around a fully furnished ten-room house. Different appropriate sounds are heard in each room, and outdoors.

Our exhibits and demonstrations were very well received.

Annual Progress

As previously discussed, all virtual worlds projects need to move forward simultaneously in four dimensions, shown in the figure. We shall discuss this year's progress under these four headings.

Faster

The Pixel-Planes 5 machine came on-line and, during the course of the year, we and the Pixel-Planes 5 team worked together to remove the initial hindrances to our realizing its speed. At SIGGRAPH, Pixel-Planes 5 was demonstrated displaying 2 million Phong-shaded on-screen triangles/second, about twice as fast as the state-of-the-art Silicon Graphics machine. Texturing substantially reduces this rate. The power of Pixel-Planes 5 is, however, sufficient for dynamic interaction of high-fidelity images.

Prettier

The major step forward this year has been the addition of anti-aliased textures. They radically improve the visual fidelity of a scene with a fixed number of polygons.

The videotape shows, for example, wood, brick, ceiling tile, linoleum, bathroom tile, etc. We even use textures for sheet music, piano keys, and art on the wall. Pixel-Planes 5 is very good at procedural textures; it is not especially good at bit-mapped (image) textures.

The second major step on scene fidelity has been the addition of location-dependent (monaural) sound cues. We adapted commercial Macintosh software; purchased a 10,000-sound CD sound-cue library; and developed the location-based sound selection, loudness control, and sound-sound mixing software.

Handier

We developed new user interfaces for

- the ceiling tracker
- interactive turning on and off of lights in the model
- full integration of our treadmill interface with the head-mounted display and Polhemus head tracker.

Realer

We gained much experience in model-building this year. The house model was refined; a sound model was built. We also built de novo, a model for a six-room furnished apartment. On the theoretical side, we developed a whole new many-level hierarchical concept of how architectural models should be organized.

On the other hand, we took a step backward on real use. We spent all our effort for six months getting everything really right for SIGGRAPH, including the new apartment model. This had the very salutary effect of bringing many in-process activities to closure. The price was that we had no effort to devote to real-user interaction with the designer of the house extension. That design and construction proceeded anyway. Our house model is now a year behind reality, and we have lost the opportunity for client feedback.

This coming year we shall try to establish and track a real client interaction, even though that will slow our technology development. It will surely provide major guidance for future technology development.

Head-Mounted Display

Technical accomplishments during this reporting period:

We developed the software architecture for HMD applications of a standard software library (VLIB, etc.), a standard file format for models used by the application (PPHIGS archive file format), and a special-purpose program (the simulation code) that runs the application. A short dummy application, which new HMD users could copy, use to get started rapidly on the HMD, and then begin to grow their own applications was also developed. We produced Vixen, an application that allows a user to view arbitrary models using the HMD (analogous to the old *xfront* for viewing models using the Pixel-Planes 4 console and joystick). Vixen supports the manually controlled actions of flying through the virtual world containing the model being viewed, scaling the world, scaling individual objects, tilting the world, picking up individual objects, and loading and saving the files that define these models. The team also built an HMD-based 3D modeler.

The team worked to make the HMD software device-independent, so that the particular HMD and tracker to be used by an application could be chosen at run-time using Unix shell environment variables. Currently supported HMDs are: EyePhone model 1, EyePhone model 2, AFIT HMD and the old see-through HMD. Supported trackers are three different Polhemus units (with 1, 2 and 4 sensors), the Ascension Bird tracker, and the UNC opto-electronic "ceiling" tracker, which was recently completed. The screen/joystick is treated as a HMD/tracker type so that HMD applications can be used simply with a joystick and screen, if desired.

We started supporting multi-person shared virtual worlds and greatly improved and enhanced the sound software, collecting a library of interesting sounds. The idea of using a HMD to superimpose real-time ultrasound images onto the tissue being imaged is also being investigated. The team worked to analyze the EyePhone optics from the EyePhone and LEEP optics specifications, and demonstrated that the critical parameters for the display software (field-of-view, convergence correction, etc.) can be calculated from the specs of the system. Custom optics were designed for the planned new see-through HMD for the medical X-ray vision application. We purchased a monochrome 1-inch CRT (a camcorder viewfinder) for use in the new see-through HMD.

Work with novel display technology using lasers and moving mirrors was proposed; but after investigation, the team decided that, at the update rates we desired, none of these deflection methods could produce a display device with resolution better than current LCDs. We built the digital hardware and the software for a 1-dimensional test of an optical tracker based on rotating planes of light. The test showed a 1D tracking accuracy of .2 mm at a range of 5 meters. We worked out on paper the expected specifications of a 6-degree-of-freedom tracker based on this method. We

implemented a preliminary 1-screen prototype of head-tracked stereo on the monitor screen (the "bathysphere" idea). A ring input device, made from banjo finger-pick, push-button and Polhemus sensor, was also built.

We acquired a versatile I/O board for the Mac, with the intent of using the Mac (in addition to playing sounds) to control various input/output devices such as vibratory feedback to the user from the manual input device. We used the I/O board to control a vibratory buzzer from a pocket pager and built a quick prototype of a manual input device with a vibrator and four switches which worked through the Mac I/O board.

We designed and implemented a simple prototype of a simulation of the solar system. The sun, planets and moons were modeled at their true scales and distances, and scaling the model up and down was used to look at various bodies in the simulation. Because the distances are so vast compared with sizes of the bodies in the simulation, graphics for the orbits and other markers were used to help the user locate the planets and moons. A modeling language was designed to simplify the creation of models in the solar system simulation and other applications.

Tracker

Our objective is to design and to build a new real-time position and orientation tracking device for head-mounted display systems that features a large working area, high resolution, rapid update rate, and immunity from environmental disturbances.

The tracker currently under development is optoelectronic in nature. A cluster of small imaging sensors is located atop the helmet of a head-mounted display. These sensors form images of light-emitting diodes (LEDs) mounted overhead in a suspended ceiling. In effect, they serve as navigation beacons in that the knowledge of their position in the room, coupled with their image formed on top of the head, allows both the position and the orientation of the head-mounted display to be computed.

Major challenges facing the project team are: the accurate placement of LED beacons on a suspended ceiling, the calibration of image sensors based on non-metric optics and lateral-effect photodiodes, and the real-time computation of head position and orientation.

Significant progress during this reporting period:

A technique for computing head position and orientation that offers advantages over Jih-Fang Wang's extension to Church's algorithm has been implemented and demonstrated. Whereas Wang's solution admitted information from three sensors and, at most, three LEDs, this approach allows an unlimited number of sensors to be used, and each sensor can image an unlimited number of LEDs. The technique has been applied to a tracker with four image sensors and 10–40 LEDs in use at any given time.

We have built a belt-mounted electronics module that interfaces up to eight head-mounted image sensors to the tracking system.

We have completed the building of related hardware that allows a workstation to accept information from the head-mounted sensors and to control the firing of LEDs. The result is a four-slot-wide VME module containing a 68030-based, single-board computer, a 100Mbit/sec serial interface, a parallel interface to the LED controllers, and a power supply.

A computer-controlled sensor calibration rig has been constructed that allows calibration maps to be constructed for each image sensor used. The calibration maps correct for nonlinearities in the sensors' lateral-effect photodiodes and their lenses.

Thirty-two ceiling panels have been produced. Each panel consists of a printed circuit board housed in an aluminum enclosure. The printed circuit board and the enclosure's front panel form a composite structure that is flat to within .040". Given that LEDs are located by holes punched in the front panel to within a true position tolerance zone of .005", this ensures that LEDs are precisely located on a given panel.

We have built a ceiling support structure that suspends thirty ceiling panels from adjustable spiders. The spiders allow the corner of each panel to be vertically adjusted. A Spectra-Physics LaserLevel was used to adjust the spiders' vertical locations to within a tolerance zone of .003". Given that the spiders locate the corner of each panel, the location of LEDs is extremely well defined.

A working tracking system with a 10' x 12" working area was demonstrated at the SIGGRAPH '91 conference in Las Vegas, July 28–August 2, 1991. This was one of seven demonstrations shown in UNC's booth in the Tomorrow's Realities Gallery. Of all the applicants, UNC had the most demonstrations accepted for this juried exhibit and the largest booth (29' x 43'). All of our demonstrations at the exhibit were single-user, "hands-on" experiences.

Future Plans:

We plan to extend the work area of the tracker to 20' x 20" and reduce the mass of the headset. We also plan to incorporate predictive tracking algorithms to compensate for lag in the tracker and graphics subsystems. Work will continue on self-calibration techniques with the goal of developing an algorithm that can compute the position of LEDs and allow less stringent tolerances on absolute LED position in the ceiling. We will also continue to develop the Self-Tracker technology.

Artifact-Based Collaboration

Our objective was to develop tools for studying and understanding decision-making by individuals and groups working in a computer environment.

Significant progress during reporting period:

We developed a new cognitive grammar, based on ATN formalism. The team also designed and implemented a prototype ATN grammar development tool. We explored the concept of group protocols and compiled a technical notebook cataloging protocol tools and their uses. We are in the process of completing a technical report describing tools for automated protocol analysis.

Plans:

We plan to complete the development of ATN tool and to implement the ATN-based parser program. We also plan to implement protocol tracking and reply in selected portions of the new hypermedia collaboration system (ABC). The team will also define the requirements for group protocols.

Long-term plans:

The team plans to develop a hypermedia-based software development environment for collaborative work that includes group protocol capabilities.

Data-Parallel Execution

Our objective is to increase utility and applicability of highly parallel computers through:

- development of high-level, machine-independent data-parallel programming languages and data-parallel programming techniques,
- compilation techniques yielding efficient execution for such programming languages, and
- demonstration of high-performance algorithms and applications on our 4096 processor MasPar MP-1.

Progress in each of these areas is detailed below.

Programming Languages and Techniques:

A preliminary design of *Proteus*, a high-level language for prototyping parallel applications, was completed in cooperation with colleagues at Duke and Kestrel. This work is part of DARPA's ProtoTech project. High-level parallel programs expressed in *Proteus* will be executed sequentially by a language interpreter that is currently under development. We rely on transformations (manual and automatic) to place a *Proteus* program in a restricted form from which parallel code may be generated. Since Proteus offers a very general model of parallelism that cannot be emulated efficiently by a given parallel machine, the refinement step is necessary if we wish to generate programs that execute with reasonable efficiency.

A staged model of parallel program development is advocated in which computations are first expressed in a "pure" data-parallel form. Subsequent steps serve to minimize communication and to balance computational load. This methodology fits well with a transformational style of program development.

One of our researchers is participating in the design of Proteus and is concentrating in particular on a type system for the language that supports the dynamic typing and high flexibility required in a prototyping language and supports type-refinement to introduce the precise static typing necessary in the use of program transformations.

Compilation Techniques:

Proteus translation will target two basic implementation models for parallel execution: Mach threads and the CVL data parallel intermediate code developed by Guy Blelloch at Carnegie-Mellon University. Researchers implemented CVL on the MP-1 and performed some preliminary performance analysis.

Some computations, such as the simulation of certain physical systems, have unpredictable computational requirements that evolve over time. For these systems, dynamic balancing of the computational load over processor is required. ONR fellow Ed Biagioni has implemented an efficient global technique on the MP-1 that determines the load at each processor and organizes the movement of data to equalize it. An important property of this movement is that it preserves locality in communication, hence the basic performance of the underlying algorithm is unaffected.

Algorithms and Applications:

At the core of many parallel algorithms lie sorting and routing steps. Routing and sorting algorithms for large arrays have been developed for the MP-1 that considerably exceed the performance of presently available algorithms. The algorithms use randomization techniques to achieve good performance over all inputs.

One researcher developed an MP-1 application to support better quality real-time force feedback in the GRIP project. An operator interactively attempts to find a receptor site for a drug molecule on a large protein receiving feedback from a continuously updated image of the molecules on a display and from the force, felt on the handgrip guiding the drug molecule, due to the interaction of the drug with the protein. The force calculation involves the summation of intra- and inter-molecular forces between all pairs of atoms in the system and can be accomplished in real-time (20 updates/sec.) using the MP-1.

We implemented two different volume rendering algorithms on the machine to perform a full computation incorporating arbitrary viewing position and illumination on a 256 x 256 x 256 voxel data set in a few seconds. Experiments with polygon-rendering algorithms were also undertaken using Z-buffer, ray-tracing, and radiosity methods. We also compared a number of radiosity algorithms on the MP-1.

This fall visiting professor William Hightower is investigating a number of molecular dynamics simulation algorithms on the MP-1.

MasPar MP-1:

Extensive use of the machine has made it clear that, to expand the class of applications for which the machine can offer greatly superior or real-time performance, a very fast sequential machine front-end and high-speed I/O to the parallel portion of the machine are critical. During the last year we have upgraded our MasPar MP-1 to incorporate high-speed parallel-I/O capabilities. A 4-disk parallel disk array is the first device to use the new facilities. The equipment to interface to a DS5000/200 front-end has been ordered but not yet delivered. One of the objectives for the MP-1 is to interface it via Hippi to Pxpl5 as a way to compute and render dynamic systems in real-time.

SoftLab

SoftLab Software Systems Laboratory is an infrastructure organization that provides the UNC Computer Science Department with software systems and software packaging and distribution services analogous to those typically found in industry. As such, SoftLab serves as a software development resource for the Department and an agent of technology transfer to other universities and to industry.

SoftLab supports the rapid prototyping of experimental VLSI architectures and distributed systems by developing simulators, drivers, compilers, interfaces, and communications software. During this reporting period, SoftLab completed a microcode preprocessor for the Intel i860 chip. This tool facilitates hand optimization of i860 assembler programs and is heavily used by Pixel-Planes 5 software developers to code graphics applications programs that require high-speed performance.

The i860 preprocessor was developed by reuse of components belonging to a similar preprocessor for the Weitek XL chip implemented earlier by SoftLab and the Pixel-Planes 4 research team. The use of IDL (Interface Description Language), a programming environment for rapid prototyping of compilers designed by Prof. Richard Snodgrass and formerly distributed by SoftLab, facilitated reuse of these components. In addition, SoftLab also developed a preliminary version of a C optimizer for the i860. Other prototyping support tool work during the reporting period included enhancements to our architectural simulator that allow simulation of C program execution.

As part of SoftLab's research software support efforts, we are porting the graphical user interface for RSpace, an interactive program designed to help crystallographers plan data-collection strategies when using diffractometers equipped with area detectors. The current version of RSpace, in use at about 50 foreign and domestic research sites, requires an Evans and Sutherland PS300 for its graphical display. We are porting this interface to the X Window System

in order to extend the user base of this popular research tool developed in 1988 by Department graduate student Mark Harris.

Special emphasis has been placed on software capitalization activities during the past year. We have continued to enhance our software manufacturing and distribution process. In particular, we have developed a preliminary version of an efficient and cost-effective methodology for releasing updates of dynamic products.

We are currently testing this methodology on the next release of COOL, a C++ library for computer vision research developed by Prof. James Coggins. In addition, we have designed new build scripts that allow us to generate executables for various hardware platforms from common source and makefile templates. We are testing these scripts by using them to package Image, a medical image processing software library developed by Prof. Stephen Pizer's research group. Finally, we are investigating techniques that would allow us to compile various components of Image (or any other large software system) in parallel.

SECTION 3: Lists of publications, presentations, reports, awards/honors/prizes during this reporting period

Principal Investigators:	Frederick P. Brooks, Jr. Donald F. Stanat Stephen F. Weiss
PI Institution:	The University of North Carolina at Chapel Hill Department of Computer Science
PI Phone Numbers:	919/962-1931 919/962-1788 919/962-1888
PI E-mail Addresses:	brooks@cs.unc.edu stanat@cs.unc.edu weiss@cs.unc.edu

Contract Title:	The Infrastructure of Command Information Systems
Contract Number:	N00014-86-K-0680
Reporting Period:	15 September 1990 through 30 September 1991

With * ..... ONR-supported.
Without * ..... Related to the project.

A. Refereed papers (to appear)

Guan, Sheng-Uei, Hussein Abdel-Wahab, and Peter Calingaert. "Jointly-Owned Objects for Collaboration: Operating-System Support and Protection Model," to appear in *The Journal of Systems and Software*, 1991.

Lansman, Marcy, John B. Smith, and Irene Weber. "Using Computer-Generated Protocols to Study Writers' Planning Strategies," accepted subject to revision in *Computers and Composition*. (See also Part E.)

*Mills, P., L. Nyland, J. Prins, J. Reif, and R. Wagner. "Prototyping Parallel and Distributed Applications in Proteus," to appear in *IEEE Symposium on Parallel and Distributed Processing*, Dallas, TX, Dec. 1-5 (see TR90-041 under Part E.)

*Neumann, Ulrich, Terry S. Yoo, Henry Fuchs, Stephen M. Pizer, Tim Cullip, John Rhoades, and Ross Whitaker. "Achieving Direct Volume Visualization with Interactive Semantic Region Selection," to appear in *Proc. IEEE Visualization '91*, San Diego, CA, Oct. 1991 (See TR91-012 under Part E.)

*Robinett, Warren and Jannick P. Rolland. "A Computational Model for the Stereoscopic Optics of a Head-Mounted Display," *Proc. SPIE Symposium on Electronic Imaging*, 1457 (Stereoscopic Displays and Applications), San Jose, CA, 16 Feb. 1991; also to appear in first issue of *PRESENCE*, Jan. 1992. (See TR91-009 under Part E.)

B. Refereed papers published

Davis, R. E., M. Levoy, J. G. Rosenman, H. Fuchs, S. M. Pizer, A. Skinner, and H. C. Pillsbury. "Three-Dimensional High-Resolution Volume Rendering (HRVR) of Computed Tomography Data: Applications to Otolaryngology—Head and Neck Surgery," *Laryngoscope*, 101(6), June 1991.

Jeffay, K., and Smith, F. D. "System Design for Workstation-Based Conferencing with Digital Audio and Video," *Proc. TriComm '91: IEEE Conference on Communications Software*, Chapel Hill, NC, April 1991.

Ohbuchi, Ryutarou, and Henry Fuchs. "Incremental Volume Rendering Algorithm for Interactive 3D Ultrasound Imaging," *Proc. Information Processing in Medical Imaging XII*, 1991. (See TR91-003 under Part E.)

*Prins, J. "A Framework for Efficient Execution of Array-based Languages on SIMD Computers," *Proc. 3rd Symposium on the Frontiers of Massively Parallel Processing*, IEEE 1990.

*Prins, J., and J. Smith. "Parallel Sorting of Large Arrays on the MasPar MP-1," *Proc. 3rd Symposium on the Frontiers of Massively Parallel Processing*, IEEE 1990.

Turk, Greg. "Generating Textures on Arbitrary Surfaces Using Reaction-Diffusion," *Computer Graphics: Proc. SIGGRAPH '91*, 25 (4), July 1991, 289-298.

C. Refereed exhibitions

The UNC Computer Science Department provided a major exhibit in the "Tomorrow's Realities" Gallery at the SIGGRAPH '91 Conference, Las Vegas, NV, 28 July-2 August, 1991. Demonstrations included:

A. Pixel-Planes 5 three rack system.

B. 10' x 12' Optical "Ceiling" Tracker.

C. 3dm—A Two-Person Modeling System.

D. Interactive Building Walkthrough Using a Steerable Treadmill.

E. Interactive Building Walkthrough Using the Optical Tracker.

F. Flying Through Molecules.

G. A Mountain Bike with Force Feedback Pedals.

H. Radiation Therapy Treatment Planning.

I. Virtual Pilot.

D. Refereed papers submitted (awaiting acceptance)

Banks, David. "Interactive Manipulation and Display of Surfaces in Four Dimensions," submitted to *1992 Symposium on Interactive 3D Graphics*, Cambridge, MA, 29 March–1 April 1992.

Butterworth, Jeff, Andrew Davidson, Stephen Hench, and T. Marc Olano. "3DM: A Three Dimensional Modeler Using a Head-Mounted Display," submitted to *1992 Symposium on Interactive 3D Graphics*, Cambridge, MA, 29 March–1 April 1992.

Chung, James C. "A Comparison of Head-Tracked and Non-Head-Tracked Steering Modes in the Targeting of Radiotherapy Treatment Beams," submitted to *1992 Symposium on Interactive 3D Graphics*, Cambridge, MA, 29 March–1 April 1992.

Jeffay, Kevin. "Scheduling Sporadic Tasks with Shared Resources in Hard-Real-Time Systems," TR90-039, Department of Computer Science, UNC at Chapel Hill, Nov. 1990. (See also Part E.)

Neumann, Ulrich. "Interactive Volume Rendering on a Multicomputer," submitted to *1992 Symposium on Interactive 3D Graphics*, Cambridge, MA, 29 March–1 April 1992.

Rhoades, John, Greg Turk, Andrew Bell, Andrei State, Ulrich Neumann, and Amitabh Varshney. "Real-Time Procedural Textures," submitted to *1992 Symposium on Interactive 3D Graphics*, Cambridge, MA, 29 March–1 April 1992.

Robinett, Warren, and Richard Holloway. "Implementation of Flying, Scaling and Grabbing in Virtual Reality," submitted to *1992 Symposium on Interactive 3D Graphics*, Cambridge, MA, 29 March–1 April 1992.

Smith , John. B., and Dana K. Smith. "Automated Protocol Analysis," submitted to *Human-Computer Interaction.*, TR91-034, Department of Computer Science, UNC at Chapel Hill, Aug. 1991. (See also Part E.)

Surles, Mark C. "Interactive Modeling Enhanced with Constraints and Physics—with Applications in Molecular Modeling," submitted to *1992 Symposium on Interactive 3D Graphics*, Cambridge, MA, 29 March–1 April 1992.

Ward, Mark, Ronald Azuma, Robert Bennett, Stefan Gottschalk, and Henry Fuchs. "A Demonstrated Optical Tracker with Scalable Work Area for Head-Mounted Display Systems," submitted to *1992 Symposium on Interactive 3D Graphics*, Cambridge, MA, 29 March–1 April 1992.

E. Unrefereed reports and articles

Brooks, Frederick P., Jr., and William V. Wright. "Seventeenth Annual Progress Report and 1992-97 Renewal Proposal—Interactive Graphics for Molecular Studies," TR91-020, Department of Computer Science, UNC at Chapel Hill, Jan. 1991.

*Eyles, John G. "Virtual-Environment Research at the University of North Carolina," abstract in *Proc. AUSGRAPH '90*, Melbourne, Australia, 10-14 Sept. 1990.

*Gauch, Susan and John B. Smith. "Search Improvement via Automatic Query Reformulation," TR91-010, Department of Computer Science, UNC at Chapel Hill, Feb. 1991.

*Hawkes, Richard M. "Mathematical Basis for a System to Manage Automated Protocol Analysis," TR91-024, Department of Computer Science, UNC at Chapel Hill, April 1991.

*Holloway, Richard L. "Art-Related Virtual Reality Applications at the University of North Carolina at Chapel Hill," *Proc. 2nd International Symposium on Electronic Art*, Groningen, Holland, 12-16 Nov. 1990.

Jeffay, Kevin. "Scheduling Sporadic Tasks with Shared Resources in Hard-Real-Time Systems," TR90-039, Department of Computer Science, UNC at Chapel Hill, Nov. 1990.

Jeffay, K. and Smith, F. D. "Designing a Workstation-Based Conferencing System Using the Real-Time Producer/Consumer Paradigm," *Proc. 1st International Workshop on Network and Operating System Support for Digital Audio and Video*, Berkeley, CA, Nov. 1990. (Also TR90-040.)

Lansman, Marcy. "Organize First or Write First? A Comparison of Alternative Writing Strategies," TR91-014, Department of Computer Science, UNC at Chapel Hill, Feb. 1991.

*Menges, John. "Providing Common Access Mechanisms for Dissimilar Network Interconnection Nodes," TR91-013, Department of Computer Science, UNC at Chapel Hill, March 1991 (M.S. thesis).

*Mills, P., L. Nyland, J. Prins, J. Reif, and R. Wagner. "Prototyping Parallel and Distributed Applications in Proteus," TR90-041, Department of Computer Science, UNC at Chapel Hill, Nov. 1990.

Molnar, Steven. "Efficient Supersampling Antialiasing for High-Performance Architectures," TR91-023, Department of Computer Science, UNC at Chapel Hill, April 1991.

*Neumann, Ulrich. "Taxonomy and Algorithms for Volume Rendering on Multicomputers," TR91-015, Department of Computer Science, UNC at Chapel Hill, Feb. 1991.

*Neumann, Ulrich, Terry S. Yoo, Henry Fuchs, Stephen M. Pizer, Tim Cullip, John Rhoades, and Ross Whitaker. "Achieving Direct Volume Visualization with Interactive Semantic Region Selection," TR91-012, Department of Computer Science, UNC at Chapel Hill, Feb. 1991.

Ohbuchi, Ryutarou, and Henry Fuchs. "Incremental Volume Rendering Algorithm for Interactive 3D Ultrasound Imaging," TR91-003, Department of Computer Science, UNC at Chapel Hill, 1991.

*Prins, J. "MP-1 Applications at UNC Chapel Hill," *MasPar News*, 1(2), March 1991.

*Prins, J. "Efficient Bitonic Sorting of Large Arrays on the MasPar, MP-1," TR91-041, Department of Computer Science, UNC at Chapel Hill, 1991.

*Prins, J. "Work-Efficient Techniques for the Highly-Parallel Execution of Sparse Grid-Based Computations," TR91-042, Department of Computer Science, UNC at Chapel Hill, 1991.

*Robinett, Warren and Jannick P. Rolland. "A Computational Model for the Stereoscopic Optics of a Head-Mounted Display," TR91-009, Department of Computer Science, UNC at Chapel Hill, 1991. (See also Part A.)

Robinett, Warren. "Electronic Expansion of Human Perception," to appear in Fall 1991 issue of *Whole Earth Review* Magazine.

*Shackelford, Douglas E., John B. Smith, Joan Boone, and Barry Elledge. "The UNC Graph Server: A Distributed Hypermedia Data Management System," TR91-019, Department of Computer Science, UNC at Chapel Hill, April 1991.

Smith, John B., Dana K. Smith, Eileen Kupstas, and Peter Calingaert. "Visualization of Computer Users' Cognitive Strategies and Behaviors," to appear in *Proc. International Symposium on Visual Analysis and Interface*, 1-4 Aug. 1991, Novosibirsk, USSR.

*Smith, John B., Dana K. Smith, and Eileen Kupstas. "Automated Protocol Analysis: Tools and Methodology," TR91-034, Department of Computer Science, UNC at Chapel Hill, Aug. 1991.

*Smith, John B., and F. D. Smith. "ABC: A Hypermedia System for Artifact-Based Collaboration," TR91-021, Department of Computer Science, UNC at Chapel Hill, April 1991.

*Smith, John B., F. D. Smith, Peter Calingaert, John R. Hayes, Dorothy Holland, Kevin Jeffay, and Marcy Lansman. "UNC Collaboratory Project: Overview," TR90-042, Department of Computer Science, UNC at Chapel Hill, Nov. 1990.

F. Books (or parts thereof) published (and to appear)

*Biagioni, E., and J. Prins. "Scan-Directed Load Balancing for Mesh-connected Highly-Parallel Computers," to appear in *Unstructured Scientific Computation on Scalable Multiprocessors*, MIT Press, 1991.

Plaisted, David A. and Shie-Jue Lee. "Inference by Clause Matching," *Intelligent Systems*, Z. Ras and M. Zemankova, eds., Ellis Horwood, 1990.

Plaisted, David. "Mechanical Theorem Proving," *Formal Techniques in Artificial Intelligence: A Sourcebook*, R. Banerji, ed., Elsevier, Amsterdam, 1990.

G. Videotapes

*Brooks, Frederick P. Jr. Interview videotaped and excerpted, with illustrations from Walkthrough demonstrations, in the SIGGRAPH Video Review, Vol. 60, Aug. 1990 (available from ACM under the title "HDTV and the Quest for Virtual Reality," *ACM SIGGRAPH Video Review*, Special Issue 60, 1990).

Yen-Ping, Shan. 1. Sample Interface Built with MoDE. 2. MoDE In Use. Department of Computer Science, UNC at Chapel Hill, 1990.

*1991 SIGGRAPH videotapes (SIGGRAPH '91, Las Vegas, NV, 1991:
- "Head-Mounted Display Research at UNC Chapel Hill," 52 minutes, July 1991.
- Robinett, Warren. "Concrete Portrayal of Mathematical Abstraction Using Computer Graphics, 10 minutes, July 1991.

Videotape accompanying proposal for UNC exhibit in the Virtual Reality Applications Gallery at SIGGRAPH '91, 30 minutes, Jan. 1991.

H. Invited presentations

Pixel-Planes 5

Eyles, John. "Virtual Worlds at the University of North Carolina at Chapel Hill," Im Cyberspace Conference, Munich, Germany, April 11-13, 1991.

Fuchs, Henry. "Computer Graphics and Visualization Technology," NCI workshop on Imaging—Guided Stereotactic Tumor Diagnosis and Treatment, Bethesda, MD, May 16-17, 1991.

Poulton, John. "Building Microelectronic Systems in a University Environment," 1991 Conference on Advanced Research in VLSI, UC–Santa Cruz, March 25-27, 1991.

Walkthrough

Brooks, Frederick P. "Virtual Worlds Research at the University of North Carolina at Chapel Hill," Senate Subcommittee on Science & Technology & Space, Washington, D.C., May 8, 1991.

Head-Mounted Display

Holloway, Richard. "Virtual Reality and Art," 2nd Intl. Symposium on Electronic Art, Groningen, Holland, Nov. 12-16, 1990.

Robinett, Warren. "Concrete Portrayal of Mathematical Abstraction Using Computer Graphics," SIGGRAPH '91 Panel on Computer Graphics in Education: "Doing With Images Makes Symbols," Las Vegas, NV, Aug. 1991.

Robinett, Warren. "Expansion of Human Perception," SRI Conference on Virtual Reality, Menlo Park, CA, June 1991.

Robinett, Warren. "Virtual Reality for Education," Intl. Conference on Education and Technology, Toronto, Canada, May 1991.

Robinett, Warren, "Synthetic Experience," Symposium on Virtual Reality, Museo Fortuny, Venice, Italy, Nov. 1990.

Robinett, Warren. "Synthetic Experience," Cyberthon (24-hour conference and exhibition on Virtual Reality), San Francisco, CA, Oct 1990.

Robinett, Warren. "The Head-Mounted Display Project," Compufest computer fair, UNC–Chapel Hill, NC, Sept.1990.

Rolland, Jannick. "Insight into Optical Properties of Wide-Angle See-Through Head-Mounted Display," SRI, June 1991.

Rolland, Jannick. "Project Grope: Haptic Displays for Scientific Visualization," IMAGINA 1991 Conference, Monte Carlo, Monaco, Feb. 1991.

Rolland, Jannick. "Synthetic Experience in Virtual Worlds," IMAGINA 1991 Conference, Monte Carlo, Monaco, Feb. 1991.

Tracker

Eyles, John. "Virtual Worlds at the University of North Carolina at Chapel Hill," Im Cyberspace Conference, Munich, Germany, April 11-13, 1991.

Fuchs, Henry. "Computer Graphics and Visualization Technology," NCI workshop on Imaging—Guided Stereotactic Tumor Diagnosis and Treatment, Bethesda, MD, May 16-17, 1991.

Artifact-Based Collaboration

Calingaert, Peter. "Visualization of Computer Users' Cognitive Strategies and Behaviors," Intl. Symposium on Visual Analysis and Interface, Novosibirsk, USSR, 1-3 Aug. 1991.

Jeffay, Kevin. "The Real-Time Producer/Consumer Paradigm: Towards Verifiable Real-Time Computations," Carnegie-Mellon U., Pittsburgh, PA, March 1991.

Jeffay, Kevin. "Systems Research in the UNC Collaboration Project," U. of Colorado, Boulder, CO, March 1991.

Smith, John. "The Social Creation of Knowledge: Multimedia and Information Technologies in the University," *MIT Writing Program*, Cambridge, MA, April 5-7, 1991.

Data-Parallel Execution

Prins, J. F. "Application Development for the MasPar MP-1," Massively Parallel Processing Seminar Series, North Carolina Supercomputer Center (broadcast to statewide CONCERT video locations), 2 April 1991.

Prins, J. F. "Derivation of Efficient Bitonic Sorting Implementations," *ONR Workshop on the Derivation of Parallel Algorithms and Program Transformation*, New York, NY, Aug. 30–Sep. 2, 1991.

I. Contributed presentations

Pixel-Planes 5

Fuchs, Henry. "Scientific Visualization on Advanced Architectures," panel presentation at SIGGRAPH '91, Las Vegas, Nevada, July 28-August 2, 1991.

Ohbuchi, Ryutarou. "Incremental Volume Rendering Algorithm for Interactive 3D Ultrasound Imaging," Information Processing in Medical Imaging XII, Wye, England, July 1991.

Turk, Greg. "Generating Textures on Arbitrary Surfaces Using Reaction-Diffusion," SIGGRAPH '91, July 1991.

Yoo, Terry. "Achieving Direct Volume Visualization with Interactive Semantic Region Selection," IEEE Visualization '91, San Diego, Calif., Oct. 1991.

Head-Mounted Display

Robinett, Warren. "A Computational Model For the Stereoscopic Optics of a Head-Mounted Display," SPIE Conference on Electronic Imaging, Santa Clara, CA, Feb 1991.

Tracker

Fuchs, Henry. "Scientific Visualization on Advanced Architectures," panel presentation at SIGGRAPH '91, Las Vegas, NV, July 28–August 2, 1991. (also HMD)

Artifact-Based Collaboration

Jeffay, Kevin. "Efficient Kernel Support for Continuous Time Media Systems," ITC Workshop on Continuous Time Media, Carnegie-Mellon U., Pittsburgh, PA, June 1991.

Jeffay, Kevin. "YARTOS: Kernel Support for Efficient, Predictable Real-Time Systems," Joint IEEE/IFAC Workshop on Real-Time Operating Systems and Software, Atlanta, GA, May 1991.

Jeffay, Kevin. "System Design for Workstation-Based Conferencing With Digital Audio and Video," IEEE Conference on Communications Software: Communications for Distributed Applications and Systems, Chapel Hill, NC, April 1991.

Jeffay, Kevin. "Designing a Workstation-Based Conferencing System Using the Real-Time Producer/Consumer Paradigm," 1st Intl. Workshop on Network and Operating System Support for Digital Audio and Video, Intl. Computer Science Institute, Berkeley, CA, Nov. 1990.

Lansman, Marcy. "Organize First or Write First? A Comparison of Alternative Writing Strategies," Penn. State Conference on Rhetoric and Composition, July 10-13, 1991.

Smith, John. 1991 BRG C(2) Research Symposium, National Defense University, Ft. McNair, Washington, DC, June 24-25, 1991.

SECTION 4: Transitions and DoD Interactions during this reporting period *(by project)*

Principal Investigators:	Frederick P. Brooks, Jr. Donald F. Stanat Stephen F. Weiss
PI Institution:	The University of North Carolina at Chapel Hill Department of Computer Science
PI Phone Numbers:	919/962-1931 919/962-1788 919/962-1888
PI E-mail Addresses:	brooks@cs.unc.edu stanat@cs.unc.edu weiss@cs.unc.edu

Contract Title:	The Infrastructure of Command Information Systems
Contract Number:	N00014-86-K-0680
Reporting Period:	15 September 1990 through 30 September 1991

A. Transitions of Results and DoD Interactions

Pixel-Planes 5

In conjunction with four other institutions (Brown University, California Institute of Technology, Cornell University, and University of Utah), we received a grant from the National Science Foundation to create a Science and Technology Center in Computer Graphics and Scientific Visualization. Collaboration with researchers at these four institutions has now begun. We anticipate that the earliest results relating to Pixel-Planes will be more rapid interaction with global lighting effects. This is a result of collaboration with our Cornell colleagues, who have pioneered these "radiosity" lighting techniques.

Groups from ABC-TV's PrimeTime Live, WGBH-TV, and a Japanese public television station have filmed in our graphics lab for their programs. The PrimeTime segment on virtual reality was broadcast September 19, 1991. The Nova series on WGBH, called "The Information Age" will be broadcast in the spring of 1992; this is a series of six one-hour segments, one of which will deal with virtual reality. Another show for WGBH-TV is currently scheduled to be broadcast in early 1992. This series, with the working title "Making It in the USA," consists of four one-hour segments; footage dealing with our research will be in the segment that currently has the working title, "On the Road Again."

A joint meeting of principal investigators on DARPA/ISTO funded projects in the Microsystems and Architectures interest groups was held at UNC–Chapel Hill, October 3-5, 1990. Approximately 150 people (including five DARPA program managers and the director of ISTO) attended the meeting. Although each interest group holds meetings semiannually, joint meetings of two interest groups occur only once every several years. Thirty universities and twenty-five industrial groups from all over the U.S. were represented at the meeting. The sharing of ideas occurred in both paper and demo sessions. Meeting attendees were given the opportunity to see several demonstrations in the UNC Graphics and Image Lab. In addition, ten universities and companies brought demos with them, which were shown on workstations in our Department.

In response to a very large number of requests to visit our facility, we now hold a monthly visit day in our graphics and image lab, and we average 60–100 visitors on each of these days. The types of people wishing to visit our lab are varied and include computer science professionals; chemists, physicists, and other scientists; engineers; architects; physicians; journalists; educators; school groups; UNC administrators trying to understand more about our projects; etc. We still host special visitors at other times. For a sample of the visitors to our graphics lab during the last fiscal year, please see the section below entitled "All Graphics Projects."

Walkthrough

Please see the section below entitled "All Graphics Projects."

Head-Mounted Display

Please see the section below entitled "All Graphics Projects."

Tracker

Please see the section below entitled "All Graphics Projects."

All Graphics Projects

Senator Al Gore
Toki Takahashi, NTT, Japan
Wally Hannum, UNC School of Education
Frank Biocca, UNC School of Journalism
John Toole, DARPA
Dean of East Carolina University, Greenville, NC
Group of 5 from SAS Institute, Cary, NC
Group of 25 North Carolina High School Chemistry Teachers
David Beaver, Information Network, Raleigh, NC
Randall Shumaker and Dale Long, Naval Research Lab
Bruce Phillips, NC Museum of Life and Science
About 15 Engineering Students who were summer fellows at the Duke Engineering Research Center in Advancing Cardiovascular Technologies
Richard Clinch, North Carolina Board of Science and Technology
About 30 members of the UNC Chancellor's Club
Chief Academic Officers from about 30 East Coast Universities
Laurent Belsie, journalist from *Christian Science Monitor*
Group of 6 from Digital Equipment Corporation
Vic Reis, Director of DARPA
Deputy Director of DARPA
Around 30 people attending a DARPA contractor's meeting on prototyping, held at UNC, May 1991
Group of 25-30 college juniors participating in a program for future teachers in NC (sponsored by the governor's office)
About 125 attendees of the Molecular Graphics Society International meeting, May 1991
Capt. Stark and Gloria Golden, Fort Huachuca, Arizona
Group of 10 from Virginia Tech, Blacksburg, VA
Group of 3 from the VA Hospital Medical Education Center, Durham, NC
Charles Grimsdale & Phil Atkins, Division Ltd., Bristol, UK
23 Students from the PreCollege Program sponsored by the UNC Math and Science Education Network
Ivan Sutherland & Robert Sproull, Sun Microsystems
Group of 3 from IVEX Corp.
Group of 4 from IBM, Research Triangle Park, NC
Group of 3 from Wright-Patterson Air Force Base
Group of 2 from Duke University School of Medicine
Class on Human–Machine Interface, UNC School of Information and Library Science (About 20 graduate students)
Class on Research Methods, UNC School of Information and Library Science (About 13 graduate students)
Architecture Class, Guilford College, Greensboro, NC (About 25 undergraduates)
Deanna Tebockhorst, Science Specialist, Frank Porter Graham School, Chapel Hill, NC
Eugene Bylinsky, journalist from *Fortune* Magazine
Group of 6 from the National Center for Supercomputing Applications
Group of 4 from the Math & Science Center, Richmond, VA
Bob Andron, architect
Robert Beck, Imaging Science Group, Univ. of Chicago

J. Honors

Edoardo Biagioni and David Ellsworth were again named ONR fellows during FY90-91.

Frederick P. Brooks, Jr. elected Foreign Member of Royal Netherlands Academy of Arts and Sciences (Science Division), April 29, 1991.

Henry Fuchs served on the Papers Committee for SIGGRAPH '91.

Kevin Jeffay served on the program committees for the IEEE Conference on Communication Software: Communications for Distributed Applications and Systems, Chapel Hill, NC, April 1991 and will serve on the program committee for the 12th IEEE Symposium on Real-Time Systems, San Antonio, TX, December 1991.

Steven Molnar and Greg Turk were once again granted IBM graduate student fellowships during this academic year.

Don Smith served as program chair for TriComm '91, the IEEE Conference on Communications Software, UNC–Chapel Hill, NC, April 17-19, 1991.

K. Prizes or awards

None during this reporting period.

L. Promotions obtained

None during this reporting period.

M. Educational productivity

Please see Section 1 and Appendix II.

Mark Cutter and Pete Litwinowicz, Apple Computer
Glen Emory, Insight Magazine
Jaroslav Folda, UNC Art Department
R. Kikinis and F. Jolesz, Brigham & Women's Hospital, Boston, MA
Tom Kominski, Astronautics
Edouard Launet, journalist from *Les Echos*, Paris, France
P. Meenan, B. Lorensen, N. Corby, A. Chin, GE Research & Development, Schenectady, NY
Tatsuo Miyazawa, IBM Tokyo Research Lab
M. Moshseghia and B. Zhu, Philips Medical Research, Briarcliff, NY
Larry Yaeger, Apple Computer, Vivarium Project
Group of 4 from Armed Forces Institute of Pathology
About 150 attendees of the DARPA Fall '90 Joint Meeting of PIs in the Microsystems and Architectures Interest Groups
Two from Disney Imagineering
Industrial Sponsors of the Duke Engineering Research Center in Advancing Cardiovascular Technologies
Gifted and Talented 6th graders, Glenwood School, Chapel Hill, NC (About 30 students and 3 teachers)
IBM Science Advisory Committee
About 12 NC State Univ. computer science undergraduates
Group of 4 from Rensselaer Polytechnic Institute
Group of 2 from UNC Physics Department
Group of 3 from UNC Department of Neurology
Group of 2 from SAIC
Max Donath, Director of Robotics and Human Motions Labs at the University of Minnesota
32 juniors and seniors from East Rowan High School, Salisbury, NC
36 mechanical engineering students from North Carolina State University
Randall Shumaker and Dale Long, NRL, visited on 28 June 1991. Saw the following demos: Pixel-Planes 5, ARM, Head-Mounted Display, Walkthrough with treadmill. Also met with Bill Wright (ARM), and John Smith and his Collaboratory project team.

Artifact-Based Collaboration

NRL Lab, Washington, DC
Jim Gray and Ronnie Sarkar, IBM SNA Studies Group
ONR site visitors, Executive Committee, and investigators
Walter Kintsch, U. of Colorado
Stephen Poltrock, Boeing
See "All Graphics projects" above (Shumaker and Long)

SoftLab

Products distributed by SoftLab during this reporting year:
(These numbers reflect only distributions made between September 1990 and August 1991. This list includes only SoftLab products for which there was distribution activity during this reporting period.)

Volume Rendering Data Sets (numbers for Volumes I and II combined)

The Volume Rendering Data Sets Volume I and II contain medical and other images as shown at the 1990 Volume Visualization Workshop. These are the first items in a planned "visual data set" product line.

13 academic distributions

24 commercial distributions

COOL 1.0

COOL is a software library developed by James Coggins. COOL, written in the object oriented language C++, contains class definitions relevant to research in computer vision, image pattern recognition, and computer graphics. We are currently working on the packaging of COOL 2.0.

6 commercial distributions

RSpace 1.3

RSpace is an interactive program developed in the Computer Science Department by Mark Harris in 1988 which is designed to help crystallographers plan data collection strategies when using diffractometers equipped with area detectors. SoftLab is currently developing RSpace 2.0, which will include some significant new user interface features. These are expected to broaden the RSpace customer base further.

6 academic distributions

1 commercial distribution

All projects:

ONR site visit team members, Sept. 1990.

SECTION 5: Software and Hardware Prototypes during this reporting period *(by project)*

Principal Investigators:	Frederick P. Brooks, Jr. Donald F. Stanat Stephen F. Weiss
PI Institution:	The University of North Carolina at Chapel Hill Department of Computer Science
PI Phone Numbers:	919/962-1931 919/962-1788 919/962-1888
PI E-mail Addresses:	brooks@cs.unc.edu stanat@cs.unc.edu weiss@cs.unc.edu

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Pixel-Planes 5

Hardware Prototypes—We have designed and built the Pixel-Planes 5 graphics system, a high-performance, scalable multicomputer for 3D graphics. Its main components include: **Graphics Processors**—general-purpose, math-oriented processors that carry out geometric transformations and other calculations; **Renderers**—fine-grain, massively parallel arrays of processors based on custom, logic-enhanced memory chips, that perform most pixel-oriented calculations in parallel over many pixels; and a **Ring Network** that moves data and control messages between system components at high speed. The machine rapidly renders polygonal images with advanced lighting models and textures, directly renders spheres (and other quadratic surfaces) as well as objects described by constructive solid geometry (CSG), performs near real-time rendering of volume data sets modelled as transparent gels, and executes a variety of image-processing algorithms. It is modular and can be configured in a variety of ways to trade cost for performance. Programming tools and graphics libraries allow applications developed in the C programming language to utilize nearly the full performance of the machine; microcoding tools are available for critical inner loops, where the user needs the highest performance. Existing applications that use the PHIGS+ standard for 3D graphics can readily be ported to the system. A fully-loaded system with about 40–50 Graphics Processors and 20 Renderers can produce Phong-shaded, z-buffered polygons at rates well in excess of 1 million triangles per second.

Commercialization—During the past year we have granted a limited license of our two patents on Pixel-Planes technology to IVEX Corporation (Norcross, Georgia) for use in vehicle and flight simulation and training. One of our former senior staff members, Trey Greer, joined IVEX's staff and now develops algorithms (that remain in the public domain) for future IVEX products based on our technology.

In February 1992, IVEX plans to ship the first product incorporating the Pixel-Planes technology. These are enhancements to current products—visual systems for flight simulators. IVEX expects FAA Phase 2 certification, based in part on the anti-aliased, polygon-generation capabilities provided by the Pixel-Planes technology.

Tracker

A tracker with a large working volume (10' x 12") has been demonstrated. It features thirty ceiling panels suspended from a free-standing ceiling structure, a headset that couples four image sensors to a VPL EyePhone, and an interface to the Pixel-Planes 5 host processor. The tracking system can resolve head motions as small as 2 mm in

translation and .2° in rotation. Its update rate is 20–100 Hz, and the lag in a given measurement ranges from 20–100 ms.

Artifact-Based Collaboration

Suite of tools for working with machine-recorded protocols

Prototype ATN grammar development environment

Data-Parallel Execution

The large-array sorting and routing facilities developed here for the MP-1 are being used by MasPar in applications and for demonstrations. These packages will be placed in the MasPar user's group repository.

SoftLab

MAST860

Mast860 is a microcode preprocessor for the Intel i860 floating point chip. It facilitates hand optimization of i860 assembler by automating register allocation and other machine details and by performing pipeline analysis. Mast860 is currently used by Pixel-Planes 5 applications programmers who code in hand optimized assembler for performance reasons. We have advertised this prototype on various bulletin boards and have also sent a preliminary copy to Intel for review. Future commercialization is a possibility.

Unix-Phone Switch Interface and Applications

Last year, SoftLab implemented a UNIX driver that allows telephone switch functions such as phone calls and networking operations to be controlled from Department workstations. This driver communicates with our InteCom switch via the InteCom Open Applications Interface (OAI) feature on the switch. This driver software was made available to InteCom, which is starting up a UNIX application development effort. In addition, we also implemented two UNIX applications on top of the driver software. The first was a voice mail application that stored and manipulated voice messages as UNIX files, and the second was a power dialer that allowed phone calls to be placed by UNIX workstation commands using online databases of numbers and speed-calling lists. This work was an initial step in setting up an integrated voice and electronic messaging system that would form a test bed for Department research in distributed computing. InteCom included a description of our applications in its advertising literature, and we have been contacted by DataTrac, Inc. about a possible joint venture for further application development.

ANNUAL SUMMARY

15 September 1989 through 14 September 1990

Y4

The Infrastructure of Command Information Systems

Submitted to

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Arlington, VA 22217-5000

Submitted by

Department of Computer Science
The University of North Carolina at Chapel Hill
Sitterson Hall
Chapel Hill, NC 27599-3175

Principal Investigators:

Frederick P. Brooks, Jr.
Donald F. Stanat
Stephen F. Weiss

October 1990

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CONTENTS

SECTION 1: Productivity Measures during this Reporting Period 1

SECTION 2: Detailed Summary of Technical Progress during this Reporting Period (by project) 2

Pixel-Planes 5 2

Walkthrough 3

Head-Mounted Display 4

Tracker 5

Protocol Analysis Tools 8

SoftLab 8

SECTION 3: Lists of Publications, Presentations, Reports, Awards, and Honors during this Reporting Period 10

A. Refereed papers (to appear) 10
B. Refereed papers published 10
C. Refereed papers submitted (awaiting acceptance) 11
D. Unrefereed reports and articles 11
E. Books (or parts thereof) published 13
F. Invited presentations 13
G. Contributed presentations 14
H. Honors 15
I. Prizes or awards 15
J. Promotions obtained / New staff 15
K. Educational productivity 15

SECTION 4: Transitions and DoD Interactions during this Reporting Period (by project) 17

A. Transitions of Results 17
B. DoD Interactions 19

SECTION 5: Software and Hardware Prototypes during this Reporting Period (by project) 21

APPENDICES

- Personnel by Project
- Research Assistants since FY86-87
- Trip/Visit Reports
- Outside Funding Received during FY89-90
- Agenda: ONR Site Visit, 25-26 September 1990
- Comprehensive Bibliography

ANNUAL REPORT for FY89-90

SECTION 1: Productivity Measures during this reporting period

Principal Investigators:	Frederick P. Brooks, Jr. Donald F. Stanat Stephen F. Weiss
PI Institution:	The University of North Carolina at Chapel Hill Department of Computer Science
PI Phone Numbers:	919/962-1931 919/962-1788 919/962-1888
PI E-mail Addresses:	brooks@cs.unc.edu stanat@cs.unc.edu weiss@cs.unc.edu

			ONR supported	Related
1.1	Refereed papers submitted (*to appear*)		0	2
1.2	Refereed papers published		10	4
1.3	Refereed papers submitted (awaiting acceptance)		1	2
1.4	Unrefereed reports and articles		4	14
1.5	Books (or parts thereof) published		0	1
1.6	Books (or parts thereof) submitted (*to appear*)		0	0
1.7	Patents filed but not yet granted		0	1
1.8	Patents granted		0	0

		Supported or Related
1.9	Invited presentations	13
1.10	Contributed presentations	11
1.11	Honors received	11
1.12	Prizes or awards received	1
1.13	Promotions obtained	0
1.14	Educational productivity (degrees received)	10
1.15	Graduate students supported $\geq$ 25% of full time	22
1.16	Post-docs supported $\geq$ 25% of full time	0
1.17	Minorities supported $\geq$ 25% of full time	2

SECTION 2: Detailed Summary of Technical Progress during this reporting period *(by project)*

Principal Investigators:	Frederick P. Brooks, Jr. Donald F. Stanat Stephen F. Weiss
PI Institution:	The University of North Carolina at Chapel Hill Department of Computer Science
PI Phone Numbers:	919/962-1931 919/962-1788 919/962-1888
PI E-mail Addresses:	brooks@cs.unc.edu stanat@cs.unc.edu weiss@cs.unc.edu

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Pixel-Planes 5

Hardware—The research team completed the major portion of the Pixel-Planes 5 (Pxpl5) prototype hardware system in early July 1990. Although not all of the hardware modules are finished, there are enough now working to form a fully functional computer graphics system. The project team continues to work on expanding the number of modules (Graphics Processors, Renderers, and Ring Network interface boards) and on removing the last few hardware bugs in existing modules. A system with 40 Ring boards, 16 Graphics Processors, and 20 Renderers is expected to be ready by early October 1990.

Laura Weaver and John Poulton have nearly completed the logic design for an NTSC-compatible frame buffer for Pxpl5. This new, low-resolution, two-channel frame buffer is intended mainly to drive the head-mounted displays of the Walkthrough project but can be used for a variety of other tasks that require television broadcast-compatible video. The team expects to complete this new module by late November 1990.

Software—The operating system and graphics software were ported to the actual Pixel-Planes 5 hardware. Pixel-Planes 5 is now a completely functional graphics system, although with reduced speed until all the hardware modules are completed. Software components successfully ported to Pixel-Planes 5 include the Ring Operating System (ROS), Render Control System (RCS) and the PHIGS+ compatible graphics library (PPHIGS). Performance measurement and optimization of this software is in progress. Although the system is far from fully optimized, we have achieved rates of 100,000+ triangles and spheres per second, with Phong shading. Our goal is to exceed 1,000,000 triangles or spheres per second.

System software was developed to allow C language programming for the i860 processors in the Graphics Processor modules. This software includes routines to create the C runtime environment, to load programs, to allow UNIX-type system calls, and to make performance measurements. The Ring Operating System was actually re-implemented rather than ported to the Pixel-Planes 5 hardware, preserving the same user interface that was previously used on the porting base.

Routines for generation of images (MIP map) and procedural textures were implemented and integrated into the PPHIGS graphics library. Procedural textures can make use of filtered noise functions to produce complex, naturalistic patterns very efficiently.

Several graphics application programs are in development. Three major ones are a building walkthrough program, a flight simulator, and a volume rendering program. These programs, although not fully complete and optimized, are now operational on the Pixel-Planes 5 system. Both the building walkthrough and flight simulator programs make heavy use of the procedural texture capabilities of PPHIGS to create a rich visual environment.

The volume rendering program produces three-dimensional renderings of volumetric data sets, such as CAT-scan data. A 128 x 128 x 128 data set can now be rendered with Phong shading in about 2 seconds on Pixel-Planes 5. The performance goal for the volume renderer is to produce renderings of this size data set at multiple frames per second, to permit interactive investigation of the data.

Funding—A new grant from NSF and DARPA has been awarded on the Pixel-Planes research. Henry Fuchs and John Poulton are the principal investigators for this grant, which is entitled "Supercomputing Power for Interactive Visualization." The grant has been awarded for a period of three years beginning 1 June 1990, and total annual direct costs are $1,100,896. The proposed work is a continuation of our current research on the Pixel-Planes graphics system, and we plan to expand our investigations into a number of graphics architecture areas.

A research agreement has been drawn up among the Corporation for National Research Initiatives, Bell South Systems, GTE, the Microelectronics Center of North Carolina, the UNC Department of Computer Science, and the UNC Department of Radiation Oncology to demonstrate an application of Pixel-Planes 5 using gigabit networking to the Cray Y/MP in Research Triangle Park at the NC Supercomputer Center. This VISTAnet project has been funded for a period of three years beginning 1 August 1990. First-year funding for the UNC components of the project is:

Dept. of Computer Science (Chi):	$732,551
Dept. of Computer Science (Fuchs):	$714,665
Dept. of Radiation Oncology (Rosenman):	$982,387

Raj Singh has been named the hardware engineer for Vernon Chi's component of the VISTAnet project. A search for a software engineer for Henry Fuchs' component of the project is now being conducted.

Walkthrough

This year saw the fruition of a number of our long-term efforts, culminating in a real-time walkthrough capability for a fully radiositized model of the Orange Church Fellowship Hall, with interactive, near-real-time ability for the user to turn on, turn off, or dim any of 20 lighting circuits. This work was first completely demonstrated and the techniques described in our paper at Snowbird, UT, in March. It now runs on UNC's Pixel-Planes 4 (PxPl4) and on the Silicon Graphics 4D series. Since then our progress has been rapid, both in modeling and in the rendering of textures using UNC's new graphics supercomputer, Pixel-Planes 5.

Update rate via model partitioning. Airey demonstrated the power of his methods of automatically partitioning large building models into cells, each with an associated potentially-visible-set of polygons. This cuts viewing time according to the average depth complexity of the model, so that it has dramatic effects on large models. Our Sitterson Hall model turned out to have about 250 active cells as a reasonable automatic partitioning.

Update rate via adaptive radiosity. Airey and Rohlf completed development of an adaptive radiosity computation technique based on ray-firing, and this was incorporated into our standard PxPl4 software.

Image quality—textures. Varshney of our project and Turk and others of the PxPl project implemented Walkthrough with procedurally textured surfaces, and incorporated about a dozen textures into the House model as run on PxPl5. Speed still needs work, but we are getting stunning pictures at one update per second. These include textures for, for example, wood paneling, furniture, bricks, piano keys, sheet music, ceiling tiles, linoleum, wallpaper, etc.

Image quality—mirrors. Varshney implemented mirrors.

Interface. Hill, Brown, and others implemented a host interface giving graphical control of lighting parameters, etc.

Model building via AutoCad. We completed the tools necessary to get from an AutoCad model of a building to the data structures necessary for a Walkthrough model.

New model—house. Per plan, we implemented a third building model this year, this one a house with over a dozen rooms, considerable furniture, and textured surfaces. This model, as well as our other ones, has been transferred to Silicon Graphics. Stardent is also using our Orange Church model to test and demonstrate their system.

Porting to new hardware. This year the Walkthrough software was ported to Silicon Graphics hardware by Rohlf after he graduated from UNC, and to Pixel-Planes 5 by the team here.

Documentation—dissertation published. Airey's thesis was completed and accepted in July, giving us quite complete published documentation of the research up to that point, and of the algorithms developed. (See technical report listed in Section 3.)

Head-Mounted Display

We continue to make progress toward the goal of having our head-mounted display/virtual reality capabilities accessible to all Department members with a minimal amount of effort. We have enhanced the hardware used, and have created easy-to-use software models for applications developers.

Hardware—A major improvement in our Head-Mounted Display system during this reporting period involved the installation of a custom board on the (1986) Pixel-Planes 4 host which permitted the generation of two NTSC signals from the single frame buffer. Stereo-pair images, each with half the horizontal resolution of the full frame buffer image, are now generated, enabling us to use our VPL Eyephones, the optical geometry of which requires two different stereo images. In addition, we can now display stereo images on the older head-mounted display, for which we had been previously displaying the same image to both eyes.

The Pixel-Planes 4 host applications can now make use of non-directional auditory display by communicating over a serial line with a dedicated Macintosh sound server. Such audio feedback is useful to indicate task completion, object selection, object collisions, and other situations. Macintosh software has been developed to enable applications developers to easily incorporate auditory display.

We have completed the installation of our two additional Polhemus tracker units in the Graphics Lab. The one-station Isotrack unit has been installed near the ARM, and we have found that the ARM produces minimal disturbance to the magnetic field of the Polhemus tracker. We have combined the ARM and the HMD in a simple demonstration program involving solid block manipulation. The eight-station 3Space tracker unit has been installed in the Graphics Lab in a relatively open area. By itself, the eight-station unit with its two sources has a larger working volume than the single-source, two-station unit already installed in the HMD room. Used together, the eight-station Polhemus and the two-station Polhemus will permit investigation of remotely located, multiple users being present in the same virtual world.

Optical engineer Jannick Rolland joined our team in June 1990, and has begun work on the optical design of a new see-through head-mounted display, initially slated for medical applications.

Software—*hmdfront*, a generic 3D dataset exploration tool that allows the user to examine arbitrary models with the HMD, has been released and installed. *hmdfront* is the basis for our standard demos, and has also been put into use to examine new molecular representations. The program is not intended nor expected, however, to satisfy all possible requirements users may have for their particular application. In many cases, special software will have to be written to implement some special feature such as a particular interaction mode. *hmdfront* provides manipulation with the 6D mouse of the global space or individual objects within the model.

We are close to finishing the initial release of a tracker library, which will enable applications builders to readily use the Polhemus trackers and any other trackers used in the Department. The library will furnish the programmer with abstractions of tracking devices, and free the programmer from worrying about details regarding specific devices, communications, and protocols.

Faculty member Kevin Jeffay and graduate student Dan Poirier have demonstrated a significant increase in the frame update rate through a restructuring of HMD software that followed a multiprogramming model. The goal was to obtain predictable real-time behavior from the non-real-time operating system (Ultrix) on which we run our HMD applications. Incorporation of their model in future HMD application development should provide dramatic performance improvement.

Funding—The work of the Head-Mounted Display project will be assisted by a contract on "Advanced Technology for Portable Personal Visualization" (Fred Brooks and Henry Fuchs, PIs) awarded by DARPA for a period of three years. The total three-year award is $2,473,081.

Tracker

We are developing a new optical tracking system, built with off-the-shelf components, that provides a very large (room-sized) working environment (see Figure 1). This system adopts an "inside-out" tracking paradigm first proposed by our research team and introduced in a paper by Gary Bishop and Henry Fuchs in 1984. The working environment is a room in which the ceiling is lined with a regular pattern of infrared light-emitting diodes (LEDs) that are flashed under the system's control. Three or more cameras are mounted on a helmet that the user wears. The measured photocoordinates of an LED, combined with their known locations on the ceiling, allow us to compute the position and orientation of the camera assembly in space (see Figure 2). Each camera uses a lateral-effect photodiode as the sensing surface. A lateral-effect photodiode provides higher resolution over its surface and faster response than a conventional CCD camera; thus higher accuracy in the reported position and a faster update rate can be achieved.

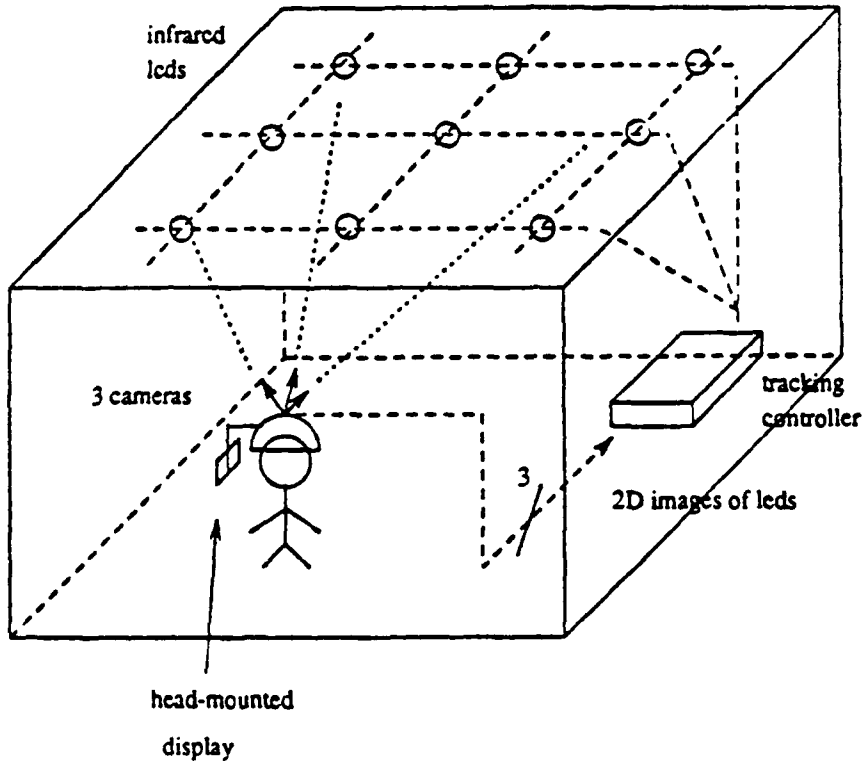


Figure 1: Configuration of the proposed tracking system

Wang presents in his dissertation an iterative algorithm to estimate the position and orientation of the camera assembly in space. The algorithm is a generalized version of the method proposed by Earl Church in 1945, which was used in aerial photogrammetry. Equations were also derived by Wang to predict the system's error. Computer simulations were carried out to verify the correctness of the theoretical analysis and to determine several important system design parameters. The requirements of accuracy, speed, adequate working volume, light weight, and small size of the tracker are also addressed.

A desktop prototype was designed and constructed to demonstrate the integration and coordination of all essential components of the new tracker. This prototype uses off-the-shelf components and can be easily duplicated. The limiting factors on the performance of the system, such as the noise inherent in the circuitry, the resolution, the nonlinear characteristics of the photodiode, and the output power of the LEDs, were carefully measured and studied.

The performance of the tracker was quantitatively measured. We designed experimental procedures to determine the speed, accuracy, and working range of the prototype tracker. Our results indicate that the new system significantly outperforms other existing systems. The new tracker provides more than 20 updates per second (and promises more than 200 updates per

second), registers 0.1-degree rotational movements and 2-millimeter translational movements, and promises a large working volume.

Our first proof-of-concept prototype had only three infrared LEDs: one for each camera's field of view. To test the multiple ceiling-panel concept, we next constructed a 48-LED, three-panel prototype. Each LED can be individually addressed, and one is turned on for each head-mounted camera. The three-panel system has been demonstrated, and it is being used to develop improved algorithms and hardware that will be used in a room-sized prototype.

We are now implementing a full-working volume system in a 26 x 12 x 9 cubic-foot room, using about one thousand LEDs. The LEDs will be arranged in 4-by-4 hexagonal grids affixed to 2 x 2 square-foot panels . The panels will be installed as a portable, false ceiling in a room. In such a full-scale system, the positions of the LEDs have to be known very accurately to provide sufficient precision in the tracking process. An improved algorithm for computing the head-position and orientation is being developed that will accommodate more LED placement error.

The algorithm is a generalized version of the technique known as *space-resection by collinearity*. For the problem of computing a camera's position and orientation given the photocoordinates of three or more landmarks (known as space-resection), this technique has several advantages over Church's method. Most importantly, if more than three landmarks can be observed, the additional information can be used in the solution. Also, the six unknowns are solved for in one step, whereas Church's algorithm directly solves for only the linear degrees of freedom. Least-squares techniques are used to accommodate the over-determined matrix equations that result from more than three landmarks.

Space-resection by collinearity has been generalized to allow the use of multiple image planes, as well as multiple landmarks per image plane. This will allow us to use more than three cameras, and if each camera is capable of imaging more than one LED, then the additional information is used to compute the camera assembly's position and orientation. Simulations have shown that when this approach is used, the effects of beacon placement error are less than with the generalized version of Church's algorithm.

In preparation for the full-scale system, considerable effort is being directed toward camera calibration. We know that the image plane of each camera must have an accuracy of 1 part in 1000 if we are to satisfy our overall system requirements. Dr. E. K. Antonsson, formerly of MIT's Biomechanics Laboratory, now with the Division of Engineering and Applied Science at the California Institute of Technology, found that this was impossible with off-the-shelf, electro-optical equipment. First, the lateral-effect photodiode possesses a systematic error that is as great as 1 part in 40. When this sensor is combined with a non-metric lens and a camera body whose tolerances are no better than .5mm, the result falls far short of our goal. Dr. Antonsson experimentally derived a two-dimensional calibration table for cameras that are nearly identical to ours and achieved the goal of 1 part in 1000 accuracy. We are working with Dr. Robert J. Hocken, of the University of North Carolina at Charlotte, to duplicate Dr. Antonsson's results. In UNC-Charlotte's metrology lab, a coordinate-measuring machine will be used to index an LED throughout the field of view of our cameras. The data gathered will then be analyzed and used to construct a calibration table.

During the calibration procedure, we hope to determine the optical parameters of the camera, as well. Because we are using non-metric lenses, the principal plane locations, focal length, and optical axis locations are poorly defined with respect to the camera body. The mathematics associated with space-resection by collinearity can also be used to compute these parameters. By precisely controlling both the camera and the LED location, equations can be derived in which the focal length and principal plane locations are unknowns. Then, if sufficient data points are taken, least-squares techniques can be used to solve for these parameters. Such a procedure is well-documented in the photogrammetry literature and is referred to as the calibration of non-metric cameras.

The calibration experiment will be conducted using an improved computational architecture, which is currently under development. The full-sized tracker prototype will be controlled by a multiprocessor system comprised of a Sun 4/260 workstation, a 68030-based single board computer, and an array processor (see Figure 2). The workstation serves as a development environment and a diagnostic graphical display device. The 68030-based single board computer manages up to 8 cameras and 256 ceiling panels. It fires selected LEDs and extracts photocoordinates from the cameras. The array processor accepts the photocoordinates and computes the position and orientation of the camera assembly using the generalized form of space-resection by collinearity.

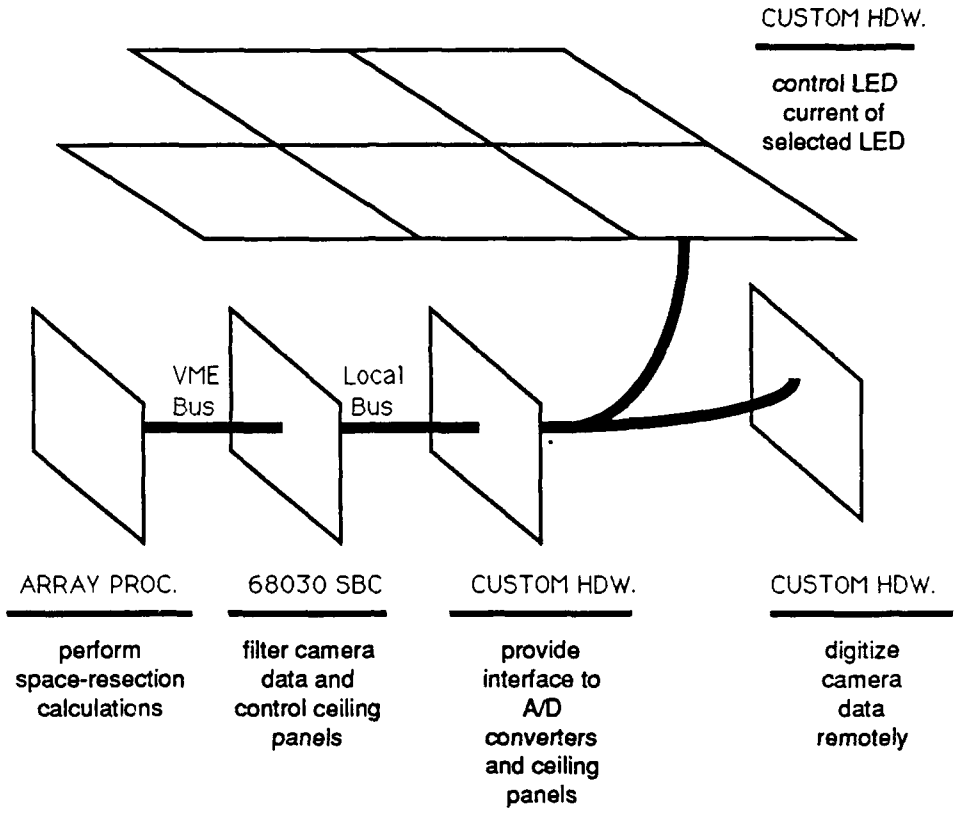


Figure 2.

Coupled with custom interface electronics (currently being designed and implemented by the department's Microelectronic Systems Laboratory), real-time control software running on the 68030 assigns a current density to an LED (out of 256 possible values), addresses one LED out of 255 panels, and turns the LED on for a specific time period. During the LED's *on-time*, the four voltage signals emerging from a camera are digitized at a rate of 1MHz.

The analog-to-digital conversion occurs at the head, using custom hardware. A parallel data link connects the head-mounted circuitry to an interface card in the workstation's VME cardcage. This 9U VME card provides an interface for the head-mounted cameras and the ceiling panels, as well as an attachment port for the single board computer. The port implements Corebus, a high-speed inter-board protocol developed by Heurikon Corporation for the attachment of mezzanine cards to generic VME cpu boards.

Upon arrival at the single board computer, the sequence of 12-bit digital codes are filtered to reject ambient light and are then fed into a calibration table for the camera. The result is a pair of photocoordinates.

A set of photocoordinates is produced by repeating this process for each camera, as well as for each LED that is in the camera's field of view. Three elements are required to compute the cameras' position and orientation. The information is communicated from the single board computer to the compute-server over the workstation's VME bus.

When the minimum number of LEDs is available, space-resection involves an iterative solution to six nonlinear equations. Each iteration requires that a 6 x 6 matrix be inverted. If more than three LEDs can be imaged, the number of equations remains the same, but the dimensionality of the matrix grows to 2N x 6, where N is the number of photocoordinates. A pseudoinverse is thus involved in the computation. We have implemented the space-resection algorithm in the C programming language and are preparing to benchmark the code on commercially available array processors.

By 1 August 1991, we hope to have a system that functions in a large working volume where the user can walk around freely. The system will provide accurate information on the user's head position and achieve a fast update rate. We expect the new tracker to enhance greatly the usefulness of head-mounted display systems.

We will also be assisted in our goal to develop this full-scale tracking system by the award of a contract from DARPA/ISTO for the period 9/5/90-9/4/93 on "Advanced Technology for Portable Personal Visualization." In this project we have proposed to investigate technical problems related to head-mounted display interactive graphics systems, including real-time methods for head and hand tracking and optical designs for the display itself that allow the computer-generated image to be superimposed on the user's view of his/her surroundings.

Protocol Analysis Tools

Support from ONR for the past year consisted of two graduate student research assistants and $10,000 in video equipment. Since TextLab is a large research program that includes a number of activities, this description will cover only those activities supported directly by ONR resources.

The two research assistants worked on systems to support management, analysis, and interpretation of machine-recorded protocols of human users' interaction with one particular computer system—the Writing Environment.

One student developed a prototype system to manage the hundreds, perhaps thousands, of protocols our methodology makes possible for researchers to collect and analyze. The system provides a tree representation of individual session protocols organized according to descriptive attributes associated with each. Using this tool, the researcher can select and organize for automated analyses protocols for particular groups of users (e.g., experts vs. novices), falling within a particular period of time, evaluated as superior or inferior, etc. Part of this work included development of a formal mathematical definition of a sort/select tree and analytic operation that can properly be applied to different data sets under varying conditions. This work has general implications beyond protocol studies for matching data with appropriate computing processes.

The second student developed a prototype system that runs simultaneously on multiple workstations to replay a user's session, based on the recorded protocol for that session, and coordinate it with additional sources of analytic and descriptive information, e.g., a parse of the protocol, comments by the subject, comments by the researcher, etc.

The video equipment was used to begin exploratory work in a new collaboratory project that began in TextLab September 1, 1990. This equipment—consisting of several video cameras and microphones, a video disk player, and a video mixer—has allowed us to get an early start in technology that is new for our research group.

SoftLab

SoftLab Software Systems Laboratory is an organization that provides the UNC Computer Science Department with software systems and manufacturing support services analogous to those typically found in industry. As such, SoftLab serves as a software development resource for the Department and as an agent of technology transfer to other universities and to industry.

In particular, SoftLab facilitates rapid prototyping of novel architectures by developing drivers, compilers, interfaces, and other systems software; by importing and integrating commercial software development tools; and by supporting an object-oriented programming environment. In addition, SoftLab's primary objectives are evolving to include support of research in distributed systems.

Finally, SoftLab pursues an educational mission with emphasis in the areas of software engineering and development of software tools for laboratory use in computer architecture and operating system courses.

Intel i860 microcode preprocessor. Pixel-Planes is a family of high-performance, 3-D raster display systems that harness the power of custom VLSI circuits. In 1989, SoftLab, working in conjunction with the Pixel-Planes research team, developed a microcode preprocessor for the Weitek XL chip, on which the Pixel-Planes 4 machine is based. This preprocessor automated register allocation and performed pipeline analysis, thus facilitating the manual optimization of Weitek assembly code, necessary for performance reasons. In summer of 1989, Pixel-Planes decided to switch from its Weitek-based architecture to an Intel i860-based architecture. Since then, SoftLab has developed a microcode preprocessor for the Intel i860 with capabilities analogous to those previously provided for Pixel-Planes 4. A working prototype now exists.

UNIX Phone System Link and Applications. Voice and data traffic in the Computer Science Department at UNC is switched by the Department's Intecom IBX digital PBX. Last year, a new capability was added to the switch's feature set that allows switch functions such as phone calls and networking operations to be monitored and partially controlled from an application host machine. As provided by Intecom, this capability worked only with VAX and IBM PC host machines.

SoftLab personnel developed UNIX drivers to allow communication between the switch and a network of UNIX workstations as well.

SoftLab personnel also designed and developed application programs based on the link described above. These programs include a voice-mail system that encodes, stores, and manipulates voice messages as UNIX files; and a power-dialer system that allows phone calls and features to be initiated from UNIX workstations.

Blitzen board design tool interface. Blitzen is the name of a project to build a massively parallel SIMD processor based on a custom chip design. The hardware design for the Blitzen prototype board is being done using various commercial design tools, originating from different vendors with incompatible interfaces. As a first step toward providing a more integrated and automated design system, SoftLab has written programs that automatically perform conversions between the output format of one tool and the input format of the next tool used in the design sequence.

Hypertext database of department software tools. SoftLab has designed and implemented a hypertext-style database that catalogs information about all software development tools available in the Department.

SECTION 3: Lists of Publications, Presentations, Reports, Awards/Honors during this reporting period

Principal Investigators:	Frederick P. Brooks, Jr. Donald F. Stanat Stephen F. Weiss
PI Institution:	The University of North Carolina at Chapel Hill Department of Computer Science
PI Phone Numbers:	919/962-1931 919/962-1788 919/962-1888
PI E-mail Addresses:	brooks@cs.unc.edu stanat@cs.unc.edu weiss@cs.unc.edu

Contract Title:	The Infrastructure of Command Information Systems
Contract Number:	N00014-86-K-0680
Reporting Period:	15 September 1989 through 14 September 1990

With * ..... ONR-supported.
Without * ..... Related to the project.

A. Refereed papers (to appear)

Guan, Sheng-Uei, Hussein Abdel-Wahab, and Peter Calingaert. "Jointly-Owned Objects for Collaboration: Operating System Support and Protection Model," to appear in *The Journal of Systems and Software*, 1991.

B. Refereed papers published

*Airey, John M., John H. Rohlf, and Frederick P. Brooks, Jr. "Towards Image Realism with Interactive Update Rates in Complex Virtual Building Environments," Best Paper Award: *Computer Graphics: Proc. 1990 Symposium on Interactive 3D Graphics*, 24(2), Snowbird, UT, 25-28 March 1990. (Also TR90-001.)

*Brooks, Frederick P. Jr., Ming Ouh-Young, James J. Batter, and P. Jerome Kilpatrick. "Project GROPE—Haptic Displays for Scientific Visualization," *Computer Graphics: Proc. SIGGRAPH '90*, 24(4), Dallas, TX, 6-10 Aug. 1990, 177-185.

*Chung, J. C., M. R. Harris, F. P. Brooks, Jr., H. Fuchs, M. T. Kelley, J. W. Hughes, M. Ouh-young, C. Cheung, R. L. Holloway, and M. Pique. "Exploring Virtual Worlds with Head-Mounted Displays," reprinted in *Proc. Ars Electronica 1990*, vol. 2: Virtuelle Welten, Linz, Austria, Sept. 1990, 138-146.

*Ellsworth, David, Howard Good, and Brice Tebbs. "Distributing Display Lists on a Multicomputer," *Computer Graphics: Proc. 1990 Symposium on Interactive 3D Graphics*, 24(2), Snowbird, UT, 25-28 March 1990, 147-154. (Also TR90-003.)

Fuchs, Henry. "Systems for Display of Three-Dimensional Medical Image Data," *3D Imaging in Medicine: Algorithms, Systems, Applications: Proc. NATO Advanced Research Workshop*, Travemüende, Germany, 25-29 June 1990, K. H. Hoëhne, H. Fuchs, and S. M. Pizer, eds., Springer-Verlag, 315-331.

*Levoy, Marc and Ross Whitaker "Gaze-directed Volume Rendering," *Computer Graphics: Proc. 1990 Symposium on Interactive 3D Graphics*, Snowbird, UT, 25-29 March 1990.

Mills, Peter H. and Henry Fuchs. "3D Ultrasound Display Using Optical Tracking," *Proc. 1st Conference on Visualization in Biomedical Computing*, 22-25 May 1990, Atlanta, Georgia, 490-497. (This paper concerns a different type of tracking device than the one being developed under this project.)

*Minsky, Margaret, Ming Ouh-young, Oliver Steele, Frederick P. Brooks, Jr., and Max Behensky. "Feeling and Seeing Issues in Force Display," *Computer Graphics: Proc. 1990 Symposium on Interactive 3D Graphics*, Snowbird, UT, 25-29 March 1990.

Ouh-young, Ming, M. Pique, M. Harris, J. Hughes, N. Srinivasan, and F. P. Brooks, Jr. "Force Display in Molecular Docking," Abstract in *Journal of Molecular Graphics*, 6(4), Dec. 1988, 224 (Ph.D. dissertation, May 1990).

*Robinett, Warren. "Head-Mounted Display Project Summary," *Proc. Ars Electronica 1990*, vol. 2: Virtuelle Welten, Linz, Austria, Sept. 1990, 119-122.

*Wang, Jih-Fang, Ronald Azuma, Gary Bishop, Vernon Chi, John Eyles, and Henry Fuchs. "Tracking a Head-mounted Display in a Room-sized Environment with Head-mounted Cameras." *Aerospace Sensing: Proc. SPIE 1990 Technical Symposium on Optical Engineering and Photonics*, 1290, Orlando, FL, 16-20 April 1990.

*Wang, Jih-Fang, Vernon Chi, and Henry Fuchs. "A Real-time Optical 3D Tracker for Head-Mounted Display Systems." *Computer Graphics: Proc. 1990 Symposium on Interactive 3D Graphics*, 24(2), Snowbird, UT, March 1990, 205-216.

*Ward, Mark. "Calibrating Lateral Effect Photodiodes for Use as Measuring Devices in Manufacturing," *Proc. Modern Manufacturing 1990 Conference*, 12-13 Sept. 1990, North Carolina State University.

Weiss, S. "Hypertext Grows Up," A Panel Discussion at the *13th International Conference on Research and Development in Information Retrieval*, Universite Libre de Bruxelles, Brussels, Belgium, 5-7 Sept. 1990.

C. Refereed papers submitted (awaiting acceptance)

Chi, Vernon L. "Salphasic Distribution of Clock Signals for Synchronous Systems," submitted to *Proc. IEEE*, June 1990. (Also TR90-026.)

*Robinett, Warren. "Practical Problems in Achieving Orthostereoscopy on a Head-Mounted Display with Computer-Generated Imagery," submitted to *SPIE Conference on Electronic Imaging*, 24 Feb. - 1 March 1991, San Jose, CA.

Trinker, Arie and Heng Chu. "MAST 860: A Microprogramming Analysis and Support Tool for Pipelined Architectures," submitted to *Proc. 23rd Annual Symposium on Microprogramming and Microarchitecture*, 27-29 Nov. 1990.

D. Unrefereed reports and articles

*Airey, John M. "Increasing Update Rates in the Building Walkthrough System with Automatic Model-Space Subdivision and Potentially Visible Set Calculations," TR90-027, Department of Computer Science, UNC at Chapel Hill, July 1990 (Ph.D. dissertation).

Calingaert, Peter, Hussein Abdel-Wahab, Gregory Bollella, Sheng-Uei Guan, F. Donelson Smith, and John B. Smith. "Synchronous and Asynchronous Collaboration: A Program of Research," TR90-024, Department of Computer Science, UNC at Chapel Hill, May 1990.

*Davis, Mark C. "A Computer for Low Context-Switch Time," TR90-012, Department of Computer Science, UNC at Chapel Hill, March 1990 (Ph.D. dissertation).

Fuchs, Henry, John Poulton, Andrei State, Roger Brusq, Edward N. Hill, Jr. "An Architecture for Advanced Avionics Displays," final report on contract number F33615-88-C-1848 to the U. S. Air Force Cockpit Integration Directorate, Wright-Patterson Air Force Base, Dayton, OH, May 1990.

Lansman, M., J. B. Smith, I. Weber. "Using Computer-Generated Protocols to Study Writers' Planning Strategies," TR90-033, Department of Computer Science, UNC at Chapel Hill, Sept. 1990.

State, Andrei. "Displaying Alphanumeric Characters on Pixel-Planes 5," TR89-049, Department of Computer Science, UNC at Chapel Hill, Dec. 1989.

*Tuck, Russ. "Porta-SIMD: An Optimally Portable SIMD Programming Language," TR90-021, Department of Computer Science, UNC at Chapel Hill, May 1990; Duke technical report CS-1990-12, Department of Computer Science, Duke, May 1990 (Ph.D. dissertation).

*Wang, Jih-Fang. "A Real-time Optical 6D Tracker for Head-mounted Display Systems," TR90-011, Department of Computer Science, UNC at Chapel Hill, March 1990 (Ph.D. dissertation).

Yen-Ping, S. "MoDE: A UIMS for Smalltalk," TR90-017, Department of Computer Science, UNC at Chapel Hill, April 1990.

Yen-Ping, S. "An Object-Oriented UIMS for Rapid Prototyping," TR90-016, Department of Computer Science, UNC at Chapel Hill, April 1990.

SoftLab (SL) Reports

Chu, Heng and Airie Trinker. "MAST860—A Microprogramming Analysis and Support Tool for Pipelined Architectures," SoftLab TR#SL04, June 1990.

Coggins, James. "The COOL Library: User's Manual, Version 1.0," SoftLab TR #C002, Department of Computer Science, UNC at Chapel Hill, Oct. 1989, 83 pp.

Coggins, James. "The COOL Library: Supplementary Documents, Version 1.0," SoftLab TR #C001, Department of Computer Science, UNC at Chapel Hill, Oct. 1989, 79 pp.

Trinker, Airie. "WE Installation Guide," SoftLab TR#WE01, 1990.

Trinker, Airie. "MAST860 User's Guide—A Microprogramming Analysis and Support Tool for Intel i860," SoftLab TR#SL05, June 1990.

SoftLab Internal Documents, available upon request:

Dunn, Jeff. "Users' Guide—Sitterson Hall Phone Enhancements," SoftLab TR#SL01, 6 May 1990.

Guin, Beth. "Administration Procedures—Sitterson Hall Phone Enhancements," SoftLab TR#SL03, 6 May 1990.

Lutz, Dave and Jonathen Whaley. "Implementation Design—Sitterson Hall Phone Enhancements," SoftLab TR#SL02, 6 May 1990.

Videotapes:

*Airey, John, John Rohlf, and Penny Rheingans. "The Virtual Lobby" *SIGGRAPH '89* Video Night, Boston, MA (sent to Ralph Wachter, Oct. 1989).

*Brooks, Frederick P. Jr. Interview videotaped and excerpted with illustrations from Walkthrough demonstrations, in the SIGGRAPH Video Review, vol. 60, Aug. 1990 (available from ACM under the title "HDTV and the Quest for Virtual Reality," *ACM SIGGRAPH Video Review*, Special Issue 60, 1990).

*Rheingans, Penny and Brice Tebbs. "A Tool for Dynamic Explorations of Color Mappings," videotape presented at *1990 Symposium on Interactive 3D Graphics*, Snowbird, UT, 25-28 March 1990 (sent to Ralph Wachter, 12 April 1990).

E. Books (or parts thereof) published

Molnar, Steven and Henry Fuchs. "Advanced Raster Graphics Architecture," chapter 18 in *Computer Graphics: Principles and Practice*, 2nd ed., J. Foley, A. van Dam, S. Feiner, and J. Hughes, Reading, MA: Addison-Wesley, 1990, 855-922. (Also TR90-003).

F. Invited presentations

Pixel-Planes

John Eyles, "Virtual-Environment Research at UNC," AUSGRAPH '90 Conference, Melbourne, Australia, 12-14 Sept. 1990.

John Eyles, "Real-Time Graphics (tutorial)," AUSGRAPH '90 Conference, Melbourne, Australia, 12-14 Sept. 1990.

Henry Fuchs, "Interactive Steering of Supercomputer Calculations," Frontiers of Supercomputing II Conference, Los Alamos, NM, 19-23 Aug. 1990.

Henry Fuchs, "High-Speed Systems for Visualization," NIH / NCI Workshop on 3D Display and Analysis for Cancer Treatment Planning, Washington, DC, 17-18 July 1990.**

Henry Fuchs, "Systems for Display of Three-Dimensional Medical Image Data," NATO Advanced Research Workshop on 3D Imaging in Medicine, Travemünde, Germany, 25-29 June 1990.**

Henry Fuchs, "Interactive Displays for the 21st Century—Beyond the Desktop Metaphor," talk given at a departmental seminar while serving as a visiting professor, Swiss Federal Institute of Technology, Lausanne, Switzerland, 31 May 1990.**

Henry Fuchs, "High-Speed Systems for Biomedical Visualization," 1st Conference on Visualization in Biomedical Computing, Atlanta, GA, 22 May 1990.**

Henry Fuchs, "High-Performance Graphics on Multicomputers," Intel-DARPA Research Community Forum, Hillsboro, OR, 28 Feb. 1990.**

Henry Fuchs, "Interactive Displays for the 21st Century—Beyond the Desktop Metaphor," National Science Foundation, Computer and Information Science and Engineering, Research Seminar, Washington, DC, 18 Jan. 1990.

***Head-Mounted Display and Tracker were also described*

Head-Mounted Display and Tracker

Henry Fuchs, "Portable Personal Visualization Systems," DARPA Workshop on "Technologies for Personal Communications Systems," Washington, DC, 18 Jan. 1990.

Henry Fuchs, "Interactive Displays for the 21st Century—Beyond the Desktop Metaphor," National Science Foundation, Computer and Information Science and Engineering Research Seminar, Washington, DC, 18 Jan. 1990.

Warren Robinett, "Synthetic Experience," Ars Electronica Conference, Linz, Austria, 10 Sept. 1990.

Warren Robinett, "Synthetic Experience," Panel at SIGGRAPH'90 on Hip, Hype, and Hope: The Three Faces of Virtual Reality, Dallas, TX, 9 Aug. 1990.

G. Contributed presentations

Pixel-Planes

David Ellsworth, "Parallel Architectures and Algorithms for Real-Time Synthesis of High-Quality Images Using Deferred Shading," Workshop on Algorithms and Parallel VLSI Architectures," Pont-a-Mousson, France, 12 June 1990.

David Ellsworth, "Distributing Display Lists on a Multicomputer," 1990 Symposium on Interactive 3D Graphics, Snowbird, UT, 27 March 1990.

Walkthrough

John Airey, "Towards Image Realism with Interactive Update Rates," 1990 Symposium on Interactive 3D Graphics, Snowbird, UT, 25-29 March 1990.

Tracker

Ron Azuma, "Tracking a head-mounted display in a room-sized environment with head-mounted cameras," Head-Mounted Displays II: SPIE's 1990 Technical Symposium on Optical Engineering and Photonics in Aerospace Sensing, Orlando, FL, April 1990.

Jih-Fang Wang, "A Real-time Optical 3D Tracker for Head-Mounted Display Systems," 1990 Symposium on Interactive 3D Graphics, Snowbird, UT, 25-28 March 1990.

Mark Ward, "Calibrating Lateral Effect Photo-diodes for Manufacturing Application," Modern Manufacturing 1990 Conference, N.C. State University, Raleigh, NC, 12-13 Sept. 1990.

Protocol Analysis Tools

John B. Smith, "Cognitive Aspects of Hypertext Systems," Hypertext '89, Pittsburgh, PA, Nov. 1989.

SoftLab

Susanna Schwab, "SoftLab: A Paradigm for Software Systems Development and Capitalization in the University," 1990 NSF CER/II Meeting, Atlanta, GA, 11-12 June 1990.

Other

Marc Levoy, "Gaze-directed Volume Rendering," 1990 Symposium on Interactive 3D Graphics, Snowbird, UT, 25-29 March 1990.

Margaret Minsky (and Ming Ouh-young), "Feeling and Seeing: Issues in Force Display," 1990 Symposium on Interactive 3D Graphics, Snowbird, UT, 25-29 March 1990.

Penny Rheingans and Brice Tebbs, "A Tool for Dynamic Explorations of Color Mappings," (Demonstration), 1990 Symposium on Interactive 3D Graphics, Snowbird, UT, 25-29 March 1990.

H. Honors

- **Henry Fuchs** was one of two keynote speakers at the 1st Conference on Visualization in Biomedical Computing, Atlanta, Georgia, 22-25 May 1990.

- **Henry Fuchs** served on the Papers Committee for the SIGGRAPH '90 conference (held in Dallas, August 1990), the 1990 Symposium on Interactive 3D Graphics (held at Snowbird, Utah, March 1990), the Technical Committee of the 1st Conference on Visualization in Biomedical Computing (held in Atlanta, May 1990), and the Program Committee of the 6th MIT Conference on Advanced Research in VLSI (held in Cambridge, Mass., April 1990). He also served as one of three co-directors of the NATO advanced research workshop on 3D Imaging in Medicine, held in Travemüende, Germany, 25-29 June 1990.

- Several graduate students working on the Pixel-Planes project have received continuation of their fellowships from outside organizations for the the 1990-91 academic year. They are:

David Ellsworth	ONR fellowship
Steve Molnar	IBM Manufacturing Research Fellowship
Greg Turk	IBM Fellowship

- **Ed Biagioni** was named one of two ONR fellows for the 1990-91 academic year. (Also see Ellsworth, above). He is working on massively parallel programming.

- **Warren Robinett** served as a member of a panel at SIGGRAPH '90 in Dallas, TX: "Hip, Hype, and Hope: the Three Faces of Virtual Reality."

I. Prizes or awards

- The paper listed above, "Towards Image Realism with Interactive Update Rates in Complex Virtual Building Environments," by **Airey, Rohlf,** and **Brooks,** received the ***Best Paper Award*** at the 1990 Symposium on Interactive 3D Graphics at Snowbird, UT, 26-28 March 1990.

J. Promotions obtained / New staff

- **Mark Ward,** an electro-mechanical engineer, was hired and began working on the Tracker project in March 1990.

- Optical engineer **Jannick Rolland** joined our team in June 1990, and has begun work on the optical design of a new see-through head-mounted display.

K. Educational productivity

- **John Airey,** who worked on the Walkthrough project for four years, graduated with the Ph.D. degree in August 1990. See technical report listed in this section.

- **Mark Davis,** ONR fellow since FY87-88, graduated with the Ph.D. degree in May 1990. Mark has worked on the CLOCS project since Spring 1987. See technical report listed in this section.

- **Russ Tuck,** A Duke University graduate student who worked on the Pixel-Planes project for two years, graduated with the Ph.D. degree in May 1990. See technical report listed in this section.

- **Jih-Fang Wang,** who worked on the Tracker project for two years, completed his dissertation on the optical tracker, and graduated with the Ph.D. degree in May 1990. See technical report listed in this section.

- **Ron Azuma,** a graduate student who is beginning his second year on the Tracker project, passed his Ph.D. written exams and is now a Ph.D. candidate. He received his M.S. degree in May 1990.

- **Howard Good,** who has been working on the Pixel-Planes Project for three years, graduated with the M.S. degree in May 1990. He is currently working toward the Ph.D. degree.

- **Richard Hawkes,** who has worked on the Protocol Analysis Tools Project, graduated with the M.S. degree in May 1990.
- **Michael T. Kelley**, who had worked on the Head-Mounted Display Project for two years, graduated with the M.S. degree in December 1989.
- **Dan Palmer**, who worked on the Head-Mounted Display Project for about two years, graduated with the M.S. degree in May 1990.
- **John Menges**, who worked on the Network Tools project, has completed his Master's Thesis: "Providing Common Access Mechanisms for Dissimilar Network Interconnection Nodes." Technical Report number to be assigned; copies (and abstract) will be distributed as soon as it is available.
- **Johnny Rhoades**, who has worked on the Pixel-Planes Project for three years, graduated with the M.S. degree in May 1990. He is currently working toward the Ph.D. degree.
- **Carl Mueller**, **Marc Olano**, and **Andrei State** have joined the Pixel-Planes project as graduate research assistants.
- **Drew Davidson and Erik Erikson** are new graduate students who have joined the Head-Mounted Display project as research assistants.
- **Phil Jacobsen** joined the Tracker project as a graduate research assistant in August 1990.

SECTION 4: Transitions and DoD Interactions during this reporting period *(by project)*

Principal Investigators:	Frederick P. Brooks, Jr. Donald F. Stanat Stephen F. Weiss
PI Institution:	The University of North Carolina at Chapel Hill Department of Computer Science
PI Phone Numbers:	919/962-1931 919/962-1788 919/962-1888
PI E-mail Addresses:	brooks@cs.unc.edu stanat@cs.unc.edu weiss@cs.unc.edu

Contract Title:	The Infrastructure of Command Information Systems
Contract Number:	N00014-86-K-0680
Reporting Period:	15 September 1989 through 14 September 1990

A. Transitions of Results

Pixel-Planes

Industry. The IVEX Corporation of Norcross, Georgia (a suburb of Atlanta), has recently purchased limited, exclusive license of the two patents for Pixel-Planes technology. IVEX manufactures flight-simulator systems currently operational for pilot training in the U.S. and in several foreign countries. The patents that have been licensed are:

1) Fuchs, Henry, "Graphics Display System Using Logic-Enhanced Pixel Memory Cells," U.S. Patent #4,590,465, May 20, 1986 (Application #349,818, February 18, 1982).
2) Fuchs, Henry, and John Poulton, "VLSI Graphic Display Image Buffer Using Logic-Enhanced Pixel Memory Cells," U.S. Patent #4,783,649, November 1988 (Application #408,045, August 13, 1982).

Other. Many people have visited our *Graphics and Imaging Laboratory* during the past year and have received demonstrations of both Pixel-Planes 4 and Pixel-Planes 5. Approximate numbers of visitors are: 69 from universities, 105 computer science professionals working in industry, 6 from the military, 11 from government agencies, and 2 professional journalists. (These figures are taken from a log kept by the person who sets up most of the demonstrations in the Graphics and Imaging Laboratory. Many demos are done on a more casual basis, however, and these are never reported to the log. Consequently, the actual number of people who have seen the Pixel-Planes systems during the past year is higher than reported here.)

Walkthrough

University. We began a collaboration with the Laboratory for Computer Graphics at Cornell University, and as part of that imported their dataset for the model of their new Cornell Theory Center (which now houses the laboratory) and brought it up on our Walkthrough system, showing it at a major site visit in April.

Industry. We provided our software and our models to Silicon Graphics. They are actively using our Orange Church Fellowship Hall model in all their demonstrations, including those at SIGGRAPH '90, and they make some use of our Sitterson Hall and Brooks House models. They ported our Walkthrough software to the Silicon Graphics 4D80 and demonstrated it at the 1990 Symposium on Interactive 3D Graphics at Snowbird.

Head-Mounted Display

NASA Ames. Warren Robinett has had several discussions with Jim Larimer of NASA Ames Research Center about a possible collaborative effort.

Other. We have also had public contact through demonstrations in the Graphics and Imaging Laboratory of our research on head-mounted displays. During the past year we have given demos to approximately 148 faculty and students from universities and high schools, 82 computer scientists and other scientists and engineers working in industry, four persons from government agencies, seven persons from various U.S. military agencies, and six professional journalists. The visitors from the military sector include: two from the Navy Research Lab on 4 June 1990, Phil Amburn from Wright-Patterson Air Force Base, and four persons from the Army Research Institute (Dr. Owen Jacobs, Dr. Ed Johnson, and two others) on 13 June 1990 (see DoD Interactions, below).

Tracker

University. As mentioned in Section 2, we are collaborating with Dr. Robert J. Hocken, of the University of North Carolina at Charlotte, in the area of camera calibration. We hope to obtain enough data to construct a calibration table for our system.

Other. In addition, we have had significant general contact with the public. We have hosted many visitors to our laboratory during the past year and have demonstrated the optical tracker to a wide variety of people. Since September 1989, we have shown the tracker to two visitors from the Naval Research Lab, four from the Army Research Institute, and one from Wright Patterson Air Force Base. Other groups of visitors who received demonstrations of the tracker include: 56 faculty and students from five universities, 33 professionals working in the computer science industry, and five journalists (see DoD Interactions, below).

Protocol Analysis Tools/Collaboratory

We have demonstrated the tools being developed with support from ONR to numerous visitors to our TextLab. These include groups from the Army Research Institute, IBM, Fujitsu, and several Universities including Carnegie-Mellon, University of Colorado, and the University of Michigan.

SoftLab

SoftLab serves as an agent of technology transfer for research software developed within the Department. SoftLab's software packaging and distribution methodology is called "productizing" and includes steps such as reviewing and revision documentation, adding configuration control, versioning, preparing for remote installation, porting, licensing, and assembling distribution.

Software productized this year:

WE (Writing Environment) is a hypertext, graphic-based system, written in Smalltalk, and designed to help professionals write more effectively and efficiently.

Volume Rendering Data Sets, Vol I and II. The Volume Rendering data sets include medical and other image data sets as shown at the recent Volume Visualization Conference. This is SoftLab's first "visual data" product and represents an extension of the productizing process to include visual data sets in addition to more conventional software products.

Product Distributions/Inquiries, October 1989—August 1990:

PRODUCT	ACADEMIC Outstanding Inquiries:	ACADEMIC Purchases:	COMMERCIAL Outstanding Inquiries:	COMMERCIAL Purchases
Chapel Hill Volume Rendering Test Dataset, Volume I	10	8	4	6
Chapel Hill Volume Rendering Test Dataset, Volume II	7	5	3	3
Research Team plans a Volume III to be released after this year's Visualization Conference.				
COOL, 1.0	19	3	36	0
IDL Toolkit *Now distributed by UniPress Software, Inc.*				
MAXL, 2.0 *Still under technical productization—bug to be fixed.*				
RSpace, 1.3	5	4	4	0

Total number of purchases also reflects customers that had beta or 1.1 versions upgraded to Version 1.3 in August, 1989. Customers who purchased Version 1.3 prior to March, 1989 were sent documentation packages only and are not included in these figures. The recent release of an article written by the original developers is currently generating new interest and more inquiries. Plans for new development have recently been discussed for enhancements that have been made. Numbers in parentheses indicate purchases made prior to March 1989.

B. DoD Interactions

Pixel-Planes, Walkthrough, Head-Mounted Display, Tracker

China Lake. Warren Robinett has contacted Bob Westbrook of the Naval Weapons Center to find out if the Navy makes a lightweight inertial tracker that our Department can purchase. He also plans a trip to China Lake this fall.

C^2 Symposium. Ralph Mason attended the Symposium on Command and Control Research from 12-14 June 1990. A Trip Report has been appended to this report.

ARI Visitors. On 13 June 1990, Owen Jacobs , Ed Johnson, and two other guests saw the Tracker, Head-Mounted Display, and Walkthrough demos, and visited our Microelectronic Systems Lab (PxPl and Tracker).

Trip to ONR/NRL. On 14 May 1990, David Richardson of Duke University (Visiting Assoc. Professor in our Dept during FY89-90) visited with Richard Miller of ONR, and Richard Gilardi of NRL. A Trip Report has been appended to this report.

ONR Visitor. Ralph F. Wachter of ONR visited our Graphics Lab during 19-20 April 1990; a Visit Report has been appended to this report.

NRL Visitors. On 8-9 November 1989, Daniel Steiger and Lawrence Rosenblum of the Marine Systems Branch, NRL, visited our Graphics Lab. Demos: PxPl, Tracker, Head-Mounted Display, and Volume Visualization. Substantial technical and general discussions were held. A Visit Report has been appended to this report.

Air Force Visitors. On 16-17 October 1989, Jerry Myers and Jerry Covert of Wright-Patterson Air Force Base visited our Graphics Lab. Demos: PxPl, Head-Mounted Display, Wallkthrough, and Avionics. Phil Amburn from Wright-Patterson Air Force Base visited on 5 April 1990: Demos: Head-Mounted Display.

Visiting Scientists to Chapel Hill. During the August-September 1989 ONR site visit at UNC-CH, Fred Brooks invited ONR/NRL scientists (or their representatives) to spend a week or more here at UNC-CH.

Head-Mounted Display

NTC. David Fowlkes of the Navy Training Center, Orlando, Florida, has been discussing with Warren Robinett the possibility of using our head-mounted display system in his training programs.

NRL Visitors. Russ Eberhart and Doug Stetson from NRL saw HMD demos on 4 June 1990.
(See above)

Protocol Analysis Tools

For this project, principally those visits described under Section 4-A.

SoftLab

We recently acquired Jim Purtillo's version of NewYacc, courtesy of Ralph Wachter. SoftLab has set up a public area where software privately acquired but of general interest can be placed for access by others. NewYacc was installed here and publicized by a graduate student volunteer.

All

On 25-26 September, the ONR site visit team heard technical presentations and saw demonstrations on Head-Mounted Display, Tracker, Pixel-Planes 5, Walkthrough, Protocol Analysis Tools/Collaboratory, and Data-Parallel Execution (see Appendix for complete agenda). Visitors included:

Mr. Peter F. Brown, Mechanical Engineer, NIST
Dr. Susan Chipman, Program Manager for Cognitive Science, ONR
Dr. Christoph M. Hoffmann, Professor, Computer Science, Purdue
Dr. William E. Isler, Asst. Dean for Research, College of Engineering, NC State University
Dr. Richard Miller, Chief Scientist, Mechanics Division, ONR
Dr. Ralph F. Wachter, Scientific Officer, Computer Science Division, ONR
Mr. Stanley H. Wilson, Consultant, Information Technology Division, NRL

SECTION 5: Software and Hardware Prototypes during this reporting period

Principal Investigators:	Frederick P. Brooks, Jr. Donald F. Stanat Stephen F. Weiss
PI Institution:	The University of North Carolina at Chapel Hill Department of Computer Science
PI Phone Numbers:	919/962-1931 919/962-1788 919/962-1888
PI E-mail Addresses:	brooks@cs.unc.edu stanat@cs.unc.edu weiss@cs.unc.edu
Contract Title:	The Infrastructure of Command Information Systems
Contract Number:	N00014-86-K-0680
Reporting Period:	15 September 1989 through 14 September 1990

Pixel-Planes

See Section 2.

Walkthrough

We have built no hardware.

Our software system prototype was first built on and for UNC's Pixel-Planes 4 machine. As indicated under Transitions, 4A above, we furnished it to Silicon Graphics, who have ported it to their equipment. They will not sell it, but will use it for demos. We will provide it to their users who ask for it. No commercial sales are planned.

Protocol Analysis Tools

- A prototype environment for managing large numbers of machine-recorded protocols, described in Section 2, above.
- A prototype system to coordinate multiple protocol streams, as described in Section 2, above.

SoftLab

MAST860, the microcode preprocessor for the Intel i860 chip described in Section 3 above, was recently completed in prototype form and is being used and evaluated by the Pixel-Planes 5 research team. We have also been asked for a review copy of this preprocessor by Intel. No commercialization has occurred to date but eventual productization of this software is planned pending the availability of staff. Commercialization is also a possibility.

Software for the UNIX phone switch driver and the associated phone system enhancement application programs is being made available to Intecom Inc, the manufacturer of our phone switch, as per previous agreement. At present, we do not plan to commercialize this software ourselves.

ANNUAL REPORT

15 September 1988 through 14 September 1989

Y3

The Infrastructure of Command Information Systems

Submitted to

Office of Naval Research
Arlington, VA 22217-5000

Submitted by

Department of Computer Science
The University of North Carolina at Chapel Hill
Sitterson Hall
Chapel Hill, NC 27599-3175

Principal Investigators:

Frederick P. Brooks, Jr.
Donald F. Stanat
Stephen F. Weiss

NOVEMBER 1989

Contract No. N00014-86-K-0680

TABLE OF CONTENTS

1 INTRODUCTION 1

1.1 Command Information Systems 1
1.2 Overall scientific goals during this reporting period 1
1.3 Overall plans for FY89-90 1
1.4 Meetings 2

2 ORGANIZATION OF REPORT 2

3 RESEARCH PROJECTS 2

3.1 Communications 2
3.1.1 Integrated Network Management System 2
3.1.2 Workshops, Symposia 3

3.2 Processing Technologies 3
3.2.1 Curved Surfaces and Enhanced Parallelism in Pixel-Planes 3
3.2.2 Compiling Data-Parallel Languages for SIMD Execution 7
3.2.3 CLOCS—Computer for Low Context Switch Time 7

3.3 Database Technologies 8
3.3.1 Temporal Database—Final Report 8
3.3.2 Full-Text Retrieval: An Expert System for Searching in Full Text 9

3.4 Display and Interaction 10
3.4.1 Head-Mounted Display 10
3.4.2 A Real-time 3D Position Tracker for Head-Mounted Display Systems 11
3.4.3 Walkthrough 12
3.4.4 Protocol Analysis Tools 13

4 MANAGEMENT, PERSONNEL, TRAVEL, EQUIPMENT 13

4.1 Management 13
4.1.1 ONR-URI Executive Committee 13

4.2 Personnel 14
4.2.1 Director of SoftLab 13
4.2.2 Technical Liaison 14
4.2.3 Fellows 14
4.2.4 ONR Participants 14

4.3 Travel 14
4.3.1 Interaction with the Navy 14

4.4 Equipment Report 15

5 DEPARTMENT INFRASTRUCTURE 15

5.1 SoftLab Software Systems Laboratory 15
5.2 Computer Services 17
5.3 Communications 18

APPENDICES

I .....Project Narratives, Copies of Foils

II .....Comprehensive Bibliography

III .....Participants

IV .....Travel/Visit Report

V .....Equipment Report

VI .....Current Contracts, Grants, Gifts

VII .....2nd Annual Triangle Telecommunications Symposium

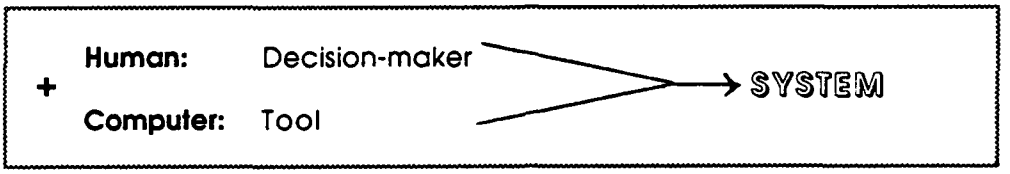
VIII .....ONR Site Visit

IX .....Miscellaneous Department News

1 INTRODUCTION

1.1 Command Information Systems

Year three of the five-year ONR contract has proven to be very successful as we continue our coordinated research efforts aimed at investigating fundamental issues in technologies associated with Command Information Systems (see Figure 1), systems in which the **human** decision-maker plays a crucial role:



Research at The University of North Carolina at Chapel Hill in real-time interactive graphics has and will continue to provide the basis for much of the work for the ONR contract. With ONR support, the three flagship projects of the Department have progressed substantially:

- Head-Mounted Display and Tracker
- Walkthrough
- Curved Surfaces and Enhanced Parallelism in Pixel-Planes

Also making good progress are investigators supporting research that concentrates on providing suitable databases and retrieval systems for decision support, and those working in the area of parallel computing and languages:

- Temporal Database
- Full-text Retrieval System
- Expression Languages (currently funded under a separate ONR contract)
- CLOCS—Computer for Low-Context Switch Time

as well as in the area of communications:

- Integrated Network Management System

1.2 Overall scientific goals during this reporting period

To investigate fundamental issues in technologies of Command Information Systems, particularly:

- human-computer interfaces
- text and temporal databases
- computer languages and architectures

Objectives:

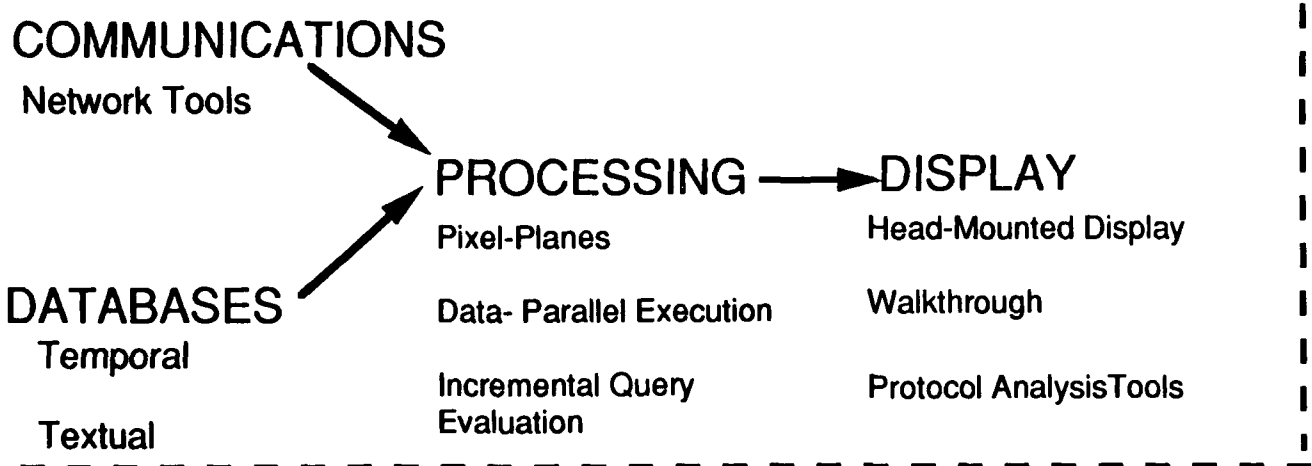
- Interactive storage, processing, and display of information for the support of decision-making.
- Training

1.3 Overall plans for FY89-90

- Main focus: human-computer interaction
  - Head-Mounted Display and Tracking (Brooks, Fuchs)
  - Walkthrough (Brooks)
  - Protocol Analysis Tools (Smith, Weiss)
- Other projects:
  - Pixel-Planes 5
  - Network Tools (through December 1989; see Section 3.1.1 below)
- Collaboration with NRL and HCI in interface technology
- ONR Fellows (see also Section 4.2.1)
  - CLOCS (Mark Davis)
  - Pixel-Planes 5 (David Ellsworth)

Information Display for Decision Making

TECHNOLOGIES FOR COMMAND INFORMATION SYSTEMS



OBJECTIVES:

- Interactive storage, processing, and display of information for the support of decision- making.
- Training

APPROACH:

Development of generalizable techniques

in application-driven projects,

tested by real users on real problems.

'88-'89 ACCOMPLISHMENTS:

Prototypes

Head-Mounted Display

Tracker System

Walkthrough System

TempIS Temporal Database System

Full-Text Retrieval System

Pixel-Planes 5(*progress)*

Department Infrastructure

CS Building Communications Networks

SoftLab Software Systems Laboratory

Tools Built

MAXL

FIGURE

1.4 Meetings

We continue to meet every several weeks in order to maintain a central focus and to provide an opportunity for mutual cooperation and interaction among the project participants. At each meeting, two or three project coordinators present their respective progress reports, both in written and verbal format.

The ONR-URI Executive Committee meets several times each year as needed to discuss overall directions of the research program, budgetary and financial matters, and other administrative items.

2 ORGANIZATION OF REPORT

Section 3 provides an overview of progress and plans for each of the projects receiving ONR support during this reporting period. Management, personnel, and travel discussions are presented in Section 4, and Section 5 provides a look at the Department's infrastructure. The **appendices** include: project narratives; a comprehensive bibliography (copies of publications and technical reports, relating to currently-supported research and written since the April 1989 Semi-annual report, are being mailed under separate cover); a list of participants; a travel report (see also Section 4.3); equipment reports; other sponsored research; program and abstracts from the *Second Annual Triangle Telecommunications Symposium* held on 17 Oct. 1988; site visit documents (see also Section 4.3.1); and finally, copies of our Spring and Fall '89 Newsletter—*News and Notes from Sitterson Hall.*

3 RESEARCH PROJECTS

A brief synopsis of research funded during this reporting period is presented below; Appendix I includes additional narratives and/or copies of presentation foils (used during Aug.-Sept. site visit) for the projects; also, kindly refer to copies of publications and technical reports, under separate cover.

3.1 Communications

3.1.1 Integrated Network Management System (Stephen F. Weiss, coordinator; report by John Menges, RA)

Other participants:

Other: Pat Richardson (collaborator, MCNC)

Objective:

The objective of this project is to design and implement an Integrated Network Management System (INMS) suitable for the proper management of the North Carolina (MCNC) Data Network. This INMS is being designed to address the network management requirements of all the component networks (including AppleTalk, Ethernet, and IBM Token Ring) and all the protocols (including TCP/IP, AppleTalk, DECnet, and XNS) used on the MCNC data network. It is also being designed so that it integrates well with the current and planned DARPA Internet network management systems.

The INMS will consist of three major components. The first is Simple Network Management Protocol (SNMP)-based network management system designed to collect information from and control network nodes, particularly network interconnection nodes. The second component is a set of network monitors for the various network types, implemented in software to run on a large proportion of the general-purpose computers attached to these networks. Third, there will be a handbook consisting of a user manual for the INMS and protocol descriptions, including packet formats, protocol sequences, and timing constraints covering most of the protocols seen on our networks.

Significant progress during reporting period:

- Completed QUIP (Query Using Internet Protocol) query/response access mechanism for IB, Vitalink, and LANmark bridges.
- Completed production SNMP proxy agent for IB bridges.
- Acquired SNMP library routines and client programs from various sources and integrated them with our proxy agent.
- Acquired Kinetics AppleTalk/Ethernet gateway SNMP agent code.
- Completed first draft of a paper (Master's thesis) describing our INMS system.

Plans for next reporting period: (through December 1989*)

- Completion of Master's thesis describing INMS system.
- Completion of Vitalink and LANmark drivers for SNMP proxy agent.
- Productizing and distribution of QUIP and SNMP proxy agent.

*As of December 1989, Menges will have completed his Master's thesis.

(See also Appendix I)

3.1.2 Workshops, Symposia

The Department continues to organize workshops and conferences on communications. On 17 October 1988, the second annual tutorial workshop was held: *Telecommunications Symposium on Image Handling*, sponsored by UNC-Chapel Hill, NC State University, ONR, IBM, and Bell Northern Research. Approximately 70 participants from the Triangle, as well as from Oregon, Texas, Virginia, Delaware, and New Jersey, were in attendance. A copy of the announcement, the revised program, and speaker abstracts are included as Appendix VII.

3.2 Processing Technologies

3.2.1 Curved Surfaces and Enhanced Parallelism in Pixel-Planes (Henry Fuchs, coordinator and PI)

Other participants:

Faculty: John Poulton (PI and project manager), John Eyles (senior engineer)
Staff: Trey Greer, Laura Israel Weaver, and Steve Molnar (research engineers) (Molnar IBM fellow FY89-90); Edward Hill (applications programmer)
RAs: Mike Bajura (MCNC fellow), Andrew Bell, David Ellsworth (ONR fellow, spring & fall 1989; FY89-90), Howard Good, Victoria Interrante, Jonathan Leech, Ulrich Neumann, John Rhoades, Brice Tebbs, Russ Tuck, Greg Turk (IBM fellow FY89-90)

Objective:

To create high-performance, 3D graphics systems that harness the highly parallel computation power of custom VLSI circuits; to make this power available in open, programmable systems that encourage invention of new parallel algorithms; and to lead and encourage the development of graphics algorithms for these parallel systems.

Significant progress during reporting period:

Hardware

The research team continues to work on the design for Pixel-Planes 5 (Pxpl5), the next generation Pixel-Planes system. Specific progress for this reporting period is itemized below:

- Custom ICs
  - Corner Turner Chip—Steve Molnar finished the design of this chip in Feb. 1989. The chip is a >33MHz design, and has 26,338 transistors. Prototypes were received in April 1989 and worked at full speed during testing.

  - Enhanced Memory Chip—This chip has 417,000 transistors and was designed to run at a speed of >40MHz. The design by John Poulton and John Eyles was completed in May 1989. Prototype chips were fabricated and tested, and they worked at the appropriate speed. Quantity fabrication of this chip is currently in progress.
  - Image Generation Controller Chip—Design by Poulton and Eyles was completed in July 1989 and was sent out for fabrication. This chip is a >40MHz design with 126,000 transistors. Prototype parts are expected to arrive in November '89. Only one part is required for each renderer circuit board in the Pxpl5 system, so no quantity fabrication or wafer probing will be required.
- Host Interface Logic Design—Laura Weaver finished the host interface logic design and is currently beginning the printed circuit board design.
- Frame Buffer—Laura Weaver has virtually completed the logic design for the frame buffer.
- Ring Network—The logic design for the ring network has now been completed, and the printed circuit board design is underway.
- Graphics Processor—Steve Molnar is working on the board design for the graphics processor, and this is about 50 percent completed. We expect this design to be completed by spring 1990.
- Back Plane Design—This has been sent out for fabrication.
- Power Cooling and Mechanicals—These designs are well underway.

Software (Pixel-Planes 5)

- Porting Base—A testbed system that allows Pxpl5 software to be simulated on a UNIX system. This system became functional during the past year. Problems with synchronization were corrected, and enhancements were made to improve significantly the speed and accuracy of the hardware simulation.
- Ring Operating System—was written and tested. This is the lowest level of software, primarily handling message passing among the hardware components: Host, Graphics Processors, Renderers, and Frame Buffer. The Porting Base system was used as a test environment. No significant changes were made since the last reporting period (ending in April '89). Some maintenance changes were needed to track changes to the porting base, and these have been made.
- Render Control—This system was designed in detail, and a simplified version was coded and tested. This software component manages the rendering process by coordinating the GPs and Renderers during the rendering of a frame. The simplified version does not attempt to overlap rendering of multiple frames. Since April this system has been upgraded to add some new functions: antialiasing, refinement, and multipass transparency.
- Rendering Library—A set of subroutines for rendering specific graphical objects. During the first part of FY88-89, the routines for generic polygons, spheres, and triangle strips were coded in the C language and tested. Since April, enhancements were made to perform antialiasing, multipass transparency, and a more elaborate shading model. Multiple colored lights and Phong shading are now supported. Code was added to sort primitives into bins corresponding to screen regions.
- PPHIGS—During the past year, a subset of the Pxpl PHIGS-compatible library was written and tested. This software is the primary programming interface for Pxpl users. Since April, most of the functions of PPHIGS have been completed. Improved distribution of the database to the GPs is now working.
- Textures—Algorithms were developed for rendering procedural and image textures. An implementation plan for including textures in the integrated software system was produced and reviewed.
- Integration of the Software—All the software was integrated to create a complete rendering pipeline. A number of fairly complex images and some film loops were created to test the pipeline. The integrated system does have some bugs that cause occasional failures when running concurrently on several UNIX systems.
- Intel i860 System—An i860 development system was acquired from Intel to write and test microcode for the graphics processors. Some small test programs were developed in order to help learn how to program this processor.
- Technical Reports—Two technical reports by members of the Pixel-Planes team are in progress:
  - Tebbs, Neumann, Turk, and Ellsworth. "Using Deferred Shading to Accelerate High-Quality Rendering."
  - Ellsworth, Good, and Tebbs. "Distributing Display Lists on a Multicomputer."

Pixel-Planes 4

Pixel-Planes 4 continues to serve as the principal display device for most of the interactive 3D projects in our Graphics Lab—Head-Mounted Display, Walkthrough project, etc—and applications programs are now being written by members of those teams. The hardware is being maintained by Graphics Lab personnel. To date, only about 8-to-10 memory chips have had to be replaced. A board to allow stereo display by two separate video streams (for use in head-mounted display) has been designed by Ulrich Neumann and built by David Harrison, a Graphics Lab staff member. This board is currently being debugged.

Although the project research assistants now devote most of their time to development of the Pixel-Planes 5 software, some work is still being done on software for Pixel-Planes 4. During this reporting period, this system was upgraded to run the X11 windows system, and the front-end display program (XFront) was upgraded to operate with X11. Several minor bug fixes and enhancements were made in support of application users in the Department.

Other

Grant proposal preparation—Vernon Chi, Henry Fuchs, and Julian Rosenman (joint appointments in the Departments of Radiation Oncology and Computer Science) are working on a grant proposal jointly with Bell Northern Research, the Microelectronics Center of North Carolina (MCNC), GTE, and Bell South to demonstrate an application of Pxpl5 using gigabit networking. A site visit including representatives from the National Science Foundation took place in October 1989.

Plans for next reporting period:

Hardware

- We are attempting to accelerate our production schedule so that a system with frame buffer and graphics processors running on a ring will be operational by early January 1990 and a full system will be operational by late March 1990.

Software

- Textures will be implemented and integrated into the rendering pipeline using the Porting Base. Both procedural (Gardner) and image textures will be supported.
- Multipass transparency will be integrated into t' e software system.
- Improvements to the database distribution in PPHIGS will be made.
- The rendering software will be ported to the Pixel-Planes 5 hardware, and the time-critical parts of the system will be microcoded. This includes primarily the Rendering Library routines and display list traverser. In all, about five percent of the C code will be converted to microcode. The software will be tuned to achieve the performance goals of the project.

Related publications and technical reports of this reporting period:

Ellsworth, David. "Pixel-Planes 5 Rendering Control," technical report TR89-003, Department of Computer Science, UNC at Chapel Hill (in press).

Fuchs, Henry, John Poulton, John Eyles, Trey Greer, Jack Goldfeather, David Ellsworth, Steve Molnar, Greg Turk, Brice Tebbs, and Laura Israel. "Pixel-Planes 5: A Heterogeneous Multiprocessor Graphics System Using Processor-Enhanced Memories," *Proc. SIGGRAPH '89*, Boston, MA, 31 July - 4 Aug. 1989; in *Computer Graphics*, 23(3), Aug. 1989, New York: ACM SIGGRAPH, 1989, 79-88. (See TR89-005)

Fuchs, Henry, John Poulton, John Eyles, Trey Greer, Jack Goldfeather, David Ellsworth, Steve Molnar, Greg Turk, Brice Tebbs, and Laura Israel. "Pixel-Planes 5: A Heterogeneous Multiprocessor Graphics System Using Processor-Enhanced Memories," *Proc. SIGGRAPH '89*, Boston, MA, 31 July - 4 Aug. 1989; in *Computer Graphics*, 23(3), Aug. 1989, New York: ACM Siggraph, 1989, 79-88.. (See TR89-005)

Goldfeather, Jack, Steven Molnar, Greg Turk, and Henry Fuchs. "Near Real-Time CSG Rendering Using Tree Normalization and Geometric Pruning," *IEEE Computer Graphics and Applications*, 9(3), May 1989, 20-28. (See TR88-006)

Goldfeather, Jack. "Progressive Radiosity Using Hemispheres," technical report TR89-002, Department of Computer Science, UNC at Chapel Hill, Feb. 1989.

Levoy, Marc. "Rendering Mixtures of Geometric and Volumetric Data," technical report TR88-052, Department of Computer Science, UNC at Chapel Hill, Dec. 1988.

Molnar, S., and H. Fuchs. "Advanced Graphics Architecture," to appear as Chapter 18 in *Computer Graphics: Principles and Practice*, Foley, J., A. van Dam, S. Feiner, and J. Hughes, Addison-Wesley, Reading, MA, 1990.

Molnar, Steven and Mark C. Surles. "A Microprogramming Support Tool for Pipelined Architectures," *MICRO 21: Proc. 21st Annual International Workshop on Microprogramming and Microarchitecture*, San Diego, CA, 2 Dec. 1988, 108-110.

Molnar, Steven. "Combining Z-buffer Engines for Higher-Speed Rendering," *Proc. Eurographics '88 3rd Workshop on Graphics Hardware*, Nice, France, Sept. 1988.

Tuck, Russ. "An Optimally Portable SIMD Programming Language," *Proc. Frontiers '88: 2nd Symposium on the Frontiers of Massively Parallel Computation*, George Mason University, Fairfax, VA, Oct. 1988, IEEE Computer Society Press, Feb. 1989, 617-624. (See also TR88-048)

Tuck, Russ. "Porta-SIMD User's Manual," technical report TR89-006, Department of Computer Science, UNC at Chapel Hill, Jan. 1989 (revised March 1989).

Related presentations in this reporting period:

By: Henry Fuchs
Topic: "An Interactive Display for the 21st Century: Beyond the Desktop Metaphor."
Event: Keynote address at the Computer Graphics International '89 conference
Place: Leeds, UK
Date: 27-30 June 1989

By: Steven Molnar
Topic: Combining Z-buffer Engines for Higher-Speed Rendering
Event: Eurographics '88 Third Workshop on Graphics Hardware
Place: Nice, France
Date: Sept. 1988

By: John Poulton
Topic: "Pixel-Planes 5: A Heterogeneous Multiprocessor Graphics System Using Processor-Enhanced Memories"
Event: SIGGRAPH '89 conference
Place: Boston, MA
Date: 31 July - 4 August 1989

By: Mark C. Surles
Topic: A Microprogramming Support Tool for Pipelined Architectures
Event: 21st Annual Workshop on Microprogramming and Microarchitecture
Place: San Diego, CA
Date: Nov. 1988

By: Russ Tuck
Topic: An Optimally Portable SIMD Programming Language
Event: Frontiers '88 Second Symposium on the Frontiers of Massively Parallel Computation, jointly sponsored by NASA/Goddard Space Flight Center and the IEEE Computer Society
Place: George Mason University, Fairfax, VA
Date: 10-12 Oct. 1989

(See also Appendix I)

3.2.2 Compiling Data-Parallel Languages for SIMD Execution (Jan F. Prins, coordinator)

Other participants:

RAs: John A. Smith, D. Poirier (Merit Assistantship)

Objective:

To identify the components of a high-level programming language that promote the expression of data-parallelism and to investigate their compilation for efficient execution on massively-parallel SIMD architectures.

Significant progress during reporting period:

- Acquisition and installation of two second-generation data-parallel programming languages: Q'Nial and APL*PLUS.
- Analysis of BLITZEN (prototype SIMD machine) architecture and data-movement techniques.
- Detailed description of project aims and proposed work submitted to ONR for consideration as a separate contract. (see below)
- Identification of a subset of data-parallel operations that can be compiled to use efficient data-movement operations in execution.

Plans for next reporting period (through March 1990):

- Description of a data-parallel programming language (DPPL) and subset language (DPSL).
- Movement generator for DPSL on torus-connected SIMD machine.
- DPPL development of Bitonic Sort Algorithm for SIMD execution.

Related presentation in this reporting period:

By: Jan Prins
Topic: Compiling Programs for Parallel Execution
Event: Department research colloquium
Place: Department of Computer Science, UNC-Chapel Hill
Date: 9 Nov. 1988

This project was presented to the Office of Naval Research as a candidate for support independent of the URI grant in a proposal dated December 1988. The proposal was approved for the period 3/15/89 - 3/14/90 and is supported under ONR contract N00014-89-J-1873; a project report is included here because it was started under URI support and falls under the more general umbrella of ONR-sponsored research at UNC-Chapel Hill.

(See also Appendix I)

3.2.3 CLOCS—Computer for Low Context Switch Time (Donald F. Stanat, coordinator; report by Mark Davis, ONR fellow)

Other participants:

Faculty: Frederick P. Brooks, Jr., advisor

Objective:

The Computer for Low Context Switch Time (CLOCS) project will design a computer architecture that can support applications needing many independent, rapidly switching tasks. To achieve fast context switching, the CLOCS architecture eliminates some levels of memory hierarchy, including registers and cache. As a result, all instructions are memory to memory. The CLOCS architecture supports modern operating systems and virtual memory in order to provide a reasonable development platform for systems. Otherwise, the architecture is quite simple to ease the task of demonstrating the capabilities of the concept. This architecture is well suited for hard-real-time applications.

Significant progress during reporting period:

- CLOCS architecture simulator completed.
- Architecture definition modified to improve performance of selected benchmarks (see Appendix I).
- Previous C Language Compiler discarded because of inefficient optimization.

- GNU C Language Compiler ported to CLOCS architecture.
- Improvements to GNU C Compiler accepted by Compiler authors.
- Assembler and simulator modified for architecture changes.
- Simulator reimplemented to improve performance.

Plans for next reporting period:

- Run benchmark programs.
- Analyze project results.

Related presentation in this reporting period:

By: Mark Davis
Topic: 1) The Penalty of Context Switch Time in Distributed Computing;
2) The Computer for Low Context Switch Time
Place: Communications Products Division, IBM, Research Triangle Park, NC
Date: 21 July 1989
Note: Mention was made of ONR's support of this research through his fellowship.

(See also Appendix I)

3.3 Database Technologies

3.3.1 Temporal Database—Final Report (Richard Snodgrass, coordinator)

Other participants:

RAs: Debashish Chatterjee (NCR Assistantship), Robert Stam

Objective:

A temporal database management system (TDBMS) by definition must support both transaction and valid time. This project involves developing a formal model of temporal information and implementing a prototype TDBMS to investigate issues of performance and functionality. Now that the formal model is in good shape, we have during the past year started focusing on the substantial implementation issues.

Significant progress during reporting period:

- TQuel prototype based on Version 8 Ingres is now fairly complete. It executes on Sun-3's and Vaxes (the original version of the prototype ran only on Vaxes). This prototype will provide a valuable baseline with which to compare functionality and performance of our new system, now under development.
- The second prototype, being built to explore incremental maintenance of materialized temporal views, is coming along nicely. We have completed lexical, syntactic, semantic analysis, and code generator phases for a significant subset of TQuel. The phases make heavy use of the Interface Description Language Toolkit, a programming environment developed during the past five years at UNC-Chapel Hill by Richard Snodgrass and students. The interpreter now executes the append, retrieve, and delete statements incrementally. A small set of queries/updates has been run through the entire system. View support is under development (interestingly, the interpreter is farther along than the rest of the phases). This prototype supports a main-memory database; the next prototype, termed TempIS, will be much larger, but will support disk-based data. We hope to build TempIS on top of an extensible DBMS such as Exodus or Genesis.
- The architecture for TempIS has been designed, and research issues concerning each component have been identified. We plan to focus on temporal partitioning and incremental view materialization to increase the performance of temporal queries. Both of these techniques involve fairly fundamental changes to the basic DBMS architecture, and thus require rethinking of many of the design decisions.

Plans for next reporting period:

There are no plans to continue this project under the ONR contract; Richard Snodgrass resigned from the Department to accept a position this fall in Computer Science at the University of Arizona at Tucson.

Related publications and technical reports of this reporting period:

Ahn, Ilsoo and Richard Snodgrass. "Performance Analysis of Temporal Queries," to appear in *Information Sciences: An International Journal*, (49)1, Oct. 1989, 44 pp.

Ahn, Ilsoo and Richard Snodgrass. "Partitioned Storage Structures for Temporal Databases," *Information Systems*, 13(4), Dec. 1988, 369-391.

McKenzie, E. and R. Snodgrass. "Schema Evolution and the Relational Algebra," to appear in *Information Systems*, 1989, 52 pp. (See TR87-003)

McKenzie, Leslie Edwin, Jr. "An Algebraic Language for Query and Update of Temporal Queries," Ph.D. Dissertation, UNC at Chapel Hill, Sept. 1988.

Stam, Robert B. and Richard Snodgrass. "A Bibliography on Temporal Databases," *Data Engineering*, 11(4), Dec. 1988, 53-61. (See TempIS Doc. No. 23)

Valiente, Juan A. "The Temporal Query Language TQuel: A Tutorial," TempIS Document No. 22, Department of Computer Science, UNC at Chapel Hill, 15 Dec. 1988.

(See also Appendix I)

3.3.2 Full-Text Retrieval: An Expert System for Searching in Full-Text (John B. Smith, coordinator; report by Susan Gauch, ONR fellow, fall 1988)

Objective:

The main focus of the full-text retrieval project is the development of an on-line search assistant using expert systems technology. Increasingly, information is available on-line in the form of full-text documents. However, people's abilities to search full-text databases vary greatly. The goal of this project is to provide an expert system so that users will need less training to find the information they seek.

Goals:

- Develop an expert system for query reformulation.
- Demonstrate that the query reformulation system improves search effectiveness for novice searchers.
- Demonstrate that the query reformulation system improves the efficiency for novice searchers.
- Demonstrate that the system can rank retrieved passages in decreasing order of relevance.

Significant progress during reporting period:

- Addition of the production rules for passage ranking to the expert system.
- Formatting of retrieved text.
- Completion of interactive and independent modes.
- Completion and testing of the expert system.
- Evaluation experiment with 12 subjects run.

Results:

- *Search effectiveness:* all three systems retrieved comparable numbers and produced comparable precision. No significant difference in effectiveness for the human user working alone, with the thesaurus, or with the expert system.
- *Search efficiency:* the expert system improved search efficiency in half the number of queries.
- *Ranking passages:* the expert system ranked relevant passages more highly than would be predicted by randomness.

Plans for next reporting period:

- Analyze experimental data.
- Write dissertation.

Gauch defended her dissertation in November 1989, and expects to complete the Ph.D. degree in December. The support she received through December 1988 allowed her to build the system and to make good progress toward the completion of her dissertation.

Related publications of this reporting period:

Gauch, Susan and John B. Smith. "An Expert System for Searching in Full-Text," to appear in *Information Processing and Management*, 1989.

Gauch, Susan and John B. Smith. "Query Reformulation Strategies for an Intelligent Search Intermediary," *Proc. Annual AI Systems in Government Conference*, Washington, DC, March 1989.

Related presentation in this reporting period:

By: Susan Gauch
Topic: Query Reformulation Strategies for an Intelligent Search Intermediary
Event: The Annual AI Systems in Government Conference
Place: Washington, DC
Date: 27-31 March 1989

(See also Appendix I)

3.4 Display and Interaction

3.4.1 Head-Mounted Display (Frederick P. Brooks, Jr., coordinator)

Other participants:

Faculty: Henry Fuchs, Vernon L. Chi
Staff: Warren Robinett (project leader since 1 September 1989), John Hughes (research associate)
RAs: Ron Azuma, William Brown, James Chung, Michael Kelley, Daniel Palmer, Jih-Fang Wang
Other: Michael Pique (collaborator, Scripps Institute)

Objective:

Dynamic interaction with a virtual world seen in stereo from a view based on user's head position.

Significant progress during reporting period:

- The new fiberglass head-mounted display came from the Air Force Institute of Technology. A third display came from VPL as a gift.

Plans for next reporting period:

- Rationalize the software and put under the Revision Control System.
- Set up tandard demos.
- Standardize the virtual world software base and data structure.
- Create several specific interesting or useful virtual worlds.
- Explore input devices and associated interaction techniques.
- Install sound, triggered by events in virtual world.

Related publication of this reporting period:

Chung, James C., Mark R. Harris, F. P. Brooks, Jr., Henry Fuchs, and Michael T. Kelley, John Hughes, Ming Ouh-young, Clement Cheung, Richard L. Holloway, and Michael Pique. "Exploring Virtual Worlds with Head-Mounted Displays," *Proc. SPIE Conference, Nonholographic True Three-Dimensional Display Technologies*, 1083, Los Angeles, CA, Jan. 1989. (Same as TR89-009)

Related presentation in this reporting period:

By: J. C. Chung
Topic: Exploring Virtual Worlds with Head-Mounted Displays
Event: Conference on Non-Holographic True Three-Dimensional Displays
Date: Los Angeles, CA
Place: 15-20 Jan. 1989

(See also Appendix I)

3.4.2 A Real-time 3D Position Tracker for Head-Mounted Display Systems (Henry Fuchs, coordinator)

Other participants:

Faculty: Vernon L. Chi, Gary Bishop, John Eyles, John Halton
RAs: Ron Azuma, Jih-Fang Wang

Objective:

Design and build a new real-time three-dimensional position and orientation tracking device for head-mounted display systems. The goal of this project is to come up with a product that provides a fast update rate (≥ 30 Hz), a large working volume (≥ 12' x 12'), high accuracy in the reported position and orientation, and immunity to environmentally induced disturbances. Furthermore, the tracker should be constructed from off-the-shelf components so that it can be easily duplicated.

The tracking system will consist of a cluster of three tiny cameras mounted on top of the helmet and a grid of hundreds or thousands of infrared LEDs mounted in the ceiling. Real-time position and orientation of the helmet is determined from the position on each camera's image plane of a flashed LED whose ceiling position is known.

Significant progress during reporting period:

Hardware:

- A proof-of-concept prototype was constructed. This prototype consists of three cameras, each using a lateral effect photodiode as the recording surface. A signal processing circuit was built to control the data acquisition and to filter out noises from the cameras. A parallel interface connects the prototype to a general-purpose computer for data analysis.
- A panel of a 4x4 grid of red LEDs was built. Address decoding circuitry was constructed to verify the ability of the system to select a particular LED.
- An optical mounting device was designed and built to position the prototype. Experiments were carried out to measure the accuracy of the prototype.

Software:

- A simulation program was developed to emulate the behavior of the system. Important design decisions were then made based on the simulation results.
- A device driver was written to allow the host computer to control the hardware functions.
- A novel method that calibrates automatically the positions of LEDs were designed and tested.
- A control program was written to direct the action of the prototype, and to integrate the whole system together.

Plans for next reporting period:

Hardware:

- Design LED circuitry. Since hundreds or even thousands of LEDs will be used in the final working system, how to place and address them efficiently is critical. We are currently planning to design 2'x2' circuit boards to mount the LEDs. The circuit boards can then replace the drop-in ceiling tiles.
- Design filter and lens assembly for outward-looking views. We plan to replace the current three-camera prototype with only one or two cameras, each with a multi-view port holographic lens. Such a lens can look into several widely separated directions simultaneously and reduce significantly the weight of the system.
- Rebuild the signal processing circuitry on a printed circuit board.

Software:

- Port the whole system to a faster workstation. Redesign the interface with the Pixel-Planes machine.
- Motion prediction.

(See also Appendix I)

3.4.3 Walkthrough (Frederick P. Brooks, Jr., coordinator)

Other participants:

Staff: John Hughes (research associate), David Lines (editorial assistant)
RAs: John Alspaugh, John Airey, Randall Brown, Curtis Hill, Penny Rheingans, John Rohlf

Objective:

Real-time, interactive graphics system for prototyping building architectures and similar structures. Hand controls and a steerable treadmill enable user to navigate within the structure; the image is updated in real time.

Significant progress during reporting period:

- Update rate:
  - Automatic partitioning with automatic visibility-set calculations yields correct images and an average 30-fold speed over naive use of Pixel-Planes 4. The current system now gives better than 15 updates/sec.
- Interface—flexible interface testbed:
  - joysticks—free and restricted
  - big screen—4 X 6 feet
  - treadmill
  - head-mounted display
- Radiosity lighting model:
  - seven-fold speed improvement over published algorithms through the use of adaptive sampling methods
  - development of an algorithm to filter finite-elements for smoother image
  - individual real-time control of lights
  - system adaptively refines from flat lighting to radiosity
- Model building:
  - AutoCad for building and importing models
  - model translator from AutoCad
  - model editing (for example, to reverse mal-oriented polygons)
  - furniture
  - lighting specifications

Plans for next reporting period:

- Update rate:
  - begin coding for PxPl5
- Interface:
  - interface comparison study with head-mounted display
  - dynamic objects: lights, doors, etc.
- Radiosity lighting model:
  - improve image quality/polygon ratio
  - incorporate specular reflection, mirrors
- Model building:
  - working with collaborating architects and start on a third building model

Related presentation in this reporting period:

By: Frederick P. Brooks, Jr.
Topic: "UNC Walkthrough," Course Notes for Course 29, *Implementing and Interacting with Real-Time Microworlds* (copy of slides in Appendix I)
Event: SIGGRAPH '89
Place: Boston, MA
Date: 31 July 1989

Related technical reports of this reporting period:

Airey, John M. and F. P. Brooks, Jr. "Walkthrough—Exploring Virtual Worlds: Second Annual Report," TR89-012, Department of Computer Science, UNC at Chapel Hill, Feb. 1989 (accompanying VHS videotape mailed to Ralph F. Wachter on 29 March 1989).

Airey, John, John Rohlf, and Penny Rheingans. Videotape: "The Virtual Lobby," *SIGGRAPH '89* Videonight, Boston, MA (sent to Ralph F. Wachter, Oct. 1989).

(See also Appendix I)

3.4.4 Protocol Analysis Tools [Newly funded project for FY89-90] (John B. Smith and Stephen F. Weiss, coordinators)

Other participants:

Faculty: Marcy Lansman (visiting research assistant professor)
Staff: Gordon Ferguson (research associate)
RAs: Murray Anderegg, Rick Hawkes

Objective:

Develop tools for understanding decision-making by individuals and groups working in a computer environment.

Plans for next reporting period:

- Develop tools for integrating machine-recorded protocols with think-aloud protocols.
- Develop tools for integrating protocols from individuals to form a protocol for the group.
- Develop tools for displaying, analyzing, and understanding integrated protocols.

(See also Appendix I)

4 MANAGEMENT, PERSONNEL, TRAVEL, EQUIPMENT

4.1 Management

Jeannie M. Walsh, administrative coordinator of the contract, continues to report to the Executive Committee (see below) and perform the necessary personnel, financial management, coordinating, and reporting duties. Laboratory and facilities management is the responsibility of the laboratory directors who report to Ralph A. Mason, associate chairman for administration.

4.1.1 ONR-URI Executive Committee

Stephen F. Weiss, appointed chairman of the Department as of 1 January 1989, has replaced J. Nievergelt as co-PI and will serve as committee chairman during FY89-90. Nievergelt has resigned from UNC-Chapel Hill, and is no longer associated with the contract. Henry Fuchs joined the committee during January 1989, while Frederick P. Brooks, Jr., Donald F. Stanat, and Ralph A. Mason continue to serve as members.

4.2 Personnel

4.2.1 Director of SoftLab

Susanna Schwab came aboard in June 1989 as research assistant professor and Director of SoftLab. Since 1 July, 10 percent of her salary has been paid by ONR funds. Please refer to Section 5.1 for a description of SoftLab's contribution to the project, and to the Department as a whole.

Dr. Schwab served as an assistant professor of computer science at the Illinois Institute of Technology, Chicago, and since 1978 has accrued additional experience as a technical manager and scientific staff member, switching systems, at AT&T Bell Laboratories. Among her many responsibilities at AT&T Bell Labs, Naperville, Illinois. Dr. Schwab managed a group of ten engineers responsible for the design and integration of test data for the system lab testing of the software to control the latest AT&T digital telephone switch; was responsible for quality certification and change control of successive official versions of software during entire development cycles; scheduled introduction of new software development tools; coordinated software packaging and helped coordinate problem resolution during site tests; and conceived, designed, and developed an automated system to facilitate parallel development of software releases. Dr. Schwab earned a Ph.D. degree in Math/Computer Science in 1976 at the University of Chicago.

4.2.2 Technical Liaison

We are pleased to announce that Warren Robinett, research associate and project leader, GRIP and Head-Mounted Display projects, has agreed to serve as technical liaison to ONR during FY89-90. Warren arrived at UNC-Chapel Hill on 1 September of this year. During his successful career as a software engineer/research scientist, he has conceived and implemented several commercially successful software products, and has 12 years of experience using C and Assembler to develop software products and design user interfaces based upon real-time interactive graphics. At the NASA-Ames Research Center, he designed and implemented the software for a head-mounted display system; designed a gestural language for an instrumented glove; and built a prototype head-mounted display using miniature CRTs. Warren holds an M.S. degree in computer science from Berkeley.

4.2.3 Fellows

Susan Gauch, ONR fellow during fall 1988, defended her dissertation in November 1989 (see Section 3.3.2). The vacancy created by her departure was offered to and accepted by David Ellsworth, a Ph.D. student working with Henry Fuchs on the Pixel-Planes project. Ellsworth continues as fellow during FY89-90.

Ph.D. student Mark Davis (a former naval officer) also continues as fellow during this academic year to work on the CLOCS project (see Section 3.2.3) under the supervision of Donald F. Stanat.

4.2.4 ONR Participants

Appendix III lists all participants during this reporting period.

4.3 Travel

Appendix IV provides a travel summary and supporting documents (see below) for this reporting period.

4.3.1 Interaction with the Navy

- NRL Project Review. On 13 October 1989, Frederick P. Brooks, Jr. was invited to attend the Review of Projects at the Human-Computer Interface Lab, Information Technology Division, NRL.

- Trip/Visit reports are included in Appendix IV for the following visitations:

  - 25 May 1989: Cdr. Rob Carter, Constance Heitmeyer, and Preston Mullen of the Information Technology Division of NRL visited the Graphics and Image Laboratory, Department of Computer Science, UNC-Chapel Hill.
  - 27-29 June 1989: Stephen F. Weiss attended the 1989 Joint Directors of Laboratories Symposium on Command and Control (C^2) Research at the National Defense University, Washington, DC.
  - 10-11 July, 1989: Donald F. Stanat attended the ONR-SEI Computer Science Workshop at Carnegie-Mellon University.

- Invitations extended during annual site visit on 31 August-1 September 1989 (*Status: pending*):

  - Ralph Wachter and Stanley Wilson of ONR and NRL, respectively, invited members of our Department to present their research at the NRL colloquia series, held at various Navy labs. Appendix IV includes four abstracts submitted (to date) to NRL on 2 October 1989.
  - Wachter and Wilson also invited interested graduate students to spend the summer of 1990 doing research at various Navy laboratories. Electronic news was posted in early October.
  - Members of the ONR-URI Executive Committee invited Ralph Wachter to solicit Navy personnel who might be interested in spending perhaps a semester working with our researchers on site here at UNC-Chapel Hill. Wachter indicated he would review applications and make a selection.
  - Richard Miller, Chief Scientist of the Mechanics Division, ONR, was unable to attend the site visit due to illness. Copies of materials distributed during the visit were mailed to him, and an invitation was extended to visit our facility at his convenience.

4.4 Equipment Report

Equipment reports for the first three years of the contract, along with a summary report, is attached as Appendix V.

5 DEPARTMENT INFRASTRUCTURE

5.1 SoftLab Software Systems Laboratory (Susanna Schwab, director)

Other participants:

Staff: Pamela Payne (secretary and SoftLab coordinator); Arie Trinker (research associate)
RAs: David Becker, Heng Chu, Charles Clark, Steve Tell, Chin Ho Yeh

Purpose:

SoftLab Software Systems Laboratory is an organization that provides the UNC-Chapel Hill Computer Science Department with software systems and manufacturing support services similar to those typically found in industry. As such, SoftLab serves as a software development resource for the Department and as an agent of technology transfer to other universities and to industry.

In addition, SoftLab facilitates rapid prototyping of novel architectures by developing drivers and interface software, by importing and integrating commercial software development tools, and by supporting an object-oriented programming environment.

Finally, SoftLab pursues an educational mission with emphasis in the areas of software engineering and development of software tools for laboratory use in computer architecture and operating system courses.

Significant progress: (Since January 1989--the inception of SoftLab)

- SoftLab has packaged and distributed the following products since it began operation in January of 1989:

	Purchased Licenses (or *Inquiries/Committed Customers)*		
PRODUCT	ACADEMIC	COMMERCIAL	Total Customers or *inquiries*
RSPACE (Reciprocal SPACE Modeling Tool)	27	17	44
IDL (Interface Description Language	33	24	57
COOL (Comprehensive Object-Oriented Library)	*17*	*29*	*46**
MAXL (Microcode Assembler for Weitek XL chip)	*0*	*2*	*2***

* *Customer inquiries (new product)*
***Committed customers (new product)*

- SoftLab has developed the following software products:
  - Device drivers for BLITZEN, a massively parallel, single instruction, multiple data machine being developed jointly between MCNC, UNC, NC State and DUKE University.
  - RCSM (Revision Control System Manager) , an enhancement to the UNIX configuration management tool RCS (Revision Control System) that increases its version management and status tracking capabilities.
  - MOSEL I (Modular Operating System Experimentation Laboratory), the first in a family of architecture and operating system experimentation tool sets that includes a hardware simulator and basic modular operating system. Later versions of MOSEL will include uni- and multi-processing operating systems and experimentation tools for monitoring and analyzing architecture and operating systems experiments. MOSEL can be used in a classroom setting or for rapid prototyping.
- As a secondary effect of the COOL productizing effort, SoftLab member Greg Bollella and faculty member James Coggins developed and published a novel way to manage large C++ libraries efficiently.
- Finally, SoftLab has acquired the following commercial tools:
  - Compiler construction: GLA, Lex, Flex, Alex, Yacc, Bison, Ayacc, GAG, CPS, ACK, GNU
  - Programming Tools: Eiffel

Plans for next reporting period:

- The following software is currently being productized:
  - WE (Writing Environment): A TextLab hypertext system for authors written in Smalltalk. It, together with MICROARRAS, a possible candidate for later productization, with form the basis for a full text retrieval system.
  - /usr/image: A graphics library for medical imaging.
  - /volume/rendering: Another library of graphics routines.
- We are also defining and implementing a procedure to productize data sets as well as programs. This procedure will be used to package and distribute the Volume Rendering data sets shown by Brooks at the Volume Visualization Workshop.
- SoftLab is developing the following software products:
  - OP860 - this is a microcode assembler for the Intel 860 chip. Pixel Planes is upgrading from the Weitek XL chip and OP860 will then replace MAXL. This tool will increase the efficiency of microcoding the I860 (a state of the art floating point chip) for graphics applications.
  - OAI UNIX Driver - OAI (Open Applications Interface) is a new feature for the Intecom telephone switch that serves the Computer Science Department. OAI will allow applications programs running on a host with a data link to the Intecom switch to interact with the switch. At present, Intecom supports the OAI feature only for VAX/VMS and IBM PC hosts. SoftLab will extend OAI features to a UNIX host in order to make the Intecom switch an effective test bed for department research in networking and telecommunications.
  - BLITZEN drivers - SoftLab will complete testing of BLITZEN device driver software and will begin work on applications programs.
  - MOSEL (Modular Operating System Experimentation Laboratory) - SoftLab will continue work on the MOSEL family. In particular, final debugging of the multiprocessing operating system will be done and work will start on the monitoring and analysis tools.
- Finally, SoftLab will continue work on establishing integration and support procedures for privately acquired but publicly used tools that lie beyond the scope of Facilities support. Currently, these tools include object oriented programming tools and text formatting software.
- SoftLab will begin planning work on interface software development for rapid prototyping. The VIEW project is an immediate customer for such interface software.

(See also Appendix I)

5.2 Computer Services (William Howell, director)

Significant progress during reporting period:

During this period, the computing requirements of our research work expanded beyond the capabilities of our 1- to 3-MIPS workstations (Sun-2, Sun-3, DEC GPX). In order to meet the needs of our research, it became necessary to acquire more powerful machines. During the first quarter, we acquired three RISC-based Sun-4 computers for specific research projects, including the Pixel-Planes front end, and the Molecular Modeling force-feedback control engine. In the second quarter, we conducted an extensive evaluation of the emerging breed of more powerful workstations; and in the third and fourth quarters, we ordered, received, and installed these new workstations.

Our evaluation resulted in the acquisition of 40 RISC workstations, primarily the DECstation 3100 and a few Sun SPARCstation-1 machines. These new RISC workstations all boast greater than 10 MIPS of performance, at least 12 megabytes of memory, a local 100 megabyte swap and temporary storage disk, and a color monitor. This configuration is a significant advance over our earlier workstations. We saw significant improvement in our computing productivity when we acquired our first workstations in 1984. We anticipate seeing as large an improvement in 1989 and 1990 with these second-generation machines.

We have ordered a DECsystem 5820 dual processor RISC-based machine that will act as our primary file and boot server for our fleet of DECstation 3100 workstations. The 5820 boasts nearly 40 MIPS of performance and has a high-speed I/O bus to support the large amount of disk space that we have on-line in support of our 3100 workstations. Until the 5820 arrives in early 1990, we are serving the 3100 workstations with a small number of DECserver 3100s that will later be converted to workstations and compute servers for specific applications.

The addition of some 30 Macintosh-II systems during this period brings our operating fleet of these personal workstations to over 100. Approximately 25 percent of the systems are used in educational laboratories, 25 percent in research laboratories, and the remaining 50 percent in supporting research roles, including drafting, design, project management, and document preparation. We have installed a Sun-3/280 file server, which will be upgraded to a 3/480 later this year, to support our fleet of Macintosh systems. We completed the hardware and software installation of this server and have centralized the accounts of our primary Macintosh users onto this machine. TOPS networki. g software is installed, and we are beginning to offer the ability to access all of our NFS-mounted file systems from the Macintosh workstations. A significant task remaining is to develop and deploy a backup mechanism for the Macintosh systems, as there are nearly 5 gigabytes of disk space across those systems.

With the addition of the RISC, UNIX, and Macintosh workstations, we were for the first time able to provide a workstation to every student who has passed the doctoral written examination. We predict that having convenient and consistent access to a personal machine will significantly increase the productivity of these key researchers and assist them to earlier completion of their degrees. We anticipate that over the next two-to-three years, we will be able to achieve a 1:1 ratio of workstations to students as we continue to bring in higher-end equipment and the older machines trickle down through the ranks.

A number of UNIX operating system upgrades were completed across our computing platforms, including the latest user interface offerings and a number of recent language releases. In order to utilize the latest enhancements and features in these foundation software products in our research, it is necessary to stay current with these releases. This is a significant undertaking requiring considerable man-hours of support staff, but it has proven beneficial in many areas of our research with payback far exceeding the costs of the upgrade work. In addition, we work closely with several vendors in the early stages of their development and are a frequent beta site, which gives us early opportunity to use many of the upcoming features and products.

The primary vision of our computing environment is to provide a fully integrated distributed computing environment. The advantages of distributed computing are widely known. It is now critical to reconnect those systems in an fully integrated fashion to realize the benefits of centralized computing layered across a distributed environment. These connections are accomplished at all levels, including networking, application software, and system software. During this period, we have undertaken a major expansion of our fiber-based Ethernet network. We are also actively evaluating high-speed bridging and routing equipment to span our many Ethernet subLANs. Included in this work is investigation into the use of FDDI as a backbone and high-speed communication network for our faster machines. We are moving forward to place larger numbers of Macintosh systems on the Ethernet network where they are capable of achieving higher performance. We have interconnected at a system software level, transparent to the researchers, all of our output devices so that it is now possible to get to virtually any output device from any of our computing systems. We are now acquiring software products that will help to harness the computing power of our workstations in a loosely coupled way for the distribution of processes to any available machine.

Plans for next reporting period:

During the next year, we will pursue five primary thrusts: 1) Continuation of our efforts to provide a consistent integrated computing environment across our distributed systems. 2) The addition of a massively parallel computing system to foster our research efforts in the development and application of such machines. 3) The investigation into optical storage technologies and how they can be implemented in our environment. 4) A continued expansion of our workstation fleet. 5) Implementation of higher-speed Ethernet subLAN bridging and routing.

5.3 Communications (Norman A. Vogel, director)

Other participants:

Staff: Steven Ornat (Televideo Communications Technician)
RA: John Menges

Significant progress during reporting period:

The InteCom Voice/Data switch and fiber optics-based Ethernet have been in continuous operation since "cut-over" on June 16, 1987. There have been no catastrophic failures; however, some parts of the system have had to be re-engineered because of the high performance requirement of our applications. The "soak test" was completed during April, 1988. We have acquired an Excelan Lanalyzer system used to monitor traffic on our Ethernet network and to assist in the location and diagnosis of problems on the network.

A Farallon AppleTalk/PhoneNet system that networks all Macintosh terminals and related laser printers has been operating extremely well. Three Kinetics bridges successfully interconnect PhoneNet to the Sitterson Hall Ethernet system. The installation of a twelve-channel Scientific Atlanta mid-split broadband system has been completed and is operating successfully. A three-meter Channel Master K_u/C Band satellite earth station and off-the-air antennas have been installed on the roof and coupled to the broadband system. Six stations of a twelve-station Token-Ring system have been installed. A Barco data video projection system has been installed on the ceiling of two classrooms, and another unit has been installed in rear-projection mode in our graphics lab. A FAX machine was installed in the Department and is operational 24 hours per day. Documents are received when sent to 919-962-1799.

Installations of a four-camera video classroom and an eight-camera teleconference facility are complete. A 10x20 RGBS (four cable per path) Dynair Switching system is being installed.

PC's have been equipped with TOPS cards and software and are attached to the Farallon PhoneNet system (Macintosh); we have attained fairly complete interconnectibility of all workstations in the building.

An Internet name server has been installed on our 4.3bsd VAXes and Suns, which allows smooth and efficient interconnection of our Department Ethernet with the rest of the Internet. Our software has been reconfigured to utilize the nameserver to its fullest. Nameserver applications have been expanded to Department Macintoshes.

During spring semester 1989, Fred Brooks conducted a three-credit-hour class entitled "Advanced Computer Architecture," which was carried not only to the usual MCNC microwave-supported sites but also to eight students at IBM via Instructional Television Fixed Service (ITFS) omnidirectional microwave.

A new software release for the Sitterson InteCom IBX switch brings with it an Open Application Interface (OAI) that will support direct attachment of external hosts to the call processing system of the IBX.

9600-bps modem service is now available for access to Sitterson Hall.

ANNUAL LETTER REPORT
FOR FISCAL YEAR 1987-88

Y2

The Infrastructure of Command Information Systems

Submitted to

Office of Naval Research
Arlington, Virginia 22217-5000

Submitted by

Department of Computer Science
The University of North Carolina at Chapel Hill
Sitterson Hall
Chapel Hill, North Carolina 27599-3175

Principal Investigators:

Frederick P. Brooks, Jr.
Jay Nievergelt
Donald F. Stanat

SEPTEMBER 1988

Contract No. N00014-86-K-0680

TABLE OF CONTENTS

1 Contract Title 1

2 Contract Number 1

3 Scientific Officer 1

4 Introduction 1

5 Scientific Goals, Significant Results, and Plans 1

5.1 Head-Mounted Display 2

5.2 Walkthrough 2

5.3 Pixel-Planes 5 Prototype 2

5.4 Temporal Databases 3

5.5 Full-text Retrieval 3

5.6 Tracking Machine 3

5.7 Expression Languages 3

6 Participants during FY 87-88 4

7 Other Sponsored Research 4

8 Electronic Mail Addresses: 4

Appendix I: Other Contracts and Grants during FY 87-88

Appendix II: List of Publications/Reports/Presentations

Appendix III: List of Awards

Appendix IV: Publications/Patents/Presentations/Honors Report

Appendix V: Four-part Foil and Project Foils, with Narrative

ANNUAL LETTER REPORT FY 87-88
ONR CONTRACT INFORMATION

1 Contract Title The Infrastructure of Command Information Systems

2 Contract Number N00014-86-K-0680

3 Scientific Officer Dr. Ralph F. Wachter, Computer Science Division, Office of Naval Research, 800 N. Quincy Street, Arlington, VA 22217-5000

4 Introduction

The ONR contract at the University of North Carolina is aimed at investigating fundamental issues in technologies associated with Command Information Systems. We are interested not in automatic systems, but systems in which the human decision-maker is a crucial part. Humans still excel in three kinds of processing:

- . pattern recognition
- . association of facts over a large context
- . judgments

while computers excel in:

- . data reduction
- . numerical calculation
- . high-volume data storage with precision

Good decisions require the use of both capabilities.

Research at the University of North Carolina in real-time interactive graphics is the basis for much of the work for the ONR contract. Three flagship projects of the Department have, with ONR support, progres ed substantially and continue to show exceptional progress:

- . Head-Mounted Display
- . Walkthrough
- . Pixel-Planes

Additional research concentrates on providing suitable databases and retrieval systems for decision support, and in the area of parallel computing and languages:

- . Temporal Databases
- . Full-text Retrieval System
- . Tracking Machine
- . Expression Languages

5 Scientific Goals, Significant Results during FY 87-88, and Plans for FY 88-89:

Overall goal: To investigate fundamental issues in technologies of Command Information Systems, particularly:

- . human-computer interfaces
- . text and temporal databases
- . computer languages and architectures

5.1 Head-Mounted Display:

Objective:

Dynamic interaction with a virtual world seen in stereo from a view based on user's head position.

Significant progress in the past year:

Improvements in speed, image quality, and user-control.
Integrated with Pixel-Planes graphics engine.
Integrated with Walkthrough prototype.

Plans for next year's research:

Increase tracking reliability.
Implement tracking in large spaces.
Improve usability and user-interface.
Further improve speed, image quality, and update lag.
Integrate with data glove.

5.2 Walkthrough

Objective:

Real-time, interactive graphics system for prototyping building architectures and similar structures. Controls enable user to navigate within the structure; image is updated in real time.

Significant progress in the past year:

Integrated with Pixel-Planes to increase update rate to 15 fps.
Integrated Head-Mounted Display with treadmill interface.
Converted model-building and model-maintenance systems to Autocad.
Developed a double-wall model of Sitterson Hall
Developed a double-wall model of a second building.

Plans for next year's research:

Develop other user interfaces, e.g., bicycle.
Develop radiosity and texture models for improved images.
Implement cellular model to improve speed.
Model a third building.

5.3 Pixel-Planes 5 Prototype

Objective:

Development of massively parallel high-speed graphics engine using smart memory chips and small-grain VLSI.

Significant progress in the past year:

Integration of Pixel-Planes 4 with Walkthrough and Head-Mounted Display prototypes.
Detailed design of Pixel-Planes 5.

Plans for next year's research:

Completion of Pixel-Planes 5 with 20X speedup using modified SIMD architecture with some MIMD capability for increased algorithm generality..
Develop algorithms for solid volume rendering.
Improve usability.

5.4 Temporal Databases

Objective:

Development of database system capable of handling queries for various time concepts, including temporal indeterminacy.

Significant progress in the past year:

Completion and evaluation of the initial implementation of TempIS (Temporal Information System) and its graphical user interface.

Plans for next year's research:

Implement second generation TempIS based on a newly designed incremental architecture.

5.5 Full-text Retrieval

Objective:

Integration of an expert system and field-specific thesaurus to permit economical search of full-text databases by unsophisticated users.

Significant progress in the past year:

Prototype expert system is complete.
Initial development of search strategies.

Plans for next year's research:

Refinement of search strategies.
Develop ranking system for responses.
Test system.

5.6 Tracking Machine

Objective:

Analysis of a tree architecture for tracking objects in multidimensional space.

Significant progress in the past year:

Simulation implementation on ADAS.

Plans for next year's research:

Refinement and testing of model.

5.7 Expression Languages

Objective:

Study of the linguistic basis for supporting scalable parallel architectures.

Significant progress in the past year:

Formulation of basic issues and concepts. Exploration of control vs. data parallelism.

Plans for next year's research:

Investigation of problems that can be programmed in a data-parallel language. Formulation of language constructs to support data parallelism.

6 Participants during FY 87-88:

ONR-URI Executive Committee:
Frederick P. Brooks*, Jr., Committee Chairman
Donald F. Stanat*, Technical Director
Jay Nievergelt*
Ralph Mason*

Other Faculty:
J. Dean Brock
Vernon L. Chi*
Peter Calingaert
James Coggins
Henry Fuchs*
Bharat Jayaraman
Gyula A. Mago'
David A. Plaisted
John Poulton*
Jan Prins*
John B. Smith
Richard T. Snodgrass*
Yuki Watanabe
Stephen F. Weiss

Vis. Faculty:
Hussein Abdel-Wahab

Staff:
Graham Gash, Software Manager*
Fred Jordan*, Electronics Technician
John Menges*, Communications Software Engineer
Steven Ornat*, Communications Hardware Technician
Raj Singh*, Project Management Engineer
Norman A. Vogel*, Director of Communications Research
Jeannie M. Walsh*, Administrative Coordinator
Sharon Walters*, Secretary (half-time)

RAs:
John Airey*
Edoardo Biagioni
Paulette Bush+
James Chung*+
Mark Davis* (Fellow FY 87-88, 88-89)
William Gallmeister+
Susan Gauch* (Fellow FY 88-89)
William Gibson+
Michael Kelley*
Marc Levoy (Fellow FY 87-88)
Richard Potter+
Penny Rheingans*
Frank Silbermann*
Robert Stam
Mark Surles
James Symon
Douglass Turner+

* *currently participating during FY 88-89*
\+ *M.S. Degree granted during FY 87-88*

7 Other Sponsored Research:

Other contracts and grants received by ONR participants during FY 87-88 are listed in Appendix I.

8 Electronic Mail Addresses:

Frederick P. Brooks, Jr. brooks@cs.unc.edu
Donald F. Stanat stanat@cs.unc.edu
Jeannie M. Walsh walsh@cs.unc.edu

Research Overview

Background:

The ONR contract at the University of North Carolina is aimed at investigating fundamental issues in technologies associated with Command Information Systems. We are interested not in automatic systems, but systems in which the human decision-maker is a crucial part. Humans still excel in three kinds of processing:

pattern recognition,
association of facts over a large context, and
judgments

while computers excel in:

data reduction,
numerical calculation, and
high-volume data storage with precision

Good decisions require the use of both capabilities.

Scientific Goals:

To investigate fundamental issues in technologies of Command Information Systems, particularly:

- human-computer interfaces
- text and temporal data bases
- computer languages and architectures

Projects:

Research at the University of North Carolina in real-time interactive graphics is the basis for much of the work for the ONR contract. Three flagship projects of the Department have, with ONR support, progressed substantially and continue to show exceptional progress:

Headmounted Display
Walkthrough
Pixel-Planes

Additional research concentrates on providing suitable data bases and retrieval systems for decision support, and in the area of parallel computing and languages:

Temporal Data Bases
Full-text Retrieval System
Tracking Machine
Expression Languages

The University of North Carolina at Chapel Hill

The Infrastructure of Command Information Systems

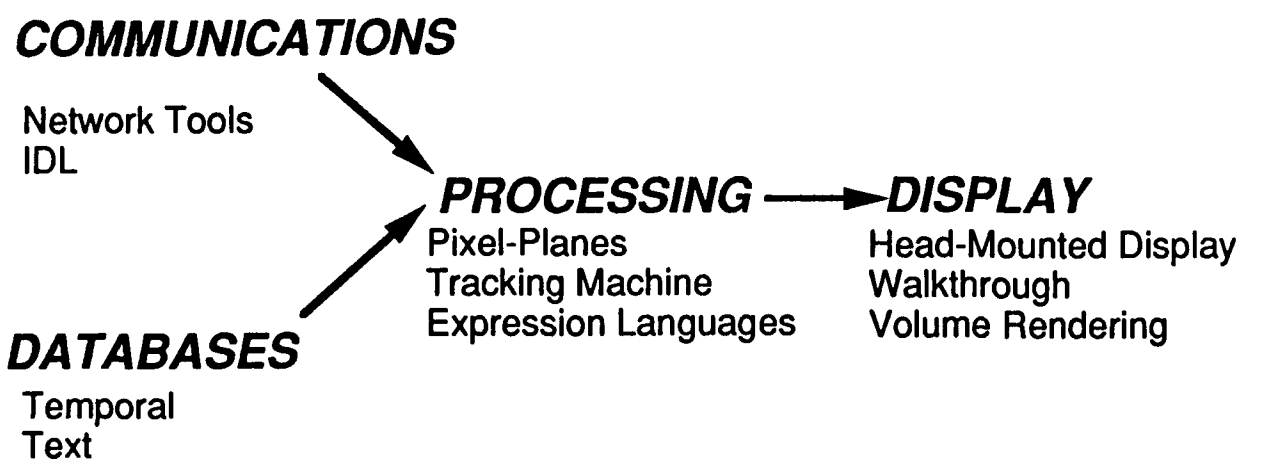
Scientific Goals:

To investigate fundamental issues in technologies of Command Information Systems, particularly:

- **human-computer interfaces**
- **text and temporal databases**
- **computer languages and architectures**

Information Display for Decision Making

The University of North Carolina at Chapel Hill



OBJECTIVE:

Interactive and real-time 2- and 3-D graphic displays of information for the support of decision making.

APPROACH:

Development of generalizable techniques in the context of vertically integrated application-driven projects, tested by real users on real problems.

'87 - '88 ACCOMPLISHMENTS:

Prototypes
- Head-Mounted Display
- Walkthrough System
- Pixel-Planes 5
- TempIS Temporal Database
- Full-text Retrieval System

Department Infrastructure
- CS Building Communications Networks

Tools Built
- IDL Programming Environment
- Volume Rendering Graphic Algorithms
- Object-oriented Image Processing Language

Head-Mounted Display

A head-mounted display (HMD) is a helmet-like device worn by the explorer of a virtual world. A 3-dimensional image is presented to the user using two screens built into the helmet. A similar system under development at NASA-Ames encloses the wearer's head so that he cannot see the real world. We feel that superimposing the virtual image on the real world makes using the device much less claustrophobic and also provides a real frame of reference for the virtual scene. (We might be wrong as to the best method, however, so we plan to try some tests to compare the approaches.)

One of our major goals is to incorporate the system into a molecular-modeling package that has been developed here, so that a chemist will be able to move about inside a room-filling molecule, grasp a piece of molecule with a data-glove, and manipulate the virtual structure as if it were a solid model.

This year's accomplishments:

This year we improved the head-mounted display system in image quality, function, and speed. Image quality was improved by

switching to a 320 x 220 resolution color screen,

developing an interface to the Pixel-Planes raster graphics system, and

algorithm refinement.

Currently the illusion suffers from a perceptible lag between when the head is moved and when the image is updated. This makes virtual objects swim about in space when they should appear to stay still. Even in this condition, the display appears to be useful, but update rate and lag remain the most difficult problems with the fidelity of the virtual-object illusion.

Plans for next year:

With the recent improvements in performance, we can at last begin application to virtual molecules, hung in space, that can be pointed to with a wand-controlled cursor. The cursor will be drug-shaped to simulate docking of molecules.

The tracking problem is by far the most serious of our technical problems. We will initiate work on optical trackers, and perhaps accelerometers, as alternates or supplements to the magnetic tracking used today. We are investigating schemes that may make tracking feasible in very large spaces rather than the cubic meter presently usable.

User interaction will be improved by the use of a data-glove sensor with its gesture libraries, and by harnessing our Votan spoken-command recognition system.

Head-Mounted Display:

Objective:

Dynamic interaction with a virtual world seen in stereo from a view based on user's head position.

Significant Progress in the past year:

1. Improvements in speed, image quality and user-control.
2. Integrated with Pixel-Planes graphics engine.
3. Integrated with Walkthrough prototype.

Plans for next year's research:

Increase reliability of tracking.

Implement tracking in large spaces.

Improve usability and user interface.

Improve speed and image quality.

Integrate with data glove.

Walkthrough - Exploring Virtual Structures

A virtual world computer graphics system allows real-time interaction with a 3-dimensional model world. The first versions of Walkthrough have as their goal a system for architects and clients to explore bulidings before they are built, so as to iteratively refine their specifications.

Most previous virtual world research at Chapel Hill has concentrated on molecular structure or anatomy. In neither of these applications do we know how the virtual world should appear to the viewer. In Walkthrough, on the other hand, the researcher can easily judge how closely the virtual world matches the real one in the ways that matter.

Any virtual world project must strive to improve in four aspects:

- Speed of image update
- Better appearance
- Providing an intuitive user interface
- Tools for building the model

We have accumulated a modest but adequate set of tools for building models of buildings; these are based on commercially available CAD software.

This year's accomplishments:

1. Integrated the system with Pixel-Planes to increase the image update rate to 15 cps. (Still much too slow, but a vast improvement over our first version.).

2. Improved the appearance by going from a 2-dimensional screen display to the stereo images available with the Head-Mounted Display.

3. Improved the user interface by integrating the system with a treadmill that allows the user to 'walk around' inside a building. This interface is not perfect ... steering is by an auxilliary device, and the user must walk straight ahead even while changing direction ... but it provides an added dimension of realism.

Plans for next year:

1. Exploring other user interfaces, such as a bicycle,
2. Getting better looking images by incorporating radiosity and texture information, and
3. Implementing a cellular model of space to reduce the information processed with each image.

Walkthrough:

Objective:

Real-time, interactive graphics system for prototyping building architectures and similar structures. Controls enable user to navigate structure; image is updated in real time.

Significant Progress in the past year:

1. Integrated with Pixel-Planes to increase update rate to 15 fps.
2. Integrated Head-Mounted Display for stereo image.
3. Integrated treadmill interface for navigation with Head-Mounted Display.

Plans for next year's research:

Develop other user interfaces, e.g., bicycle.

Develop radiosity and texture models for improved images.

Implement cellular model to improve speed.

PIXEL-PLANES: A Parallel Architecture for Raster Graphics

Pixel-Planes is a raster graphics system for high-speed rendering of 3D objects and scenes. It features a 'frame buffer' composed of custom logic-enhanced memory chips that can be programmed to perform most of the time-consuming pixel-oriented tasks in parallel at each pixel. The novel feature of this approach is a unified mathematical formulation for these tasks and an efficient tree-structured computation unit that calculates inside eacn chip the proper values for every pixel in parallel. The current system, Pixel-Planes 4 (Pxpl4), contains 512 x 512 pixels x 72 bits/pixel, implemented with 2,048 custom 3-micron nMOS chips (63,000 transistors in each, operating at 8 million micro-instructions per second). Algorithms for rendering spheres (for molecular modeling), for adding shadows, for enhancing medical images, and for rendering objects described by constructive solid geometry (CSG) directly from the CSG description have been devised by various individuals within and also outside our research group. The Pxpl4 system is in daily use in our department's Computer Graphics Laboratory, where applications in molecular modeling, medical imaging, and building architecture are being developed.

Accomplishments this year:

1. Pixel-Planes 4 has been integrated into the ongoing research projects of the Department, including Walkthrough and Head-Mounted Display.

2. Detailed design of the next Pixel-Planes machine was completed. This design promises greater speed and architectural enhancements that will allow, among other things, direct rendering of some curved surfaces.

Plans for next year:

Completion of Pixel-Planes 5, with perhaps 20x improvement in speed and various architectural enhancements that will allow, among other things, direct rendering of some curved surfaces.

Develop algorithms for solid volume rendering, a computation-intensive approach that makes it possible for the same scan data to provide a variety of views of the same object.

Improve the usability of the architecture so that it can be incorporated in a project by someone not familiar with the architectural details of the machine.

Pixel-Planes 5 Prototype:

Objective:

Development of massively parallel high-speed graphics engine using smart memory chips and small-grain VLSI.

Significant Progress in the past year:

1. Integration of Pixel-Planes 4 with Walkthrough and Head-Mounted Display prototypes.

2. Detailed design of Pixel-Planes 5.

Plans for next year's research:

Completion of Pixel-Planes 5 with 20X Speedup using modified SIMD architecture with some MIMD capability for increased algorithm generality.

Develop algorithms for solid volume rendering.

Improve usability.

Annual Report to the
Office of Naval Research
Arlington, Virginia 22217-5000
September 15, 1986 through September 14, 1987

Y1

The Infrastructure of Command Information Systems

Submitted by
Department of Computer Science
The University of North Carolina at Chapel Hill
Campus Box 3175, Sitterson Hall
Chapel Hill, North Carolina 27599

Principal Investigators:
Frederick P. Brooks, Jr.
Jay Nievergelt
Donald F. Stanat

October 1987

Contract No. N00014-86-K-0680

Table of Contents

1. Introduction 2

Table 1. Organization of Clusters 2
Table 2. Principal Affiliations by Cluster 2
Table 3. Projects by Cluster 3

2. User Interfaces and Graphics Cluster 5

2.1 PIXAR Image Computer Development 5
2.2 Integrated Object-Oriented Environment for Image Pattern Recognition and Computer Graphics (COOL) 6
2.3 Symbolic Graphical Display 7
2.4 Walk-Through 7
2.5 Head-Mounted Display (Project Planned for Year 2) 8

3. Communications Cluster 8

3.1 Research Projects 8
3.1.1 Remotely Shared Workspaces for Distributed Collaborative Writing 8
3.1.2 Hypertext '87 Workshop 9
3.1.3 Systems Support for Remotely Shared Workspaces 10
3.1.4 Distributed Temporal Database 10
3.2 Education Projects 11
3.2.1 Tutorial on Communications Software, UNC-Chapel Hill, October 19-20, 1987 11
3.2.2 Softlab: An Educational Environment for Distributed Systems Implementation 12
3.2.3 Comp 243 — Projects Course on Distributed Systems 12
3.3 Infrastructure Projects 13
3.3.1 Installation and Tuning of an Advanced In-house Communications System 13
3.3.2 An Internet Name Server 13

4. Decision Support Cluster 13

4.1 Architectures 14
4.1.1 A Prototype FFP Machine 14
4.1.2 Fuzzy Logic Inference Engine 15
4.1.3 Computer with LO Context Switch time (CLOCS) 15
4.2 Languages 16
4.2.1 Declarative Languages and Implementations 16

5. Management, Facilities, and Laboratories Cluster 17

5.1 Management 18
5.1.1 Personnel 18
5.1.2 Travel 18
5.2 Facilities 18
5.2.1 New Building 18
5.2.2 Equipment Report 19
5.2.3 Software Installation and Maintenance 19
5.3 Laboratories 19
5.3.1 Graphics and Imaging Laboratory 19
5.3.2 Microelectronics Design Laboratory 19
5.3.3 Microelectronic Systems Laboratory 19
5.3.3.1 Acquiring a Scanning Electron Microscope for MSL's E-Beam Probe 20
5.3.3.2 Direct Inking Technology 20
5.3.4 Communications Facilities 20
5.3.5 Natural Language and Text Processing Laboratory 20
5.3.6 Software Systems Laboratory 21

6. Site Visits 21

6.1 May 27, 1987 21
6.2 July 8, 1987 21

7. External Contacts 22

7.1 Program Advisory Panel 22
7.2 Mutual Cooperation with NRL 22
7.3 Graphics Open House 23

Appendix I 24
Project Narratives 25

Appendix II 27
Complete Bibliography 28
Selected Publications (enclosed)

Appendix III 30
Equipment Report — Year 1

Appendix IV 31
Travel Report — Year 1 32

Appendix V 34
Agenda — ONR Site Visit, May 27, 1987 35

Appendix VI 37
Sitterson Hall Network

1 Introduction

The ONR-supported research project on Command Information Systems calls upon faculty, staff, and resources of the entire Department. In order to reacquaint the reader with the organisational management of research and support activities, we include Tables 1 and 2 (amended) from the semi-annual report.

Table 1. Organization of Clusters	
Clusters	Executive Committee
User Interfaces and Graphics	Frederick P. Brooks, Jr.
Communications	Jay Nievergelt
Decision Support	Donald F. Stanat
Management, Facilities, Laboratories	Ralph A. Mason

A "cluster" is defined as a set of interrelated research and/or support projects and is managed by one of the four members of the Executive Committee.

Table 2. Principal Affiliations by Cluster
User Interfaces and Graphics: Beard, Brooks, Coggins, Eyles, Fuchs, Pixer. Adjunct: Whitted
Communications: Calingaert, Menges, Nievergelt, Ornat, Smith, Snodgrass, Weiss, Vogel Adjuncts/Visiting: Abdel-Wahab, Marsland, Pitt
Decision Support: Brock, Halton, Hedlund, Jayaraman, Magó, Plaisted, Prins, Stanat, Tyagi, Watanabe
Management, Facilities, Laboratories: Chi, Core, Gash, Howell, Kusminski, Mason, Poulton, Singh, Walsh

Sections 2 through 5 describe the research, education, and infrastructure projects, organised by cluster, as well as the organisational and administrative activities of the first year of this grant (see Table 3). Please refer to the appendices for project narratives and for copies of related publications and reports.

Section 6 gives an overview of this year's site visits. Section 7 proposes members of the Program Advisory Panel to the Executive Committee, addresses mutual cooperation with NRL, and mentions our graphics lab open house.

Table 3. Projects by Cluster

User Interfaces and Graphics

- Pixar (Coggins, Brooks, Piser)
- COOL (Coggins)
- Symbolic Graphical Display (Snodgrass, Magó)
- Walk-Through (Brooks)
- Head-Mounted Display–Year 2 (Brooks)

Communications

- Research
  - Remotely Shared Workspaces for Distributed Collaboration (Smith, Weiss)
  - Hypertext '87 Workshop (Smith)
  - Systems Support for Remotely Shared Workspaces (Nievergelt, Abdel-Wahab)
  - Distributed Temporal Database (Snodgrass)
- Education
  - Conferences on Communications Software (Calingaert, Nievergelt)
  - Softlab: An Educational Environment for Distributed Systems Implementation (Snodgrass)
  - Projects Course on Distributed Systems (Brock)
- Infrastructure
  - Installation and Tuning of an Advanced In-house Communications System (Vogel)
  - An Internet Name Server (Menges)

Decision Support

- Architectures
  - A Prototype FFP Machine (Mago)
  - Fuzzy Logic Inference Engine (Watanabe)
  - Computer with LO Context Switch Time (Stanat)
- Languages
  - Equational Languages (Jayaraman, Plaisted)

Management, Facilities, and Laboratories

- Management
  - Financial Accounting
  - Personnel and Payroll Accounting
  - Equipment Purchases
  - Contract Negotiations
  - Patents and Copyrights
- Facilities
  - Computer Installation and Maintenance
  - Communications
  - Software Installation and Maintenance
  - Facilities Coordination
- Laboratories
  - Graphics and Imaging
  - Microelectronics Design
  - Microelectronic Systems
  - Communications
  - Natural Language and Text Processing
  - Software Systems

2 User Interfaces and Graphics Cluster

The Graphics Cluster has several projects in graphics and image processing. A unifying theme is that we test new ideas and technology by using them in systems for real applications, tested by real users. Most of our work emphasizes real-time processing, and most is concerned with 3-D graphics.

The first project is concerned with installing, mastering, supporting, and exploiting a very powerful off-the-shelf image and graphics engine, the Pixar, loaned to us by Phillips Medical Systems, Inc. This gives us a powerful enhancement to our graphics infrastructure.

Professor Coggins has been overseeing the Pixar project and developing an object-oriented library to serve as a base for image pattern recognition research.

Professor Snodgrass has been exploring 2-D graphics for showing subtle relationships among abstract concepts, and for the contents of temporal databases.

Professor Brooks has a 3-D interactive system aimed at the rapid prototyping of buildings while still under design. This is almost up to the level necessary for testing with real architects. Its real-time nature pushes hard against many present boundaries in the graphics technology.

2.1 PIXAR Image Computer Development

Coordinator: James M. Coggins

Participants: Frederick P. Brooks, Jr., Stephen M. Pixer

RA Participants: Russell Tuck, Robert Stam

Key Words: Pixar, SIMD architecture, image processing, graphics.

Objective: To develop software to incorporate the Pixar Image Computer into the graphics lab facilities; to teach potential users about the Pixar and its use.

Results to Date: *Machine administration.* The Pixar and its host Sun have been incorporated into the Department's network. *Product testing.* We are a beta test site for the Pixar Chap C compiler. *Data compatibility.* We have developed routines for converting image data produced elsewhere in the lab for use on the Pixar. *Software development.* COLORTOOL, a color design and matching tool, has been completed. Real-time 2-D Fast Fourier Transforms have been encapsulated and used in research software. An interface module between Chap C and microcode has been developed. *Education.* Two seminars on Pixar usage were held, resulting in increased usage of the system.

Expected Results: Further integration of Pixar into Department network; development of software to make Pixar a display server on the network. Software for object definition research involving continuous blurring. Development of medical imaging applications over next six months.

Related Presentations:

By: James Coggins
Topic: Object-Oriented Programming,
Computer Science Department
Place: Furman University, Greenville, SC
Date: October 16, 1987

By: James Coggins
Topic: Pixar Development Objectives
Event: First Pegasus Users Group Meeting
Place: Philips Medical Systems, Inc., Shelton, CT
Date: July 6-7, 1987

By: Russell Tuck
Topic: Pixar Development Progress
Event: Second Pegasus Users Group Meeting
Place: Philips Medical Systems, Inc., Shelton, CT
Date: October 6-7, 1987

By: James Coggins
Topic: Integrated Class Structures for Image Pattern Recognition and Computer Graphics
Event: First USENIX C++ Workshop
Place: Sante Fe, NM
Date: November 8-11, 1987

By: James Coggins
Topic: A Summary of C++ Applications Under Development at UNC-Chapel Hill
Event: First USENIX C++ Workshop
Place: Sante Fe, NM
Date: November 8-11, 1987

By: James Coggins
Topic: Object-Oriented Programming in C++
Event: IEEE Software Technology Conference
Place: Atlanta, GA
Date: November 12-13, 1987

2.2 Integrated Object-Oriented Environment for Image Pattern Recognition and Computer Graphics (COOL)

Coordinator: James M. Coggins

RA Participants: Bryce Tebbs, John Rohlf, Muru Palaniappan

Key Words: Image pattern recognition, software engineering.

Objective: Dr. Coggins joined the faculty one year ago. He has been supported by the ONR grant to reestablish his software tools for pursuing research in image pattern recognition.

The main objective has been to develop an object-oriented implementation of image pattern recognition strategies and simple computer graphcis tools.

Results to Date: The initial phase of tool development work is nearing completion; tools for image analysis, statistical pattern recognition, and simple computer graphics are now available in an integrated object-oriented environment in the C++ programming language.

Expected Results: With the object-oriented tools now available, Dr. Coggins' main research into object definition strategies has begun again. Experiments are under way to determine how objects in images can be represented and identified. In addition, investigation into the feasibility of object-oriented redesign of other tools in the Graphics Cluster are underway.

Related Presentations: please see Section 2.1.

2.3 Symbolic Graphical Display

Coordinators: Richard T. Snodgrass and Gyula A. Magó

RA Participants: Tai-sook Han (summer, 1987)

Key Words: Temporal database, graphical objects, Interface Description Language.

Objective: This project involves two separate activities that intersect in providing support for displaying, in a graphical fashion, symbolic information which has no inherent graphical aspects. The first activity concerns the graphical display of temporal databases. The second concerns graphical display of IDL instances during programming environment development.

Results to Date: Only the first activity was pursued during the first year. We completed a prototype temporal database displayer and experimented with various representations of a temporal database containing information on the dynamic behavior of a simulator for the Magó FFP machine.

2.4 Walk-Through

Coordinator: Frederick P. Brooks, Jr.

RA Participants: John Airey, Curtis Hill (Sept. 1987 only), Penny Rheingans, Douglas Turner

Key Words: Interactive 3-D graphics, virtual worlds, building architecture, rapid prototyping.

Objective: To develop the real-time, interactive 3-D graphics techniques necessary to make a *rapid-prototyping system for building architecture*. The architect and his client use interactive controls to navigate, in real time, over a floor plan of a planned building. On a raster screen, they see a continuously updated shaded, lighted, perspective view of the building as viewed in the specified direction from the currently specified spot.

Results to Date:

1. We can now automatically partition building models into chunks that are mostly invisible from each other.
2. A 6-degree of freedom "Eyeball" control allows the user to control his viewing position and direction dynamically and naturally.
3. We can walk with 9-frames/second update—almost real time, using the UNC Pixel-planes graphics engine.
4. We can project the view on a 4' X 6' screen, with great improvement in naturalism.
5. We have installed Autocad on the Sun and are using it for building models.

Expected Results:

1. Twenty frames/second.
2. New interactive devices—treadmill or exercycle.
3. More buildings in database.
4. More realistic scenes.

Related Publication (see appendix):

Brooks, Frederick P., Jr., "Walkthough–A Dynamic Graphics System for Simulating Virtual Buildings," *Proceedings of the SIGGRAPH-NSF Workshop of 3-D Interactive Graphics*, 1986.

2.5 Head-Mounted Display (Project Planned for Year 2)

Coordinator: Dr. Frederick P. Brooks, Jr.

Participants: Henry Fuchs, Mark Harris, John Hughes, Michael Pique, Helga Thorvaldsdottir

RA Participants: Jim Chung, Ouh-young Ming

Key Words: Head-mounted display.

Objective: To create a display and interaction system in which the scene from a virtual world is projected in stereo in the user's field of view, and the user's own movements control the display. We are concentrating in this project on the user's head movements; the display shows the view of the virtual world based on the position and orientation of the user's head.

This project will be the main thrust of this cluster's research during the next year.

Expected Results: Real-time motion (at least 20 updates per second) in stereo views of the virtual world. At present, we manipulate wire mesh models only; we hope to incorporate Pixel-planes to render more complex models as quickly. We intend to experiment with different interaction devices and methods, including a bicycle interface to move the viewpoint with head-mounted sensors for view orientation. We want the interaction to feel real and look real.

3 Communications Cluster

In 1985, the Department of Computer Science initiated a major new research area in the fields of in-house communications, communications software, and distributed systems. As an integral part of our new building, Sitterson Hall, we designed and installed an advanced voice/data and video communications plant. With support from ONR, we initiated major thrusts in research and graduate education to take advantage of the unique infrastructure we now have installed.

Our research focuses on systems support for real-time remote collaboration, and applications thereof, in particular to distributed temporal databases and team writing.

Our educational activities have resulted in starting an annual series of tutorial conferences in communications software, in conjunction with universities and industrial research labs in the Research Triangle. The first conference was held in October 1987 (see Section 3.2.1); the next one will be organised by North Carolina State University's Center for Research on Signal Processing. We have also developed a Projects Course on Distributed Systems, taught this fall 1987 semester by J. D. Brock. (See Section 3.2.3).

Further developments of the communications infrastructure in Sitterson Hall focus on video communication and interconnection of heterogeneous local area networks.

3.1 Research Projects

3.1.1 Remotely Shared Workspaces for Distributed Collaborative Writing

Coordinator: John B. Smith

Participants: Stephen F. Weiss, Gordon J. Ferguson

RA Participant: Yen-Ping Shan, Paulette Bush

Key Words: Collaborative writing, distributed systems.

Objective: Our long-term objective is to develop a system that supports collaborative writing by a group of widely distributed users. The system would then be used to study the collaborative process.

Doing this requires, first, that we extend the current, single-user writing system to accommodate a group of users. Second, we must design the remotely shared workspace, data structures, and communi-

cation techniques needed to support the collaboration. We must also develop a collaborative paradigm to manage the collaboration. And once the system is in operation, we must design and carry out experiments to evaluate system performance and, more importantly, to investigate the collaboration process.

Results to Date: We have developed, with support from NSF, ARI, and IBM, a prototype, single-user writing support system (called WE for Writing Environment). Under ONR support, we are extending WE toward our goal of a system to support remote collaboration. The first step is to translate WE from the prototype language Smalltalk to Objective C. So far, we have translated the underlying support functions and two of the four user modes. We expect to finish by early 1988.

Expected Results: We are just beginning to explore the shared visual space needed to support simultaneous collaborative writing. We expect to begin design of the support functions for both simultaneous and non-simultaneous collaboration next spring. ONR support will provide both equipment and personnel for this work.

Related Publications, Technical Reports (see appendix):

Smith, John B., Weiss, Stephen F., Ferguson, Gordon F. "A Hypertext Writing Environment and its Cognitive Basis," Technical Report TR87-033, University of North Carolina, Chapel Hill, October 1987.

Smith, John B., Weiss, Stephen F., Ferguson, Gordon J., Bolter, Jay D., Lansman, Marcy, Beard, David V. "WE: A Writing Environment for Professionals," Technical Report TR86-025, University of North Carolina, Chapel Hill, August 1986.

Related Presentations:

By: John B. Smith
Topic: Writing Environment
Event: National Computer Conference
Place: Chicago, IL
Date: June 15-18, 1987

By: John B. Smith
Topic: A Hypertext Writing Environment and its Cognitive Basis
Event: Hypertext '87 Workshop
Place: UNC-Chapel Hill
Date: November 13-15, 1987

3.1.2 Hypertext '87 Workshop

Coordinator: John B. Smith, workshop co-chairman

Participants: Stephen Weiss, program committee co-chairman; Jay Nievergelt, summariser; Frederick P. Brooks, Jr., invited speaker; Sandra Cunningham and Rebecca Highsmith, administrative assistants; with assistance from departmental support groups, as well as workshop assistance from several RAs.

Key Words: Hypertext, electronic document, multimedia systems.

Objective: To bring system developers, people interested in applications, and individuals concerned about issues raised by Hypertext from around the world to discuss common interests. (See Appendix I for information sheet.)

Results to Date: ONR support was used in planning the Hypertext '87 Workshop that will take place in Chapel Hill, November 13-15. The workshop has generated a great deal of interest and enthusiasm. More than 80 technical papers were submitted, and more people applied to attend than we could possibly accommodate.

3.1.3 Systems Support for Remotely Shared Workspaces

Coordinator: Jay Nievergelt

Participants: Hussein Abdel-Wahab

RA Participant: Sheng-uei Guan

Key Words: Remote real-time collaboration, interprocess communication.

Objective: Computer networks have been used mainly for file transfer and electronic mail—applications which are not subject to real-time constraints.

There is now increased research interest in remote collaboration where users at different locations operate on shared objects in "what you see is what I see" mode. In contrast to other work which focuses on special-purpose systems, we wish to show that remotely shared workspaces can be implemented efficiently on existing hardware and software systems.

Results to Date: A software package has been implemented using the UNIX Interprocess Communication facilities that turns any interactive single-user application into a multi-user tool.

Expected Results: Develop techniques for efficient implementation of remotely shared workspaces in heterogeneous networks. Demonstrate and test in prototype implementations.

Related Publications, Technical Reports (see appendix):

Abdel-Wahab, Hussein M., Guan, Sheng-Uei, Nievergelt, J. "Shared Workspaces for Real-time Collaboration in Distributed Networks: Concepts, Techniques, Problems," submitted for publication.

Abdel-Wahab, Hussein M., Guan, Sheng-Uei, Nievergelt, J. "A Prototype for Remotely Shared Textual Workspaces," submitted for publication.

Abdel-Wahab, Hussein M., "Experience with Berkeley UNIX Interprocess Communications," submitted for publication.

Staunstrup, Jorgen, Nievergelt, J. "The Behavior of Shared Objects: Concepts, Pitfalls, and a New Model," submitted for publication.

Related Presentations:

By: Hussein Abdel-Wahab
Topic: Remotely Shared Workspaces
Event: Communications Software Conference
Place: UNC-Chapel Hill
Date: October 19, 1987

3.1.4 Distributed Temporal Database

Coordinator: Richard Snodgrass

Key Words: Historical database, Quel, relational model, rollback database, temporal database, transaction time, valid time, concurrency control, recovery.

Objective: A temporal database management system (TDBMS) by definition must support both transaction and valid time. This project involves developing a formal model of temporal information and implementing a prototype TDBMS to investigate issues of performance and functionality.

Results to Date: See publications, listed below.

Related Publications, Technical Reports (see appendix):

Ahn, Ilsoo, Snodgrass, Richard. "The TempIS Project: Performance Analysis of Temporal Queries," TempIS Document No. 17, Department of Computer Science, University of North Carolina, Chapel Hill, August 11, 1987.

McKenzie, Edwin, Snodgrass, Richard. "An Evaluation of Historical Algebras," Technical Report 87-020, Department of Computer Science, University of North Carolina, Chapel Hill, October, 1987.

McKenzie, Edwin, Snodgrass, Richard. "Supporting Valid Time: An Historical Algebra," Technical Report TR87-008, Department of Computer Science, University of North Carolina, Chapel Hill, August 1987.

Snodgrass, Richard. "The TempIS Project: Current Status," TempIS Document No. 15, University of North Carolina, Chapel Hill, June 19, 1987.

Snodgrass, Richard, Gomes, Santiago, McKenzie, Edwin. "The TempIS Project: Aggregates in the Temporal Query Language TQuel," TempIS Document No. 16, Department of Computer Science, University of North Carolina, Chapel Hill, July 27, 1987.

Related Presentations:

By: Richard Snodgrass
Topic: Adding Transaction Time to the Relational Algebra
Event: ACM-SIGMod International Conference on Management of Data
Place: San Francisco, CA
Date: May, 1987

3.2 Education Projects

3.2.1 Tutorial on Communications Software, UNC-Chapel Hill, October 19-20, 1987

Coordinator: Peter Calingaert

Key Words: Communications software, tutorial. Message passing: design options, implementation. Remote procedure calls: design options, implementation, security. Communication system design principles, non-OSI architectures. Reliable group communication. Virtual shared memory as a communication paradigm.

Participants: Organised jointly with UNC-CH, North Carolina State University, Duke University, and IBM. Supported in part by ONR; co-sponsored by the IBM Corporation.

Objective: To increase awareness of and knowledge about fundamental issues in communications software design. (See Appendix I for information sheet.)

Presenters: F. Donelson Smith (senior programmer, IBM) on networking at Carnegie-Mellon University; J. Dean Brock (professor, UNC-CH) on distributed systems architecture; Robert B. Bailey (product manager, IBM) on networking management; Hussein Abdel-Wahab (professor, NCSU) on remote shared workspaces; T. Anthony Marsland (professor, University of Alberta) on distributed computation; James P. Gray (IBM Fellow) on SNA's distributed systems; Norman Vogel (director of communications, Comp. Science, UNC-CH) on the Sitterson Hall network; James Jones (system engineer, Southern Bell) on its installation; technical tour.

Results to Date: Approximately 100 participants from universities and practicing software engineers in the Research Triangle were in attendance.

3.2.2 Softlab: An Educational Environment for Distributed Systems Implementation

Coordinator: Richard T. Snodgrass

RA Participant: Vikram Biyani (fall 1987–spring 1988)

Key Words: Hardware simulation, compiler generation, intermediate representation, Interface Description Language.

Objective: SoftLab is a laboratory for software engineering education. It offers a collection of tools that support experimentation in software systems, specifically operating systems, programming environments, and database systems. The tools are programs that construct, manipulate, test, simulate, and display portions of a particular software system.

When completed, the laboratory will include tools to automate the construction of compilers. We are investigating these issues in the context of the Interface Description Language (IDL).

Another major tool of SoftLab is the reconfigurable hardware simulator, consisting of a collection of device simulators interacting through message passing.

Results to Date: We released Version 3.0 of the IDL Toolkit in March, 1987. This version is organised around an internal description of IDL called Candle. Naturally, Candle is also specified in IDL.

We have completed a Modula-2 compiler that generates Mcode, an Mcode linker, a program that produces core images for bootstrapping, and a CPU device module that executes Mcode.

Expected Results: We are working on adapting the implementation of an assertion checker to use Candle, and on adding Pascal support to the IDL translator.

We are debugging the CPU device module with a simple operating system written in Modula-2.

3.2.3 Comp 243 – Projects Course on Distributed Systems

Coordinator: J. Dean Brock

Participant: Sailesh Chutani

Participated in the Course: 35 students, as follows:

- 28 full-time graduate students in our Department
- 2 part-time graduate students in our Department, but also working in communications at IBM
- 5 "evening-college" (unadmitted) students:
  - 3 employed by MCNC
  - 1 employed by Data General
  - 1 employed by IBM (in communications)

Key Words: Distributed systems, communications education.

Objective: Comp 243 is a graduate-level course in distributed systems. Students are introduced to the protocols used in widely-used computer networks and then shown how computer operating systems can support these networks. Common paradigms for inter-machine communications, such as remote procedure calls, and important distributed applications, such as network file systems, are studied.

Expected Results: The students in Comp 243 are working on twelve communications-related projects. Among the projects are:

- An investigation of extensions to Modula/II to support inter-processor communication.
- A study of the contributions of the hardware and software of Sitterson Hall to inter-processor response time.
- Searching number spaces using a network of computers.

— A distributed scheduler to support parallel processing of a single task across several networked Suns.

In addition to providing some useful applications, the projects are also developing a great deal of local expertise in the construction of distributed applications.

Class projects will be presented at the end of the semester.

3.3 Infrastructure Projects

3.3.1 Installation and Tuning of an Advanced In-house Communications System

Coordinator: Norman A. Vogel

Participants: John Menges, Steven Ornat

Key Words: Network, integration voice/data communications, broadband, Ethernet, satellite communications, gateway, bridge, AppleTalk, PhoneNet, video conferencing, teleclassing.

Objective: To provide the communication systems infrastructure required for computer science graduate training and research.

Results to Date: The telecommunication construction contract with Southern Bell Advanced Systems, Inc., achieved "cut-over" on June 16, 1987. The installed communications system is in full use during the six month long "soak test". The target date for final acceptance is December 16, 1987. The InteCom Data-Voice switch and the fiber-optics based Ethernet systems are fully operational.

Expected Results: Additional network capability is being installed by University personnel. An AppleTalk/PhoneNet system which ties together all MacIntosh terminals and Laser Printers has been fully installed. A Kinetics bridge/gateway which internetworks PhoneNet and the building Ethernet system is being installed. A twelve video channel mid-split broadband system, an eight-station IBM token ring system, and a voice-directed eight-camera video conference facility are being installed. Sitterson Hall networks have been interconnected to the University of North Carolina's broadband system and the MCNC statewide microwave network.

3.3.2 An Internet Name Server

Coordinator: John Menges

Key Words: Nameserver, Arpanet.

Objective: To link to Arpanet via TUCC, the Triangle Universities Computer Center; the Arpanet name server will insure smooth and efficient interconnection of our Ethernet with Arpanet.

Results to Date: The implementation of a local name server for the Internet is nearly complete. There are still a few minor problems that we want to resolve before we are ready to take over the name server function for our local domain.

Expected Results: We expect to complete this project by December 1987.

4 Decision Support Cluster

The Decision Support cluster emphasises research in areas that will support the computational aspects of decision making. This includes special- and general-purpose languages and machines. It is our belief that successful architectures of the future will be language-based; that is, they will be designed to exploit and

accommodate features of a language that is itself chosen to make programming (either general or special purpose) more tractable.

Our special emphasis has been on declarative languages and parallel architectures that will support them. A secondary emphasis is that of more modest but novel architectures, such as ones to support rule-based systems using fuzzy logic, and an architecture for fast context-switching.

The language aspects of our work include a number of deep mathematical areas, such as theorem proving, programming with sets, and logic programming, all of which are particularly amenable to parallel processing if suitable computational paradigms are developed. We are pursuing a spectrum of topics in this area, ranging from theoretical investigations to the implementation of a new general-purpose language.

We are actively working on the design and implementation of several machines. The Microelectronics Center of North Carolina, located in the nearby Research Triangle Park, provides an excellent environment and support for the VLSI design aspects of the architectures on which we are working, and the Microelectronic Systems Laboratory, one of our departmental facilities, is actively participating in the design and construction of two of these machines.

4.1 Architectures

4.1.1 A Prototype FFP Machine

Coordinator: Gyula A. Magó

RA Participants: Will Partain, William Gibson, Eduoardo Biagioni

Key Words: Small grain parallel architectures, declarative programming.

Objective: To develop a small grain asynchronous parallel machine that uses a high-level declarative machine language.

Results to Date: A small grain parallel machine has been designed. It uses Backus's FFP language as its machine language. The machine consists of a binary tree of processors of two types. In cooperation with the Institute of Biomedical Computing of Washington University, we are in the process of developing the specifications for the two processors. Because the machine is inherently asynchronous, the specifications must be given with great care. The design has been supported by ONR and various other sources. Major funding was received from NSF late last summer to get the machine implementation started.

Expected Results: After specifications are complete and have been approved by Washington University, we will proceed with designing VLSI implementations of the two processor types and the chips that will hold them.

Related Publications (see appendix):

Magó, G. A., Stanat, D. F. The FFP Machine. A chapter of a forthcoming book: *High Level Language Computer Architectures*, edited by V.M. Milutinovic, to be published by Computer Science Press.

Magó, G. A., Partain, W. "Implementing dynamic arrays: a challenge for high-performance machines." *Proceedings of the Second International Conference on Supercomputing*, Santa Clara, CA, May 3-8, 1987.

Magó, G. A., Middleton, D. "The FFP Machine—A Progress Report." *International Workshop on High-Level Computer Architecture 84* (Los Angeles, California, May 23-25, 1984). (Reprinted in *Dataflow and reduction architecture* by S.S. Thakkar, IEEE Computer Society Press, 1987, and in *Computer architecture* by D.D. Gajski, V.M. Milutinovic, H.J. Siegel, and B.P. Furht, IEEE Computer Society Press, 1986, pp. 456-468.)

Magó, G. A. "Making parallel computation simple: the FFP machine." Digest of Papers, *IEEE Computer Society COMPCON* (Spring 1985), pp. 424-428. (Reprinted in *Computers for artificial inteiligence applications* by Benjamin Wah and G.J. Li, IEEE Computer Society Press, 1986, pp. 324-328.)

Magó, G. A. "A cellular computer architecture for functional programming." Digest of Papers, *IEEE Computer Society COMPCON* (Spring 1980), pp. 179-187.

Magó, G. A. "A network of microprocessors to execute reduction languages." Two parts. *International Journal of Computer and Information Sciences* 8, 5 (1979), pp. 349-385, 8, 6 (1979), pp. 435-471.

4.1.2 Fuzzy Logic Inference Engine

Coordinator: Hiroyuki Watanabe

Participants: Wayne Dettloff (Microelectronics Center of North Carolina–MCNC)

RA Participant: James Symon

Key Words: Fuzzy logic, VLSI, expert system, process control

Results to Date: The CMOS full custom design of the inference machine is almost complete. The VLSI chip is designed for MCNC 1 micron n-well CMOS technology and consists of approximately 614,000 transistors. A single chip can store and execute up to 102 control rules. Operational speed is expected to be 40MHz and 645,000 fuzzy inference per second. We are testing correctness of design by simulation, and we are developing a software support system for testing our chip after fabrication. This software is also useful as a base for development environment for control rule set.

Expected Results: The chip will be integrated on a single board system with a standard bus interface to an available personal computer (IBM PC/AT) or a workstation (Sun). The chip, a host computer, and software support system together constitute a general-purpose fuzzy controller for real-time application.

Related Publication (see appendix):

Watanabe, Hiroyuki, "Fuzzy Logic Inference Processor for Real Time Control: A Second Generation Full Custom Design," to appear in *Proceedings of IEEE 21st Annual Asilomar Conference on Signals, Systems, and Computers*, November 2-4, 1987 (Co-sponsored by IEEE and Naval Postgraduate School).

Related Presentations:

By: Hiroyuki Watanabe
Topic: Fuzzy Logic
Event: MCNC VLSI Design Seminar Series,
Place: MCNC, Research Triangle Park, NC
Date: March 1986.

By: Hiroyuki Watanabe
Topic: Fuzzy Logic
Place: Department of Information Science, University of
Tokyo, Japan
Date: June 11, 1987

By: Hiroyuki Watanabe
Topic: Fuzzy Logic
Place: Ricoh Central Research and Development Laboratory, Yokohama, Japan
Date: June 22, 1987

4.1.3 Computer with LO Context Switch time (CLOCS)

Coordinator: Donald F. Stanat

RA Participants: Mark C. Davis, Bill O. Gallmeister

Key Words: Microprocessor, real time, general purpose.

Objective: The CLOCS project will design a computer architecture and operating system that will switch context (change executing tasks) up to 10,000 times faster that current designs.

Results to Date: Progress to date includes forming two research teams of graduate students. The main team consists of Davis and Gallmeister who are working on the computer's architecture and design of the operating system to run on it. The second team consists of three unsupported students in an advanced compiler course who are writing a C language compiler for the computer.

Expected Results: Simulations of the CLOCS architecture and operating system will show the ability of CLOCS to support many applications that current design computers cannot run.

4.2 Languages

4.2.1 Declarative Languages and Implementations

Coordinators: Bharat Jayaraman and David A. Plaisted

RA Participants: Gopal Gupta, Amos Omondi, Frank Silbermann

Key Words: Functional and logic programming, equations, sets, sequential and parallel execution.

Objective: To develop a practical, declarative language suitable for symbolic computation and multiprocessor execution. Existing languages, such as LISP and Prolog, have too many imperative features to be considered 'declarative'; furthermore, they cannot fully take advantage of the parallelism offered by multiprocessor systems. We seek to combine the capabilities of LISP and Prolog in a declarative language based on equations and sets.

Results to Date: We have developed a language called EqL which provides the capabilities of first-order functional and Horn-logic programming. The declarative semantics of EqL is based on the notion of complete set of solutions, and the computational paradigm of EqL is equation-solving. We completed a sequential interpreter for EqL in May 1987 and will soon distribute it to a number of sites. (Our first user was Prof. Valdes Bersins at the Naval Postgraduate School.) Our first version, which was not specially fine-tuned, runs about half as fast as C-Prolog on Vaxes and Suns.

We have also been developing a language called SEL (Set-Equation Language) which allows David Turner's set-abstraction construct to be specified more declaratively. A SEL program is a collection of equation and subset assertions. In SEL, we can also declaratively specify many programming paradigms of Prolog, including uses of the 'cut' and 'setof' constructs. We are at present implementing a sequential interpreter for SEL.

Expected Results: Our next step is to integrate the capabilities of EqL and SEL. We would like to define sets as the collection of solutions arising from EqL-like equation-solving, and also support higher-order functions. The net result would be a declarative language with good expressiveness, yet retaining potential for highly efficient implementation.

One of the benefits of SEL is that and- and or-parallelism is much more tractable than for Prolog. Also, formulating problems in terms of sets rather than lists gives more parallelism, because elements of the set can be produced in parallel. We would like to demonstrate these benefits through an actual parallel implementation. We have already started developing conceptual techniques for the parallel implementation of SEL and EqL.

Related Publications, Technical Reports (see appendix):

Jayaraman, B. "Semantics of EqL," Invited paper for a special issue of *IEEE Transactions on Software Engineering*, to appear, March 1988.

Jayaraman, B., Gupta, G. "EqL: the language and its implementation," submitted to *IEEE Transactions of Software Engineering*, September 1987, 32 pages.

Jayaraman, B., Plaisted, D. "Functional Programming with Sets," *Third International Conference on Functional Programming Languages and Computer Architecture*, Portland, OR, September 1987, pp. 194–210.

Jayaraman, B., Gupta, G. "EqL User's Guide," Technical Report TR87-010, Department of Computer Science, University of North Carolina, Chapel Hill, May 1987 (revised September 1987).

Jayaraman, B. Gupta, G. "Parallel Execution of an Equational Language," *1986 Graph Reduction Workshop*, Santa Fe, proceedings published by Springer-Verlag, October 1986, LNCS Vol. 279.

Jayaraman, B., Silbermann, F. S. K., Gupta, G. "Equational Programming: a Unifying Approach to Functional and Logic Programming," *Proceedings of the 1986 International Conference on Computer Languages*,, Miami Beach, October 1986, pp. 47-57.

Jayaraman, B., Silbermann, F.S.K. "Equations, Sets, and Reduction Semantics for Functional and Logic Programming," In *Proceedings of 1986 ACM Conference on LISP and Functional Programming*, M. I. T., August 1986, pp. 320-331. Magó, G. A. "A network of microprocessors to execute reduction languages." Two parts. *International Journal of Computer and Information Sciences* 8, 5 (1979), 349-385, 8, 6 (1979), 435-471.

Related Presentations:

By: Bharat Jayaraman
Topic: Parallel Execution of an Equational Language
Event: Graph Reduction Workshop
Place: Santa Fe, NM
Date: September 28 - October 2, 1986

By: Bharat Jayaraman
Topic: Equational Programming: A Unifying Approach to
Functional and Logic Programming
Event: International Conference of Computer Languages
Place: Miami Beach, FL
Date: October 26-28, 1986

By: Bharat Jayaraman
Topic: Functional Programming with Sets
Event: 3rd International Conference on Functional Programming
Languages and Computer Architecture
Place: Portland, OR
Date: September 14-16, 1987

5 Management, Facilities, and Laboratories Cluster

The contract with the Office of Naval Research demands full-time management of both personnel and facilities to insure optimization of existing resources. Mrs. Jeannie Walsh is the administrative assistant to the Executive Committee and as such performs the necessary personnel and financial management duties. Laboratory and facilities management is the responsibility of the laboratory directors who report to Ralph Mason for overall coordination.

5.1 Management

5.1.1 Personnel

Eight new positions were created during the first year (see p. 1, Semi-annual Report, January 1987). Since January, two additional vacancies were filled: Sharon Core filled the half-time position of Secretary IV, and Raj Singh was hired as Project Management Engineer.

The Department is fortunate to have hired two additional faculty members (funded by the State)—bringing our total full-time faculty to 22. Jan Prins brings to us the experience in program specification and correctness which he gained at Cornell and Wisconsin; Akhilesh Tyagi from the University of Washington adds to our expertise in VLSI and computer architecture.

Table 4 below lists the names of research assistants supported by ONR during the first year.

Table 4.
Research Assistants Supported by ONR During Year 1

J. Airey	H. Lander	J. Symon
E. Biagioni	M. Levoy	M. Surles
P. Bush	S. Molnar	B. Tebbs
K. Clapp	R. Potter	R. Tuck
M. Davis	P. Rheingans	G. Turk
D. Ellsworth	D. Schiff	D. Turner
W. Gallmeister	K. Shannon	L. Westover
W. Gibson	F. Silbermann	B. White
E. Grant	S. Southard	M. Winslett
R. Holloway	R. Stam	

5.1.2 Travel

Appendix IV includes all travel funded (fully or partially) by the Office of Naval Research during the first year.

5.2 Facilities

5.2.1 New Building

The Department's physical resources have changed significantly since it moved into its new home, J. Carlyle Sitterson Hall, during July 1987. The new $10 million, 74,000 square foot building, dedicated on University Day, October 12, was designed to provide sophisticated communication support for the Department's research programs. The building provides space for offices, two teleclassrooms, several conference areas, and devotes nearly 10,000 square feet to its six major laboratories (see Section 5.3 below). The building is equipped to switch video and integrated voice-data signals and is wired with fiber optic and coaxial cables, in addition to the cooper plant, to provide state-of-the-art communications. All of the Department's major computing resources are accessible from anywhere in the building through six separate local area networks that are themselves connected by a high-speed digital switch.

The Department's general computing facilities include one 16-MB VAX-11/785, one 4-MB VAX-11/780, one 8-MB VAX-11/750, one 10-MB DG-MV/10000, a Sun-4 compute server, eight Sun file servers, more than 60 Sun Microsystems workstations with the Network File System (NSF), and more than 50 other workstations and personal computers. These machines are supported by over 13 gigabytes of on-line disk storage, and an assortment of high-speed dot matrix printers through typeset quality laser printers.

5.2.2 Equipment Report

Please refer to Appendix III for the report of equipment purchased during the first year, 15 September 86 through 14 September 87.

5.2.3 Software Installation and Maintenance

At the time of this report, all Sun workstations have been upgraded to the Sun Version 3.3 UNIX Operating System. The Department VAXES are presently being upgraded to Berkeley 4.3 UNIX with the Sun Network File System (NFS). The Department has been a beta test site for MAC II software and is currently beta testing the MAC II A/UX, an Apple UNIX product.

5.3 Laboratories

5.3.1 Graphics and Imaging Laboratory

Specialized image-generating systems include the unique UNC Pixel-planes machine (27,000 rendered polygons/second), a 4-processor Pixar, an Evans and Sutherland PS-300 color vector system, a Vector-General 3300 vector display, a varifocal mirror true-3D display, and two Adage Ikonas 3000's, each with a high-precision Tektronix 690 SR monitor. Each display, including projected video, can be viewed in stereo via Tektronix liquid-crystal shutters.

The image-generators are hosted and supported by a dedicated Vax-11/780, a Sun-4 file server, a color Sun-3, three monochrome Sun-3's, two color Masscomp 5500 workstations, and more than four gigabytes of disk storage. All raster display and some vector display can be converted to NTSC for recording or display on a Barcodata precision video projector.

5.3.2 Microelectronics Design Laboratory

The Microelectronics Design Laboratory (MDL) is a facility for the design and simulation of MOS integrated circuits. The laboratory contains four VAXstation GPX color workstations and two color Sun-3 workstations. All workstations have 8-MB of main memory and floating point accelerators. Additional equipment includes a Sun-4 file server, a Vax-11/750, more than three gigabytes of disk storage, and a Hewlett Packard plotter. MDL is networked via a high speed microwave link to two Convex mini-supercomputers at the Microelectronics Center of North Carolina. Each Convex has 64-MB of main memory, and they are used for design simulation and testing.

5.3.3 Microelectronic Systems Laboratory

The Microelectronic Systems Laboratory (MSL) provides facilities for the rapid prototyping of large scale, high-performance VLSI systems. It supports architectural research by fabrication of prototypes based on custom designed VLSI chips. A full-time staff of ten enables the laboratory to implement functioning systems of significant size and complexity, containing hundreds or thousands of custom VLSI circuits designed in-house.

State-of-the-art equipment allows in-circuit real-time diagnostic probing of IC's using SEM E-beam technology, fabrication of dense, high-performance thick-film mutilayer hybrid circuit modules, and integration of chip, module, and board design. Coordinated design and test tools as well as computer controlled fabrication equipment provide the ability to produce prototypes of entire systems with extremely fast turn-around.

The MSL has nearly $2M of major capital equipment as well as an extensive inventory of engineering stock, hand tools, and plant facilities such as plant air, vacuum, and chemical fume hood.

5.3.3.1 Acquiring a Scanning Electron Microscope for MSL's E-Beam Probe

Coordinator: Vernon L. Chi

Participants: Mark E. Monger, Raj K. Singh

Key Words: IC Testing, E-beam probe.

Objective: To refurbish E-beam probe for use on an SS40 Scanning Electron Microscope (SEM) to be purchased from ONR equipment funds.

Results to Date: The MSL has acquired an E-beam probe capability for in-circuit, non-invasive testing of IC chips running at full speed. Raj K. Singh, member of the MSL staff, has overseen the effort of receiving, installing, and learning to use the International Scientific Instruments Model SS-60 Scanning Electron Microscope column, and will be following through with installation of the Applied Beam Technology Model IL-200 SEM E-beam Probe.

Expected Results: This facility will give the MSL a state-of-the-art capability for diagnostic, performance, and functional testing of custom-designed integrated circuits.

5.3.3.2 Direct Inking Technology

Coordinator: Vernon L. Chi

Participants: Mark E. Monger, Raj E. Singh, John E. Thomas

Key Words: Thick film hybrid, CAD/CAM, rapid prototyping.

Objective: To rewrite the inker software in C language which operates in a VAX Unix environment rather than the HP micro which came with the equipment. This new interface will allow the lab to do rapid thick film hybrid prototying using its existing tools and design environment.

Results to Date: Dr. Singh has been developing interfaces and control systems to connect intimately our Micropen Model 302 Direct Inking Thick Film Hybrid machine to our VAX/UNIX environment.

Expected Results: This modification will allow us to use our entire array of computing resources and design software for the rapid design and prototyping of Thick Film Hybrid packages for integrated circuits.

5.3.4 Communications Facilities

Sitterson Hall has Ethernet, voice, synchronous, and asynchronous data, and token ring ports in its 232 offices, laboratories, and conference rooms. In addition, about half of the rooms have broadband and high resolution RGBS 75 ohm cable facilities. The InteCom IBX digital PBX switches all voice and data paths below 64 kilobits per second, and in addition, the LANmark feature provides one megabit per second switching between six fiber optic-based Ethernet subLANs which provide high-speed networking. An Appletalk Phone-net system is provided. This network is coupled to a microwave-based extended Ethernet providing communications with the Microelectronics Center of North Carolina, Research Triangle Institute, and universities across the state. This microwave network also provides two-way motion video teleconferencing and teleclassing facilities to these universities and organizations. (See Appendix VI.)

5.3.5 Natural Language and Text Processing Laboratory

Current TextLab equipment includes Sun workstations, IBM PC-AT's, and Macintoshes, plus a broad range of development and application software. The building's state-of-the-art communications system will be used as a laboratory, particularly to study collaborative use and authorship of documents in a distributed environment, models of human-human and human-system interaction, and other related topics.

5.3.6 Software Systems Laboratory

SoftLab is a software laboratory, similar in concept to a physics or chemistry laboratory. This laboratory consists of a collection of tools that support experimentation in software systems, specifically operating systems, programming environments, and database systems. The tools are programs that construct, manipulate, test, simulate, and display portions of a particular software system.

6 Site Visits

6.1 May 27, 1987

The following individuals from the Office of Naval Research visited the Computer Science Department on May 27: Dr. A. F. Norcio, Computer Scientist, Computer Science & Systems Branch, NRL, and Scientific Advisor, Computer Science Division, ONR; Dr. Ralph Wachter, Program Manager, Computer Science Division, ONR; Mr. Stanley H. Wilson, Head, Computer Science & Systems Branch, Information Technology Division, NRL.

Each member of the ONR Executive Committee gave an overview of his respective cluster; cluster participants presented their project reports; demonstrations were provided where appropriate; and guests were taken for a tour of the new Computer Science building. Please see Appendix V for complete agenda.

Finally, members of the ONR site visit team:

- provided positive feedback relating to the Computer Science Department's research efforts;
- discussed their need for software engineering security systems;
- invited a group of our faculty/students to their facility this fall and the A7 Project class next spring;
- discussed the June 18-19 meetings of URI Principal Investigators in Washington, DC;
- stated their desire for mutual cooperation between NRL and the Computer Science Department on human-factors research (please see Section 7.2);
- suggested that the Department establish a videoconference link with NRL;
- invited the Department to suggest possible members of the Program Advisory Panel (see Section 7.1).

Jay Nievergelt invited NRL members to provide the Department with specific applications with regard to the remote graphical workspace project, along with some of their current technologies (see Section 7.2).

6.2 July 8, 1987

Dr. Charles Holland, Science Officer, Office of Naval Research, visited the Department on July 8. He was provided with detailed information required for financial reporting purposes (Walsh); heard progress reports from each Principal Investigator (Executive Committee); listened to presentations about the new communications plant (Vogel) as well as the distributed temporal database project (Snodgrass) and the COOL project (Coggins); observed a demonstration of the remotely shared textual workspace project (Abdel-Wahab) and various Graphics demonstrations; and was given a tour of the new building.

Dr. Holland also suggested the implementation of an ONR fellowship program for our outstanding Ph.D. students. We have chosen two advanced Ph.D. students as departmental ONR fellows:

> Mark Davis (Decision Support Cluster): His Ph.D. thesis, supervised by F. P. Brooks, Jr., involves the design of CLOCS, a computer with low context-switching time.
>
> Marc Levoy (Graphics Cluster): His Ph.D. thesis, supervised by H. Fuchs, is on rendering volume elements without imposing any surface artifacts.

The next site visit is planned for Spring 1988.

7 External Contacts

7.1 Program Advisory Panel

The following individuals have agreed to serve on the Program Advisory Panel to the Executive Committee. They will be invited to participate at the next site visit, subject to the approval of Dr. Charles Holland.

All clusters:

Mr. Stanley Wilson
Head, Computer Science & Systems Branch
Information Technology Division
Naval Research Lab
Code 5590
4555 Overlook Avenue, SW
Washington, DC 20375-5000

User Interfaces and Graphics:

Dr. Andries Van Dam
Department of Computer Science
Brown University
Providence, RI 02912

Communications:

Dr. Edward H. Sussenguth
IBM
P. O. Box 12195
Research Triangle Park, NC 27709

Decision Support:

Dr. Bruce MacLennan
Department of Computer Science
University of Tennessee
Knoxville, TN 37996

7.2 Mutual Cooperation with NRL

Some NRL researchers will participate at the UNC Hypertext Conference (see Section 3.1.2) and explore possible cooperation with our TextLab researchers.

NRL plans to bring us into contact with some avionics software experts so that Dr. James Coggins might use this topic as a case study in his software engineering course during spring 1988.

7.3 Graphics Open House

The Department plans to host demonstrations in its new graphics laboratory during an open house to be held immediately after the 1988 SIGGRAPH Conference in Atlanta next summer.

Selected Project Narratives

User Interfaces and Graphics Cluster

Faculty Research Initiation Support

Dr. Coggins, an expert in image pattern recognition, joined the UNC faculty in the fall of 1986. Dr. Coggins brought with him a research methodology and software tools developed over the last ten years. Unfortunately, the software was incompatible with the UNC computing environment. Thus, Dr. Coggins faced a massive rewriting effort to make his tools available for further research. About the same time that he arrived at UNC, the Department obtained a compiler for the recently-developed object-oriented programming language C++. Dr. Coggins worked on learning C++ and led efforts by several graduate students to develop an object-oriented implementation of his image pattern recognition strategies. This effort is nearing completion, and tools for image analysis, statistical pattern recognition, and simple computer graphics are now available in an integrated object-oriented environment.

With the object-oriented tools now available, Dr. Coggins' main research into object definition strategies has begun again. Experiments are under way to determine how objects in images can be represented and identified. Several preliminary problems of increasing complexity are driving this effort. The easiest driving problem is recognition of certain geometrical shapes. Further problems in increasing difficulty are recognition of printed English characters, recognition of printed Tamil characters (Tamil is an Indian dialect with a large, highly structured alphabet), identification of cells in a microscope image, and identification of organs in a computed tomography image.

Dr. Coggins has also established contacts in the Departments of Opthalmology and Pathology where other kinds of image analysis problems are waiting to be solved. These problems include 3-D modelling of the surface of the cornea, stereo image analysis and subsequent measurement of the optic disk, and automatic segmentation of 2-D and 3-D electron microscope images.

Dr. Coggins has also guided the development of the Pixar Image Computer as a research tool. This work is described in another section.

PIXAR Image Computer Development

The Pixar Image Computer and its host, a Sun-3 workstation, were installed in the Department's graphics lab in mid-May. A team consisting of Dr. James Coggins, a faculty member, and Robert Stam and Russell Tuck, graduate students, began work immediately to explore the Pixar's capabilities and make them available to other members of the Department. Two members of this team had previously traveled to Pixar's headquarters for a three-day course on programming the Pixar.

This team's work can be divided roughly into six categories. These include: machine administration, product testing, data compatibility, software development, education, and research.

Machine administration included integrating the host into the departmental network, which provides disk and printer sharing, electronic mail, and daily disk backups. Software from Pixar and CEMAX was installed, as were subsequent updates to that software. The host had inadequate disk space, so some software and data were migrated to another machine and are now accessed through the network. Access permission to proprietary Pixar and CEMAX software was restricted to authorised users in accordance with our obligations to those companies. Continuing tasks include adding users, installing software updates, and making weekly backup copies of disk storage.

In order to improve our software development productivity, we applied for and were granted status as a beta test site for Pixar's Chap C compiler. As part of this arrangement, we have found, reported, and in some cases fixed problems in this compiler and related libraries.

Image and graphics data in the Department are stored in two data formats. An important early task was to make it possible to use the Pixar on data stored in these formats. We wrote a program to load data from one of these formats into the Pixar, and one of the first users we trained in Pixar programming wrote a similar program for the other image format. These conversion programs make it possible for existing Pixar software to operate on our data. The Pixar demonstration software was augmented to use local data.

The team has developed other software in addition to these conversion programs. An interactive program called "cclortool" was written in microcode (before the C compiler was available) to allow users to explore easily the vast selection of colors (more than 8 billion) representable on the Pixar. A variety of color models

are supported, and the host window system and Pixar processor and display are closely integrated. This tool has been used by other projects in the Graphics Cluster to select realistic colors for rendering a variety of objects.

Another software development effort involved the real-time 2-dimensional Discrete Fourier Transform microcode inside one of the Pixar demonstration programs. This code can also do filtering and convolution in real time. These operations are important to image processing research in the Graphics Cluster and take minutes to compute on other available machines, rather than a fraction of a second. In order to make this code accessible to researchers, code was written in microcode and C to encapsulate the important operations performed by the demonstration program. The result of this work is that programs written in C and running on the host or the Pixar can invoke these operations with a simple subroutine call.

An important role of the team has been to educate users in the Graphics Cluster. One focus has been to demonstrate the Pixar's capabilities, so users whose needs can be met by the Pixar are aware of this. Self-guided demonstrations have been made available to all users in the Graphics Cluster, and the team has given many narrated demonstrations and descriptions of the Pixar's capabilities. The second, complimentary function has been to teach interested people how to use existing software and how to program the Pixar to do new things. Early users were taught individually. A four-hour mini course which is just finishing has given twenty individuals an introduction to Pixar software and programming. The team will continue to be available to answer questions and provide additional guidance to these users.

Work with the Pixar is part of ongoing research projects. Dr. James Coggins' work in image processing will utilise the real-time filtering and convolution software described above. Russell Tuck expects to use the Pixar as a test case in his work on programming machines with SIMD parallel architectures. Bobby Stam plans to make some of the Pixar's capabilities available from any machine on the network. The team has also communicated with other researchers. We received software from Mallinckrodt Institute through direct interaction with their researchers. A team member participates in each Philips Pegasus Project users group meeting, where ideas, experiences, and software are exchanged.

Head-Mounted Display (Year 2)

Ming, Hughes, and Pique fabricated a prototype using two Casio tiny TV's, half-silvered mirrors, the Polhemus sensor, and the PS300 as an image-generator. Pique and Thorvaldsdottir took the head unit prototype to the May meeting of the Molecular Graphics Society in France.

Work has concentrated on calibration and on speeding up the Polhemus sensing loop. We are getting 4-10 updates/second and must achieve 20 updates/second to achieve steady, realistic virtual objects. Getting to 20 updates/second requires meticulous, detail-by-detail engineering of the whole system. We are getting closer month by month by switching from ASCII to binary transmission, moving calculation of matrices downstream to the faster machine, using faster PS300 GSR subroutines, etc. The next effort is to get 19,200 baud transmission working.

Meanwhile, we have started fabricating a second-generation display, using Seiko color TV's with about two times the former resolution.

Decision Support Cluster

Computer with LO Context Switch Time (CLOCS)

Many applications need computers that can switch tasks quickly. Real-time systems require physical events to be serviced rapidly before the next event. General-purpose operating systems need many processes to handle a multitude of background activities. Current computer architecture emphasize throughput at the expense of response time for context switching. Our project will design a microprocessor that will switch context fast enough for the applications mentioned in the main report, and the design will have throughput performance comparable to current designs.

THE UNIVERSITY OF NORTH CAROLINA
AT
CHAPEL HILL

Stephen F. Weiss
Professor and Chairman
Phone: (919) 962-1800
FAX: (919) 962-1799

Department of Computer Science
Campus Box 3175, Sitterson Hall
Chapel Hill, NC 27599-3175
Internet mail: weiss@cs.unc.edu

18 November 1991

Dr. Ralph F. Wachter
Scientific Officer
Office of Naval Research
800 North Quincy Street
Arlington, VA 22217-5000

Dear Ralph:

Ref: Contract #N00014-86-K-0680
The Infrastructure of Command Information Systems

Enclosed is a copy of the **Final Five-Year Summary Report** for the above-referenced contract. Copies are also being sent to those individuals listed in the distribution list, as noted below. If we can clarify or expand upon any area in the report, please let us know.

Our research efforts have been greatly enhanced as a direct result of this contract, and we have certainly enjoyed our association with the Office of Naval Research. On behalf of the members of the Executive Committee and all of our investigators, let me extend our sincere thanks to you, Ralph, for your help, unwavering support, and valued friendship during these five years. We hope that you will continue to come and see us whenever you can, and we look forward to working with you and your fine organization again in the future. Please stay in touch.

Sincerely,

Stephen F. Weiss
Chairman, ONR-URI Executive Committee

Enclosure

Distribution:

Christoph Hoffmann, Professor of Computer Science, Purdue
Stanley Wilson, Consultant, NRL
Elaine Cohen, Professor of Computer Science, University of Utah
Norman A. Meeks, Administrative Contracting Officer, ONR
R. Timothy Arnold, Contracting Officer, ONR
Defense Technical Information Center (12 copies)
Director, Naval Research Laboratory (6 copies)
Annette Crabtree, Contract Administrator, UNC-CH
Members, ONR-URI Executive Committee, UNC-CH
Investigators, UNC-CH

Final Five-Year Summary Report

15 September 1986 through 30 September 1991

The Infrastructure of Command Information Systems

Submitted to

Office of Naval Research
Arlington, VA 22217-5000

Submitted by

Department of Computer Science
The University of Nortn Carolina at Chapel Hill
Campus Box 3175, Sitterson Hall
Chapel Hill, NC 27599-3175

Principal Investigators:

Frederick P. Brooks, Jr.
Donald F. Stanat
Stephen F. Weiss

November 1991

Contract No. N00014-86-K-0680

CONTENTS

SECTION 1: Productivity measures during contract period 1

SECTION 2: Executive Summary/highlights/accomplishments *(by project)* during contract period 2

Head-Mounted Display 2
Tracker 2
Pixel-Planes 5 3
Walkthrough 4
Artifact-Based Collaboration 4
Data-Parallel Execution 4
SoftLab 5

SECTION 3: Publications, reports, presentations, honors/prizes/awards during contract period 7

A. Publications, technical reports (appeared and to appear); books, chapters, videotapes 7
B. Refereed exhibitions 7
C. Refereed papers submitted (awaiting acceptance) 7
D. Presentations 8
E. Honors received 8
F. Prizes or awards received 8
G. Promotions obtained 8
H. Educational productivity 8

SECTION 4: Transitions and DoD Interactions *(by project);* follow-on research 9

APPENDICES

Appendix I	Participants
Appendix II	Educational productivity
Appendix III	Comprehensive bibliography
Appendix IV	Equipment Reports
Appendix V	Travel Reports
Appendix VI	ANNUAL REPORTS, for each of the five years

FINAL SUMMARY REPORT

Principal Investigators:	Frederick P. Brooks, Jr. Donald F. Stanat Stephen F. Weiss
PI Institution:	The University of North Carolina at Chapel Hill Department of Computer Science
PI Phone Numbers:	919/962-1931 919/962-1788 919/962-1888
PI E-mail Addresses:	brooks@cs.unc.edu stanat@cs.unc.edu weiss@cs.unc.edu

Contract Title:	The Infrastructure of Command Information Systems
Contract Number:	N00014-86-K-0680
Contract Period:	15 September 1986 through 30 September 1991

SECTION 1: Productivity measures during contract period

		ONR supported	Related
1.1	Refereed papers submitted *(awaiting acceptance)*	0	10
1.2	Refereed papers submitted *(to appear)*	2	2
1.3	Refereed papers published	41	54
1.4	Unrefereed reports and articles *(published or to appear)*	78	51
1.5	Books (or parts thereof) submitted (*to appear*)	0	0
1.6	Books (or parts thereof) published	1	9
1.7	Patents filed but not yet granted	0	0
1.8	Patents granted (includes software copyrights)	0	1

1.9 Educational productivity (see Appendix II for details)
Degrees earned by RAs supported by ONR ≥ 25% of full time during any year of contract period:
M.S. degree 29
Ph.D. degree 6

		Supported or Related
1.10	Presentations	85
1.11	Honors received	15
1.12	Prizes or awards received	3
1.13	Promotions obtained	5
1.14	Graduate students supported ≥ 25% of full time during any year of contract	47
1.15	Post-docs supported ≥ 25% of full time	1
1.16	Minorities supported ≥ 25% of full time during any year of contract period	4

SECTION 2: Executive Summary/highlights/accomplishments *(by project)* during contract period (including hardware/software prototypes developed)

Head-Mounted Display

Key words: Virtual reality; head-mounted displays; helmet-mounted displays; interactive 3D graphics; head-movement tracking.

Summary:

Our primary objective is the exploration and development of dynamic interaction techniques between human users and computer-generated virtual worlds. This interaction depends upon the image of the virtual world responding to the user's movements in the same manner that the user's view of the real world does. A second objective is the dissemination of our research results to applications developers within our Department who wish to make use of virtual world technology.

The head-mounted display (HMD) project obtained ONR support during the 1987–88 project year (the second year of this contract). Our team had already been conducting research on the development and use of head-mounted display systems, but with ONR funding we were able to accelerate our effort. During that first year, we integrated our UNC-designed, head-mounted display prototype with the Pixel-Planes graphics engine, resulting in overall improvements in speed, image quality, and user control. The head-mounted display was also integrated with the Walkthrough prototype. The following year we obtained a fiberglass head-mounted display from the Air Force Institute of Technology and a VPL EyePhone, and began using those devices in our research. In addition, an effort to design and build a new real-time three-dimensional position and orientation-tracking device for head-mounted displays spun off the main head-mounted display research project that year.

In subsequent years, we have made significant progress in head-mounted display research, including the display of stereo images in the head-mounted display systems, user-controlled flying in virtual environments, the addition of sound triggered by events in a virtual environment, and the addition of a speech recognition capability. We began supporting multi-person shared virtual worlds. We also released Quatlib, Trackerlib, and Vlib standard software libraries, making the head-mounted display and other virtual world technology accessible by applications developers in the Department. Quatlib is a collection of quaternion-handling routines used by Trackerlib and Vlib. Trackerlib is a library of functions representing a level of abstraction between the applications programmer and the tracking device being used. Vlib enables the programmer to build, maintain, and interact with a virtual world. In the summer of 1991, we migrated the software and peripheral hardware to the newly developed Pixel-Planes 5 graphics engine and its attendant host. Pixel-Planes 5 is approximately 60 times faster and has greater generality than Pixel-Planes 4 and thus greatly enhances the image display for our HMDs.

Work with a novel display technology using lasers and moving mirrors was proposed and investigated. Upon further study, however, it was decided that none of these deflection methods could produce today a display device with resolution better than the current CRTs.

The idea of using a head-mounted display to superimpose real-time ultrasound images onto the tissue being imaged is also being investigated.

Jannick Rolland joined our team in June 1990, and has designed the custom optics for the planned new see-through head-mounted display for the medical "X-ray vision" and other applications.

Tracker

Key words: Optoelectronic tracker; lateral-effect photodiodes; head-mounted display; head tracker.

Summary:

An optical head tracking system has been developed that is easily scalable in size, has an update rate of 20-100 Hz with 20-100 milliseconds of lag, and resolves head motions of .080" and .2°. The system adopts an inside-out optical tracking paradigm first proposed by our research team and introduced in a paper by Gary Bishop and Henry Fuchs in 198 . A prototype was demonstrated at SIGGRAPH '91 with a 10 x12-foot working environment. The working environment is defined by a suspended ceiling of standard-sized, but custom 2 x 2-foot ceiling panels. Each ceiling panel precisely locates and controls 32 light emitting diodes (LEDs). Any LED in the ceiling can be addressed and then lighted with a programmable current level. With the 10 x 12-foot ceiling presently in place, 30 ceiling panels provide 960 LEDs as navigation beacons. In operation, four camera-like image sensors mounted on a head-mounted display measure—relative to the head—the photocoordinates of sequentially lighted LEDs. Given this two-dimensional information for three or more

LEDs, as well as the known location of the LEDs in the environment, the position and orientation of the headset can be computed. We have extended a photogrammetric technique known as space-resection by collinearity to allow the photocoordinates emerging from a variable number of sensors to be used in the computation.

Pixel-Planes 5

Key words: 3D graphics; raster graphics; graphics architectures; VLSI, VLSI systems; multiprocessors; parallel processors; display algorithms.

Summary:

Our objective has been to design and to build multicomputer architecture (both hardware and software) for 3D interactive graphics that delivers in excess of one million polygons per second to real applications and that supports a wide variety of rendering algorithms.

The Pixel-Planes 4 raster graphics system was introduced at SIGGRAPH '86; design enhancements continued, and the three-year-long hardware development was essentially completed during 1987. At its introduction Pixel-Planes 4 was one of the fastest raster graphics machines and one of greater generality than most, capable of displaying rapidly not only polygons, but also spheres, shadows, Mandelbrot fractal images, and other types of imagery. Since 1986 the machine has been in daily service in our Graphics and Image Lab, where it is used by several research groups: in molecular modeling, in 3D medical imaging, and in building architecture previewing.

Work on algorithms and applications on Pixel-Planes 4 continued until 1991. A graphics library that implements a subset of the PHIGS+ standard was developed and is now in regular use.

The next generation graphics system, Pixel-Planes 5, was designed and built over a period of about three years: from late 1987 through 1991. (The hardware prototype became operational in July 1990, and the full three-rack system was completed during the summer of 1991.) This system is approximately 60 times faster than Pixel-Planes 4 and has greater generality (it can render some curved surfaces, textures, volume imagery) and greater modularity to allow various configurations and to upgrade components. Its architecture takes advantage of, and in some cases pioneers, several major trends in graphics algorithm and architecture research. In algorithms: rendering of curved surface primitives and more realistic lighting models. In architecture: virtual pixel maps; virtual pixel processors; composite parallel processing, combining fine-grained SIMD parallelism with large-grained MIMD parallelism, interconnected with a 5Gbit ring network, using a message-passing distributed operating system.

Work continues on refining software to use the hardware more efficiently, and developing algorithms, applications, and system software.

We transported a Pixel-Planes 5 three-rack system and exhibited it in the Tomorrow's Realities Gallery at the SIGGRAPH '91 conference, July 28–August 2, 1991. Of all the applicants, UNC–CH had the largest number of demonstrations accepted for this juried exhibit and had the largest booth (29 x 43 feet). We showed a number of applications running on Pixel-Planes 5, including the head-mounted display, volume rendering, and polygon and sphere rendering at over two million polygons/sec. The demonstrations were: 3dm—A Two-Person Modeling System, Interactive Building Walkthrough Using a Steerable Treadmill, Interactive Building Walkthrough Using the Optical Tracker, Flying Through Molecules, A Mountain Bike with Force Feedback Pedals, Radiation Therapy Treatment Planning, and the Virtual Pilot. All of our demonstrations at the exhibit were single-user, "hands-on" experiences. Because each demonstration takes about five minutes, we were able to show demos to a relatively limited number of people. During the five days that the exhibit was open, approximately 600 people were able to experience our virtual reality demos. Crowds were able to experience demos second-hand by observing monitors that showed the same images that were being fed to the head-mounted display and being seen by the single interactive user.

In 1991, we granted a limited license of our two patents to IVEX Corporation (Norcross, Georgia) for use in vehicle and flight simulation and training. One of our former senior staff members, Thomas "Trey" Greer, has joined IVEX's staff but continues to work part-time in our laboratory developing algorithms (that remain in the public domain) for future IVEX products based on our technology (IVEX pays UNC–CH for Greer's use of the facilities). In February 1992 IVEX plans to ship the first product incorporating the Pixel-Planes technology. These are enhancements to current products—visual systems for flight simulators. IVEX expects FAA Phase 2 certification, based in part on the anti-aliased, polygon-generation capabilities provided by the Pixel-Planes technology.

The major funding for Pixel-Planes research during the past decade has come from DARPA and NSF. Support by ONR has accelerated our research efforts.

Walkthrough

Key words: Computer graphics.

Summary:

We developed and refined a prototype software system enabling a user to walk through a virtual building in real time and to get rather good visual and aural impressions of how the spaces will feel. 1991 user studies confirm this adequacy.

Accomplishing this required us to make advances in four areas:

- Faster—During the five years, we improved our image generation rate 200 times, from one image each four seconds to 56 images per second. This was done by hardware and algorithm advances.
- Prettier—During the five years, we went from monocular views to stereo, and from flat-shaded polygons lighted uniformly to
  - –Phong-shaded polygons
  - –quite realistic radiosity lighting
  - –textured polygons

  The user also hears sounds appropriate to the virtual space he is in.
- Handier—We developed, in conjunction with other projects, a very natural interface that allows the viewer to freely roam a 10 x 12-foot space and to translate that space through building models. The interface also allows the user to turn individual lights on and off almost instantaneously.
- Realer—We developed better modeling techniques for highly detailed, substantial buildings and produced three models that are extensively used in the virtual worlds research community.

Artifact-Based Collaboration

Key words: Collaboration strategies; machine-recorded protocols; automated analysis; cognitive grammars; visualization tools.

Summary:

During the last five years, ONR has supported our work toward two major goals. First, we have developed new tools and methodology for studying how people work with computers. By understanding users' strategies and behaviors better, we can, in turn, build computer systems that more closely match the way they think and work. Toward that end, we have developed tools that automatically record users' actions, replay sessions for study and analysis, tools to analyze these data automatically, and tools to display the data in ways that make it easier to understand and characterize. Second, we have extended our work in this area from single users to groups of users working collaboratively. In this latest project—which is supported primarily by NSF and IBM with additional support from ONR—we are studying the process of collaboration, building an advanced hypermedia system to support collaboration on software development and other similar design projects, and studying users working with our system. ONR has helped us explore tools for recording and analyzing the actions of groups, analogous to the earlier tools we built to study individual users.

Data-Parallel Execution

Key words: Highly parallel computing; data-parallel programming languages; MasPar MP-1; dynamic load-balancing.

Summary:

Programming Highly parallel computers

While highly parallel computers now offer the highest computing performance available, the principal impediment to their general use lies in the difficulty of programming them. A portion of this contract has sponsored work aimed at the understanding, simplification, and application of data-parallel programming techniques to program these machines. To yield *efficient* programs, we have identified an expressive class of data-parallel expressions and a compilation technique to make direct use of mesh and hypercube connectivity in target machines. To yield *portable* programs, we target CVL, a data-parallel intermediate language developed at CMU, which has implementations on a wide class of machines.

MasPar MP-1 acquisition

The first MasPar MP-1 massively parallel computer to be placed in a University was installed in our Department in January of 1990. Acquisition of the 4,096-processor MP-1 was jointly funded by ONR (this contract), The University of North Carolina at Chapel Hill, and NIH. This machine has enabled the data-parallel execution work to expand from theory into practice. In the 18 months since its installation, we have designed and implemented new sorting and graphics algorithms, implemented the CVL data-parallel intermediate language, and demonstrated a variety of applications, including real-time force calculation and feedback for the molecular docking experiment in the GRIP project, applications in image processing, neural-network computations, and physical system simulations.

A new course on programming highly parallel computers was developed to use the MP-1 as its practicum. More than 60 students undertook projects on the machine through this course.

Scan-directed load balancing

A dynamic technique for equalizing the computational work without sacrificing the locality properties of a parallel computation was developed and is the subject of ONR fellow Ed Biagioni's Ph.D. thesis (expected Nov 1991). Extensive experiments with its application were run on the MP-1.

SoftLab (Infrastructure)

Key words: Software engineering; technology transfer; software capitalization; software development environments; software tools.

Summary:

SoftLab Software Systems Laboratory is an infrastructure organization that provides the UNC–CH Computer Science Department with software systems and software packaging and distribution services analogous to those typically found in industry. As such, SoftLab serves as a software development resource for the Department and as an agent of technology transfer to other universities and to industry.

Since it was established in 1989, SoftLab has supported the rapid prototyping of experimental VLSI architectures and distributed systems by developing simulators, drivers, compilers, interfaces, and communications software. During this three-year period, SoftLab completed microcode preprocessors for two custom-built graphics engines, one partly based on the Weitek XL chip and the other partly based on the Intel i860 chips. Both preprocessors facilitate hand optimization of assembler and are heavily used by Department software developers to code graphics applications programs that require high-speed performance.

IDL (Interface Description Language), a programming environment for rapid prototyping of compilers, designed by Richard Snodgrass, was an early SoftLab project. IDL has been widely distributed and is regularly used by SoftLab to develop other software, including the preprocessors described above. In addition, SoftLab also developed a preliminary version of a C optimizer for the i860. Other prototyping support tool work during this period included major enhancements to an architectural simulator, drivers for downloading program and text from a UNIX workstation to BLITZEN, a custom SIMD machine developed jointly by Duke, UNC–CH, and MCNC, and a driver to integrate our Department's network of UNIX workstations with our telephone switch.

One very important SoftLab function is the capitalization of its own software and the software developed by other research groups within the Department. To this end, SoftLab has defined and implemented a software packaging, distribution, and support methodology that serves a customer base of almost 200 domestic and foreign academic and commercial institutions. This methodology includes code and documentation review and revision, configuration control, versioning, preparing for remote installation, porting to various hardware platforms, testing, advertising, licensing, acquiring copyright protection, assembling distribution, customer interfacing, and, in some cases, making future enhancements. This centralizes the Department's software distribution function achieving economy of scale and freeing individual researchers from associated administrative burdens.

Finally, SoftLab has served as a software engineering practicum for students. Work on SoftLab software capitalization projects provides graduate student research assistants with exposure to issues, methods, and solutions needed for software development in the large. In addition, SoftLab has been a client for Software Engineering course programming teams. This has given course students the opportunity to experience work for a real client on real projects. Finally, SoftLab has served as a consultant on software engineering issues arising in the development of research software in the Department. It has participated in the design of the build mechanisms for several major software systems in the Department and has developed guidelines for documentation and configuration management.

PROTOTYPES:

IDL

The IDL Toolkit is a programming environment for rapid prototyping of compilers designed and implemented by Richard Snodgrass and his students. IDL was originally packaged and distributed by SoftLab, but distribution and support were later assumed by a commercial software distributor, UniPress Software, Inc.

MAXL 2.0

Pixel-Planes 4 is a high-performance, 3D raster display system that harnesses the power of custom VLSI circuits. Pixel-Planes 4 architecture is partly based on the Weitek XL chip, and many application programs are written in Weitek assembler for performance reasons. SoftLab, working in conjunction with Pixel-Planes application programmers, developed a microcode preprocessor that automated register allocation, pipeline analysis and other machine details. This preprocessor has significantly improved Pixel-Planes 4 programmer productivity. Weitek has a copy of the code, and there was discussion about commercialization. However, commercialization is unlikely since the chip is becoming obsolete.

MAST860

MAST860 is a microcode preprocessor for the Intel i860 floating point chip. It facilitates hand optimization of i860 assembler by automating register allocation and other machine details and by performing pipeline analysis. MAST860 is currently used by Pixel-Planes 5 applications programmers who code in-hand optimized assembler for performance reasons. We have advertised this prototype on various bulletin boards and have also sent a preliminary copy to Intel for review. Future commercialization is a possibility.

UNIX-PHONE SWITCH INTERFACE AND APPLICATIONS

Last year, SoftLab implemented a UNIX driver that allows telephone switch functions such as phone calls and networking operations to be controlled from Department workstations. This driver communicates with our InteCom switch via the InteCom Open Applications Interface (OAI) feature on the switch. Our UNIX driver software was made available to InteCom, which is starting up a UNIX application development effort. In addition, we also implemented two UNIX applications on top of the driver software. The first was a voice mail application that stored and manipulated voice messages as UNIX files; and the second was a power dialer that allowed phone calls to be placed by UNIX workstation commands using online databases of numbers and speed-calling lists. This work was an initial step in setting up an integrated voice and electronic messaging system that would form a test bed for Department research in distributed computing. InteCom included a description of our applications in its advertising literature, and we have been contacted by DataTrac, Inc. about a possible joint venture for further application development.

MOSEL

MOSEL (Modular Operating System Experimentation Laboratory) is a family of architecture and operating system experimentation tools that will include a hardware simulator for M-code architectures with the ability to simulate execution of both Modula-2 and C programs, some extensible operating systems for two basic machine simulations, and various tools for monitoring and analyzing architectures and operating systems. MOSEL is intended for both classroom and rapid prototyping use. At this time, the simulator is largely complete and execution of modula-2 programs can be simulated. We are currently working on the C program simulation tools. We also have a single process operating system, and the beginnings of the multi-process version in place. Work continues.

Refer to Appendix VI for information about projects supported by ONR during only the first 2–3 years of the contract.

SECTION 3: Publications, reports, presentations, honors/prizes/awards during contract period

A. Publications, technical reports (appeared and to appear); books, book chapters; videotapes

See Appendix III—Comprehensive Bibliography—for a complete categorized list, to date.

B. Refereed exhibitions

The UNC–CH Computer Science Department provided a major exhibit in the "Tomorrow's Realities" Gallery at the SIGGRAPH '91 Conference, Las Vegas, NV, 28 July-2 August, 1991. Demonstrations included:

A. Pixel-Planes 5 three rack system.

B. 10 x 12-foot Optical "Ceiling" Tracker.

C. 3dm—A Two-Person Modeling System.

D. Interactive Building Walkthrough Using a Steerable Treadmill.

E. Interactive Building Walkthrough Using the Optical Tracker.

F. Flying Through Molecules.

G. A Mountain Bike with Force Feedback Pedals.

H. Radiation Therapy Treatment Planning.

I. Virtual Pilot.

C. Refereed papers submitted *(awaiting acceptance)*

Banks, David. "Interactive Manipulation and Display of Surfaces in Four Dimensions," submitted to *1992 Symposium on Interactive 3D Graphics*, Cambridge, MA, 29 March–1 April 1992.

Butterworth, Jeff, Andrew Davidson, Stephen Hench, and T. Marc Olano. "3DM: A Three Dimensional Modeler Using a Head-Mounted Display," submitted to *1992 Symposium on Interactive 3D Graphics*, Cambridge, MA, 29 March–1 April 1992.

Chung, James C. "A Comparison of Head-Tracked and Non-Head-Tracked Steering Modes in the Targeting of Radiotherapy Treatment Beams," submitted to *1992 Symposium on Interactive 3D Graphics*, Cambridge, MA, 29 March–1 April 1992.

Jeffay, Kevin. "Scheduling Sporadic Tasks with Shared Resources in Hard-Real-Time Systems," submitted to *IEEE Trans. on Computers*, TR90-039, Department of Computer Science, UNC at Chapel Hill, Nov. 1990.

Neumann, Ulrich. "Interactive Volume Rendering on a Multicomputer," submitted to *1992 Symposium on Interactive 3D Graphics*, Cambridge, MA, 29 March–1 April 1992.

Rhoades, John, Greg Turk, Andrew Bell, Andrei State, Ulrich Neumann, and Amitabh Varshney. "Real-Time Procedural Textures," submitted to *1992 Symposium on Interactive 3D Graphics*, Cambridge, MA, 29 March–1 April 1992.

Robinett, Warren, and Richard Holloway. "Implementation of Flying, Scaling and Grabbing in Virtual Reality," submitted to *1992 Symposium on Interactive 3D Graphics*, Cambridge, MA, 29 March–1 April 1992.

Smith, John. B., and Dana K. Smith. "Automated Protocol Analysis," submitted to *Human-Computer Interaction*, TR91-034, Department of Computer Science, UNC at Chapel Hill, Aug. 1991

Surles, Mark C. "Interactive Modeling Enhanced with Constraints and Physics—with Applications in Molecular Modeling," submitted to *1992 Symposium on Interactive 3D Graphics*, Cambridge, MA, 29 March–1 April 1992.

Ward, Mark, Ronald Azuma, Robert Bennett, Stefan Gottschalk, and Henry Fuchs. "A Demonstrated Optical Tracker with Scalable Work Area for Head-Mounted Display Systems," submitted to *1992 Symposium on Interactive 3D Graphics*, Cambridge, MA, 29 March–1 April 1992.

D. Presentations

See individual Annual Reports, included as Appendix VI. See also Section I, Productivity Measures.

E. Honors received

Frederick P. Brooks, Jr.:

- elected Foreign Member of the Royal Netherlands Academy of Arts and Sciences (Science Division), April 1991.
- has served on the National Science Board since 1987.
- has served on the IBM Science Advisory Committee since 1979.

John Eyles served on the Program Committee of the Third Workshop on Graphics Hardware, sponsored by Eurographics, September 1988.

Henry Fuchs:

- co-director (with Karl Heinz Höhne and Stephen M. Pizer) of the NATO Advanced Research Workshop on 3D Imaging in Medicine, Travemünde, Germany, June 1990.
- served on the following conference program committees: Symposium on Interactive 3D Graphics, 1990; Chapel Hill Workshop on Volume Visualization, 1989, Conference on Advanced Research in VLSI, 1986–1990; Computer Graphics International, 1987 & 1988.
- served on the following conference papers committees: ACM SIGGRAPH, 1986–1991; Conference on Advanced Research in VLSI, 1986–1990; Eurographics, 1986; International Electronic Image Week (CESTA, SIGGRAPH), 1986 & 1987; Computer Graphics International, 1987 & 1988.
- chaired the 1986 Workshop on Interactive 3D Graphics, held at UNC–Chapel Hill, October 22-24, 1986.
- served as associate editor of ACM's *Transactions on Graphics*, 1983–1988.

John Poulton became a Senior Member of IEEE in 1990.

F. Prizes or awards received

Frederick P. Brooks, Jr.:

- Harry Goode Memorial Award, American Federation of Information Processing Societies, 1989
- Distinguished Service Award, ACM, 1987
- Thomas Jefferson Award, University of North Carolina at Chapel Hill, 1986

G. Promotions obtained

Gary Bishop joined our faculty as Research Associate Professor in May 1991.

John Eyles was promoted from Senior Research Associate to Research Assistant Professor in 1988.

Henry Fuchs:

- was named Federico Gil Professor of Computer Science in 1988.
- was appointed Adjunct Professor of Radiation Oncology in 1988.

John Poulton was promoted to Research Associate Professor in 1988.

H. Educational productivity

See Appendix II.

SECTION 4: Transitions and DoD interactions *(by project);* follow-on research

A. Transitions of results and DoD interactions

For years 4 and 5, please also see Section 4 of FY89-90 and 90-91 Annual Reports, included with this report as Appendix VI. Please also see "Presentations," included in each annual report.

ONR site visitors, years 1 through 5:

27 May 1987:

A. F. Tony Norcio, Computer Scientist, NRL
Andre van Tilborg, Computer Scientist, ONR
Ralph F. Wachter, Program Manager, Computer Science Division, ONR
Stanley H. Wilson, Chief Scientist for Computation, Information Technology Division, NRL

8 July 1987:

Charles Holland, Scientific Officer, ONR

4-5 April 1988:

Charles Holland, Scientific Officer, ONR
Andre van Tilborg, Computer Scientist, ONR
Ralph F. Wachter, Program Manager, Computer Science Division, ONR
Stanley H. Wilson, Chief Scientist for Computation, Information Technology Division, NRL

31 August–1 September 1989

Peter Brown, Mechanical Engineer, National Institute of Standards and Technology (NIST)
Christoph M. Hoffmann, Professor, Computer Science, Purdue University
Cmdr. John Sheridan, Deputy Director, Engineering Sciences Directorate, ONR
Andre van Tilborg, Director, Computer Science Division, ONR
Ralph F. Wachter, Scientific Officer, ONR
Stanley H. Wilson, Chief Scientist for Computation, Information Technology Division, NRL

25-26 September 1990

Peter Brown, Mechanical Engineer, National Institute of Standards and Technology (NIST)
Susan Chipman, Program Manager for Cognitive Science, ONR
Christoph M. Hoffmann, Professor, Computer Science, Purdue University
William E. Isler, Assistant Dean for Research, College of Engineering, NC State University
Richard Miller, Chief Scientist, Mechanics Division, ONR
Ralph F. Wachter, Scientific Officer, ONR
Stanley H. Wilson, Consultant, Information Technology Division, NRL

Agendas for each site visit were appended to each Annual Report (see Appendix VI of this report).

Pixel-Planes 5

In summary: Ideas from Pixel-Planes 4 and some of its predecessors have been adopted by several commercial high-performance systems, among them the Stellar GS-1000, the Silicon Graphics IRIS VGX, and the AT&T Pixel Machine.

From October 1988 to May 1990, we conducted a study for the U.S. Air Force (monitoring organization was the Cockpit Integration Directorate at Wright-Patterson Air Force Base) entitled "An Architecture for Advanced Avionics Displays." In this study we investigated several existing and emerging high-performance graphics architectures. We also performed an analysis of the specific requirements for airborne graphics systems in order to identify the most critical requirements. The graphics architectures were evaluated with regard to their applicability to an airborne system, and a candidate architecture was selected. A high-level design of an airborne system meeting the requirements and based on the candidate architecture was performed, with detailed analysis of the actual implementation of features identified as critical, including the algorithms to be used.

SoftLab (Infrastructure)

Products distributed by SoftLab:

These numbers reflect distributions made between January 1989 and August 1991.

Volume Rendering Data Sets (numbers for Volumes I and II combined)

The Volume Rendering Data Sets Volume I and II contain medical and other images as shown at the 1990 Volume Visualization Workshop. These are the first items in a planned "visual data set" product line.

37 academic distributions
34 industry distributions

COOL 1.0

COOL is a software library developed by James Coggins. COOL, written in the object-oriented language C++, contains class definitions relevant to research in computer vision, image pattern recognition, and computer graphics. We are currently working on the packaging of COOL 2.0.

6 industry distributions

RSpace 1.3

RSpace is an interactive program, developed in the Computer Science Department by Mark Harris in 1988, which is designed to help crystallographers plan data collection strategies when using diffractometers equipped with area detectors. SoftLab is currently developing RSpace 2.0, which will include some significant new user interface features. These are expected to broaden the RSpace customer base further.

36 academic distributions
19 industry distributions

IDL ToolKit

The IDL (Interface Description Language) ToolKit was implemented by Richard Snodgrass and his students. IDL is essentially a programming environment for rapid prototyping of compilers, although it has more extensive application than this. IDL was originally packaged and distributed by SoftLab, but distribution and support responsibilities were later assumed by a commercial software distributor, UniPress Software, Inc.

The numbers below include only SoftLab distributions.

33 academic distributions
24 industry distributions

WE

WE (Writing Environment) is a hypertext, graphic-based system, written in Smalltalk, designed to help professionals write more effectively and efficiently. Unlike many conventional documentation systems, WE is much more than a word processor; it carries the user through all phases of the writing process, from organizing ideas to editing text.

New Product

B. Follow-on research

Head-Mounted Display and Tracker

During this reporting period, we received funding for a proposal entitled, "Advanced Technology for Portable Personal Visualization." Funded by DARPA/ISTO (order no. 7508), this effort will accelerate dramatically our ongoing work in head-mounted display systems by developing four technological thrusts crucial to the realization of portable personal visualization computer systems: portable image generation, optical and inertial head tracking, optical hand tracking, and improved design of headgear optics.

In conjunction with four other institutions (Brown University, California Institute of Technology, Cornell University, and University of Utah), we received a grant from the National Science Foundation (cooperative agreement no. ASC-8920219) to create a Science and Technology Center in Computer Graphics and Scientific Visualization. The funding of this grant will offer the opportunity for collaborative efforts among researchers and graduate students at the five participating institutions.

UNC–CH points of contact for additional information: Frederick P. Brooks, Jr. and Henry Fuchs.

Pixel-Planes 5

Several closely related projects have been launched at UNC–CH during this reporting period:

VISTAnet: A Very High Bandwidth Prototype Network for Interactive 3D Medical Imaging Research. This prototype network is one of five nationwide, funded by NSF and DARPA through the Corporation for National Research Initiatives, and by BellSouth and GTE. It will link researchers in the UNC–CH Department of Radiation Oncology with the North Carolina Supercomputing Center's Cray Y-MP and UNC–CH Computer Science Department's Pixel-Planes 5 graphics engine. The network will deliver powerful computing and visualization capabilities for real-time 3D radiation treatment planning.

Advanced Technology for Portable Personal Visualization. Funded by DARPA ISTO (Order No 7508), this effort will accelerate dramatically our ongoing work in head-mounted display systems by developing four technological thrusts crucial to the realization of portable personal visualization computer systems: portable image generation; optical and inertial head tracking; optical hand tracking; improved design of headgear optics.

Three-Dimensional Display for Read-Time 3D Ultrasound Imaging. Part of Duke University's NSF-sponsored Engineering Research Center for Emerging Cardiovascular Technologies, this project seeks to provide real-time display of 3D ultrasound data to be acquired in real time by a new ultrasound imaging system under development at Duke. Started several years ago, significant hardware construction has waited for the availability of Pixel-Planes 5. We plan to build a prototype system based on Pixel-Planes 5 that will interactively generate volume imagery incrementally built up from multiple image slices as they are acquired by a conventional 2D ultrasound scanner.

Science and Technology Center in Computer Graphics and Scientific Visualization. In conjunction with four other institutions (Brown University, California Institute of Technology, Cornell University, and University of Utah), we received a grant from NSF and DARPA to create a Science and Technology Center in Computer Graphics and Scientific Visualization. Collaboration with researchers at these four institutions has now begun. We anticipate that the earliest results relating to Pixel-Planes may be more rapid interaction in images with global lighting effects. This would be a result of collaboration with our Cornell colleagues, who have pioneered these "radiosity" lighting techniques.

UNC–CH point of contact for additional information: Henry Fuchs.

Walkthrough

The follow-on research is jointly funded by DARPA and NSF in a five-year grant The scope of the grant includes developing technology and applications for personal portable virtual reality systems. Lance Glasser at DARPA is one of the contract officers.

UNC–CH points of contact for additional information: Frederick P. Brooks, Jr., and Henry Fuchs.

Artifact-Based Collaboration

Follow-on grants for collaboratory research include:

"Building and Using a Collaboratory: A Foundation for Supporting and Studying Group Collaborations," grant from the National Science Foundation (IRI-9015443), for the period 09/01/90 through 08/31/93.

"A Hypermedia Environment for Software Development," grant from IBM Corporation (#866), for the period 09/01/89 through 08/31/92.

UNC–CH point of contact for additional information: John B. Smith.

Data-Parallel Execution

Initial research undertaken as part of the URI contract led to a separate ONR proposal entitled, "Compiling Data-Parallel Programming Languages for SIMD Execution," (Contract #N00014-89-J-1873), for the period 03/15/89 through 06/30/90.

Complementary interests between our data-parallel programming languages group and a group led by John Reif at Duke University studying parallel algorithms led to the formation of a joint research group on high-level, data-parallel programming languages. In conjunction with Kestrel Institute, we proposed to DARPA that we design a high-level language for prototyping parallel and distributed applications. This effort was funded by DARPA (monitored by ONR under contracts N00014-90-K-0004 and N00014-91-C-0114) from 05/01/90 to 05/01/92 at approximately a $1.2 million funding level, of which currently one-third comes to our group at UNC–CH. Further work in the implementation of the language has been proposed to start in the summer of 1992.

UNC–CH point of contact for additional information: Jan Prins.

APPENDIX I

Personnel By Project, FY90-91

(during full or partial year)

ONR Executive Committee:

Frederick P. Brooks, Jr.
Henry Fuchs
Ralph A. Mason
Donald F. Stanat
Stephen F. Weiss, chairman
Warren Robinett, technical liaison
Jeannie M. Walsh, administrative coordinator

PIXEL-PLANES 5

Coordinators:

Henry Fuchs, PI
John Poulton, PI and project manager

Staff:

Laura Weaver (research engineer)
Edward Hill (applications programmer)

RAs:

Mike Bajura (MCNC fellow)
Andrew Bell
Jeff Butterworth
David Ellsworth (ONR fellow, FY89-90, 90-91)
Howard Good
Victoria Interrante
Jonathan Leech
Steve Molnar (IBM Mfg. Research fellow, FY89-90, 90-91)

Other Faculty:

John Eyles (senior engineer)
Anselmo Lastra

Carl Mueller
Ulrich Neumann
Marc Olano
Mark Parris
John Rhoades
Andrei State
Greg Turk (IBM fellow, FY89-90, 90-91)

WALKTHROUGH

Coordinator:

Frederick P. Brooks, Jr.

Staff:

John Hughes (research associate)
Deep Jawa (research associate)
David Lines (editorial assistant)

RAs:

John Alspaugh
Randall Brown
Curtis Hill

Amitabh Varshney
Yulan Wang
Xialin Yuan

HEAD-MOUNTED DISPLAY

Coordinators:
Frederick P. Brooks, Jr.
Henry Fuchs

Other Faculty:
Stephen M. Pizer
Vernon L. Chi (director of MSL)

Staff:
Warren Robinett (project leader)
Jannick Rolland (optical engineer)
John Hughes (research associate)

RAs:
Ron Azuma
William Brown
James Chung
Andrew Davidson
Erik Erikson
Richard Holloway

Other:
Michael Pique (collaborator, Scripps Institute)

TRACKER

Coordinator:
Henry Fuchs

Other Faculty:
Vernon L. Chi
Gary Bishop
John Eyles

Staff:
Brad Bennett (electronic technician)
Stefan Gottschalk (programmer)
Jack Kite (research engineer)
Mark Ward (research engineer)

RAs:
Ron Azuma
Carney Clegg
Phil Jacobsen

ARTIFACT-BASED COLLABORATION

Coordinators:
John B. Smith and Stephen F. Weiss

Other Faculty:
Peter Calingaert
Kevin Jeffay
Marcy Lansman
Dana Kay Smith
F. Donelson Smith

RAs:
Murray Anderegg
Eileen Kupstas

DATA-PARALLEL EXECUTION

Coordinator:
Jan Prins

RAs:
Ed Biagioni (ONR fellow, FY90-91)
Quan Zhou

SOFTLAB (infrastructure)

Coordinator:
Susanna Schwab (director of SoftLab)

RAs:
David Becker
Charles Clark
Heng Chu
Steve Tell

Staff:
Arie Trinker (research associate)
Madelyn Mann (secretary and SoftLab coord.)

30 September 1991
jmw

All participants during FY90-91
(includes infrastructure)

ONR-URI Executive Committee:

Frederick P. Brooks, Jr.
Henry Fuchs
Ralph A. Mason, Jr.
Donald F. Stanat
Stephen F. Weiss (Chairman)

Other Faculty:

Gary Bishop
Peter Calingaert
Vernon L. Chi
John G. Eyles
Kevin Jeffay
Marcy Lansman
Anselmo Lastra
Stephen M. Pizer
John W. Poulton
Jan F. Prins *
Susanna Schwab *
Dana Kay Smith
F. Donelson Smith
John B. Smith

Staff:

Wanda Andrews *	Secretary (half-time)
Brad Bennett	Electronic technician
Coldwell/Christensen/Folda *	Secretaries (part-time)
Lynne Cohen Duncan *	Systems software manager
Stefan Gottschalk	Programmer
Edward Hill	Applications programmer
John Hughes	Research associate
Deep Jawa	Research associate
Frederick Jordan *	Lead computing services technician
Jack Kite	Research engineer
David Lines	Editorial assistant
Ransom Murphy *	Systems programmer (temporary)
Steven Ornat *	Televideo communications technician
Madelyn Mann	Secretary and SoftLab coordinator
Warren Robinett (technical liaison to ONR)	Research associate and project leader, Head-Mounted Display project
Jannick Rolland	Visiting optical engineer (see-through optics)
Arie Trinker	Research associate
Norman A. Vogel *	Director of communications research (Research engineer, Head-Mounted Display project, effective 3 April 1991)
Jeannie M. Walsh *	Research assoc. and admin. coordinator, ONR Contract
Mark Ward	Mechanical engineer (optical tracker)
Laura (Israel) Weaver	Research engineer

Research Assistants:

John Alspaugh *
Murray Anderegg *mp* *
Ron Azuma *
Mike Bajura *mp* *
David Becker
Andrew Bell *mp*
Ed Biagioni * ..... ONR Fellow
Randall Brown *m* *
William Brown *m* *
Jeff Butterworth
Jijun Chen
Heng Chu
James Chung *
Carney Clegg
Andrew Davidson
David Ellsworth * ..... ONR Fellow
Erik Erikson
Howard Good *
Curtis Hill *
Richard Holloway *
Victoria Interrante
Phil Jacobsen *
Eileen Kupstas *
John Lusk *
Jonathan Leech *
Peter Mills *
Steven Molnar
Carl Mueller *
Ulrich Neumann
Marc Olano
Mark Parris
John Rhoades
Andrei State *m*
Steve Tell
Greg Turk
Amitabh Varshney *mp*
Yulan Wang
Xialin Yuan
Quan Zhou

Undergraduate assistants (facilities):

Doug Corbett *

Other:

Michael Pique (collaborator, Scripps Institute)

* *Salary support provided in full or in part by ONR during this reporting period (RAs: ≥ 25%)*
m *M.S. Degree granted during this reporting period*
mp *M.S. Degree granted during this reporting period; on to Ph.D.*

PERSONNEL BY PROJECT, FY89-90

* *Salary partially or fully supported by ONR*

(Degree listed if participant left UNC.)

ONR Executive Committee:

Stephen F. Weiss, chairman
Frederick P. Brooks, Jr.
Henry Fuchs
Ralph A. Mason
Donald F. Stanat

*Warren Robinett, technical liaison
*Jeannie M. Walsh, administrative coordinator

PIXEL-PLANES

Coordinators:
Henry Fuchs, PI
John Poulton, PI and project manager

Staff:
Trey Greer (research engineer)
Laura Weaver (research engineer)
Edward Hill (applications programmer)

RAs:
Mike Bajura (MCNC fellow)
*Andrew Bell
*David Ellsworth (ONR fellow, FY89-90, 90-91)
*Howard Good
Victoria Interrante
*Jonathan Leech
*Steve Molnar (IBM Mfg. Research fellow, FY89-90, 90-91), *summer 1990

Other Faculty:
John Eyles (senior engineer)

Carl Mueller (fall 90)
*Ulrich Neumann
Marc Olano (fall 90)
*John Rhoades
Andrei State (fall 90)
*Brice Tebbs
Russ Tuck (Ph.D.—Duke, May 90)
Greg Turk (IBM fellow, FY89-90, 90-91)

WALKTHROUGH

Coordinator:
Frederick P. Brooks, Jr.

Staff:
John Hughes (research associate)
David Lines (editorial assistant)

RAs:
John Alspaugh
John Airey (Ph.D. Aug 90)
Randall Brown

Visiting Faculty:
Jane Richardson, Duke (starting fall 90)
David Richardson, Duke (FY89-90)
William Wright (Director of GRIP)

Curtis Hill
Penny Rheingans
John Rohlf (M.S. May 90)

HEAD-MOUNTED DISPLAY

Coordinators:
Frederick P. Brooks, Jr.
Henry Fuchs

Other Faculty:
Stephen M. Pizer
Vernon L. Chi (director of MSL)

Staff:
*Warren Robinett (project manager)
*Jannick Rolland (optical engineer)
John Hughes (research associate)

RAs:
Ron Azuma
*William Brown
*James Chung
*Richard Holloway
*Michael T. Kelley (M.S. Dec 89)
*Phil Jacobsen
Jih-Fang Wang (Ph.D. May 1990)

Other:
Michael Pique (collaborator, Scripps Institute)

TRACKER

Coordinator:
Henry Fuchs

Other Faculty:
Vernon L. Chi
Gary Bishop
John Eyles

Staff:
*Mark Ward (research engineer)

RAs:
*Ron Azuma
Phil Jacobsen (since June 1990)
Jih-Fang Wang (Ph.D. May 1990)

PROTOCOL ANALYSIS TOOLS/COLLABORATORY

Coordinators:
John B. Smith
F. Donelson Smith

Other Faculty:
Stephen F. Weiss
*Marcy Lansman, Psychology

Staff:
Gordon Ferguson (research associate), through Feb. 1990

RAs:
*Murray Anderegg
Barry Elledge (M.S. May 90)
*Richard Hawkes (M.S. May 90)
*Eileen Kupstas
Doug Shackelford

DATA-PARALLEL EXECUTION

Coordinator:
*Jan Prins

RAs:
*Ed Biagioni (ONR fellow, FY90-91), *fall 90
*Dan Poirier
*John A. Smith

CLOCS (ONR Fellow)

Coordinator:
Donald F. Stanat

RA:
*Mark Davis (ONR fellow, FY87-88, 88-89, 89-90 thru March '90) (Ph.D. May 90)

INFRASTRUCTURE

Coordinator:
Ralph A. Mason (assoc. chairman for admin.)

Staff: (technical)
*Lynne C. Duncan (systems software manager)
*Frederick Jordan (computing services hdw tech)
*Ransom Murphy (systems programmer)
*Steve Ornat (communications hardware tech)
*Norman Vogel (director of comm. research)

(administrative)
*Jeannie M. Walsh (admin. coordinator)
*Wanda Andrews (secretary)

Students (facilities):
*Jeff Lewis
*Jonathan Whaley

SOFTLAB

Coordinator:
*Susanna Schwab (director of SoftLab)

RAs:
David Becker
Charles Clark

Staff:
Arie Trinker (research associate)
Pam Payne (secretary and SoftLab coord.)

Heng Chu
Steve Tell

21 September 1990
jmw

Participants During FY88-89

ONR-URI Executive Committee:

Donald F. Stanat (Chairman FY88-89)
Frederick P. Brooks, Jr.
Henry Fuchs
Ralph A. Mason
Stephen F. Weiss (Chairman FY89-90)

Other Faculty:

Gary Bishop
Vernon L. Chi
John G. Eyles
John Halton
Marcy Lansman
John W. Poulton
Jan F. Prins (separate contract)
Susanna Schwab*
John B. Smith
Richard Snodgrass*

Staff:

Andrew Certain*	temporary (student)
Lynne Cohen Duncan*	systems software manager
Gordon Ferguson	research associate
Trey Greer	research engineer
Willard Hewitt*	temporary (student)
Edward Hill	applications programmer
John Hughes	research associate
Frederick Jordan*	lead computing services technician
David Lines	editorial assistant
Steven Molnar	research engineer
Steven Ornat*	televideo communications technician
Pamela Payne	secretary and SoftLab coordinator
Warren Robinett*	research associate and project leader, GRIP and Head-Mounted Display projects
Raj Singh*	project management engineer
Arie Trinker	research associate
Norman A. Vogel*	director of communications research
Jeannie M. Walsh*	research associate and administrative coordinator, ONR Contract
Sharon Walters*	secretary (half-time)
Laura (Israel) Weaver	research engineer
Jonathan Whaley*	temporary (student)

Research Assistants:

John Airey*
John Alspaugh
Murray Anderegg*
Ron Azuma*
Mike Bajura*
David Becker
Andrew Bell
Gregory Bollella*
Randall Brown*
William Brown*
Debashish Chatterjee
Heng Chu
James Chung*
Charles Clark
Mark Davis* (Fellow, FY88, 89, 90)
Barry Elledge*
David Ellsworth* (Fellow, spring '89; FY90)
Susan Gauch* (Fellow, fall '88)
Howard Good
Richard Hawkes
Curtis Hill
Victoria Interrante
Robert Katz*
Michael T. Kelley*
Mike Kotliar*
Jonathan Leech
John Menges
Ulrich Neumann
Daniel Palmer*
Dan Poirier
Penny Rheingans*#
John Rhoades
John Rohlf%
Frank Silbermann*
John A. Smith
Robert Stam*#
Brice Tebbs#
Steve Tell
Russ Tuck
Greg Turk#
Jih-Fang Wang
Chin Ho Yeh

* *Salary support provided in full or in part by ONR during this reporting period*
% *M.S. Degree granted during FY88-89*
\# *M.S. Degree granted during FY88-89; on to Ph.D.*

Participants during FY 87-88

ONR-URI Executive Committee:

Frederick P. Brooks*, Jr., Committee Chairman
Donald F. Stanat*^, Technical Director
Jay Nievergelt*
Ralph Mason*

Other Faculty:

J. Dean Brock
Vernon L. Chi*
Peter Calingaert
James Coggins
Henry Fuchs*
Bharat Jayaraman
Gyula A. Mago'
David A. Plaisted
John Poulton*
Jan Prins* ^
John B. Smith
Richard T. Snodgrass* ^
Yuki Watanabe
Stephen F. Weiss

Vis. Faculty:

Hussein Abdel-Wahab
Tony Marsland^

Staff^:

Graham Gash, Software Manager
Lynne C. Duncan*, Software Research Manager
Fred Jordan*, Electronics Technician
John Menges*, Communications Software Engineer (through 16 Aug 88/RA)
Steven Ornat*, Communications Hardware Technician
Raj Singh*, Project Management Engineer
Norman A. Vogel*, Director of Communications Research
Jeannie M. Walsh*, Administrative Coordinator
Sharon Walters*, Secretary (half-time)

RAs^:

John Airey*
Edoardo Biagioni
Paulette Bush+
James Chung*+
Mark Davis* (Fellow FY88, FY89)
William Gallmeister+
Susan Gauch* (Fellow FY89)
William Gibson+
Michael Kelley*
Marc Levoy (Fellow FY88)
Richard Potter+
Penny Rheingans*
Frank Silbermann*
Robert Stam*
Mark Surles
James Symon
Douglass Turner+

* *currently participating during FY 88-89*
\+ *M.S. Degree granted during FY 87-88*
^ *Salary support provided in full or in part by ONR during FY 87-88*

Participants, FY86-87

ONR-URI Executive Committee:

Frederick P. Brooks, Jr.
Ralph A. Mason, Jr.
Jay Nievergelt (Chairman)
Donald F. Stanat

Other Faculty:

Hussein Abdel-Wahab, David Beard, Dean Brock, Peter Calingaert, Vern Chi, James Coggins, Henry Fuchs, John Halton, Kye Hedlund, Bharat Jayaraman, Gyula Mago, Tony Marsland, Daniel Pitt, David Plaisted, John Poulton, Jan Prins, Stephen Pizer, John Smith, Richard Snodgrass, Akhilesh Tyagi, Yuki Watanabe, Steve Weiss, Turner Whitted

Staff:

Sharon Core, John Eyles, Graham Gash, William Howell, David Kuzminski, John Menges, Steve Ornat, Raj Singh, Norm Vogel, Jeannie Walsh

Research Assistants:

John Airey
Edoardo Biagioni
Vikram Biyani
Paulette Bush
Jim Chung
Sailesh Chutani
Mark Davis
William Gallmeister
William Gibson
Sheng-uei Guan
Gopal Gupta
Tai-Sook Han
Curtis Hill
Ming Ouh-Young
Amos Omondi
Muru Palaniappan
Penny Rheingans
John Rohlf
Robert Stam
Bryce Tebbs
Russell Tuck
Douglas Turner
Yen-Ping Shan
Will Partain
James Symon
Frank Silbermann

APPENDIX II

Educational Productivity

Degrees Received by Year 1986–1991

RAs who received full or partial ONR salary support

M.S.

1986

Shannon, Karen
Westover, Lee

1987

Clapp, Katherine
Davis, Mark
White, Brian

1988

Bush, Paulette
Ellsworth, David
Gallmeister, Bill
Gibson, William
Potter, Richard
Rheingans, Penny
Stam, Robert
Surles, Mark
Symon, James
Turner, Doug

1989

Jacobsen, Phil
Kelley, Michael T.
Neumann, Ulrich
Rhoades, Johnny

1990

Azuma, Ron
Bajura, Mike
Bollella, Greg
Brown, Randy
Brown, William
Good, Howard
Hawkes, Richard
Palmer, Dan

1991

Anderegg, Murray
Bell, Andrew

Ph.D.

1989

Levoy, Marc
Silbermann, Frank

1990

Airey, John
Davis, Mark
Gauch, Susan

1991

Westover, Lee

Note: ONR fellow Ed Biagioni defends his Ph.D dissertation on 19 November 1991. A copy of his dissertation will be forwarded to Ralph Wachter as soon as it is available.

RAs SUPPORTED by ONR

(RAs who received full or partial ONR salary support)

Name	minority	86-87	87-88	88-89	89-90	90-91
Airey, John				X		
Alspaugh, John					X	X
Anderegg, Murray					X	X
Azuma, Ron	m				X	
Bajura, Mike						X
Bell, Andrew					X	
Biagioni, Edoardo		X	X		X	X*
Bollella, Greg				X		
Brown, Randy				X	X	X
Brown, William				X	X	X
Bush, Paulette			X			
Clapp, Katie		X				
Chung, Jim	m			X	X	X
Davis, Mark		X	X*	X*	X*	
Ellsworth, David		X		X*	X*	X*
Gallmeister, Bill			X			
Gauch, Susan				X*		
Gibson, William		X	X			
Good, Howard					X	X
Hawkes, Richard					X	
Hill, Curtis					X	X
Holloway, Rich					X	X
Jacobsen, Phil					X	X
Kelley, Michael T.			X	X	X	
Kupstas, Eileen					X	X
Leech, Jonathan					X	X
Levoy, Marc		X	X*			
Lewis, Jeff					X	
Lusk, John						X
Mills, Peter						X
Molnar, Steve					X	
Murphy, Ransom						X
Neumann, Ulrich					X	
Palmer, Dan				X		
Potter, Richard		X	X			
Rheingans, Penny			X	X		
Rhoades, Johnny					X	
Shannon, Karen		X				
Silbermann, Frank		X	X	X		
Stahl, David						X
Stam, Robert		X	X	X		
Surles, Mark		X	X			
Symon, Jim		X	X			
Tebbs, Brice					X	
Turner, Doug	m	X	X			
Westover, Lee		X				
White, Brian		X				
TOTALS:	3	15	14	13	23	17
Approx FTE:		14	11	11	11	11

ONR fellows

APPENDIX III

COMPREHENSIVE BIBLIOGRAPHY

Through September 1991

Publications supported by ONR, or related to ONR-supported research projects on Command Information Systems

Contract No. N00014-86-K-0680

(ONR-supported)

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*Airey, John M., John H. Rohlf, and Frederick P. Brooks, Jr. "Towards Image Realism with Interactive Update Rates in Complex Virtual Building Environments," **Best Paper Award:** *Computer Graphics: Proc. 1990 Symposium on Interactive 3D Graphicss*, 24(2), Snowbird, UT, 25-28 March 1990, 41-50. (See TR90-001.)

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Goldfeather, Jack. "Progressive Radiosity Using Hemispheres," TR89-002, Department of Computer Science, UNC at Chapel Hill, Feb. 1989.

Goldfeather, Jack, Steven Molnar, Greg Turk, and Henry Fuchs. "Near Real-Time CSG Rendering Using Tree Normalization and Geometric Pruning," TR88-006, Department of Computer Science, UNC at Chapel Hill, Jan. 1988. (See Publications bibliography under Goldfeather.)

Guin, Beth. "Administration Procedures—Sitterson Hall Phone Enhancements," SoftLab TR#SL03, 6 May 1990 (internal document).

Halton, John H. "On the Geometry of a General Three-Camera Headmounted System," TR89-019, Department of Computer Science, UNC at Chapel Hill, April 1989.

Halton, John H. "Monte-Carlo Anti-Aliasing," TR88-018, Department of Computer Science, UNC at Chapel Hill, April 1988.

Jeffay, K. and Smith, F. D. "Designing a Workstation-Based Conferencing System Using the Real-Time Producer/Consumer Paradigm," TR90-040, Department of Computer Science, UNC at Chapel Hill, Nov. 1990. (See Publications bibliography under Jeffay.)

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Jenkins, I., M. Lansman, and J. B. Smith. "A Tutorial for WE 1.0 for Experimental Studies," TR89-016, Department of Computer Science, UNC at Chapel Hill, April 1989.

Lansman, Marcy. "Organize First or Write First? A Comparison of Alternative Writing Strategies," TR91-014, Department of Computer Science, UNC at Chapel Hill, Feb. 1991.

Lansman, M., J. B. Smith, I. Weber. "Using Computer-Generated Protocols to Study Writers' Planning Stretegies," TR90-033, Department of Computer Science, UNC at Chapel Hill, Sept. 1990.

Levoy, Marc and Ross Whitaker. "Gaze-Directed Volume Rendering," TR89-048, Department of Computer Science, UNC at Chapel Hill, Dec. 1989. (See Publications bibliography under Levoy.)

Levoy, Marc. "Design for a Real-Time High-Quality Volume Rendering Workstation," TR89-010, Department of Computer Science, UNC at Chapel Hill, Feb. 1989.

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McKenzie, Leslie Edwin, Jr. "An Algebraic Language for Query and Update of Temporal Queries," Ph.D. Dissertation, UNC at Chapel Hill, Sept. 1988.

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Nie, Xumin and David Plaisted. "Some Experimental Results on Dynamic Subgoal Reordering," TR87-027, Department of Computer Science, UNC at Chapel Hill, Sept. 1987. (See Publications bibliography under Nie.)

Nievergelt, Jurg. "7 ± 2 Criteria for Assessing and Comparing Spatial Data Structures," TR89-041, Department of Computer Science, UNC at Chapel Hill, Oct. 1989. (See Publications under Nievergelt.)

Ohbuchi, Ryutarou, and Henry Fuchs. "Incremental Volume Rendering Algorithm for Interactive 3D Ultrasound Imaging," TR91-003, Department of Computer Science, UNC at Chapel Hill, 1991. (See Publications bibliography under Ohbuchi.)

Plaisted, David. "A Sequent Style Model Elimination Strategy and a Positive Refinement," TR89-014, Department of Computer Science, UNC at Chapel Hill, Feb. 1989. (See Publications under Plaisted.)

Smith, John B., Mark C. Rooks, and Gordon J. Ferguson. "A Cognitive Grammar for Writing: Version 1.0," TR89-011, Department of Computer Science, UNC at Chapel Hill, April 1989.

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Smith, John B., Stephen F. Weiss, and Gordon J. Ferguson. "A Hypertext Writing Environment and its Cognitive Basis," TR87-033, Department of Computer Science, UNC at Chapel Hill, Oct. 1987.

Smith, John B. and Catherine F. Smith. "A Strategic Method for Writing," TR87-024, Department of Computer Science, UNC at Chapel Hill, Aug. 1987.

Smith, John B., Stephen F. Weiss, Gordon J. Ferguson, Jay D. Bolter, Marcy Lansman, and David V. Beard. "WE: A Writing Environment for Professionals," TR86-025, Department of Computer Science, UNC at Chapel Hill, Aug. 1986. (See Publications bibliography under Smith.)

Southard, Scott, John B. Smith, Stephen F. Weiss, and Gordon J. Ferguson. "An Overview of the Architecture for MicroArras 1.0," TR88-042, Department of Computer Science, UNC at Chapel Hill, Sept. 1988.

State, Andrei. "Displaying Alphanumeric Characters on Pixel-Planes 5," TR89-049, Department of Computer Science, UNC at Chapel Hill, Dec. 1989.

Trinker, Airie. "WE Installation Guide," SoftLab TR#WE01, 1990 (SoftLab Report).

Trinker, Airie. "MAST860 User's Guide—A Microprogramming Analysis and Support Tool for Intel i860," SoftLab TR#SL05, June 1990.

Yen-Ping, S. "MoDE: An Object-Oriented User Interface Development Environment Based on the Concept of Mode," TR90-028a, Department of Computer Science, UNC at Chapel Hill, July 1990. (See Videotapes.)

Yen-Ping, S. "MoDE: A UIMS for Smalltalk," TR90-017, Department of Computer Science, UNC at Chapel Hill, April 1990.

Yen-Ping, S. "An Object-Oriented UIMS for Rapid Prototyping," TR90-016, Department of Computer Science, UNC at Chapel Hill, April 1990.

Yen-Ping, S. "An Event-Driven Model -View-Controller Framework for Smalltalk," TR89-025, Department of Computer Science, UNC at Chapel Hill, June 1989.

Yen-Ping, S. "WE 1.0 User's Manual," TR88-036, Department of Computer Science, UNC at Chapel Hill, July 1988.

Young, F., and J. B. Smith. "Structured Data Analysis: A Cognition-Based Design for Data Analysis Software," TR89-027, Department of Computer Science, UNC at Chapel Hill, 1989.

Updated September 1991

ONR-SUPPPORTED PROJECTS: Asterisk next to the entry indicates research has received (or continues to receive) ONR support; technical reports lists are split (supported/not supported). Other papers are considered *related* to ONR research.

Copies of papers/tech reports (*related* to currently-funded projects) were forwarded to Ralph Wachter, Scientific Officer, as soon as they were available; copies were sent to ONR personnel listed on the Contract continuation sheet (for Block 25 DD Form 2222) every six months during semi-annual and annual report distribution.

Abstracts (ONR-supported research only) were mailed electronically to ONR (baux) upon receipt.

NOTE: Copies of <u>new</u> papers/reports that will be completed up to six months AFTER the contract period ends will be provided to Ralph Wachter as soon as they are available. Copies f papers/reports created after that time will be provided upon request.

APPENDIX IV

ONR 35740-5211

Revised
1-Nov-91

EQUIPMENT
SUMMARY REPORT

For Contract Years FY87 through FY91

ONR-URI CONTRACT #N00014-86-K-0680

ITEM	NUMBER OF UNITS (equivalent)						TOTAL ONR
	86-87	87-88	88-89	89-90	90-91	TOT	$ Contrib.
DEC workstations, systems	1	1	0	0	5	7	94,325
SUN workstations, systems	17	1	1	1	0	20	174,928
SUN servers w/disks	2	1	0	1	0	4	181,487
Macintosh systems	4	7	8	1	2	22	94,361
Other workstations	0	2	0	0	0	2	17,129
Terminals	5	0	0	0	0	5	2,141
Parallel processor	0	0	1	0	0	1	98,430
Printers, plotters	0	3	11	0	0	14	18,211
Other monitors (& periph)	0	9	8	0	0	17	17,721
Other disks/drives/tape sys	6	11	0	0	29	47	141,192
Miscellaneous							88,205
TOTAL							928,130

ONR Contract
5-35740-5211

ANNUAL EQUIP. REPORT, Y5

Encumb/expen 15 Sept. '90–30 Sept. '91

FY90-91
as of:
1-Nov-91

QTY	% FROM ONR	VENDOR	DESCRIPTION	ONR CONTRIB.	REQ. NO.
WORKSTATIONS/MINIS/MICROS:					
4	100%	Digital Equip.	PM339-BY DECstation 5000/120, 16mb, LK401-AA Keyboard; PMAG-BB 8-plane color frame buffer; VR297-DA 16" color Trinitron monitor; RZ24-FF 209 MB disk dr.	59,307.85	180937
1	100%	Digital Equip.	PM339-BY DECstation 5000/120, 16mb, LK401-AA Keyboard; PMAG-BB CX color framebuffer; VR297-DA 16" color trin. mon.; RZ24-FF 209 MB disk drive.	12,814.57	180941
2 ea	100%	Apple Computer	M5722LL/A Mac IIsi 5MB Disk; M0404 Apple Mac Portrait Display	7,218.00	344955
TAPE SYSTEMS, DISKS, DRIVES, PLAYERS:					
3	100%	Aviv Corp.	ACT840DS-SB Exabyte 8500 8mm tape subsys	10,801.19	14222
25	100%	Digital Equip.	RZ24-FF 209 MB disk drives	15,701.72	180952
1	100%	Digital Equip.	Rz24-FL 209 MB disk internal for 5000/120	1,075.83	14214
MISCELLANEOUS:					
1	83%	Circuit City	Sony ccdf55 8mm camera, sonnp77h battery, tripod, camera bag.	1,120.50	344543
	100%	Cary Machine Co	Modify XY sliding table	1,260.00	180674
1	100%	Total A/V Svcs.	Electrohome ECP-4101 Model 38-B09980-AC Projector	20,343.65	14205
1	100%	Total A/V Svcs.	ECP ceiling mount, Sun Sparc Harness, IR remote video/data switcher and rack mount brackets, splitter, input module, & decoder	3,032.90	344900
1 ea	100%	Heurikon Corp	68030 processor board; ROM for VX Works OS	3,908.22	180993
TOTAL:				136,584.43	

ONR Contract
5-35740-5211

ANNUAL EQUIP. REPORT, Y4

Encumb/expen since 15 Sept. '89

FY89-90

as of: 20-Sep-91

QTY	% FROM ONR	VENDOR	DESCRIPTION	ONR CONTRIB.	REQ. NO.
WORKSTATIONS/MINIS/MICROS:					
1	100%	Apple Computer	MacII system: M5740LL/A MacIIci w/80 HDisk & 4MB, M0116 keybd, M0410LL/A ethertalk card, M0401 monitor, M0324 video card, stand, M0402 monitor, M0260 video card, M0213 expansion kit.	10,090.21	180305
1	25%	Computerland	POQET Computer, #POQT-AO164	853.12	181589
1	58%	Sun	SPARC station w/16" color monitor, 8bm, 104MB SCSI internal disk, 4/65FC-8-Pe	4,283.28	180429
1	85%	Sun	4/280S-P14 Sun file server	31,250.44	180427
OTHER COMPUTERS:					
1	87%	MasPar Corp.	Parallel processor	53,132.97	344476
DISKS, DRIVES, PLAYERS:					
1	22%	Camera Corner	Pioneer laser disc player LD-V2200	168.41	180474
MISCELLANEOUS:					
1	100%	Clark-Powell	Sony VPH-1270Q video projector	12,315.45	180204
1	100%	Midwest Comm.	Broadcast video encoder #EN-300 & rack	1,796.40	014385
1	100%	Hamamatsu	Passive position sensor #C2399-01H	2,039.46	181294
1	100%	Apple Computer	M0401 monitor, M0324 video card, stand	1,331.40	180305
1	100%	Currie-Peak-Fr	AD9003 KM A/D Converter	2,024.33	014400
	100%	Newport Corp	Breadboards, posts, clamps for trkr system	2,586.93	180709
	100%	Newport Corp	Breadboards, posts, clamps for HMD system	2,641.53	180710
4	100%	MPCS Video	JVC Tk-870u color video CCD camera with RGB & composite outputs; JVC Hz-C611AFU power zoom lens w/C mount; power supply and cable.	6,594.26	180484
1	100%	Circuit City and Camera Corner	Panasonic WJ450 digital color quad system; Sony KU-13TR20 Trinitron color monitors (4 ea) w/RF tuner, baseband video & audio	2,378.28	180713
TOTAL:				133,486.47	

ONR Contract
5-35740-5211

ANNUAL EQUIP. REPORT, Y3 FY88-89

Expenditures 15 Sept. '88 - 14 Sept. '89 1-Dec-89 revised

QTY	% FROM ONR	VENDOR	DESCRIPTION	ONR CONTRIB.	REQ. NO.
WORKSTATIONS/MINIS/MICROS:					
5	97%	Apple Computer	M5680 MacIICX w/4 mb and 80 mb disk	20,978.15	013554
1	100%	Apple Computer	M5680 MacIICX w/4 mb, 80mb disk, keyboard	4,855.05	014373
2	100%	Apple Computer	MacII systems: M5680 MacIICS w/4 mb and 80 mb disk; M0115 keyboard; M0402 mono monitors; M0260 video cards; M0404 portr. displays; M0119 display video cards; M0213 expns. kit	14,317.32	014371
OTHER COMPUTERS:					
1	53%	Sun Microsystems	4/60M1-8 SPARC station w/8 mb, 19" mon.	2,779.00	013382
1	100%	MasPar Corp.	Parallel processor	45,296.45	344476
MONITORS and THEIR PERIPHERALS:					
4 ea	100%	Apple Computer	M0402 mono monitors and M0250 videocards	7,000.00	014371
4 ea	100%	Apple Computer	M0404 portrait displays and M0119 display video cards	4,356.00	014371
20	100%	Apple Computer	M0213 video card expansn. kits	1,742.72	014371
16	100%	Apple Computer	M0403 monitor stands	1,051.00	014371
PRINTERS/PLOTTERS:					
2	100%	Apple Computer	A9P0500 ImageWriter LQ	2,010.00	014371
8	100%	Apple Computer	A9P0329 ImageWriter II	3,525.00	014371
11	100%	Apple Computer	A9B0314 ImageWriter LQ/LocalTalk option	1,042.00	014371
1	100%	Apple Computer	M6215 Laserwriter II NTX w/M6006 4MB exp	5,904.26	181124
MISCELLANEOUS:					
1	100%	Hamamatsu	C2399-01H Photodiode Sensor Head	2,050.13	013143
2	100%	Hamamatsu	C2399-01H Photodiode Sensor Head	4,076.43	013031
1	100%	UNC Instrumt.	Alum. Mount for 3-camera tracking system	890.95	OR-749
TOTAL:				121,874.46	

ONR Contract
5-35740-5211

ANNUAL EQUIP. REPORT, Y2

Expenditures 15 Sept. '87 - 14 Sept. '88

FY87-88

1-Jul-89 revised

QTY	% FROM ONR	VENDOR	DESCRIPTION	ONR CONTRIB.	REQ. NO.
WORKSTATIONS/MINIS/MICROS:					
1	37%	Sun Microsystems	Sun-4 workstation	27,564.05	012920
2	100%	IBM Corp.	PS/2 Model 80/071 with drive, mouse interfaces, coprocessor, display adapter, 16" high res. color monitor	16,276.05	617383
1	100%	Digital Equip.	Workstation VS450-GA VS2000, 6MB, 19", mono., keyboard, mouse, 159MB disk, base	6,707.28	565306
4	100%	Apple Computer	M5333 Macintosh II CPU	9,181.20	683647
3	100%	Apple Computer	M5300/A Macintosh II CPU	6,885.90	617389
FILE SERVERS:					
1	100%	Sun Microsystems	4/280S-P14 data center server	68,355.00	617393
DISKS/DRIVES/TAPE DRIVES:					
7	100%	Apple Computer	M0233 internal 80SC hard disks	13,090.35	617389
1	100%	Sun Microsystems	631FR1 2X892 MB formatted disk subsystem	26,964.00	617393
1	26%	Sun Microsystems	X675A 6250/1600 bpi 1/2" tape drive subsys.	2,820.60	617393
3	100%	Apple Computer	M0233/A Macintosh internal 80SC hard disks	5,817.00	683647
PRINTERS/PLOTTERS:					
1	53%	Hewlett-Packard	HP7596A Draftmaster II plotter	4,062.90	617396
2	100%	Apple Computer	M6006 LaserWriter IINTX, 4MB memry exp kit	1,661.10	617389
MONITORS:					
6	100%	UNC Student Stores	M0400 Apple high-res. monochrome monitors	1,668.70	683584
1	100%	UNC Student Stores	M0401 Apple high-res. color RGB monitor	687.75	683584
2	96%	Apple Computer	M0401 Apple high-res. color RGB monitor	1,215.80	683647
MISCELLANEOUS:					
1	18%	Internat'l Scient.	Demonstrator SS-40 E-Beam probing system	8,291.96	683691
7	100%	UNC Student Stores	M0211 Macintosh II video cards	2,534.45	683584
4	100%	UNC Student Stores	M0213 Macintosh II video expansion kits	102.90	683584
2	100%	Apple Computer	M0405 Ethertalk interface cards	1,073.77	
TOTAL:				204,960.76	

ONR Contract
5-35740-5211

ANNUAL EQUIP. REPORT, Y1

Expenditures 15 Sept. '86 - 14 Sept. '87

FY86-87

1-Jul-89 revised

QTY	% FROM ONR	VENDOR	DESCRIPTION	ONR CONTRIB.	REQ. NO.
WORKSTATIONS/MINIS/MICROS:					
14	100%	Sun Microsystems	Model #3/60M-8, Sun 3/60M 8MB monoch.	90,847.90	571090
1	100%	Sun Microsystems	Model #3/60FC-8, Sun 3/60FC 8MB w/16" mon.	7,372.05	571090
1	100%	Sun Microsystems	Model #3/60C-20, Sun 3/60C 20MB w/19" mon	12,947.55	571090
1	50%	Sun Microsystems	Model #3/110C-8, Sun 8MB w/19" color mon.	10,639.64	339248
1	100%	Sun Microsystems	Model #3/110C-4, Sun 3/110 4MB w/19" mon. 150A FPA, RTU license	18,495.13	472504
4	100%	Apple Computer	M5300 MACIIs w/keyboard, 80SC hard disk, 1MB expansion kit, Apple Ethertalk card, monochr. monitor, video card; Imagewriter	10,699.83 10,136.04	565241 276019
1	25%	Digital Equipment	Model #SU-LV55U-EK MVII/GPX Workstation	4,987.12	339193
4	10%	Digital Equipment	3 of Model #SU-LV55U-EK MVII/GPX Workstations, disks, interface, cable kit; 1 Model #SU-LV598-EK MVII/GPX Workstation, disks, cables, controllers, memory, cable kits	10,509.59	276101
FILE SERVERS:					
1	100%	Sun Microsystems	Model #4/280S-P2, Sun 4/280S Data Center Server w/ cabinet, disk subsystem, expansion disk, tape subsystem	64,985.55	571090
1	100%	Sun Microsystems	Model #3/180S-8, Sun 3/180 Server w/8MB	16,896.42	339251
TERMINALS					
5	100%	Data Term	WYSE 60 Terminals w/ambr screen, ASCII keybd	2,140.95	565327
DISKS/DRIVES:					
2	100%	Sun Microsystems	Model #626A, 575 MB formatted expan. disks	24,656.10	571090
4	83%	Systems Industr.	Fujitsu Super Eagle Disk Drives w/cables, terminator, rack slides, documentation	9,555.00 19,110.00 3,415.20	339204 276022 339174
1	100%	Systems Industr.	Eagle Disk Drive w/cables, termin., slide, docum.	8,015.70	276163
MISCELLANEOUS:					
2	100%	Helios Systems	MSV-8 Sun 3/110 Add-On Memory, 8MB	4,972.80	472508
1	100%	Newark Electr.	Stock #99F1070, 79" rack w/4 #91F094 castrs	841.09	2760
TOTAL:				331,223.66	

APPENDIX V

Travel Report

FY90-91

ONR-Supported (full or partial)

Traveler	Title	Place/Date	Purpose
Ed Biagioni	Research Assistant	Nags Head, NC 10/28/90–10/31/90	Present paper at Workshop on Unstructured Scientific Computation on Scalable Multiprocessors
Vernon Chi	Director, MSL	San Jose, CA	Attend Microelectron. System Education Conference & Expo
		Las Vegas, NV 07/21/91–08/04/91	Attend SIGGRAPH '91 Conference
Lynne Cohen Duncan	Systems Software Manager	Raleigh, NC 08/12/91–08/15/91	Technical training, ULTRIX (run by Digital)
Henry Fuchs	Federico Gil Professor	Las Vegas, NV 07/25/91-08/04/91	Chair session, serve on panel, supervise virtual reality exhibit, SIGGRAPH '91
John Hughes	Research Associate	Las Vegas, NV 07/25/91–08/03/91	Technical support, SIGGRAPH '91 Conference
		Bethesda, MD 12/02/90–12/14/90	Technical training, Silicon Graphics
David Plaisted	Professor	Palo Alto, CA 06/02/91–06/09/91	Attend committee meeting of International Logic Programming Symposium
John Poulton	Research Assoc. Prof.	Las Vegas, NV 07/25/91–08/03/91	Attend SIGGRAPH '91 Conference
Jan Prins	Assistant Professor	Hilton Head, SC 07/20/91–07/24/91	Attend SPAA 1991 Conference
Jannick Rolland	Visiting Res. Associate	Las Vegas, NV 07/27/91–08/03/91	Attend SIGGRAPH '91 Conference
John Smith	Associate Professor	Washington, DC 06/23/91–06/26/91	Speaker at BRG C2 Research Symposium

Travel Report
FY89-90
ONR-Supported (full or partial)

Traveler	Title	Place/Date	Purpose
Ronald Azuma	Research Associate	Orlando, FL 18-22 April 1990	Present paper at Technical Symposium on Optical Engr. & Photonics in Aerospace Sensing
		Dallas, TX 4-10 August 1990	Attend SIGGRAPH '90
		Atlanta, GA 13 June 1990	Attend Architectural/Engr/Construc-tions '90 Conf. & Exposition
Frederick P. Brooks, Jr.	Kenan Professor	Santa Barbara, CA 3-8 March 1990	Present paper at MIT Foundation Conference
		Salt Lake City and Snowbird, UT 21-28 March 1990	Attend pre-site visit at U of UT; and Symposium on Interactive 3D Graphics
William Brown	Research Associate	Snowbird, UT and Seattle, WA 22 March - 8 April 1990	Attend Symposium on Interactive 3D Graphics; and SIGCHI Conference on Human Factors & Computing Systems
		Dallas, TX 4-10 August 1990	Attend SIGGRAPH '90
David Ellsworth	Research Assistant	Snowbird, UT 25-28 March 1990	Present paper at Symposium on Interactive 3D Graphics
Henry Fuchs	Federico Gil Professor	Snowbird, UT 25-28 March 1990	On Program Committee and panel moderator, Symposium on Interactive 3D Graphics
Curtis Hill	Research Associate	Monterey, CA 12-14 June 1990	Present paper (if accepted) at 1990 Symposium on Command and Control Research
Rich Holloway	Research Associate	Atlanta, GA 21-26 May 1990	Attend conference on visualiza-tion in biomedical computing
		Dallas, TX 4-10 August 1990	Attend SIGGRAPH '90
Ralph A. Mason, Jr.	Assoc. Chairman	Monterey, CA 12-14 June 1990	Attend 1990 Symposium on Command and Control Research
David Richardson	Visiting Assoc. Professor	Arlington, VA	Met with R. Wachter re: ARM and molecular visualization
Warren Robinett	Project Leader, HMD	Snowbird, UT 24-29 March 1990	Attend Symposium on Interactive 3D Graphics

Traveler	Title	Place/Date	Purpose
		Santa Clara, CA 11-21 February 1990	Attend SPIE Conference
		Dallas, TX 6-10 August 1990	Attend SIGGRAPH '90
		Boston, MA 28-30 July 1990	Partic. in 8th National Conference on AI
Jeannie M. Walsh	Administrative Coord.	Research Triangle Park, NC 27 February 1990	Attend EXCEL macros workshop
		Raleigh, NC 22 March 1990	Attend workshop on document editing, design, and production

Travel Report, FY88-89

ONR-Supported (fully or partially)

Traveller	Title	Place/Date	Purpose
Peter Calingaert	Professor and Assoc. Chairman for Academics	Ithaca, NY 07/08/89-07/21/89	Attend course on distributed systems
James Chung	Research Assistant	Los Angeles, CA 01/16/8')1/21/89	Present paper, SPIE OE/LASE '89 Conference
Susan Gauch	ONR Fellow, fall '88	Washington, DC 03/29/89	Present paper at AI System in Government conference
Richard Snodgrass	Associate Professor	to UNC-CH from Tuscon, AZ	Present at 1989 ONR Site Visit
Donald Stanat	Professor	CMU, Pittsburgh, PA	Attend ONR-SEI Computer Science Workshop
Steve Weiss	Prof. & Chairman	Washington, DC 06/27/89-06/29/89	Attend C^3 Symposium
RAs to SIGGRAPH: John Airey, Ron Azuma, Mike Bajura, William Brown, James Chung, David Ellsworth, Michael Kelley, Dan Palmer	Research Assistants	Boston, MA 07/30/89-08/04/89	Attend SIGGRAPH '89

TRAVEL REPORT--FY 87-88

ONR Supported (fully or partially)

TRAVELLER	TITLE	PLACE/DATE:	PURPOSE
J. Dean Brock	Assistant Professor	Sydney, BC, Canada 04/06-04/08/88	present paper at Internat'l Symposium on Lucid and Intentional Programming
Frederick P. Brooks, Jr.	Kenan Professor	San Diego, CA 05/09/88	to NOSC for information exchange
Peter Calingaert	Professor	Chicago, IL 09/28-09/30/87	attend National Communications Forum
Vernon Chi*	Director, MSL	Portland, OR 09/13-09/20/87	attend FPCA '87 Conference and meeting at ESI
James Chung	Research Asst.	Atlanta, GA 07/31-08/05/88	attend SIGGRAPH '88 Conference
Bharat Jayaraman*	Assistant Professor	Portland, OR 09/12-09/17/87	present paper at FPL&CA '87 Conference
Marc Levoy	Research Asst.	Atlanta, GA 07/31-08/05/88	attend SIGGRAPH '88 Conference
Ralph Mason	Assoc. Chairman for Adminis.	Washington, DC 04/19-04/20/88	attend National Net 88 Telecom. Conf. and meeting with Aegis Project Mgr.
Jay Nievergelt	Chairman and Kenan Professor	Monterey, CA 06/07-06/09/88	attend Communications and Control Symposium
Steven Ornat	Communications Technician	Washington, DC 01/26-01/27/88	attend Communications Network Conference
		Plano, TX 07/19-07/29/88	attend InteCom communications classes
David Plaisted	Professor	Argonne, IL 05/23-05/26/88	attend 9th International Conference on Automated Deduction
Jan Prins	Assistant Professor	Atlanta, GA 06/21-06/24/88	attend SIGPLAN '88 Conference
Richard Snodgrass	Assistant Professor	Chicago, IL 05/31-06/03/88	attend ACM SIGMod '88 Internat'l Conference on Mgmt. of Data

TRAVELLER	TITLE	PLACE/DATE:	PURPOSE
Donald F. Stanat	Professor and Assoc. Chairman for Academic Affairs	San Diego, CA 05/09-05/10/88	to NOSC for information exchange
Russ Tuck	Research Asst.	Shelton, CT 10/05-10/07/87	attend Pegasus Users Group meeting
Norman Vogel	Director of Communications Research	Napa Valley, CA 10/03-10/08/87	participate in 10th Annual Data Communications Symposium
		Washington, DC 01/27/88	attend Communications Network Conference
		Washington, DC 03/06-03/09/88	attend TeleStrategies Conference
		Washington, DC 04/18-04/20/88	attend National Net '88 Telecom. Conference

**also listed in Year 1 Annual Report*

Travel Report FY 86-87

September 15, 1986 through September 14, 1987

TRAVELLER	TITLE	PLACE/DATE	PURPOSE
Vernon Chi	Director of MSL	San Diego, CA 11/02-11/03/86	visit the Dynair Co.
Vernon Chi	Director of MSL	Washington, DC 06/18/87	attend meeting at DARPA
Vernon Chi	Director of MSL	Portland, OR 09/13-09/20/87	attend FPCA '87 Conference and meeting at ESI
James Coggins	Assistant Professor	Shelton, CT 07/06-07/07/87	discuss PIXAR project
Bharat Jayaraman	Assistant Professor	Portland, OR 09/12-09/17/87	present paper at FPL& CA '87 Conference
Gyula Mago	Professor	Washington, DC 06/18/87	attend meeting at DARPA
John Menges	Communications Sftwre Engineer	Dallas, TX 03/14-04/05/87	training at InteCom (IBX database design)
John Menges	Communications Sftwre Engineer	Washington, DC 06/26-06/27/87	investigate InteCom IBX switch
Jay Nievergelt	Professor and Chairman	Washington, DC 10/20-10/22/86	attend ONR workshop and meeting
Jay Nievergelt	Professor and Chairman	Washington, DC 05/29-06/19/87	meeting of URI P.I.'s
Steve Ornat	Communications Technician	Washington, DC 02/10/87	attend Communications Networks '87 Conference

TRAVELLER	TITLE	PLACE/DATE	PURPOSE
Steve Ornat	Communications Technician	Dallas, TX 04/06-05/01/87 05/26-06/19/87	training at InteCom
David Plaisted	Professor	Bordeaux, France 05/21-05/28/87	attend 2nd Internat'l Conf. on Rewriting Techniques & Applications
Rick Snodgrass	Assistant Professor	San Francisco, CA 05/26-05/29/87	present paper to '87 SIGMod Conference
Donald Stanat	Professor and Assoc. Chairman, Academic Affairs	Austin, TX 06/06-06/13/87	participate in Institute on Logical Foundations of Functional Progrmg.
Donald Stanat	Professor and Assoc. Chairman, Academic Affairs	Austin, TX 08/22-08/29/87	participate in Institute of Declarative Programming
Norman Vogel	Director of Communications Research	Dallas, TX 05/06-05/08/87	attend InteCom IBX University Users meeting

APPENDIX VI:

Annual Reports and Summaries
FY87 through FY91

Note: To assist the reader in finding information, pertinent parts of each Annual Report appendix were extracted and are currently included as Appendix I through V of this Final Five-Year Summary report.

ANNUAL REPORT

15 September 1990 through 30 September 1991

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The Infrastructure of Command Information Systems

Submitted to

Office of Naval Research
Arlington, VA 22217-5000

Submitted by

Department of Computer Science
The University of North Carolina at Chapel Hill
Campus Box 3175, Sitterson Hall
Chapel Hill, NC 27599-3175

Principal Investigators:

Frederick P. Brooks, Jr.
Donald F. Stanat
Stephen F. Weiss

1 October 1991

Contract No. N00014-86-K-0680

CONTENTS

SECTION 1: Productivity measures during this reporting period 1

SECTION 2: Detailed Summary of Technical Results *(by project)* during this reporting period 2

Pixel-Planes 5 2

Walkthrough 3

Head-Mounted Display 4

Tracker 5

Artifact-Based Collaboration 6

Data-Parallel Execution 6

SoftLab 7

SECTION 3: Lists of publications, presentations, reports, awards/honors/prizes during this reporting period 9

A. Refereed papers (to appear) 9
B. Refereed papers published 9
C. Refereed exhibitions 10
D. Refereed papers submitted (awaiting acceptance) 10
E. Unrefereed reports and articles 11
F. Books (or parts thereof) published (and to appear) 12
G. Videotapes 12
H. Invited presentations 12
I. Contributed presentations 14
J. Honors 15
K. Prizes or awards 15
L. Promotions obtained 15
M. Educational productivity 15

SECTION 4: Transitions and DoD Interactions during this reporting period *(by project)* 16

SECTION 5: Software and Hardware Prototypes during this reporting period *(by project)* 20

APPENDICES

Appendix I	Comprehensive Bibliography
Appendix II	Personnel by Project, FY90–91
Appendix III	Travel Report, FY90-91
Appendix IV	Equipment Report

ANNUAL REPORT for FY90-91

SECTION 1: Productivity measures during this reporting period

Principal Investigators:	Frederick P. Brooks, Jr. Donald F. Stanat Stephen F. Weiss
PI Institution:	The University of North Carolina at Chapel Hill Department of Computer Science
PI Phone Numbers:	919/962-1931 919/962-1788 919/962-1888
PI E-mail Addresses:	brooks@cs.unc.edu stanat@cs.unc.edu weiss@cs.unc.edu

Contract Title:	The Infrastructure of Command Information Systems		
Contract Number:	N00014-86-K-0680		
Reporting Period:	15 September 1990 through 30 September 1991		

		ONR supported	Related
1.1	Refereed papers submitted *(awaiting acceptance)*	0	10
1.2	Refereed papers *(to appear)*	3	2
1.3	Refereed papers published	2	4
1.4	Unrefereed reports and articles *(published or to appear)*	16	8
1.5	Books (or parts thereof) submitted (*to appear*)	0	0
1.6	Books (or parts thereof) published	2	1
1.7	Patents filed but not yet granted	0	0
1.8	Patents granted (includes software copyrights)	0	0

		Supported or Related
1.9	Invited Presentations	22
1.10	Contributed Presentations	12
1.11	Honors received	9
1.12	Prizes or awards received	0
1.13	Promotions obtained	0
1.14	Educational productivity	
	degrees received during FY by those supported ≥ 25% of full time during FY	4
	degrees received during FY by those not ONR supported during FY but working on project	3
1.15	Graduate students supported ≥ 25% of full time	19
1.16	Post-docs supported ≥ 25% of full time	0
1.17	Minorities supported ≥ 25% of full time	8

SECTION 2: Detailed Summary of Technical Results *(by project)* during this reporting period

Principal Investigators:	Frederick P. Brooks, Jr. Donald F. Stanat Stephen F. Weiss
PI Institution:	The University of North Carolina at Chapel Hill Department of Computer Science
PI Phone Numbers:	919/962-1931 919/962-1788 919/962-1888
PI E-mail Addresses:	brooks@cs.unc.edu stanat@cs.unc.edu weiss@cs.unc.edu

Contract Title:	The Infrastructure of Command Information Systems
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Pixel-Planes 5

Our objective is to design and build multicomputer architecture (both hardware and software) for 3D interactive graphics that delivers in excess of one million polygons/sec. to real applications and that supports a wide variety of rendering algorithms.

In the past fiscal year, we have made significant progress in our research on the Pixel-Planes 5 system, described below.

We have built and installed a third rack of boards for Pixel-Planes 5. We will continue to configure the system as one large machine when top performance is desired or as two independent machines to better support multiple developers and users.

The polygon rendering speed of the Pixel-Planes 5 prototype has now exceeded our performance goal of 1 million polygons/sec. In fact, with one detailed model of terrain of the Sierra Nevada Mountains we sustain more than 2 million on-screen triangles per second (full-color, Phong-shaded, with specular highlights). The data set consists of approximately 166,000 triangles and is rendered at 12 frames per second, a rate that allows quite reasonable user interaction. This 2.3 million triangles per second is, to our knowledge, the highest polygon-rendering rate achieved anywhere to date. This rate is achieved on a three-rack system with 45 GPs and 24 Renderers (each Graphics Processor (GP) is an i860 with 8 megabytes of memory, each Renderer is an SIMD array of 16,384 1-bit processors and custom parallel polynomial evaluation circuitry). Besides the hardware additions made during the last six months, several factors have contributed to these improvements: a more stable, faster Ring Operating System (ROS), i860 assembly language coding of a few critical routines, and extensive event tracing to determine where the bottlenecks are.

We developed an NTSC frame buffer and modified ROS and Rendering Control System (RCS) to support it. We have completed the PPHIGS work needed to support the NTSC frame buffer in stereo mode and interface the head-mounted display to the system.

Trey Greer (now with IVEX Corp.) developed a tiny system of only one GP and one Renderer that renders anti-aliased triangles at a rate of 50,000 per second.

The VISTAnet project successfully connected a Cray Y-MP computer located in Research Triangle Park to the Pixel-Planes Ring via a dedicated T3 fiber line potentially operating at 45 Mbits/sec. (only about 5 Mbits/sec. achieved application-to-application so far). The Cray computes radiation dose levels based on user input at a workstation in UNC-CH Department of Radiation Oncology, and transmits the dose to Pixel-Planes for interactive display.

Significant progress was made in doing volume rendering on Pixel-Planes 5. Tim Cullip developed an all-GP algorithm that can render coarse images of a 128-cubed voxel data set at better than 10 frames/sec. Ulrich Neumann developed a volume renderer based on using the Renderers to do splat buffering that produces up to five frames/sec. for a 128-cubed

voxel data set. Neumann is now preparing a volume rendering animation sequence for Apple Computer. Apple will distribute this on their "Multimedia" CD ROM.

We are now implementing a new volume renderer on Pixel-Planes based on Tim Cullip's design concept, but which will permit the use of larger (up to 27,000,000 voxels) data sets and provide at least the full function of the existing *vrn* program.

The performance of Pixel-Planes 5 with large numbers of procedural textures is being optimized. Our local colleagues on the Walkthrough project built a radiosity model of a house that now uses about 20 procedural textures (such as brick, kitchen tile, ceilings) to create a complex and interesting visual environment. The current frame rates are up to around 25 frames/sec on a "low resolution" 640- x 480-pixel monitor, and the textures are now anti-aliased.

A high-level design for a new graphics system based on image-composition was developed and reviewed. Because the system looks so promising, we decided to undertake a full, detailed design of the hardware and are now in the beginning stages of this.

We transported a Pixel-Planes 5 three-rack system and exhibited it in the Tomorrow's Realities Gallery at the SIGGRAPH '91 conference, July 28-August 2, 1991. Of all the applicants, UNC had the largest number of demonstrations accepted for this juried exhibit and had the largest booth (29' x 43'). We showed a number of applications, including the head-mounted display, volume rendering, and polygon and sphere rendering at over 2 million polygons/sec. The demonstrations were: 3dm—A Two-Person Modeling System, Interactive Building Walkthrough Using a Steerable Treadmill, Interactive Building Walkthrough Using the Optical Tracker, Flying Through Molecules, A Mountain Bike with Force Feedback Pedals, Radiation Therapy Treatment Planning, and the Virtual Pilot. All of our demonstrations at the exhibit were single-user, "hands-on" experiences. Because each demonstration takes about five minutes, we were able to show demos to a relatively limited number of people. During the five days that the exhibit was open, approximately 600 people were able to experience our virtual reality demos.

Walkthrough

Major Milestone Reached

The Walkthrough Project reached a major milestone with the demonstration in July at SIGGRAPH '91 of two Walkthrough systems, each at a new level of performance. These systems were part of the UNC Exhibit in the Virtual Reality Gallery.

The scenes are shown with radiosity illumination, lights that can be switched on or off with only 100 msec. delays, textured surfaces, and near-real-time display from changing viewpoints. Update rates realized by the Pixel-Planes 5 graphics scene generator are 30-40 updates/second (15-20 stereo images/second) on scenes consisting of thousands of polygons, many textured.

One system uses a head-mounted display and the new UNC Ceiling Tracker to allow the viewer literally to walk freely about a 10' x 12' living room in an imaginary apartment. Both systems include the display of scene-appropriate sounds.

The second system uses our UNC steerable treadmill and a head-mounted display to allow viewers to virtually walk around a fully furnished ten-room house. Different appropriate sounds are heard in each room, and outdoors.

Our exhibits and demonstrations were very well received.

Annual Progress

As previously discussed, all virtual worlds projects need to move forward simultaneously in four dimensions, shown in the figure. We shall discuss this year's progress under these four headings.

Faster

The Pixel-Planes 5 machine came on-line and, during the course of the year, we and the Pixel-Planes 5 team worked together to remove the initial hindrances to our realizing its speed. At SIGGRAPH, Pixel-Planes 5 was demonstrated displaying 2 million Phong-shaded on-screen triangles/second, about twice as fast as the state-of-the-art Silicon Graphics machine. Texturing substantially reduces this rate. The power of Pixel-Planes 5 is, however, sufficient for dynamic interaction of high-fidelity images.

Prettier

The major step forward this year has been the addition of anti-aliased textures. They radically improve the visual fidelity of a scene with a fixed number of polygons.

The videotape shows, for example, wood, brick, ceiling tile, linoleum, bathroom tile, etc. We even use textures for sheet music, piano keys, and art on the wall. Pixel-Planes 5 is very good at procedural textures; it is not especially good at bit-mapped (image) textures.

The second major step on scene fidelity has been the addition of location-dependent (monaural) sound cues. We adapted commercial Macintosh software; purchased a 10,000-sound CD sound-cue library; and developed the location-based sound selection, loudness control, and sound-sound mixing software.

Handier

We developed new user interfaces for

- the ceiling tracker
- interactive turning on and off of lights in the model
- full integration of our treadmill interface with the head-mounted display and Polhemus head tracker.

Realer

We gained much experience in model-building this year. The house model was refined; a sound model was built. We also built de novo, a model for a six-room furnished apartment. On the theoretical side, we developed a whole new many-level hierarchical concept of how architectural models should be organized.

On the other hand, we took a step backward on real use. We spent all our effort for six months getting everything really right for SIGGRAPH, including the new apartment model. This had the very salutary effect of bringing many in-process activities to closure. The price was that we had no effort to devote to real-user interaction with the designer of the house extension. That design and construction proceeded anyway. Our house model is now a year behind reality, and we have lost the opportunity for client feedback.

This coming year we shall try to establish and track a real client interaction, even though that will slow our technology development. It will surely provide major guidance for future technology development.

Head-Mounted Display

Technical accomplishments during this reporting period:

We developed the software architecture for HMD applications of a standard software library (VLIB, etc.), a standard file format for models used by the application (PPHIGS archive file format), and a special-purpose program (the simulation code) that runs the application. A short dummy application, which new HMD users could copy, use to get started rapidly on the HMD, and then begin to grow their own applications was also developed. We produced Vixen, an application that allows a user to view arbitrary models using the HMD (analogous to the old *xfront* for viewing models using the Pixel-Planes 4 console and joystick). Vixen supports the manually controlled actions of flying through the virtual world containing the model being viewed, scaling the world, scaling individual objects, tilting the world, picking up individual objects, and loading and saving the files that define these models. The team also built an HMD-based 3D modeler.

The team worked to make the HMD software device-independent, so that the particular HMD and tracker to be used by an application could be chosen at run-time using Unix shell environment variables. Currently supported HMDs are: EyePhone model 1, EyePhone model 2, AFIT HMD and the old see-through HMD. Supported trackers are three different Polhemus units (with 1, 2 and 4 sensors), the Ascension Bird tracker, and the UNC opto-electronic "ceiling" tracker, which was recently completed. The screen/joystick is treated as a HMD/tracker type so that HMD applications can be used simply with a joystick and screen, if desired.

We started supporting multi-person shared virtual worlds and greatly improved and enhanced the sound software, collecting a library of interesting sounds. The idea of using a HMD to superimpose real-time ultrasound images onto the tissue being imaged is also being investigated. The team worked to analyze the EyePhone optics from the EyePhone and LEEP optics specifications, and demonstrated that the critical parameters for the display software (field-of-view, convergence correction, etc.) can be calculated from the specs of the system. Custom optics were designed for the planned new see-through HMD for the medical X-ray vision application. We purchased a monochrome 1-inch CRT (a camcorder viewfinder) for use in the new see-through HMD.

Work with novel display technology using lasers and moving mirrors was proposed; but after investigation, the team decided that, at the update rates we desired, none of these deflection methods could produce a display device with resolution better than current LCDs. We built the digital hardware and the software for a 1-dimensional test of an optical tracker based on rotating planes of light. The test showed a 1D tracking accuracy of .2 mm at a range of 5 meters. We worked out on paper the expected specifications of a 6-degree-of-freedom tracker based on this method. We

implemented a preliminary 1-screen prototype of head-tracked stereo on the monitor screen (the "bathysphere" idea). A ring input device, made from banjo finger-pick, push-button and Polhemus sensor, was also built.

We acquired a versatile I/O board for the Mac, with the intent of using the Mac (in addition to playing sounds) to control various input/output devices such as vibratory feedback to the user from the manual input device. We used the I/O board to control a vibratory buzzer from a pocket pager and built a quick prototype of a manual input device with a vibrator and four switches which worked through the Mac I/O board.

We designed and implemented a simple prototype of a simulation of the solar system. The sun, planets and moons were modeled at their true scales and distances, and scaling the model up and down was used to look at various bodies in the simulation. Because the distances are so vast compared with sizes of the bodies in the simulation, graphics for the orbits and other markers were used to help the user locate the planets and moons. A modeling language was designed to simplify the creation of models in the solar system simulation and other applications.

Tracker

Our objective is to design and to build a new real-time position and orientation tracking device for head-mounted display systems that features a large working area, high resolution, rapid update rate, and immunity from environmental disturbances.

The tracker currently under development is optoelectronic in nature. A cluster of small imaging sensors is located atop the helmet of a head-mounted display. These sensors form images of light-emitting diodes (LEDs) mounted overhead in a suspended ceiling. In effect, they serve as navigation beacons in that the knowledge of their position in the room, coupled with their image formed on top of the head, allows both the position and the orientation of the head-mounted display to be computed.

Major challenges facing the project team are: the accurate placement of LED beacons on a suspended ceiling, the calibration of image sensors based on non-metric optics and lateral-effect photodiodes, and the real-time computation of head position and orientation.

Significant progress during this reporting period:

A technique for computing head position and orientation that offers advantages over Jih-Fang Wang's extension to Church's algorithm has been implemented and demonstrated. Whereas Wang's solution admitted information from three sensors and, at most, three LEDs, this approach allows an unlimited number of sensors to be used, and each sensor can image an unlimited number of LEDs. The technique has been applied to a tracker with four image sensors and 10–40 LEDs in use at any given time.

We have built a belt-mounted electronics module that interfaces up to eight head-mounted image sensors to the tracking system.

We have completed the building of related hardware that allows a workstation to accept information from the head-mounted sensors and to control the firing of LEDs. The result is a four-slot-wide VME module containing a 68030-based, single-board computer, a 100Mbit/sec serial interface, a parallel interface to the LED controllers, and a power supply.

A computer-controlled sensor calibration rig has been constructed that allows calibration maps to be constructed for each image sensor used. The calibration maps correct for nonlinearities in the sensors' lateral-effect photodiodes and their lenses.

Thirty-two ceiling panels have been produced. Each panel consists of a printed circuit board housed in an aluminum enclosure. The printed circuit board and the enclosure's front panel form a composite structure that is flat to within .040". Given that LEDs are located by holes punched in the front panel to within a true position tolerance zone of .005", this ensures that LEDs are precisely located on a given panel.

We have built a ceiling support structure that suspends thirty ceiling panels from adjustable spiders. The spiders allow the corner of each panel to be vertically adjusted. A Spectra-Physics LaserLevel was used to adjust the spiders' vertical locations to within a tolerance zone of .003". Given that the spiders locate the corner of each panel, the location of LEDs is extremely well defined.

A working tracking system with a 10' x 12" working area was demonstrated at the SIGGRAPH '91 conference in Las Vegas, July 28–August 2, 1991. This was one of seven demonstrations shown in UNC's booth in the Tomorrow's Realities Gallery. Of all the applicants, UNC had the most demonstrations accepted for this juried exhibit and the largest booth (29' x 43'). All of our demonstrations at the exhibit were single-user, "hands-on" experiences.

Future Plans:

We plan to extend the work area of the tracker to 20' x 20" and reduce the mass of the headset. We also plan to incorporate predictive tracking algorithms to compensate for lag in the tracker and graphics subsystems. Work will continue on self-calibration techniques with the goal of developing an algorithm that can compute the position of LEDs and allow less stringent tolerances on absolute LED position in the ceiling. We will also continue to develop the Self-Tracker technology.

Artifact-Based Collaboration

Our objective was to develop tools for studying and understanding decision-making by individuals and groups working in a computer environment.

Significant progress during reporting period:

We developed a new cognitive grammar, based on ATN formalism. The team also designed and implemented a prototype ATN grammar development tool. We explored the concept of group protocols and compiled a technical notebook cataloging protocol tools and their uses. We are in the process of completing a technical report describing tools for automated protocol analysis.

Plans:

We plan to complete the development of ATN tool and to implement the ATN-based parser program. We also plan to implement protocol tracking and reply in selected portions of the new hypermedia collaboration system (ABC). The team will also define the requirements for group protocols.

Long-term plans:

The team plans to develop a hypermedia-based software development environment for collaborative work that includes group protocol capabilities.

Data-Parallel Execution

Our objective is to increase utility and applicability of highly parallel computers through:

- development of high-level, machine-independent data-parallel programming languages and data-parallel programming techniques,
- compilation techniques yielding efficient execution for such programming languages, and
- demonstration of high-performance algorithms and applications on our 4096 processor MasPar MP-1.

Progress in each of these areas is detailed below.

Programming Languages and Techniques:

A preliminary design of *Proteus*, a high-level language for prototyping parallel applications, was completed in cooperation with colleagues at Duke and Kestrel. This work is part of DARPA's ProtoTech project. High-level parallel programs expressed in *Proteus* will be executed sequentially by a language interpreter that is currently under development. We rely on transformations (manual and automatic) to place a *Proteus* program in a restricted form from which parallel code may be generated. Since Proteus offers a very general model of parallelism that cannot be emulated efficiently by a given parallel machine, the refinement step is necessary if we wish to generate programs that execute with reasonable efficiency.

A staged model of parallel program development is advocated in which computations are first expressed in a "pure" data-parallel form. Subsequent steps serve to minimize communication and to balance computational load. This methodology fits well with a transformational style of program development.

One of our researchers is participating in the design of Proteus and is concentrating in particular on a type system for the language that supports the dynamic typing and high flexibility required in a prototyping language and supports type-refinement to introduce the precise static typing necessary in the use of program transformations.

Compilation Techniques:

Proteus translation will target two basic implementation models for parallel execution: Mach threads and the CVL data-parallel intermediate code developed by Guy Blelloch at Carnegie-Mellon University. Researchers implemented CVL on the MP-1 and performed some preliminary performance analysis.

Some computations, such as the simulation of certain physical systems, have unpredictable computational requirements that evolve over time. For these systems, dynamic balancing of the computational load over processor is required. ONR fellow Ed Biagioni has implemented an efficient global technique on the MP-1 that determines the load at each processor and organizes the movement of data to equalize it. An important property of this movement is that it preserves locality in communication, hence the basic performance of the underlying algorithm is unaffected.

Algorithms and Applications:

At the core of many parallel algorithms lie sorting and routing steps. Routing and sorting algorithms for large arrays have been developed for the MP-1 that considerably exceed the performance of presently available algorithms. The algorithms use randomization techniques to achieve good performance over all inputs.

One researcher developed an MP-1 application to support better quality real-time force feedback in the GRIP project. An operator interactively attempts to find a receptor site for a drug molecule on a large protein receiving feedback from a continuously updated image of the molecules on a display and from the force, felt on the handgrip guiding the drug molecule, due to the interaction of the drug with the protein. The force calculation involves the summation of intra- and inter-molecular forces between all pairs of atoms in the system and can be accomplished in real-time (20 updates/sec.) using the MP-1.

We implemented two different volume rendering algorithms on the machine to perform a full computation incorporating arbitrary viewing position and illumination on a 256 x 256 x 256 voxel data set in a few seconds. Experiments with polygon-rendering algorithms were also undertaken using Z-buffer, ray-tracing, and radiosity methods. We also compared a number of radiosity algorithms on the MP-1.

This fall visiting professor William Hightower is investigating a number of molecular dynamics simulation algorithms on the MP-1.

MasPar MP-1:

Extensive use of the machine has made it clear that, to expand the class of applications for which the machine can offer greatly superior or real-time performance, a very fast sequential machine front-end and high-speed I/O to the parallel portion of the machine are critical. During the last year we have upgraded our MasPar MP-1 to incorporate high-speed parallel-I/O capabilities. A 4-disk parallel disk array is the first device to use the new facilities. The equipment to interface to a DS5000/200 front-end has been ordered but not yet delivered. One of the objectives for the MP-1 is to interface it via Hippi to Pxpl5 as a way to compute and render dynamic systems in real-time.

SoftLab

SoftLab Software Systems Laboratory is an infrastructure organization that provides the UNC Computer Science Department with software systems and software packaging and distribution services analogous to those typically found in industry. As such, SoftLab serves as a software development resource for the Department and an agent of technology transfer to other universities and to industry.

SoftLab supports the rapid prototyping of experimental VLSI architectures and distributed systems by developing simulators, drivers, compilers, interfaces, and communications software. During this reporting period, SoftLab completed a microcode preprocessor for the Intel i860 chip. This tool facilitates hand optimization of i860 assembler programs and is heavily used by Pixel-Planes 5 software developers to code graphics applications programs that require high-speed performance.

The i860 preprocessor was developed by reuse of components belonging to a similar preprocessor for the Weitek XL chip implemented earlier by SoftLab and the Pixel-Planes 4 research team. The use of IDL (Interface Description Language), a programming environment for rapid prototyping of compilers designed by Prof. Richard Snodgrass and formerly distributed by SoftLab, facilitated reuse of these components. In addition, SoftLab also developed a preliminary version of a C optimizer for the i860. Other prototyping support tool work during the reporting period included enhancements to our architectural simulator that allow simulation of C program execution.

As part of SoftLab's research software support efforts, we are porting the graphical user interface for RSpace, an interactive program designed to help crystallographers plan data-collection strategies when using diffractometers equipped with area detectors. The current version of RSpace, in use at about 50 foreign and domestic research sites, requires an Evans and Sutherland PS300 for its graphical display. We are porting this interface to the X Window System

in order to extend the user base of this popular research tool developed in 1988 by Department graduate student Mark Harris.

Special emphasis has been placed on software capitalization activities during the past year. We have continued to enhance our software manufacturing and distribution process. In particular, we have developed a preliminary version of an efficient and cost-effective methodology for releasing updates of dynamic products.

We are currently testing this methodology on the next release of COOL, a C++ library for computer vision research developed by Prof. James Coggins. In addition, we have designed new build scripts that allow us to generate executables for various hardware platforms from common source and makefile templates. We are testing these scripts by using them to package Image, a medical image processing software library developed by Prof. Stephen Pizer's research group. Finally, we are investigating techniques that would allow us to compile various components of Image (or any other large software system) in parallel.

SECTION 3: Lists of publications, presentations, reports, awards/honors/prizes during this reporting period

Principal Investigators:	Frederick P. Brooks, Jr. Donald F. Stanat Stephen F. Weiss
PI Institution:	The University of North Carolina at Chapel Hill Department of Computer Science
PI Phone Numbers:	919/962-1931 919/962-1788 919/962-1888
PI E-mail Addresses:	brooks@cs.unc.edu stanat@cs.unc.edu weiss@cs.unc.edu

Contract Title:	The Infrastructure of Command Information Systems
Contract Number:	N00014-86-K-0680
Reporting Period:	15 September 1990 through 30 September 1991

With * ..... ONR-supported.
Without * ..... Related to the project.

A. Refereed papers (to appear)

Guan, Sheng-Uei, Hussein Abdel-Wahab, and Peter Calingaert. "Jointly-Owned Objects for Collaboration: Operating-System Support and Protection Model," to appear in *The Journal of Systems and Software*, 1991.

Lansman, Marcy, John B. Smith, and Irene Weber. "Using Computer-Generated Protocols to Study Writers' Planning Strategies," accepted subject to revision in *Computers and Composition*. (See also Part E.)

*Mills, P., L. Nyland, J. Prins, J. Reif, and R. Wagner. "Prototyping Parallel and Distributed Applications in Proteus," to appear in *IEEE Symposium on Parallel and Distributed Processing*, Dallas, TX, Dec. 1-5 (see TR90-041 under Part E.)

*Neumann, Ulrich, Terry S. Yoo, Henry Fuchs, Stephen M. Pizer, Tim Cullip, John Rhoades, and Ross Whitaker. "Achieving Direct Volume Visualization with Interactive Semantic Region Selection," to appear in *Proc. IEEE Visualization '91*, San Diego, CA, Oct. 1991 (See TR91-012 under Part E.)

*Robinett, Warren and Jannick P. Rolland. "A Computational Model for the Stereoscopic Optics of a Head-Mounted Display," *Proc. SPIE Symposium on Electronic Imaging*, 1457 (Stereoscopic Displays and Applications), San Jose, CA, 16 Feb. 1991; also to appear in first issue of *PRESENCE*, Jan. 1992. (See TR91-009 under Part E.)

B. Refereed papers published

Davis, R. E., M. Levoy, J. G. Rosenman, H. Fuchs, S. M. Pizer, A. Skinner, and H. C. Pillsbury. "Three-Dimensional High-Resolution Volume Rendering (HRVR) of Computed Tomography Data: Applications to Otolaryngology—Head and Neck Surgery," *Laryngoscope*, 101(6), June 1991.

Jeffay, K., and Smith, F. D. "System Design for Workstation-Based Conferencing with Digital Audio and Video," *Proc. TriComm '91: IEEE Conference on Communications Software*, Chapel Hill, NC, April 1991.

Ohbuchi, Ryutarou, and Henry Fuchs. "Incremental Volume Rendering Algorithm for Interactive 3D Ultrasound Imaging," *Proc. Information Processing in Medical Imaging XII*, 1991. (See TR91-003 under Part E.)

*Prins, J. "A Framework for Efficient Execution of Array-based Languages on SIMD Computers," *Proc. 3rd Symposium on the Frontiers of Massively Parallel Processing*, IEEE 1990.

*Prins, J., and J. Smith. "Parallel Sorting of Large Arrays on the MasPar MP-1," *Proc. 3rd Symposium on the Frontiers of Massively Parallel Processing*, IEEE 1990.

Turk, Greg. "Generating Textures on Arbitrary Surfaces Using Reaction-Diffusion," *Computer Graphics: Proc. SIGGRAPH '91*, 25 (4), July 1991, 289-298.

C. Refereed exhibitions

The UNC Computer Science Department provided a major exhibit in the "Tomorrow's Realities" Gallery at the SIGGRAPH '91 Conference, Las Vegas, NV, 28 July-2 August, 1991. Demonstrations included:

A. Pixel-Planes 5 three rack system.

B. 10' x 12' Optical "Ceiling" Tracker.

C. 3dm—A Two-Person Modeling System.

D. Interactive Building Walkthrough Using a Steerable Treadmill.

E. Interactive Building Walkthrough Using the Optical Tracker.

F. Flying Through Molecules.

G. A Mountain Bike with Force Feedback Pedals.

H. Radiation Therapy Treatment Planning.

I. Virtual Pilot.

D. Refereed papers submitted (awaiting acceptance)

Banks, David. "Interactive Manipulation and Display of Surfaces in Four Dimensions," submitted to *1992 Symposium on Interactive 3D Graphics*, Cambridge, MA, 29 March–1 April 1992.

Butterworth, Jeff, Andrew Davidson, Stephen Hench, and T. Marc Olano. "3DM: A Three Dimensional Modeler Using a Head-Mounted Display," submitted to *1992 Symposium on Interactive 3D Graphics*, Cambridge, MA, 29 March–1 April 1992.

Chung, James C. "A Comparison of Head-Tracked and Non-Head-Tracked Steering Modes in the Targeting of Radiotherapy Treatment Beams," submitted to *1992 Symposium on Interactive 3D Graphics*, Cambridge, MA, 29 March–1 April 1992.

Jeffay, Kevin. "Scheduling Sporadic Tasks with Shared Resources in Hard-Real-Time Systems," TR90-039, Department of Computer Science, UNC at Chapel Hill, Nov. 1990. (See also Part E.)

Neumann, Ulrich. "Interactive Volume Rendering on a Multicomputer," submitted to *1992 Symposium on Interactive 3D Graphics*, Cambridge, MA, 29 March–1 April 1992.

Rhoades, John, Greg Turk, Andrew Bell, Andrei State, Ulrich Neumann, and Amitabh Varshney. "Real-Time Procedural Textures," submitted to *1992 Symposium on Interactive 3D Graphics*, Cambridge, MA, 29 March–1 April 1992.

Robinett, Warren, and Richard Holloway. "Implementation of Flying, Scaling and Grabbing in Virtual Reality," submitted to *1992 Symposium on Interactive 3D Graphics*, Cambridge, MA, 29 March–1 April 1992.

Smith , John. B., and Dana K. Smith. "Automated Protocol Analysis," submitted to *Human-Computer Interaction.*, TR91-034, Department of Computer Science, UNC at Chapel Hill, Aug. 1991. (See also Part E.)

Surles, Mark C. "Interactive Modeling Enhanced with Constraints and Physics—with Applications in Molecular Modeling," submitted to *1992 Symposium on Interactive 3D Graphics*, Cambridge, MA, 29 March–1 April 1992.

Ward, Mark, Ronald Azuma, Robert Bennett, Stefan Gottschalk, and Henry Fuchs. "A Demonstrated Optical Tracker with Scalable Work Area for Head-Mounted Display Systems," submitted to *1992 Symposium on Interactive 3D Graphics*, Cambridge, MA, 29 March–1 April 1992.

E. Unrefereed reports and articles

Brooks, Frederick P., Jr., and William V. Wright. "Seventeenth Annual Progress Report and 1992-97 Renewal Proposal—Interactive Graphics for Molecular Studies," TR91-020, Department of Computer Science, UNC at Chapel Hill, Jan. 1991.

*Eyles, John G. "Virtual-Environment Research at the University of North Carolina," abstract in *Proc. AUSGRAPH '90*, Melbourne, Australia, 10-14 Sept. 1990.

*Gauch, Susan and John B. Smith. "Search Improvement via Automatic Query Reformulation," TR91-010, Department of Computer Science, UNC at Chapel Hill, Feb. 1991.

*Hawkes, Richard M. "Mathematical Basis for a System to Manage Automated Protocol Analysis," TR91-024, Department of Computer Science, UNC at Chapel Hill, April 1991.

*Holloway, Richard L. "Art-Related Virtual Reality Applications at the University of North Carolina at Chapel Hill," *Proc. 2nd International Symposium on Electronic Art*, Groningen, Holland, 12-16 Nov. 1990.

Jeffay, Kevin. "Scheduling Sporadic Tasks with Shared Resources in Hard-Real-Time Systems," TR90-039, Department of Computer Science, UNC at Chapel Hill, Nov. 1990.

Jeffay, K. and Smith, F. D. "Designing a Workstation-Based Conferencing System Using the Real-Time Producer/Consumer Paradigm," *Proc. 1st International Workshop on Network and Operating System Support for Digital Audio and Video*, Berkeley, CA, Nov. 1990. (Also TR90-040.)

Lansman, Marcy. "Organize First or Write First? A Comparison of Alternative Writing Strategies," TR91-014, Department of Computer Science, UNC at Chapel Hill, Feb. 1991.

*Menges, John. "Providing Common Access Mechanisms for Dissimilar Network Interconnection Nodes," TR91-013, Department of Computer Science, UNC at Chapel Hill, March 1991 (M.S. thesis).

*Mills, P., L. Nyland, J. Prins, J. Reif, and R. Wagner. "Prototyping Parallel and Distributed Applications in Proteus," TR90-041, Department of Computer Science, UNC at Chapel Hill, Nov. 1990.

Molnar, Steven. "Efficient Supersampling Antialiasing for High-Performance Architectures," TR91-023, Department of Computer Science, UNC at Chapel Hill, April 1991.

*Neumann, Ulrich. "Taxonomy and Algorithms for Volume Rendering on Multicomputers," TR91-015, Department of Computer Science, UNC at Chapel Hill, Feb. 1991.

*Neumann, Ulrich, Terry S. Yoo, Henry Fuchs, Stephen M. Pizer, Tim Cullip, John Rhoades, and Ross Whitaker. "Achieving Direct Volume Visualization with Interactive Semantic Region Selection," TR91-012, Department of Computer Science, UNC at Chapel Hill, Feb. 1991.

Ohbuchi, Ryutarou, and Henry Fuchs. "Incremental Volume Rendering Algorithm for Interactive 3D Ultrasound Imaging," TR91-003, Department of Computer Science, UNC at Chapel Hill, 1991.

*Prins, J. "MP-1 Applications at UNC Chapel Hill," *MasPar News*, 1(2), March 1991.

*Prins, J. "Efficient Bitonic Sorting of Large Arrays on the MasPar, MP-1," TR91-041, Department of Computer Science, UNC at Chapel Hill, 1991.

*Prins, J. "Work-Efficient Techniques for the Highly-Parallel Execution of Sparse Grid-Based Computations," TR91-042, Department of Computer Science, UNC at Chapel Hill, 1991.

*Robinett, Warren and Jannick P. Rolland. "A Computational Model for the Stereoscopic Optics of a Head-Mounted Display," TR91-009, Department of Computer Science, UNC at Chapel Hill, 1991. (See also Part A.)

Robinett, Warren. "Electronic Expansion of Human Perception," to appear in Fall 1991 issue of *Whole Earth Review* Magazine.

*Shackelford, Douglas E., John B. Smith, Joan Boone, and Barry Elledge. "The UNC Graph Server: A Distributed Hypermedia Data Management System," TR91-019, Department of Computer Science, UNC at Chapel Hill, April 1991.

Smith, John B., Dana K. Smith, Eileen Kupstas, and Peter Calingaert. "Visualization of Computer Users' Cognitive Strategies and Behaviors," to appear in *Proc. International Symposium on Visual Analysis and Interface*, 1-4 Aug. 1991, Novosibirsk, USSR.

*Smith, John B., Dana K. Smith, and Eileen Kupstas. "Automated Protocol Analysis: Tools and Methodology," TR91-034, Department of Computer Science, UNC at Chapel Hill, Aug. 1991.

*Smith, John B., and F. D. Smith. "ABC: A Hypermedia System for Artifact-Based Collaboration," TR91-021, Department of Computer Science, UNC at Chapel Hill, April 1991.

*Smith, John B., F. D. Smith, Peter Calingaert, John R. Hayes, Dorothy Holland, Kevin Jeffay, and Marcy Lansman. "UNC Collaboratory Project: Overview," TR90-042, Department of Computer Science, UNC at Chapel Hill, Nov. 1990.

F. Books (or parts thereof) published (and to appear)

*Biagioni, E., and J. Prins. "Scan-Directed Load Balancing for Mesh-connected Highly-Parallel Computers," to appear in *Unstructured Scientific Computation on Scalable Multiprocessors*, MIT Press, 1991.

Plaisted, David A. and Shie-Jue Lee. "Inference by Clause Matching," *Intelligent Systems*, Z. Ras and M. Zemankova, eds., Ellis Horwood, 1990.

Plaisted, David. "Mechanical Theorem Proving," *Formal Techniques in Artificial Intelligence: A Sourcebook*, R. Banerji, ed., Elsevier, Amsterdam, 1990.

G. Videotapes

*Brooks, Frederick P. Jr. Interview videotaped and excerpted, with illustrations from Walkthrough demonstrations, in the SIGGRAPH Video Review, Vol. 60, Aug. 1990 (available from ACM under the title "HDTV and the Quest for Virtual Reality," *ACM SIGGRAPH Video Review*, Special Issue 60, 1990).

Yen-Ping, Shan. 1. Sample Interface Built with MoDE. 2. MoDE In Use. Department of Computer Science, UNC at Chapel Hill, 1990.

*1991 SIGGRAPH videotapes (SIGGRAPH '91, Las Vegas, NV, 1991:
- "Head-Mounted Display Research at UNC Chapel Hill," 52 minutes, July 1991.
- Robinett, Warren. "Concrete Portrayal of Mathematical Abstraction Using Computer Graphics, 10 minutes, July 1991.

Videotape accompanying proposal for UNC exhibit in the Virtual Reality Applications Gallery at SIGGRAPH '91, 30 minutes, Jan. 1991.

H. Invited presentations

Pixel-Planes 5

Eyles, John. "Virtual Worlds at the University of North Carolina at Chapel Hill," Im Cyberspace Conference, Munich, Germany, April 11-13, 1991.

Fuchs, Henry. "Computer Graphics and Visualization Technology," NCI workshop on Imaging—Guided Stereotactic Tumor Diagnosis and Treatment, Bethesda, MD, May 16-17, 1991.

Poulton, John. "Building Microelectronic Systems in a University Environment," 1991 Conference on Advanced Research in VLSI, UC-Santa Cruz, March 25-27, 1991.

Walkthrough

Brooks, Frederick P. "Virtual Worlds Research at the University of North Carolina at Chapel Hill," Senate Subcommittee on Science & Technology & Space, Washington, D.C., May 8, 1991.

Head-Mounted Display

Holloway, Richard. "Virtual Reality and Art," 2nd Intl. Symposium on Electronic Art, Groningen, Holland, Nov. 12-16, 1990.

Robinett, Warren. "Concrete Portrayal of Mathematical Abstraction Using Computer Graphics," SIGGRAPH '91 Panel on Computer Graphics in Education: "Doing With Images Makes Symbols," Las Vegas, NV, Aug. 1991.

Robinett, Warren. "Expansion of Human Perception," SRI Conference on Virtual Reality, Menlo Park, CA, June 1991.

Robinett, Warren. "Virtual Reality for Education," Intl. Conference on Education and Technology, Toronto, Canada, May 1991.

Robinett, Warren, "Synthetic Experience," Symposium on Virtual Reality, Museo Fortuny, Venice, Italy, Nov. 1990.

Robinett, Warren. "Synthetic Experience," Cyberthon (24-hour conference and exhibition on Virtual Reality), San Francisco, CA, Oct 1990.

Robinett, Warren. "The Head-Mounted Display Project," Compufest computer fair, UNC–Chapel Hill, NC, Sept.1990.

Rolland, Jannick. "Insight into Optical Properties of Wide-Angle See-Through Head-Mounted Display," SRI, June 1991.

Rolland, Jannick. "Project Grope: Haptic Displays for Scientific Visualization," IMAGINA 1991 Conference, Monte Carlo, Monaco, Feb. 1991.

Rolland, Jannick. "Synthetic Experience in Virtual Worlds," IMAGINA 1991 Conference, Monte Carlo, Monaco, Feb. 1991.

Tracker

Eyles, John. "Virtual Worlds at the University of North Carolina at Chapel Hill," Im Cyberspace Conference, Munich, Germany, April 11-13, 1991.

Fuchs, Henry. "Computer Graphics and Visualization Technology," NCI workshop on Imaging—Guided Stereotactic Tumor Diagnosis and Treatment, Bethesda, MD, May 16-17, 1991.

Artifact-Based Collaboration

Calingaert, Peter. "Visualization of Computer Users' Cognitive Strategies and Behaviors," Intl. Symposium on Visual Analysis and Interface, Novosibirsk, USSR, 1-3 Aug. 1991.

Jeffay, Kevin. "The Real-Time Producer/Consumer Paradigm: Towards Verifiable Real-Time Computations," Carnegie-Mellon U., Pittsburgh, PA, March 1991.

Jeffay, Kevin. "Systems Research in the UNC Collaboration Project," U. of Colorado, Boulder, CO, March 1991.

Smith, John. "The Social Creation of Knowledge: Multimedia and Information Technologies in the University," *MIT Writing Program*, Cambridge, MA, April 5-7, 1991.

Data-Parallel Execution

Prins, J. F. "Application Development for the MasPar MP-1," Massively Parallel Processing Seminar Series, North Carolina Supercomputer Center (broadcast to statewide CONCERT video locations), 2 April 1991.

Prins, J. F. "Derivation of Efficient Bitonic Sorting Implementations," *ONR Workshop on the Derivation of Parallel Algorithms and Program Transformation*, New York, NY, Aug. 30–Sep. 2, 1991.

I. Contributed presentations

Pixel-Planes 5

Fuchs, Henry. "Scientific Visualization on Advanced Architectures," panel presentation at SIGGRAPH '91, Las Vegas, Nevada, July 28-August 2, 1991.

Ohbuchi, Ryutarou. "Incremental Volume Rendering Algorithm for Interactive 3D Ultrasound Imaging," Information Processing in Medical Imaging XII, Wye, England, July 1991.

Turk, Greg. "Generating Textures on Arbitrary Surfaces Using Reaction-Diffusion," SIGGRAPH '91, July 1991.

Yoo, Terry. "Achieving Direct Volume Visualization with Interactive Semantic Region Selection," IEEE Visualization '91, San Diego, Calif., Oct. 1991.

Head-Mounted Display

Robinett, Warren. "A Computational Model For the Stereoscopic Optics of a Head-Mounted Display," SPIE Conference on Electronic Imaging, Santa Clara, CA, Feb 1991.

Tracker

Fuchs, Henry. "Scientific Visualization on Advanced Architectures," panel presentation at SIGGRAPH '91, Las Vegas, NV, July 28–August 2, 1991. (also HMD)

Artifact-Based Collaboration

Jeffay, Kevin. "Efficient Kernel Support for Continuous Time Media Systems," ITC Workshop on Continuous Time Media, Carnegie-Mellon U., Pittsburgh, PA, June 1991.

Jeffay, Kevin. "YARTOS: Kernel Support for Efficient, Predictable Real-Time Systems," Joint IEEE/IFAC Workshop on Real-Time Operating Systems and Software, Atlanta, GA, May 1991.

Jeffay, Kevin. "System Design for Workstation-Based Conferencing With Digital Audio and Video," IEEE Conference on Communications Software: Communications for Distributed Applications and Systems, Chapel Hill, NC, April 1991.

Jeffay, Kevin. "Designing a Workstation-Based Conferencing System Using the Real-Time Producer/Consumer Paradigm," 1st Intl. Workshop on Network and Operating System Support for Digital Audio and Video, Intl. Computer Science Institute, Berkeley, CA, Nov. 1990.

Lansman, Marcy. "Organize First or Write First? A Comparison of Alternative Writing Strategies," Penn. State Conference on Rhetoric and Composition, July 10-13, 1991.

Smith, John. 1991 BRG C(2) Research Symposium, National Defense University, Ft. McNair, Washington, DC, June 24-25, 1991.

J. Honors

Edoardo Biagioni and David Ellsworth were again named ONR fellows during FY90-91.

Frederick P. Brooks, Jr. elected Foreign Member of Royal Netherlands Academy of Arts and Sciences (Science Division), April 29, 1991.

Henry Fuchs served on the Papers Committee for SIGGRAPH '91.

Kevin Jeffay served on the program committees for the IEEE Conference on Communication Software: Communications for Distributed Applications and Systems, Chapel Hill, NC, April 1991 and will serve on the program committee for the 12th IEEE Symposium on Real-Time Systems, San Antonio, TX, December 1991.

Steven Molnar and Greg Turk were once again granted IBM graduate student fellowships during this academic year.

Don Smith served as program chair for TriComm '91, the IEEE Conference on Communications Software, UNC–Chapel Hill, NC, April 17-19, 1991.

K. Prizes or awards

None during this reporting period.

L. Promotions obtained

None during this reporting period.

M. Educational productivity

Please see Section 1 and Appendix II.

SECTION 4: Transitions and DoD Interactions during this reporting period *(by project)*

Principal Investigators:	Frederick P. Brooks, Jr. Donald F. Stanat Stephen F. Weiss
PI Institution:	The University of North Carolina at Chapel Hill Department of Computer Science
PI Phone Numbers:	919/962-1931 919/962-1788 919/962-1888
PI E-mail Addresses:	brooks@cs.unc.edu stanat@cs.unc.edu weiss@cs.unc.edu
Contract Title:	The Infrastructure of Command Information Systems
Contract Number:	N00014-86-K-0680
Reporting Period:	15 September 1990 through 30 September 1991

A. Transitions of Results and DoD Interactions

Pixel-Planes 5

In conjunction with four other institutions (Brown University, California Institute of Technology, Cornell University, and University of Utah), we received a grant from the National Science Foundation to create a Science and Technology Center in Computer Graphics and Scientific Visualization. Collaboration with researchers at these four institutions has now begun. We anticipate that the earliest results relating to Pixel-Planes will be more rapid interaction with global lighting effects. This is a result of collaboration with our Cornell colleagues, who have pioneered these "radiosity" lighting techniques.

Groups from ABC-TV's PrimeTime Live, WGBH-TV, and a Japanese public television station have filmed in our graphics lab for their programs. The PrimeTime segment on virtual reality was broadcast September 19, 1991. The Nova series on WGBH, called "The Information Age" will be broadcast in the spring of 1992; this is a series of six one-hour segments, one of which will deal with virtual reality. Another show for WGBH-TV is currently scheduled to be broadcast in early 1992. This series, with the working title "Making It in the USA," consists of four one-hour segments; footage dealing with our research will be in the segment that currently has the working title, "On the Road Again."

A joint meeting of principal investigators on DARPA/ISTO funded projects in the Microsystems and Architectures interest groups was held at UNC–Chapel Hill, October 3-5, 1990. Approximately 150 people (including five DARPA program managers and the director of ISTO) attended the meeting. Although each interest group holds meetings semiannually, joint meetings of two interest groups occur only once every several years. Thirty universities and twenty-five industrial groups from all over the U.S. were represented at the meeting. The sharing of ideas occurred in both paper and demo sessions. Meeting attendees were given the opportunity to see several demonstrations in the UNC Graphics and Image Lab. In addition, ten universities and companies brought demos with them, which were shown on workstations in our Department.

In response to a very large number of requests to visit our facility, we now hold a monthly visit day in our graphics and image lab, and we average 60–100 visitors on each of these days. The types of people wishing to visit our lab are varied and include computer science professionals; chemists, physicists, and other scientists; engineers; architects; physicians; journalists; educators; school groups; UNC administrators trying to understand more about our projects; etc. We still host special visitors at other times. For a sample of the visitors to our graphics lab during the last fiscal year, please see the section below entitled "All Graphics Projects."

Walkthrough

Please see the section below entitled "All Graphics Projects."

Head-Mounted Display

Please see the section below entitled "All Graphics Projects."

Tracker

Please see the section below entitled "All Graphics Projects."

All Graphics Projects

Senator Al Gore
Toki Takahashi, NTT, Japan
Wally Hannum, UNC School of Education
Frank Biocca, UNC School of Journalism
John Toole, DARPA
Dean of East Carolina University, Greenville, NC
Group of 5 from SAS Institute, Cary, NC
Group of 25 North Carolina High School Chemistry Teachers
David Beaver, Information Network, Raleigh, NC
Randall Shumaker and Dale Long, Naval Research Lab
Bruce Phillips, NC Museum of Life and Science
About 15 Engineering Students who were summer fellows at the Duke Engineering Research Center in Advancing Cardiovascular Technologies
Richard Clinch, North Carolina Board of Science and Technology
About 30 members of the UNC Chancellor's Club
Chief Academic Officers from about 30 East Coast Universities
Laurent Belsie, journalist from *Christian Science Monitor*
Group of 6 from Digital Equipment Corporation
Vic Reis, Director of DARPA
Deputy Director of DARPA
Around 30 people attending a DARPA contractor's meeting on prototyping, held at UNC, May 1991
Group of 25-30 college juniors participating in a program for future teachers in NC (sponsored by the governor's office)
About 125 attendees of the Molecular Graphics Society International meeting, May 1991
Capt. Stark and Gloria Golden, Fort Huachuca, Arizona
Group of 10 from Virginia Tech, Blacksburg, VA
Group of 3 from the VA Hospital Medical Education Center, Durham, NC
Charles Grimsdale & Phil Atkins, Division Ltd., Bristol, UK
23 Students from the PreCollege Program sponsored by the UNC Math and Science Education Network
Ivan Sutherland & Robert Sproull, Sun Microsystems
Group of 3 from IVEX Corp.
Group of 4 from IBM, Research Triangle Park, NC
Group of 3 from Wright-Patterson Air Force Base
Group of 2 from Duke University School of Medicine
Class on Human–Machine Interface, UNC School of Information and Library Science (About 20 graduate students)
Class on Research Methods, UNC School of Information and Library Science (About 13 graduate students)
Architecture Class, Guilford College, Greensboro, NC (About 25 undergraduates)
Deanna Tebockhorst, Science Specialist, Frank Porter Graham School, Chapel Hill, NC
Eugene Bylinsky, journalist from *Fortune* Magazine
Group of 6 from the National Center for Supercomputing Applications
Group of 4 from the Math & Science Center, Richmond, VA
Bob Andron, architect
Robert Beck, Imaging Science Group, Univ. of Chicago

Mark Cutter and Pete Litwinowicz, Apple Computer
Glen Emory, Insight Magazine
Jaroslav Folda, UNC Art Department
R. Kikinis and F. Jolesz, Brigham & Women's Hospital, Boston, MA
Tom Kominski, Astronautics
Edouard Launet, journalist from *Les Echos*, Paris, France
P. Meenan, B. Lorensen, N. Corby, A. Chin, GE Research & Development, Schenectady, NY
Tatsuo Miyazawa, IBM Tokyo Research Lab
M. Moshseghia and B. Zhu, Philips Medical Research, Briarcliff, NY
Larry Yaeger, Apple Computer, Vivarium Project
Group of 4 from Armed Forces Institute of Pathology
About 150 attendees of the DARPA Fall '90 Joint Meeting of PIs in the Microsystems and Architectures Interest Groups
Two from Disney Imagineering
Industrial Sponsors of the Duke Engineering Research Center in Advancing Cardiovascular Technologies
Gifted and Talented 6th graders, Glenwood School, Chapel Hill, NC (About 30 students and 3 teachers)
IBM Science Advisory Committee
About 12 NC State Univ. computer science undergraduates
Group of 4 from Rensselaer Polytechnic Institute
Group of 2 from UNC Physics Department
Group of 3 from UNC Department of Neurology
Group of 2 from SAIC
Max Donath, Director of Robotics and Human Motions Labs at the University of Minnesota
32 juniors and seniors from East Rowan High School, Salisbury, NC
36 mechanical engineering students from North Carolina State University
Randall Shumaker and Dale Long, NRL, visited on 28 June 1991. Saw the following demos: Pixel-Planes 5, ARM, Head-Mounted Display, Walkthrough with treadmill. Also met with Bill Wright (ARM), and John Smith and his Collaboratory project team.

Artifact-Based Collaboration

NRL Lab, Washington, DC
Jim Gray and Ronnie Sarkar, IBM SNA Studies Group
ONR site visitors, Executive Committee, and investigators
Walter Kintsch, U. of Colorado
Stephen Poltrock, Boeing
See "All Graphics projects" above (Shumaker and Long)

SoftLab

Products distributed by SoftLab during this reporting year:
(These numbers reflect only distributions made between September 1990 and August 1991. This list includes only SoftLab products for which there was distribution activity during this reporting period.)

Volume Rendering Data Sets (numbers for Volumes I and II combined)

The Volume Rendering Data Sets Volume I and II contain medical and other images as shown at the 1990 Volume Visualization Workshop. These are the first items in a planned "visual data set" product line.

13 academic distributions

24 commercial distributions

COOL 1.0

COOL is a software library developed by James Coggins. COOL, written in the object oriented language C++, contains class definitions relevant to research in computer vision, image pattern recognition, and computer graphics. We are currently working on the packaging of COOL 2.0.

6 commercial distributions

RSpace 1.3

RSpace is an interactive program developed in the Computer Science Department by Mark Harris in 1988 which is designed to help crystallographers plan data collection strategies when using diffractometers equipped with area detectors. SoftLab is currently developing RSpace 2.0, which will include some significant new user interface features. These are expected to broaden the RSpace customer base further.

6 academic distributions

1 commercial distribution

All projects:

ONR site visit team members, Sept. 1990.

SECTION 5: Software and Hardware Prototypes during this reporting period *(by project)*

Principal Investigators:	Frederick P. Brooks, Jr. Donald F. Stanat Stephen F. Weiss
PI Institution:	The University of North Carolina at Chapel Hill Department of Computer Science
PI Phone Numbers:	919/962-1931 919/962-1788 919/962-1888
PI E-mail Addresses:	brooks@cs.unc.edu stanat@cs.unc.edu weiss@cs.unc.edu
Contract Title:	The Infrastructure of Command Information Systems
Contract Number:	N00014-86-K-0680
Reporting Period:	15 September 1990 through 30 September 1991

Pixel-Planes 5

Hardware Prototypes—We have designed and built the Pixel-Planes 5 graphics system, a high-performance, scalable multicomputer for 3D graphics. Its main components include: **Graphics Processors**—general-purpose, math-oriented processors that carry out geometric transformations and other calculations; **Renderers**—fine-grain, massively parallel arrays of processors based on custom, logic-enhanced memory chips, that perform most pixel-oriented calculations in parallel over many pixels; and a **Ring Network** that moves data and control messages between system components at high speed. The machine rapidly renders polygonal images with advanced lighting models and textures, directly renders spheres (and other quadratic surfaces) as well as objects described by constructive solid geometry (CSG), performs near real-time rendering of volume data sets modelled as transparent gels, and executes a variety of image-processing algorithms. It is modular and can be configured in a variety of ways to trade cost for performance. Programming tools and graphics libraries allow applications developed in the C programming language to utilize nearly the full performance of the machine; microcoding tools are available for critical inner loops, where the user needs the highest performance. Existing applications that use the PHIGS+ standard for 3D graphics can readily be ported to the system. A fully-loaded system with about 40–50 Graphics Processors and 20 Renderers can produce Phong-shaded, z-buffered polygons at rates well in excess of 1 million triangles per second.

Commercialization—During the past year we have granted a limited license of our two patents on Pixel-Planes technology to IVEX Corporation (Norcross, Georgia) for use in vehicle and flight simulation and training. One of our former senior staff members, Trey Greer, joined IVEX's staff and now develops algorithms (that remain in the public domain) for future IVEX products based on our technology.

In February 1992, IVEX plans to ship the first product incorporating the Pixel-Planes technology. These are enhancements to current products—visual systems for flight simulators. IVEX expects FAA Phase 2 certification, based in part on the anti-aliased, polygon-generation capabilities provided by the Pixel-Planes technology.

Tracker

A tracker with a large working volume (10' x 12") has been demonstrated. It features thirty ceiling panels suspended from a free-standing ceiling structure, a headset that couples four image sensors to a VPL EyePhone, and an interface to the Pixel-Planes 5 host processor. The tracking system can resolve head motions as small as 2 mm in

translation and .2° in rotation. Its update rate is 20–100 Hz, and the lag in a given measurement ranges from 20–100 ms.

Artifact-Based Collaboration

Suite of tools for working with machine-recorded protocols

Prototype ATN grammar development environment

Data-Parallel Execution

The large-array sorting and routing facilities developed here for the MP-1 are being used by MasPar in applications and for demonstrations. These packages will be placed in the MasPar user's group repository.

SoftLab

MAST860

Mast860 is a microcode preprocessor for the Intel i860 floating point chip. It facilitates hand optimization of i860 assembler by automating register allocation and other machine details and by performing pipeline analysis. Mast860 is currently used by Pixel-Planes 5 applications programmers who code in hand optimized assembler for performance reasons. We have advertised this prototype on various bulletin boards and have also sent a preliminary copy to Intel for review. Future commercialization is a possibility.

Unix-Phone Switch Interface and Applications

Last year, SoftLab implemented a UNIX driver that allows telephone switch functions such as phone calls and networking operations to be controlled from Department workstations. This driver communicates with our InteCom switch via the InteCom Open Applications Interface (OAI) feature on the switch. This driver software was made available to InteCom, which is starting up a UNIX application development effort. In addition, we also implemented two UNIX applications on top of the driver software. The first was a voice mail application that stored and manipulated voice messages as UNIX files, and the second was a power dialer that allowed phone calls to be placed by UNIX workstation commands using online databases of numbers and speed-calling lists. This work was an initial step in setting up an integrated voice and electronic messaging system that would form a test bed for Department research in distributed computing. InteCom included a description of our applications in its advertising literature, and we have been contacted by DataTrac, Inc. about a possible joint venture for further application development.

ANNUAL SUMMARY

15 September 1989 through 14 September 1990

Y4

The Infrastructure of Command Information Systems

Submitted to

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Submitted by

Department of Computer Science
The University of North Carolina at Chapel Hill
Sitterson Hall
Chapel Hill, NC 27599-3175

Principal Investigators:

Frederick P. Brooks, Jr.
Donald F. Stanat
Stephen F. Weiss

October 1990

Contract No. N00014-86-K-0680

CONTENTS

SECTION 1: Productivity Measures during this Reporting Period 1

SECTION 2: Detailed Summary of Technical Progress during this Reporting Period (by project) 2

Pixel-Planes 5 2

Walkthrough 3

Head-Mounted Display 4

Tracker 5

Protocol Analysis Tools 8

SoftLab 8

SECTION 3: Lists of Publications, Presentations, Reports, Awards, and Honors during this Reporting Period 10

A. Refereed papers (to appear) 10
B. Refereed papers published 10
C. Refereed papers submitted (awaiting acceptance) 11
D. Unrefereed reports and articles 11
E. Books (or parts thereof) published 13
F. Invited presentations 13
G. Contributed presentations 14
H. Honors 15
I. Prizes or awards 15
J. Promotions obtained / New staff 15
K. Educational productivity 15

SECTION 4: Transitions and DoD Interactions during this Reporting Period (by project) 17

A. Transitions of Results 17
B. DoD Interactions 19

SECTION 5: Software and Hardware Prototypes during this Reporting Period (by project) 21

APPENDICES

- Personnel by Project
- Research Assistants since FY86-87
- Trip/Visit Reports
- Outside Funding Received during FY89-90
- Agenda: ONR Site Visit, 25-26 September 1990
- Comprehensive Bibliography

ANNUAL REPORT for FY89-90

SECTION 1: Productivity Measures during this reporting period

Principal Investigators:	Frederick P. Brooks, Jr. Donald F. Stanat Stephen F. Weiss
PI Institution:	The University of North Carolina at Chapel Hill Department of Computer Science
PI Phone Numbers:	919/962-1931 919/962-1788 919/962-1888
PI E-mail Addresses:	brooks@cs.unc.edu stanat@cs.unc.edu weiss@cs.unc.edu

Contract Title:	The Infrastructure of Command Information Systems
Contract Number:	N00014-86-K-0680
Reporting Period:	15 September 1989 through 14 September 1990

		ONR supported	Related
1.1	Refereed papers submitted (*to appear*)	0	2
1.2	Refereed papers published	10	4
1.3	Refereed papers submitted (awaiting acceptance)	1	2
1.4	Unrefereed reports and articles	4	14
1.5	Books (or parts thereof) published	0	1
1.6	Books (or parts thereof) submitted (*to appear*)	0	0
1.7	Patents filed but not yet granted	0	1
1.8	Patents granted	0	0

		Supported or Related
1.9	Invited presentations	13
1.10	Contributed presentations	11
1.11	Honors received	11
1.12	Prizes or awards received	1
1.13	Promotions obtained	0
1.14	Educational productivity (degrees received)	10
1.15	Graduate students supported $\geq$ 25% of full time	22
1.16	Post-docs supported $\geq$ 25% of full time	0
1.17	Minorities supported $\geq$ 25% of full time	2

SECTION 2: Detailed Summary of Technical Progress during this reporting period *(by project)*

Principal Investigators:	Frederick P. Brooks, Jr. Donald F. Stanat Stephen F. Weiss
PI Institution:	The University of North Carolina at Chapel Hill Department of Computer Science
PI Phone Numbers:	919/962-1931 919/962-1788 919/962-1888
PI E-mail Addresses:	brooks@cs.unc.edu stanat@cs.unc.edu weiss@cs.unc.edu

Contract Title:	The Infrastructure of Command Information Systems
Contract Number:	N00014-86-K-0680
Reporting Period:	15 September 1989 through 14 September 1990

Pixel-Planes 5

Hardware—The research team completed the major portion of the Pixel-Planes 5 (Pxpl5) prototype hardware system in early July 1990. Although not all of the hardware modules are finished, there are enough now working to form a fully functional computer graphics system. The project team continues to work on expanding the number of modules (Graphics Processors, Renderers, and Ring Network interface boards) and on removing the last few hardware bugs in existing modules. A system with 40 Ring boards, 16 Graphics Processors, and 20 Renderers is expected to be ready by early October 1990.

Laura Weaver and John Poulton have nearly completed the logic design for an NTSC-compatible frame buffer for Pxpl5. This new, low-resolution, two-channel frame buffer is intended mainly to drive the head-mounted displays of the Walkthrough project but can be used for a variety of other tasks that require television broadcast-compatible video. The team expects to complete this new module by late November 1990.

Software—The operating system and graphics software were ported to the actual Pixel-Planes 5 hardware. Pixel-Planes 5 is now a completely functional graphics system, although with reduced speed until all the hardware modules are completed. Software components successfully ported to Pixel-Planes 5 include the Ring Operating System (ROS), Render Control System (RCS) and the PHIGS+ compatible graphics library (PPHIGS). Performance measurement and optimization of this software is in progress. Although the system is far from fully optimized, we have achieved rates of 100,000+ triangles and spheres per second, with Phong shading. Our goal is to exceed 1,000,000 triangles or spheres per second.

System software was developed to allow C language programming for the i860 processors in the Graphics Processor modules. This software includes routines to create the C runtime environment, to load programs, to allow UNIX-type system calls, and to make performance measurements. The Ring Operating System was actually re-implemented rather than ported to the Pixel-Planes 5 hardware, preserving the same user interface that was previously used on the porting base.

Routines for generation of images (MIP map) and procedural textures were implemented and integrated into the PPHIGS graphics library. Procedural textures can make use of filtered noise functions to produce complex, naturalistic patterns very efficiently.

Several graphics application programs are in development. Three major ones are a building walkthrough program, a flight simulator, and a volume rendering program. These programs, although not fully complete and optimized, are now operational on the Pixel-Planes 5 system. Both the building walkthrough and flight simulator programs make heavy use of the procedural texture capabilities of PPHIGS to create a rich visual environment.

The volume rendering program produces three-dimensional renderings of volumetric data sets, such as CAT-scan data. A 128 x 128 x 128 data set can now be rendered with Phong shading in about 2 seconds on Pixel-Planes 5. The performance goal for the volume renderer is to produce renderings of this size data set at multiple frames per second, to permit interactive investigation of the data.

Funding—A new grant from NSF and DARPA has been awarded on the Pixel-Planes research. Henry Fuchs and John Poulton are the principal investigators for this grant, which is entitled "Supercomputing Power for Interactive Visualization." The grant has been awarded for a period of three years beginning 1 June 1990, and total annual direct costs are $1,100,896. The proposed work is a continuation of our current research on the Pixel-Planes graphics system, and we plan to expand our investigations into a number of graphics architecture areas.

A research agreement has been drawn up among the Corporation for National Research Initiatives, Bell South Systems, GTE, the Microelectronics Center of North Carolina, the UNC Department of Computer Science, and the UNC Department of Radiation Oncology to demonstrate an application of Pixel-Planes 5 using gigabit networking to the Cray Y/MP in Research Triangle Park at the NC Supercomputer Center. This VISTAnet project has been funded for a period of three years beginning 1 August 1990. First-year funding for the UNC components of the project is:

Dept. of Computer Science (Chi):	$732,551
Dept. of Computer Science (Fuchs):	$714,665
Dept. of Radiation Oncology (Rosenman):	$982,387

Raj Singh has been named the hardware engineer for Vernon Chi's component of the VISTAnet project. A search for a software engineer for Henry Fuchs' component of the project is now being conducted.

Walkthrough

This year saw the fruition of a number of our long-term efforts, culminating in a real-time walkthrough capability for a fully radiositized model of the Orange Church Fellowship Hall, with interactive, near-real-time ability for the user to turn on, turn off, or dim any of 20 lighting circuits. This work was first completely demonstrated and the techniques described in our paper at Snowbird, UT, in March. It now runs on UNC's Pixel-Planes 4 (PxPl4) and on the Silicon Graphics 4D series. Since then our progress has been rapid, both in modeling and in the rendering of textures using UNC's new graphics supercomputer, Pixel-Planes 5.

Update rate via model partitioning. Airey demonstrated the power of his methods of automatically partitioning large building models into cells, each with an associated potentially-visible-set of polygons. This cuts viewing time according to the average depth complexity of the model, so that it has dramatic effects on large models. Our Sitterson Hall model turned out to have about 250 active cells as a reasonable automatic partitioning.

Update rate via adaptive radiosity. Airey and Rohlf completed development of an adaptive radiosity computation technique based on ray-firing, and this was incorporated into our standard PxPl4 software.

Image quality—textures. Varshney of our project and Turk and others of the PxPl project implemented Walkthrough with procedurally textured surfaces, and incorporated about a dozen textures into the House model as run on PxPl5. Speed still needs work, but we are getting stunning pictures at one update per second. These include textures for, for example, wood paneling, furniture, bricks, piano keys, sheet music, ceiling tiles, linoleum, wallpaper, etc.

Image quality—mirrors. Varshney implemented mirrors.

Interface. Hill, Brown, and others implemented a host interface giving graphical control of lighting parameters, etc.

Model building via AutoCad. We completed the tools necessary to get from an AutoCad model of a building to the data structures necessary for a Walkthrough model.

New model—house. Per plan, we implemented a third building model this year, this one a house with over a dozen rooms, considerable furniture, and textured surfaces. This model, as well as our other ones, has been transferred to Silicon Graphics. Stardent is also using our Orange Church model to test and demonstrate their system.

Porting to new hardware. This year the Walkthrough software was ported to Silicon Graphics hardware by Rohlf after he graduated from UNC, and to Pixel-Planes 5 by the team here.

Documentation—dissertation published. Airey's thesis was completed and accepted in July, giving us quite complete published documentation of the research up to that point, and of the algorithms developed. (See technical report listed in Section 3.)

Head-Mounted Display

We continue to make progress toward the goal of having our head-mounted display/virtual reality capabilities accessible to all Department members with a minimal amount of effort. We have enhanced the hardware used, and have created easy-to-use software models for applications developers.

Hardware—A major improvement in our Head-Mounted Display system during this reporting period involved the installation of a custom board on the (1986) Pixel-Planes 4 host which permitted the generation of two NTSC signals from the single frame buffer. Stereo-pair images, each with half the horizontal resolution of the full frame buffer image, are now generated, enabling us to use our VPL Eyephones, the optical geometry of which requires two different stereo images. In addition, we can now display stereo images on the older head-mounted display, for which we had been previously displaying the same image to both eyes.

The Pixel-Planes 4 host applications can now make use of non-directional auditory display by communicating over a serial line with a dedicated Macintosh sound server. Such audio feedback is useful to indicate task completion, object selection, object collisions, and other situations. Macintosh software has been developed to enable applications developers to easily incorporate auditory display.

We have completed the installation of our two additional Polhemus tracker units in the Graphics Lab. The one-station Isotrack unit has been installed near the ARM, and we have found that the ARM produces minimal disturbance to the magnetic field of the Polhemus tracker. We have combined the ARM and the HMD in a simple demonstration program involving solid block manipulation. The eight-station 3Space tracker unit has been installed in the Graphics Lab in a relatively open area. By itself, the eight-station unit with its two sources has a larger working volume than the single-source, two-station unit already installed in the HMD room. Used together, the eight-station Polhemus and the two-station Polhemus will permit investigation of remotely located, multiple users being present in the same virtual world.

Optical engineer Jannick Rolland joined our team in June 1990, and has begun work on the optical design of a new see-through head-mounted display, initially slated for medical applications.

Software—*hmdfront*, a generic 3D dataset exploration tool that allows the user to examine arbitrary models with the HMD, has been released and installed. *hmdfront* is the basis for our standard demos, and has also been put into use to examine new molecular representations. The program is not intended nor expected, however, to satisfy all possible requirements users may have for their particular application. In many cases, special software will have to be written to implement some special feature such as a particular interaction mode. *hmdfront* provides manipulation with the 6D mouse of the global space or individual objects within the model.

We are close to finishing the initial release of a tracker library, which will enable applications builders to readily use the Polhemus trackers and any other trackers used in the Department. The library will furnish the programmer with abstractions of tracking devices, and free the programmer from worrying about details regarding specific devices, communications, and protocols.

Faculty member Kevin Jeffay and graduate student Dan Poirier have demonstrated a significant increase in the frame update rate through a restructuring of HMD software that followed a multiprogramming model. The goal was to obtain predictable real-time behavior from the non-real-time operating system (Ultrix) on which we run our HMD applications. Incorporation of their model in future HMD application development should provide dramatic performance improvement.

Funding—The work of the Head-Mounted Display project will be assisted by a contract on "Advanced Technology for Portable Personal Visualization" (Fred Brooks and Henry Fuchs, PIs) awarded by DARPA for a period of three years. The total three-year award is $2,473,081.

Tracker

We are developing a new optical tracking system, built with off-the-shelf components, that provides a very large (room-sized) working environment (see Figure 1). This system adopts an "inside-out" tracking paradigm first proposed by our research team and introduced in a paper by Gary Bishop and Henry Fuchs in 1984. The working environment is a room in which the ceiling is lined with a regular pattern of infrared light-emitting diodes (LEDs) that are flashed under the system's control. Three or more cameras are mounted on a helmet that the user wears. The measured photocoordinates of an LED, combined with their known locations on the ceiling, allow us to compute the position and orientation of the camera assembly in space (see Figure 2). Each camera uses a lateral-effect photodiode as the sensing surface. A lateral-effect photodiode provides higher resolution over its surface and faster response than a conventional CCD camera; thus higher accuracy in the reported position and a faster update rate can be achieved.

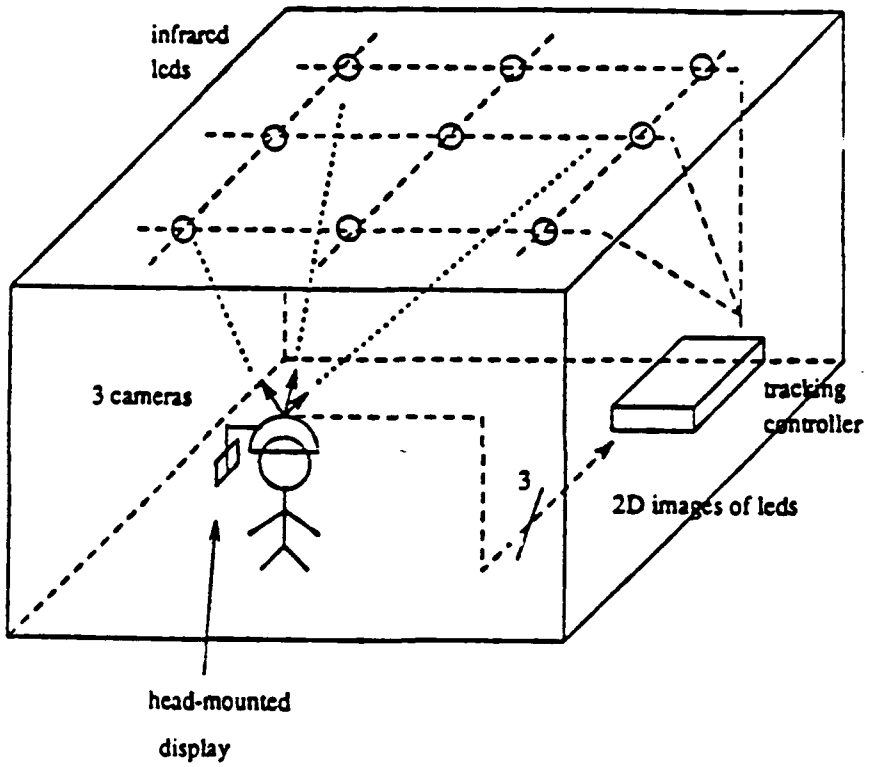


Figure 1: Configuration of the proposed tracking system

Wang presents in his dissertation an iterative algorithm to estimate the position and orientation of the camera assembly in space. The algorithm is a generalized version of the method proposed by Earl Church in 1945, which was used in aerial photogrammetry. Equations were also derived by Wang to predict the system's error. Computer simulations were carried out to verify the correctness of the theoretical analysis and to determine several important system design parameters. The requirements of accuracy, speed, adequate working volume, light weight, and small size of the tracker are also addressed.

A desktop prototype was designed and constructed to demonstrate the integration and coordination of all essential components of the new tracker. This prototype uses off-the-shelf components and can be easily duplicated. The limiting factors on the performance of the system, such as the noise inherent in the circuitry, the resolution, the nonlinear characteristics of the photodiode, and the output power of the LEDs, were carefully measured and studied.

The performance of the tracker was quantitatively measured. We designed experimental procedures to determine the speed, accuracy, and working range of the prototype tracker. Our results indicate that the new system significantly outperforms other existing systems. The new tracker provides more than 20 updates per second (and promises more than 200 updates per

second), registers 0.1-degree rotational movements and 2-millimeter translational movements, and promises a large working volume.

Our first proof-of-concept prototype had only three infrared LEDs: one for each camera's field of view. To test the multiple ceiling-panel concept, we next constructed a 48-LED, three-panel prototype. Each LED can be individually addressed, and one is turned on for each head-mounted camera. The three-panel system has been demonstrated, and it is being used to develop improved algorithms and hardware that will be used in a room-sized prototype.

We are now implementing a full-working volume system in a 26 x 12 x 9 cubic-foot room, using about one thousand LEDs. The LEDs will be arranged in 4-by-4 hexagonal grids affixed to 2 x 2 square-foot panels . The panels will be installed as a portable, false ceiling in a room. In such a full-scale system, the positions of the LEDs have to be known very accurately to provide sufficient precision in the tracking process. An improved algorithm for computing the head-position and orientation is being developed that will accommodate more LED placement error.

The algorithm is a generalized version of the technique known as *space-resection by collinearity*. For the problem of computing a camera's position and orientation given the photocoordinates of three or more landmarks (known as space-resection), this technique has several advantages over Church's method. Most importantly, if more than three landmarks can be observed, the additional information can be used in the solution. Also, the six unknowns are solved for in one step, whereas Church's algorithm directly solves for only the linear degrees of freedom. Least-squares techniques are used to accommodate the over-determined matrix equations that result from more than three landmarks.

Space-resection by collinearity has been generalized to allow the use of multiple image planes, as well as multiple landmarks per image plane. This will allow us to use more than three cameras, and if each camera is capable of imaging more than one LED, then the additional information is used to compute the camera assembly's position and orientation. Simulations have shown that when this approach is used, the effects of beacon placement error are less than with the generalized version of Church's algorithm.

In preparation for the full-scale system, considerable effort is being directed toward camera calibration. We know that the image plane of each camera must have an accuracy of 1 part in 1000 if we are to satisfy our overall system requirements. Dr. E. K. Antonsson, formerly of MIT's Biomechanics Laboratory, now with the Division of Engineering and Applied Science at the California Institute of Technology, found that this was impossible with off-the-shelf, electro-optical equipment. First, the lateral-effect photodiode possesses a systematic error that is as great as 1 part in 40. When this sensor is combined with a non-metric lens and a camera body whose tolerances are no better than .5mm, the result falls far short of our goal. Dr. Antonsson experimentally derived a two-dimensional calibration table for cameras that are nearly identical to ours and achieved the goal of 1 part in 1000 accuracy. We are working with Dr. Robert J. Hocken, of the University of North Carolina at Charlotte, to duplicate Dr. Antonsson's results. In UNC-Charlotte's metrology lab, a coordinate-measuring machine will be used to index an LED throughout the field of view of our cameras. The data gathered will then be analyzed and used to construct a calibration table.

During the calibration procedure, we hope to determine the optical parameters of the camera, as well. Because we are using non-metric lenses, the principal plane locations, focal length, and optical axis locations are poorly defined with respect to the camera body. The mathematics associated with space-resection by collinearity can also be used to compute these parameters. By precisely controlling both the camera and the LED location, equations can be derived in which the focal length and principal plane locations are unknowns. Then, if sufficient data points are taken, least-squares techniques can be used to solve for these parameters. Such a procedure is well-documented in the photogrammetry literature and is referred to as the calibration of non-metric cameras.

The calibration experiment will be conducted using an improved computational architecture, which is currently under development. The full-sized tracker prototype will be controlled by a multiprocessor system comprised of a Sun 4/260 workstation, a 68030-based single board computer, and an array processor (see Figure 2). The workstation serves as a development environment and a diagnostic graphical display device. The 68030-based single board computer manages up to 8 cameras and 256 ceiling panels. It fires selected LEDs and extracts photocoordinates from the cameras. The array processor accepts the photocoordinates and computes the position and orientation of the camera assembly using the generalized form of space-resection by collinearity.

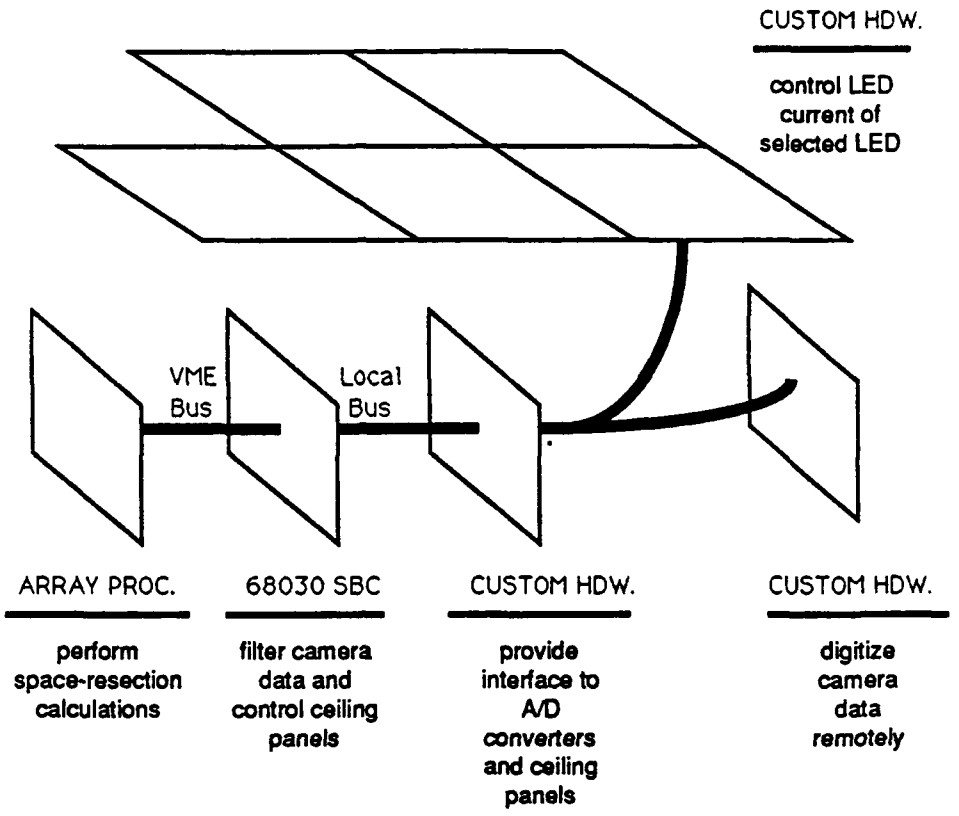


Figure 2.

Coupled with custom interface electronics (currently being designed and implemented by the department's Microelectronic Systems Laboratory), real-time control software running on the 68030 assigns a current density to an LED (out of 256 possible values), addresses one LED out of 255 panels, and turns the LED on for a specific time period. During the LED's *on-time*, the four voltage signals emerging from a camera are digitized at a rate of 1MHz.

The analog-to-digital conversion occurs at the head, using custom hardware. A parallel data link connects the head-mounted circuitry to an interface card in the workstation's VME cardcage. This 9U VME card provides an interface for the head-mounted cameras and the ceiling panels, as well as an attachment port for the single board computer. The port implements Corebus, a high-speed inter-board protocol developed by Heurikon Corporation for the attachment of mezzanine cards to generic VME cpu boards.

Upon arrival at the single board computer, the sequence of 12-bit digital codes are filtered to reject ambient light and are then fed into a calibration table for the camera. The result is a pair of photocoordinates.

A set of photocoordinates is produced by repeating this process for each camera, as well as for each LED that is in the camera's field of view. Three elements are required to compute the cameras' position and orientation. The information is communicated from the single board computer to the compute-server over the workstation's VME bus.

When the minimum number of LEDs is available, space-resection involves an iterative solution to six nonlinear equations. Each iteration requires that a 6 x 6 matrix be inverted. If more than three LEDs can be imaged, the number of equations remains the same, but the dimensionality of the matrix grows to 2N x 6, where N is the number of photocoordinates. A pseudoinverse is thus involved in the computation. We have implemented the space-resection algorithm in the C programming language and are preparing to benchmark the code on commercially available array processors.

By 1 August 1991, we hope to have a system that functions in a large working volume where the user can walk around freely. The system will provide accurate information on the user's head position and achieve a fast update rate. We expect the new tracker to enhance greatly the usefulness of head-mounted display systems.

We will also be assisted in our goal to develop this full-scale tracking system by the award of a contract from DARPA/ISTO for the period 9/5/90-9/4/93 on "Advanced Technology for Portable Personal Visualization." In this project we have proposed to investigate technical problems related to head-mounted display interactive graphics systems, including real-time methods for head and hand tracking and optical designs for the display itself that allow the computer-generated image to be superimposed on the user's view of his/her surroundings.

Protocol Analysis Tools

Support from ONR for the past year consisted of two graduate student research assistants and $10,000 in video equipment. Since TextLab is a large research program that includes a number of activities, this description will cover only those activities supported directly by ONR resources.

The two research assistants worked on systems to support management, analysis, and interpretation of machine-recorded protocols of human users' interaction with one particular computer system—the Writing Environment.

One student developed a prototype system to manage the hundreds, perhaps thousands, of protocols our methodology makes possible for researchers to collect and analyze. The system provides a tree representation of individual session protocols organized according to descriptive attributes associated with each. Using this tool, the researcher can select and organize for automated analyses protocols for particular groups of users (e.g., experts vs. novices), falling within a particular period of time, evaluated as superior or inferior, etc. Part of this work included development of a formal mathematical definition of a sort/select tree and analytic operation that can properly be applied to different data sets under varying conditions. This work has general implications beyond protocol studies for matching data with appropriate computing processes.

The second student developed a prototype system that runs simultaneously on multiple workstations to replay a user's session, based on the recorded protocol for that session, and coordinate it with additional sources of analytic and descriptive information, e.g., a parse of the protocol, comments by the subject, comments by the researcher, etc.

The video equipment was used to begin exploratory work in a new collaboratory project that began in TextLab September 1, 1990. This equipment—consisting of several video cameras and microphones, a video disk player, and a video mixer—has allowed us to get an early start in technology that is new for our research group.

SoftLab

SoftLab Software Systems Laboratory is an organization that provides the UNC Computer Science Department with software systems and manufacturing support services analogous to those typically found in industry. As such, SoftLab serves as a software development resource for the Department and as an agent of technology transfer to other universities and to industry.

In particular, SoftLab facilitates rapid prototyping of novel architectures by developing drivers, compilers, interfaces, and other systems software; by importing and integrating commercial software development tools; and by supporting an object-oriented programming environment. In addition, SoftLab's primary objectives are evolving to include support of research in distributed systems.

Finally, SoftLab pursues an educational mission with emphasis in the areas of software engineering and development of software tools for laboratory use in computer architecture and operating system courses.

Intel i860 microcode preprocessor. Pixel-Planes is a family of high-performance, 3-D raster display systems that harness the power of custom VLSI circuits. In 1989, SoftLab, working in conjunction with the Pixel-Planes research team, developed a microcode preprocessor for the Weitek XL chip, on which the Pixel-Planes 4 machine is based. This preprocessor automated register allocation and performed pipeline analysis, thus facilitating the manual optimization of Weitek assembly code, necessary for performance reasons. In summer of 1989, Pixel-Planes decided to switch from its Weitek-based architecture to an Intel i860-based architecture. Since then, SoftLab has developed a microcode preprocessor for the Intel i860 with capabilities analogous to those previously provided for Pixel-Planes 4. A working prototype now exists.

UNIX Phone System Link and Applications. Voice and data traffic in the Computer Science Department at UNC is switched by the Department's Intecom IBX digital PBX. Last year, a new capability was added to the switch's feature set that allows switch functions such as phone calls and networking operations to be monitored and partially controlled from an application host machine. As provided by Intecom, this capability worked only with VAX and IBM PC host machines.

SoftLab personnel developed UNIX drivers to allow communication between the switch and a network of UNIX workstations as well.

SoftLab personnel also designed and developed application programs based on the link described above. These programs include a voice-mail system that encodes, stores, and manipulates voice messages as UNIX files; and a power-dialer system that allows phone calls and features to be initiated from UNIX workstations.

Blitzen board design tool interface. Blitzen is the name of a project to build a massively parallel SIMD processor based on a custom chip design. The hardware design for the Blitzen prototype board is being done using various commercial design tools, originating from different vendors with incompatible interfaces. As a first step toward providing a more integrated and automated design system, SoftLab has written programs that automatically perform conversions between the output format of one tool and the input format of the next tool used in the design sequence.

Hypertext database of department software tools. SoftLab has designed and implemented a hypertext-style database that catalogs information about all software development tools available in the Department.

SECTION 3: Lists of Publications, Presentations, Reports, Awards/Honors during this reporting period

Principal Investigators:	Frederick P. Brooks, Jr. Donald F. Stanat Stephen F. Weiss
PI Institution:	The University of North Carolina at Chapel Hill Department of Computer Science
PI Phone Numbers:	919/962-1931 919/962-1788 919/962-1888
PI E-mail Addresses:	brooks@cs.unc.edu stanat@cs.unc.edu weiss@cs.unc.edu
Contract Title:	The Infrastructure of Command Information Systems
Contract Number:	N00014-86-K-0680
Reporting Period:	15 September 1989 through 14 September 1990

With * ..... ONR-supported.
Without * ..... Related to the project.

A. Refereed papers (to appear)

Guan, Sheng-Uei, Hussein Abdel-Wahab, and Peter Calingaert. "Jointly-Owned Objects for Collaboration: Operating System Support and Protection Model," to appear in *The Journal of Systems and Software*, 1991.

B. Refereed papers published

*Airey, John M., John H. Rohlf, and Frederick P. Brooks, Jr. "Towards Image Realism with Interactive Update Rates in Complex Virtual Building Environments," Best Paper Award: *Computer Graphics: Proc. 1990 Symposium on Interactive 3D Graphics*, 24(2), Snowbird, UT, 25-28 March 1990. (Also TR90-001.)

*Brooks, Frederick P. Jr., Ming Ouh-Young, James J. Batter, and P. Jerome Kilpatrick. "Project GROPE—Haptic Displays for Scientific Visualization," *Computer Graphics: Proc. SIGGRAPH '90*, 24(4), Dallas, TX, 6-10 Aug. 1990, 177-185.

*Chung, J. C., M. R. Harris, F. P. Brooks, Jr., H. Fuchs, M. T. Kelley, J. W. Hughes, M. Ouh-young, C. Cheung, R. L. Holloway, and M. Pique. "Exploring Virtual Worlds with Head-Mounted Displays," reprinted in *Proc. Ars Electronica 1990*, vol. 2: Virtuelle Welten, Linz, Austria, Sept. 1990, 138-146.

*Ellsworth, David, Howard Good, and Brice Tebbs. "Distributing Display Lists on a Multicomputer," *Computer Graphics: Proc. 1990 Symposium on Interactive 3D Graphics*, 24(2), Snowbird, UT, 25-28 March 1990, 147-154. (Also TR90-003.)

Fuchs, Henry. "Systems for Display of Three-Dimensional Medical Image Data," *3D Imaging in Medicine: Algorithms, Systems, Applications: Proc. NATO Advanced Research Workshop*, Travemünde, Germany, 25-29 June 1990, K. H. Hoëhne, H. Fuchs, and S. M. Pizer, eds., Springer-Verlag, 315-331.

*Levoy, Marc and Ross Whitaker "Gaze-directed Volume Rendering," *Computer Graphics: Proc. 1990 Symposium on Interactive 3D Graphics*, Snowbird, UT, 25-29 March 1990.

Mills, Peter H. and Henry Fuchs. "3D Ultrasound Display Using Optical Tracking," *Proc. 1st Conference on Visualization in Biomedical Computing*, 22-25 May 1990, Atlanta, Georgia, 490-497. (This paper concerns a different type of tracking device than the one being developed under this project.)

*Minsky, Margaret, Ming Ouh-young, Oliver Steele, Frederick P. Brooks, Jr., and Max Behensky. "Feeling and Seeing Issues in Force Display," *Computer Graphics: Proc. 1990 Symposium on Interactive 3D Graphics*, Snowbird, UT, 25-29 March 1990.

Ouh-young, Ming, M. Pique, M. Harris, J. Hughes, N. Srinivasan, and F. P. Brooks, Jr. "Force Display in Molecular Docking," Abstract in *Journal of Molecular Graphics*, 6(4), Dec. 1988, 224 (Ph.D. dissertation, May 1990).

*Robinett, Warren. "Head-Mounted Display Project Summary," *Proc. Ars Electronica 1990*, vol. 2: Virtuelle Welten, Linz, Austria, Sept. 1990, 119-122.

*Wang, Jih-Fang, Ronald Azuma, Gary Bishop, Vernon Chi, John Eyles, and Henry Fuchs. "Tracking a Head-mounted Display in a Room-sized Environment with Head-mounted Cameras." *Aerospace Sensing: Proc. SPIE 1990 Technical Symposium on Optical Engineering and Photonics*, 1290, Orlando, FL, 16-20 April 1990.

*Wang, Jih-Fang, Vernon Chi, and Henry Fuchs. "A Real-time Optical 3D Tracker for Head-Mounted Display Systems." *Computer Graphics: Proc. 1990 Symposium on Interactive 3D Graphics*, 24(2), Snowbird, UT, March 1990, 205-216.

*Ward, Mark. "Calibrating Lateral Effect Photodiodes for Use as Measuring Devices in Manufacturing," *Proc. Modern Manufacturing 1990 Conference*, 12-13 Sept. 1990, North Carolina State University.

Weiss, S. "Hypertext Grows Up," A Panel Discussion at the *13th International Conference on Research and Development in Information Retrieval*, Universite Libre de Bruxelles, Brussels, Belgium, 5-7 Sept. 1990.

C. Refereed papers submitted (awaiting acceptance)

Chi, Vernon L. "Salphasic Distribution of Clock Signals for Synchronous Systems," submitted to *Proc. IEEE*, June 1990. (Also TR90-026.)

*Robinett, Warren. "Practical Problems in Achieving Orthostereoscopy on a Head-Mounted Display with Computer-Generated Imagery," submitted to *SPIE Conference on Electronic Imaging*, 24 Feb. - 1 March 1991, San Jose, CA.

Trinker, Arie and Heng Chu. "MAST 860: A Microprogramming Analysis and Support Tool for Pipelined Architectures," submitted to *Proc. 23rd Annual Symposium on Microprogramming and Microarchitecture*, 27-29 Nov. 1990.

D. Unrefereed reports and articles

*Airey, John M. "Increasing Update Rates in the Building Walkthrough System with Automatic Model-Space Subdivision and Potentially Visible Set Calculations," TR90-027, Department of Computer Science, UNC at Chapel Hill, July 1990 (Ph.D. dissertation).

Calingaert, Peter, Hussein Abdel-Wahab, Gregory Bollella, Sheng-Uei Guan, F. Donelson Smith, and John B. Smith. "Synchronous and Asynchronous Collaboration: A Program of Research," TR90-024, Department of Computer Science, UNC at Chapel Hill, May 1990.

*Davis, Mark C. "A Computer for Low Context-Switch Time," TR90-012, Department of Computer Science, UNC at Chapel Hill, March 1990 (Ph.D. dissertation).

Fuchs, Henry, John Poulton, Andrei State, Roger Brusq, Edward N. Hill, Jr. "An Architecture for Advanced Avionics Displays," final report on contract number F33615-88-C-1848 to the U. S. Air Force Cockpit Integration Directorate, Wright-Patterson Air Force Base, Dayton, OH, May 1990.

Lansman, M., J. B. Smith, I. Weber. "Using Computer-Generated Protocols to Study Writers' Planning Strategies," TR90-033, Department of Computer Science, UNC at Chapel Hill, Sept. 1990.

State, Andrei. "Displaying Alphanumeric Characters on Pixel-Planes 5," TR89-049, Department of Computer Science, UNC at Chapel Hill, Dec. 1989.

*Tuck, Russ. "Porta-SIMD: An Optimally Portable SIMD Programming Language," TR90-021, Department of Computer Science, UNC at Chapel Hill, May 1990; Duke technical report CS-1990-12, Department of Computer Science, Duke, May 1990 (Ph.D. dissertation).

*Wang, Jih-Fang. "A Real-time Optical 6D Tracker for Head-mounted Display Systems," TR90-011, Department of Computer Science, UNC at Chapel Hill, March 1990 (Ph.D. dissertation).

Yen-Ping, S. "MoDE: A UIMS for Smalltalk," TR90-017, Department of Computer Science, UNC at Chapel Hill, April 1990.

Yen-Ping, S. "An Object-Oriented UIMS for Rapid Prototyping," TR90-016, Department of Computer Science, UNC at Chapel Hill, April 1990.

SoftLab (SL) Reports

Chu, Heng and Airie Trinker. "MAST860—A Microprogramming Analysis and Support Tool for Pipelined Architectures," SoftLab TR#SL04, June 1990.

Coggins, James. "The COOL Library: User's Manual, Version 1.0," SoftLab TR #C002, Department of Computer Science, UNC at Chapel Hill, Oct. 1989, 83 pp.

Coggins, James. "The COOL Library: Supplementary Documents, Version 1.0," SoftLab TR #C001, Department of Computer Science, UNC at Chapel Hill, Oct. 1989, 79 pp.

Trinker, Airie. "WE Installation Guide," SoftLab TR#WE01, 1990.

Trinker, Airie. "MAST860 User's Guide—A Microprogramming Analysis and Support Tool for Intel i860," SoftLab TR#SL05, June 1990.

SoftLab Internal Documents, available upon request:

Dunn, Jeff. "Users' Guide—Sitterson Hall Phone Enhancements," SoftLab TR#SL01, 6 May 1990.

Guin, Beth. "Administration Procedures—Sitterson Hall Phone Enhancements," SoftLab TR#SL03, 6 May 1990.

Lutz, Dave and Jonathen Whaley. "Implementation Design—Sitterson Hall Phone Enhancements," SoftLab TR#SL02, 6 May 1990.

Videotapes:

*Airey, John, John Rohlf, and Penny Rheingans. "The Virtual Lobby," *SIGGRAPH '89* Video Night, Boston, MA (sent to Ralph Wachter, Oct. 1989).

*Brooks, Frederick P. Jr. Interview videotaped and excerpted, with illustrations from Walkthrough demonstrations, in the SIGGRAPH Video Review, vol. 60, Aug. 1990 (available from ACM under the title "HDTV and the Quest for Virtual Reality," *ACM SIGGRAPH Video Review*, Special Issue 60, 1990).

*Rheingans, Penny and Brice Tebbs. "A Tool for Dynamic Explorations of Color Mappings," videotape presented at *1990 Symposium on Interactive 3D Graphics*, Snowbird, UT, 25-28 March 1990 (sent to Ralph Wachter, 12 Apr 1990).

E. Books (or parts thereof) published

Molnar, Steven and Henry Fuchs. "Advanced Raster Graphics Architecture," chapter 18 in *Computer Graphics: Principles and Practice*, 2nd ed., J. Foley, A. van Dam, S. Feiner, and J. Hughes, Reading, MA: Addison-Wesley, 1990, 855-922. (Also TR90-003).

F. Invited presentations

Pixel-Planes

John Eyles, "Virtual-Environment Research at UNC," AUSGRAPH '90 Conference, Melbourne, Australia, 12-14 Sept. 1990.

John Eyles, "Real-Time Graphics (tutorial)," AUSGRAPH '90 Conference, Melbourne, Australia, 12-14 Sept. 1990.

Henry Fuchs, "Interactive Steering of Supercomputer Calculations," Frontiers of Supercomputing II Conference, Los Alamos, NM, 19-23 Aug. 1990.

Henry Fuchs, "High-Speed Systems for Visualization," NIH / NCI Workshop on 3D Display and Analysis for Cancer Treatment Planning, Washington, DC, 17-18 July 1990.**

Henry Fuchs, "Systems for Display of Three-Dimensional Medical Image Data," NATO Advanced Research Workshop on 3D Imaging in Medicine, Travemünde, Germany, 25-29 June 1990.**

Henry Fuchs, "Interactive Displays for the 21st Century—Beyond the Desktop Metaphor," talk given at a departmental seminar while serving as a visiting professor, Swiss Federal Institute of Technology, Lausanne, Switzerland, 31 May 1990.**

Henry Fuchs, "High-Speed Systems for Biomedical Visualization," 1st Conference on Visualization in Biomedical Computing, Atlanta, GA, 22 May 1990.**

Henry Fuchs, "High-Performance Graphics on Multicomputers," Intel-DARPA Research Community Forum, Hillsboro, OR, 28 Feb. 1990.**

Henry Fuchs, "Interactive Displays for the 21st Century—Beyond the Desktop Metaphor," National Science Foundation, Computer and Information Science and Engineering, Research Seminar, Washington, DC, 18 Jan. 1990.

***Head-Mounted Display and Tracker were also described*

Head-Mounted Display and Tracker

Henry Fuchs, "Portable Personal Visualization Systems," DARPA Workshop on "Technologies for Personal Communications Systems," Washington, DC, 18 Jan. 1990.

Henry Fuchs, "Interactive Displays for the 21st Century—Beyond the Desktop Metaphor," National Science Foundation, Computer and Information Science and Engineering Research Seminar, Washington, DC, 18 Jan. 1990.

Warren Robinett, "Synthetic Experience," Ars Electronica Conference, Linz, Austria, 10 Sept. 1990.

Warren Robinett, "Synthetic Experience," Panel at SIGGRAPH'90 on Hip, Hype, and Hope: The Three Faces of Virtual Reality, Dallas, TX, 9 Aug. 1990.

G. Contributed presentations

Pixel-Planes

David Ellsworth, "Parallel Architectures and Algorithms for Real-Time Synthesis of High-Quality Images Using Deferred Shading," Workshop on Algorithms and Parallel VLSI Architectures," Pont-a-Mousson, France, 12 June 1990.

David Ellsworth, "Distributing Display Lists on a Multicomputer," 1990 Symposium on Interactive 3D Graphics, Snowbird, UT, 27 March 1990.

Walkthrough

John Airey, "Towards Image Realism with Interactive Update Rates," 1990 Symposium on Interactive 3D Graphics, Snowbird, UT, 25-29 March 1990.

Tracker

Ron Azuma, "Tracking a head-mounted display in a room-sized environment with head-mounted cameras," Head-Mounted Displays II: SPIE's 1990 Technical Symposium on Optical Engineering and Photonics in Aerospace Sensing, Orlando, FL, April 1990.

Jih-Fang Wang, "A Real-time Optical 3D Tracker for Head-Mounted Display Systems," 1990 Symposium on Interactive 3D Graphics, Snowbird, UT, 25-28 March 1990.

Mark Ward, "Calibrating Lateral Effect Photo-diodes for Manufacturing Application," Modern Manufacturing 1990 Conference, N.C. State University, Raleigh, NC, 12-13 Sept. 1990.

Protocol Analysis Tools

John B. Smith, "Cognitive Aspects of Hypertext Systems," Hypertext '89, Pittsburgh, PA, Nov. 1989.

SoftLab

Susanna Schwab, "SoftLab: A Paradigm for Software Systems Development and Capitalization in the University," 1990 NSF CER/II Meeting, Atlanta, GA, 11-12 June 1990.

Other

Marc Levoy, "Gaze-directed Volume Rendering," 1990 Symposium on Interactive 3D Graphics, Snowbird, UT, 25-29 March 1990.

Margaret Minsky (and Ming Ouh-young), "Feeling and Seeing: Issues in Force Display," 1990 Symposium on Interactive 3D Graphics, Snowbird, UT, 25-29 March 1990.

Penny Rheingans and Brice Tebbs, "A Tool for Dynamic Explorations of Color Mappings," (Demonstration), 1990 Symposium on Interactive 3D Graphics, Snowbird, UT, 25-29 March 1990.

H. Honors

- **Henry Fuchs** was one of two keynote speakers at the 1st Conference on Visualization in Biomedical Computing, Atlanta, Georgia, 22-25 May 1990.

- **Henry Fuchs** served on the Papers Committee for the SIGGRAPH '90 conference (held in Dallas, August 1990), the 1990 Symposium on Interactive 3D Graphics (held at Snowbird, Utah, March 1990), the Technical Committee of the 1st Conference on Visualization in Biomedical Computing (held in Atlanta, May 1990), and the Program Committee of the 6th MIT Conference on Advanced Research in VLSI (held in Cambridge, Mass., April 1990). He also served as one of three co-directors of the NATO advanced research workshop on 3D Imaging in Medicine, held in Travemüende, Germany, 25-29 June 1990.

- Several graduate students working on the Pixel-Planes project have received continuation of their fellowships from outside organizations for the the 1990-91 academic year. They are:

David Ellsworth	ONR fellowship
Steve Molnar	IBM Manufacturing Research Fellowship
Greg Turk	IBM Fellowship

- **Ed Biagioni** was named one of two ONR fellows for the 1990-91 academic year. (Also see Ellsworth, above). He is working on massively parallel programming.

- **Warren Robinett** served as a member of a panel at SIGGRAPH '90 in Dallas, TX: "Hip, Hype, and Hope: the Three Faces of Virtual Reality."

I. Prizes or awards

- The paper listed above, "Towards Image Realism with Interactive Update Rates in Complex Virtual Building Environments," by **Airey, Rohlf, and Brooks**, received the ***Best Paper Award*** at the 1990 Symposium on Interactive 3D Graphics at Snowbird, UT, 26-28 March 1990.

J. Promotions obtained / New staff

- **Mark Ward**, an electro-mechanical engineer, was hired and began working on the Tracker project in March 1990.

- Optical engineer **Jannick Rolland** joined our team in June 1990, and has begun work on the optical design of a new see-through head-mounted display.

K. Educational productivity

- **John Airey**, who worked on the Walkthrough project for four years, graduated with the Ph.D. degree in August 1990. See technical report listed in this section.

- **Mark Davis**, ONR fellow since FY87-88, graduated with the Ph.D. degree in May 1990. Mark has worked on the CLOCS project since Spring 1987. See technical report listed in this section.

- **Russ Tuck**, A Duke University graduate student who worked on the Pixel-Planes project for two years, graduated with the Ph.D. degree in May 1990. See technical report listed in this section.

- **Jih-Fang Wang**, who worked on the Tracker project for two years, completed his dissertation on the optical tracker, and graduated with the Ph.D. degree in May 1990. See technical report listed in this section.

- **Ron Azuma**, a graduate student who is beginning his second year on the Tracker project, passed his Ph.D. written exams and is now a Ph.D. candidate. He received his M.S. degree in May 1990.

- **Howard Good**, who has been working on the Pixel-Planes Project for three years, graduated with the M.S. degree in May 1990. He is currently working toward the Ph.D. degree.

- **Richard Hawkes,** who has worked on the Protocol Analysis Tools Project, graduated with the M.S. degree in May 1990.
- **Michael T. Kelley**, who had worked on the Head-Mounted Display Project for two years, graduated with the M.S. degree in December 1989.
- **Dan Palmer**, who worked on the Head-Mounted Display Project for about two years, graduated with the M.S. degree in May 1990.
- **John Menges**, who worked on the Network Tools project, has completed his Master's Thesis: "Providing Common Access Mechanisms for Dissimilar Network Interconnection Nodes." Technical Report number to be assigned; copies (and abstract) will be distributed as soon as it is available.
- **Johnny Rhoades**, who has worked on the Pixel-Planes Project for three years, graduated with the M.S. degree in May 1990. He is currently working toward the Ph.D. degree.
- **Carl Mueller, Marc Olano,** and **Andrei State** have joined the Pixel-Planes project as graduate research assistants.
- **Drew Davidson and Erik Erikson** are new graduate students who have joined the Head-Mounted Display project as research assistants.
- **Phil Jacobsen** joined the Tracker project as a graduate research assistant in August 1990.

SECTION 4: Transitions and DoD Interactions during this reporting period *(by project)*

Principal Investigators:	Frederick P. Brooks, Jr. Donald F. Stanat Stephen F. Weiss
PI Institution:	The University of North Carolina at Chapel Hill Department of Computer Science
PI Phone Numbers:	919/962-1931 919/962-1788 919/962-1888
PI E-mail Addresses:	brooks@cs.unc.edu stanat@cs.unc.edu weiss@cs.unc.edu

Contract Title:	The Infrastructure of Command Information Systems
Contract Number:	N00014-86-K-0680
Reporting Period:	15 September 1989 through 14 September 1990

A. Transitions of Results

Pixel-Planes

Industry. The IVEX Corporation of Norcross, Georgia (a suburb of Atlanta), has recently purchased limited, exclusive license of the two patents for Pixel-Planes technology. IVEX manufactures flight-simulator systems currently operational for pilot training in the U.S. and in several foreign countries. The patents that have been licensed are:

1) Fuchs, Henry, "Graphics Display System Using Logic-Enhanced Pixel Memory Cells," U.S. Patent #4,590,465, May 20, 1986 (Application #349,818, February 18, 1982).
2) Fuchs, Henry, and John Poulton, "VLSI Graphic Display Image Buffer Using Logic-Enhanced Pixel Memory Cells," U.S. Patent #4,783,649, November 1988 (Application #408,045, August 13, 1982).

Other. Many people have visited our *Graphics and Imaging Laboratory* during the past year and have received demonstrations of both Pixel-Planes 4 and Pixel-Planes 5. Approximate numbers of visitors are: 69 from universities, 105 computer science professionals working in industry, 6 from the military, 11 from government agencies, and 2 professional journalists. (These figures are taken from a log kept by the person who sets up most of the demonstrations in the Graphics and Imaging Laboratory. Many demos are done on a more casual basis, however, and these are never reported to the log. Consequently, the actual number of people who have seen the Pixel-Planes systems during the past year is higher than reported here.)

Walkthrough

University. We began a collaboration with the Laboratory for Computer Graphics at Cornell University, and as part of that imported their dataset for the model of their new Cornell Theory Center (which now houses the laboratory) and brought it up on our Walkthrough system, showing it at a major site visit in April.

Industry. We provided our software and our models to Silicon Graphics. They are actively using our Orange Church Fellowship Hall model in all their demonstrations, including those at SIGGRAPH '90, and they make some use of our Sitterson Hall and Brooks House models. They ported our Walkthrough software to the Silicon Graphics 4D80 and demonstrated it at the 1990 Symposium on Interactive 3D Graphics at Snowbird.

Head-Mounted Display

NASA Ames. Warren Robinett has had several discussions with Jim Larimer of NASA Ames Research Center about a possible collaborative effort.

Other. We have also had public contact through demonstrations in the Graphics and Imaging Laboratory of our research on head-mounted displays. During the past year we have given demos to approximately 148 faculty and students from universities and high schools, 82 computer scientists and other scientists and engineers working in industry, four persons from government agencies, seven persons from various U.S. military agencies, and six professional journalists. The visitors from the military sector include: two from the Navy Research Lab on 4 June 1990, Phil Amburn from Wright-Patterson Air Force Base, and four persons from the Army Research Institute (Dr. Owen Jacobs, Dr. Ed Johnson, and two others) on 13 June 1990 (see DoD Interactions, below).

Tracker

University. As mentioned in Section 2, we are collaborating with Dr. Robert J. Hocken, of the University of North Carolina at Charlotte, in the area of camera calibration. We hope to obtain enough data to construct a calibration table for our system.

Other. In addition, we have had significant general contact with the public. We have hosted many visitors to our laboratory during the past year and have demonstrated the optical tracker to a wide variety of people. Since September 1989, we have shown the tracker to two visitors from the Naval Research Lab, four from the Army Research Institute, and one from Wright Patterson Air Force Base. Other groups of visitors who received demonstrations of the tracker include: 56 faculty and students from five universities, 33 professionals working in the computer science industry, and five journalists (see DoD Interactions, below).

Protocol Analysis Tools/Collaboratory

We have demonstrated the tools being developed with support from ONR to numerous visitors to our TextLab. These include groups from the Army Research Institute, IBM, Fujitsu, and several Universities including Carnegie-Mellon, University of Colorado, and the University of Michigan.

SoftLab

SoftLab serves as an agent of technology transfer for research software developed within the Department. SoftLab's software packaging and distribution methodology is called "productizing" and includes steps such as reviewing and revision documentation, adding configuration control, versioning, preparing for remote installation, porting, licensing, and assembling distribution.

Software productized this year:

WE (Writing Environment) is a hypertext, graphic-based system, written in Smalltalk, and designed to help professionals write more effectively and efficiently.

Volume Rendering Data Sets, Vol I and II. The Volume Rendering data sets include medical and other image data sets as shown at the recent Volume Visualization Conference. This is SoftLab's first "visual data" product and represents an extension of the productizing process to include visual data sets in addition to more conventional software products.

Product Distributions/Inquiries, October 1989—August 1990:

PRODUCT	ACADEMIC Outstanding Inquiries:	ACADEMIC Purchases:	COMMERCIAL Outstanding Inquiries:	COMMERCIAL Purchases
Chapel Hill Volume Rendering Test Dataset, Volume I	10	8	4	6
Chapel Hill Volume Rendering Test Dataset, Volume II	7	5	3	3

Research Team plans a Volume III to be released after this year's Visualization Conference.

COOL, 1.0	19	3	36	0

IDL Toolkit
Now distributed by UniPress Software, Inc.

MAXL, 2.0
Still under technical productization—bug to be fixed.

RSpace, 1.3	5	4	4	0

Total number of purchases also reflects customers that had beta or 1.1 versions upgraded to Version 1.3 in August, 1989. Customers who purchased Version 1.3 prior to March, 1989 were sent documentation packages only and are not included in these figures. The recent release of an article written by the original developers is currently generating new interest and more inquiries. Plans for new development have recently been discussed for enhancements that have been made. Numbers in parentheses indicate purchases made prior to March 1989.

B. DoD Interactions

Pixel-Planes, Walkthrough, Head-Mounted Display, Tracker

China Lake. Warren Robinett has contacted Bob Westbrook of the Naval Weapons Center to find out if the Navy makes a lightweight inertial tracker that our Department can purchase. He also plans a trip to China Lake this fall.

C^2 Symposium. Ralph Mason attended the Symposium on Command and Control Research from 12-14 June 1990. A Trip Report has been appended to this report.

ARI Visitors. On 13 June 1990, Owen Jacobs , Ed Johnson, and two other guests saw the Tracker, Head-Mounted Display, and Walkthrough demos, and visited our Microelectronic Systems Lab (PxPl and Tracker).

Trip to ONR/NRL. On 14 May 1990, David Richardson of Duke University (Visiting Assoc. Professor in our Dept during FY89-90) visited with Richard Miller of ONR, and Richard Gilardi of NRL. A Trip Report has been appended to this report.

ONR Visitor. Ralph F. Wachter of ONR visited our Graphics Lab during 19-20 April 1990; a Visit Report has been appended to this report.

NRL Visitors. On 8-9 November 1989, Daniel Steiger and Lawrence Rosenblum of the Marine Systems Branch, NRL, visited our Graphics Lab. Demos: PxPl, Tracker, Head-Mounted Display, and Volume Visualization. Substantial technical and general discussions were held. A Visit Report has been appended to this report.

Air Force Visitors. On 16-17 October 1989, Jerry Myers and Jerry Covert of Wright-Patterson Air Force Base visited our Graphics Lab. Demos: PxPl, Head-Mounted Display, Wallkthrough, and Avionics. Phil Amburn from Wright-Patterson Air Force Base visited on 5 April 1990: Demos: Head-Mounted Display.

Visiting Scientists to Chapel Hill. During the August-September 1989 ONR site visit at UNC-CH, Fred Brooks invited ONR/NRL scientists (or their representatives) to spend a week or more here at UNC-CH.

Head-Mounted Display

NTC. David Fowlkes of the Navy Training Center, Orlando, Florida, has been discussing with Warren Robinett the possibility of using our head-mounted display system in his training programs.

NRL Visitors. Russ Eberhart and Doug Stetson from NRL saw HMD demos on 4 June 1990.
(See above)

Protocol Analysis Tools

For this project, principally those visits described under Section 4-A.

SoftLab

We recently acquired Jim Purtillo's version of NewYacc, courtesy of Ralph Wachter. SoftLab has set up a public area where software privately acquired but of general interest can be placed for access by others. NewYacc was installed here and publicized by a graduate student volunteer.

All

On 25-26 September, the ONR site visit team heard technical presentations and saw demonstrations on Head-Mounted Display, Tracker, Pixel-Planes 5, Walkthrough, Protocol Analysis Tools/Collaboratory, and Data-Parallel Execution (see Appendix for complete agenda). Visitors included:

Mr. Peter F. Brown, Mechanical Engineer, NIST
Dr. Susan Chipman, Program Manager for Cognitive Science, ONR
Dr. Christoph M. Hoffmann, Professor, Computer Science, Purdue
Dr. William E. Isler, Asst. Dean for Research, College of Engineering, NC State University
Dr. Richard Miller, Chief Scientist, Mechanics Division, ONR
Dr. Ralph F. Wachter, Scientific Officer, Computer Science Division, ONR
Mr. Stanley H. Wilson, Consultant, Information Technology Division, NRL

SECTION 5: Software and Hardware Prototypes during this reporting period

Principal Investigators:	Frederick P. Brooks, Jr. Donald F. Stanat Stephen F. Weiss
PI Institution:	The University of North Carolina at Chapel Hill Department of Computer Science
PI Phone Numbers:	919/962-1931 919/962-1788 919/962-1888
PI E-mail Addresses:	brooks@cs.unc.edu stanat@cs.unc.edu weiss@cs.unc.edu
Contract Title:	The Infrastructure of Command Information Systems
Contract Number:	N00014-86-K-0680
Reporting Period:	15 September 1989 through 14 September 1990

Pixel-Planes

See Section 2.

Walkthrough

We have built no hardware.

Our software system prototype was first built on and for UNC's Pixel-Planes 4 machine. As indicated under Transitions, 4A above, we furnished it to Silicon Graphics, who have ported it to their equipment. They will not sell it, but will use it for demos. We will provide it to their users who ask for it. No commercial sales are planned.

Protocol Analysis Tools

- A prototype environment for managing large numbers of machine-recorded protocols, described in Section 2, above.
- A prototype system to coordinate multiple protocol streams, as described in Section 2, above.

SoftLab

MAST860, the microcode preprocessor for the Intel i860 chip described in Section 3 above, was recently completed in prototype form and is being used and evaluated by the Pixel-Planes 5 research team. We have also been asked for a review copy of this preprocessor by Intel. No commercialization has occurred to date but eventual productization of this software is planned pending the availability of staff. Commercialization is also a possibility.

Software for the UNIX phone switch driver and the associated phone system enhancement application programs is being made available to Intecom Inc, the manufacturer of our phone switch, as per previous agreement. At present, we do not plan to commercialize this software ourselves.

ANNUAL REPORT

15 September 1988 through 14 September 1989

Y3

The Infrastructure of Command Information Systems

Submitted to

Office of Naval Research
Arlington, VA 22217-5000

Submitted by

Department of Computer Science
The University of North Carolina at Chapel Hill
Sitterson Hall
Chapel Hill, NC 27599-3175

Principal Investigators:

Frederick P. Brooks, Jr.
Donald F. Stanat
Stephen F. Weiss

NOVEMBER 1989

Contract No. N00014-86-K-0680

TABLE OF CONTENTS

1 INTRODUCTION 1

1.1 Command Information Systems 1
1.2 Overall scientific goals during this reporting period 1
1.3 Overall plans for FY89-90 1
1.4 Meetings 2

2 ORGANIZATION OF REPORT 2

3 RESEARCH PROJECTS 2

3.1 Communications 2
3.1.1 Integrated Network Management System 2
3.1.2 Workshops, Symposia 3

3.2 Processing Technologies 3
3.2.1 Curved Surfaces and Enhanced Parallelism in Pixel-Planes 3
3.2.2 Compiling Data-Parallel Languages for SIMD Execution 7
3.2.3 CLOCS—Computer for Low Context Switch Time 7

3.3 Database Technologies 8
3.3.1 Temporal Database—Final Report 8
3.3.2 Full-Text Retrieval: An Expert System for Searching in Full Text 9

3.4 Display and Interaction 10
3.4.1 Head-Mounted Display 10
3.4.2 A Real-time 3D Position Tracker for Head-Mounted Display Systems 11
3.4.3 Walkthrough 12
3.4.4 Protocol Analysis Tools 13

4 MANAGEMENT, PERSONNEL, TRAVEL, EQUIPMENT 13

4.1 Management 13
4.1.1 ONR-URI Executive Committee 13

4.2 Personnel 14
4.2.1 Director of SoftLab 13
4.2.2 Technical Liaison 14
4.2.3 Fellows 14
4.2.4 ONR Participants 14

4.3 Travel 14
4.3.1 Interaction with the Navy 14

4.4 Equipment Report 15

5 DEPARTMENT INFRASTRUCTURE 15

5.1 SoftLab Software Systems Laboratory 15
5.2 Computer Services 17
5.3 Communications 18

APPENDICES

I.....Project Narratives, Copies of Foils

II.....Comprehensive Bibliography

III.....Participants

IV.....Travel/Visit Report

V.....Equipment Report

VI.....Current Contracts, Grants, Gifts

VII.....2nd Annual Triangle Telecommunications Symposium

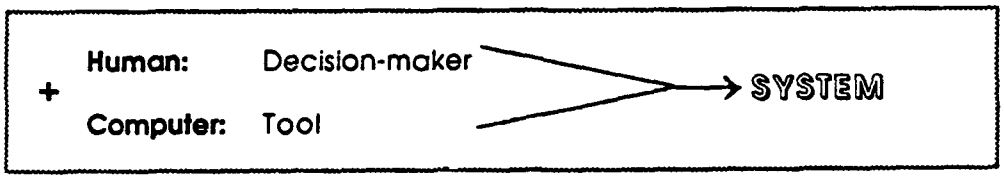
VIII.....ONR Site Visit

IX.....Miscellaneous Department News

1 INTRODUCTION

1.1 Command Information Systems

Year three of the five-year ONR contract has proven to be very successful as we continue our coordinated research efforts aimed at investigating fundamental issues in technologies associated with Command Information Systems (see Figure 1), systems in which the **human** decision-maker plays a crucial role:



Research at The University of North Carolina at Chapel Hill in real-time interactive graphics has and will continue to provide the basis for much of the work for the ONR contract. With ONR support, the three flagship projects of the Department have progressed substantially:

- Head-Mounted Display and Tracker
- Walkthrough
- Curved Surfaces and Enhanced Parallelism in Pixel-Planes

Also making good progress are investigators supporting research that concentrates on providing suitable databases and retrieval systems for decision support, and those working in the area of parallel computing and languages:

- Temporal Database
- Full-text Retrieval System
- Expression Languages (currently funded under a separate ONR contract)
- CLOCS—Computer for Low-Context Switch Time

as well as in the area of communications:

- Integrated Network Management System

1.2 Overall scientific goals during this reporting period

To investigate fundamental issues in technologies of Command Information Systems, particularly:

- human-computer interfaces
- text and temporal databases
- computer languages and architectures

Objectives:

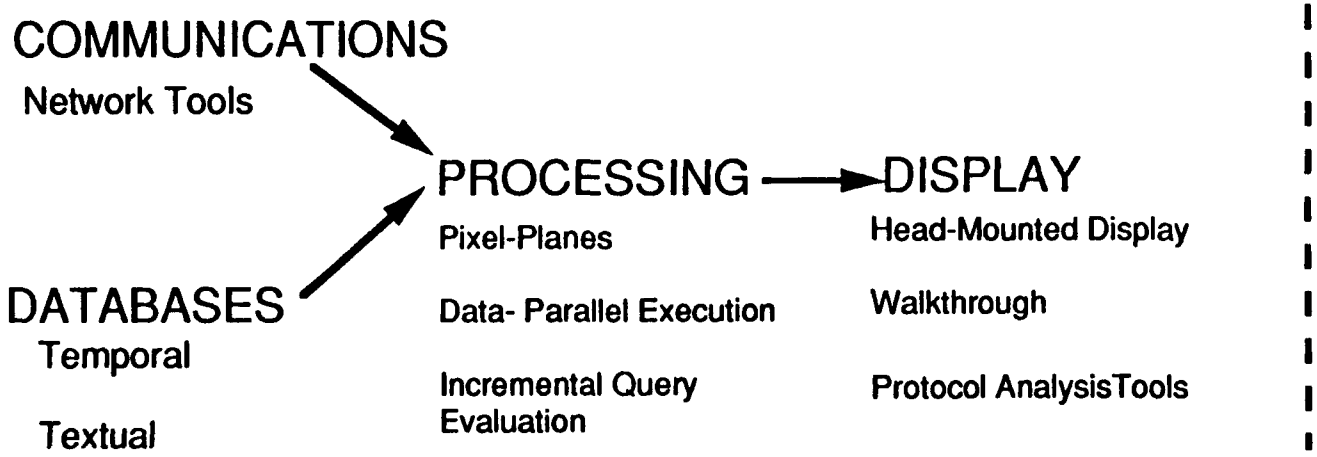
- Interactive storage, processing, and display of information for the support of decision-making.
- Training

1.3 Overall plans for FY89-90

- Main focus: human-computer interaction
  - Head-Mounted Display and Tracking (Brooks, Fuchs)
  - Walkthrough (Brooks)
  - Protocol Analysis Tools (Smith, Weiss)
- Other projects:
  - Pixel-Planes 5
  - Network Tools (through December 1989; see Section 3.1.1 below)
- Collaboration with NRL and HCI in interface technology
- ONR Fellows (see also Section 4.2.1)
  - CLOCS (Mark Davis)
  - Pixel-Planes 5 (David Ellsworth)

Information Display for Decision Making

TECHNOLOGIES FOR COMMAND INFORMATION SYSTEMS



OBJECTIVES:

- Interactive storage, processing, and display of information for the support of decision- making.
- Training

APPROACH:

Development of generalizable techniques

in application-driven projects,

tested by real users on real problems.

'88-'89 ACCOMPLISHMENTS:

Prototypes

Head-Mounted Display — Tracker System

Walkthrough System — TempIS Temporal Database System

Full-Text Retrieval System — Pixel-Planes 5(*progress)*

Department Infrastructure

CS Building Communications Networks

SoftLab Software Systems Laboratory

Tools Built

MAXL

FIGURE

1.4 Meetings

We continue to meet every several weeks in order to maintain a central focus and to provide an opportunity for mutual cooperation and interaction among the project participants. At each meeting, two or three project coordinators present their respective progress reports, both in written and verbal format.

The ONR-URI Executive Committee meets several times each year as needed to discuss overall directions of the research program, budgetary and financial matters, and other administrative items.

2 ORGANIZATION OF REPORT

Section 3 provides an overview of progress and plans for each of the projects receiving ONR support during this reporting period. Management, personnel, and travel discussions are presented in Section 4, and Section 5 provides a look at the Department's infrastructure. The **appendices** include: project narratives; a comprehensive bibliography (copies of publications and technical reports, relating to currently-supported research and written since the April 1989 Semi-annual report, are being mailed under separate cover); a list of participants; a travel report (see also Section 4.3); equipment reports; other sponsored research; program and abstracts from the *Second Annual Triangle Telecommunications Symposium* held on 17 Oct. 1988; site visit documents (see also Section 4.3.1); and finally, copies of our Spring and Fall '89 Newsletter—*News and Notes from Sitterson Hall.*

3 RESEARCH PROJECTS

A brief synopsis of research funded during this reporting period is presented below; Appendix I includes additional narratives and/or copies of presentation foils (used during Aug.-Sept. site visit) for the projects; also, kindly refer to copies of publications and technical reports, under separate cover.

3.1 Communications

3.1.1 Integrated Network Management System (Stephen F. Weiss, coordinator; report by John Menges, RA)

Other participants:

Other: Pat Richardson (collaborator, MCNC)

Objective:

The objective of this project is to design and implement an Integrated Network Management System (INMS) suitable for the proper management of the North Carolina (MCNC) Data Network. This INMS is being designed to address the network management requirements of all the component networks (including AppleTalk, Ethernet, and IBM Token Ring) and all the protocols (including TCP/IP, AppleTalk, DECnet, and XNS) used on the MCNC data network. It is also being designed so that it integrates well with the current and planned DARPA Internet network management systems.

The INMS will consist of three major components. The first is Simple Network Management Protocol (SNMP)-based network management system designed to collect information from and control network nodes, particularly network interconnection nodes. The second component is a set of network monitors for the various network types, implemented in software to run on a large proportion of the general-purpose computers attached to these networks. Third, there will be a handbook consisting of a user manual for the INMS and protocol descriptions, including packet formats, protocol sequences, and timing constraints covering most of the protocols seen on our networks.

Significant progress during reporting period:

- Completed QUIP (Query Using Internet Protocol) query/response access mechanism for IB, Vitalink, and LANmark bridges.
- Completed production SNMP proxy agent for IB bridges.
- Acquired SNMP library routines and client programs from various sources and integrated them with our proxy agent.
- Acquired Kinetics AppleTalk/Ethernet gateway SNMP agent code.
- Completed first draft of a paper (Master's thesis) describing our INMS system.

Plans for next reporting period: (through December 1989*)

- Completion of Master's thesis describing INMS system.
- Completion of Vitalink and LANmark drivers for SNMP proxy agent.
- Productizing and distribution of QUIP and SNMP proxy agent.

*As of December 1989, Menges will have completed his Master's thesis.

(See also Appendix I)

3.1.2 Workshops, Symposia

The Department continues to organize workshops and conferences on communications. On 17 October 1988, the second annual tutorial workshop was held: *Telecommunications Symposium on Image Handling*, sponsored by UNC-Chapel Hill, NC State University, ONR, IBM, and Bell Northern Research. Approximately 70 participants from the Triangle, as well as from Oregon, Texas, Virginia, Delaware, and New Jersey, were in attendance. A copy of the announcement, the revised program, and speaker abstracts are included as Appendix VII.

3.2 Processing Technologies

3.2.1 Curved Surfaces and Enhanced Parallelism in Pixel-Planes (Henry Fuchs, coordinator and PI)

Other participants:

Faculty: John Poulton (PI and project manager), John Eyles (senior engineer)

Staff: Trey Greer, Laura Israel Weaver, and Steve Molnar (research engineers) (Molnar IBM fellow FY89-90); Edward Hill (applications programmer)

RAs: Mike Bajura (MCNC fellow), Andrew Bell, David Ellsworth (ONR fellow, spring & fall 1989; FY89-90), Howard Good, Victoria Interrante, Jonathan Leech, Ulrich Neumann, John Rhoades, Brice Tebbs, Russ Tuck, Greg Turk (IBM fellow FY89-90)

Objective:

To create high-performance, 3D graphics systems that harness the highly parallel computation power of custom VLSI circuits; to make this power available in open, programmable systems that encourage invention of new parallel algorithms; and to lead and encourage the development of graphics algorithms for these parallel systems.

Significant progress during reporting period:

Hardware

The research team continues to work on the design for Pixel-Planes 5 (Pxpl5), the next generation Pixel-Planes system. Specific progress for this reporting period is itemized below:

- Custom ICs
  - Corner Turner Chip—Steve Molnar finished the design of this chip in Feb. 1989. The chip is a >33MHz design, and has 26,338 transistors. Prototypes were received in April 1989 and worked at full speed during testing.

  - Enhanced Memory Chip—This chip has 417,000 transistors and was designed to run at a speed of >40MHz. The design by John Poulton and John Eyles was completed in May 1989. Prototype chips were fabricated and tested, and they worked at the appropriate speed. Quantity fabrication of this chip is currently in progress.
  - Image Generation Controller Chip—Design by Poulton and Eyles was completed in July 1989 and was sent out for fabrication. This chip is a >40MHz design with 126,000 transistors. Prototype parts are expected to arrive in November '89. Only one part is required for each renderer circuit board in the Pxpl5 system, so no quantity fabrication or wafer probing will be required.
- Host Interface Logic Design—Laura Weaver finished the host interface logic design and is currently beginning the printed circuit board design.
- Frame Buffer—Laura Weaver has virtually completed the logic design for the frame buffer.
- Ring Network—The logic design for the ring network has now been completed, and the printed circuit board design is underway.
- Graphics Processor—Steve Molnar is working on the board design for the graphics processor, and this is about 50 percent completed. We expect this design to be completed by spring 1990.
- Back Plane Design—This has been sent out for fabrication.
- Power Cooling and Mechanicals—These designs are well underway.

Software (Pixel-Planes 5)

- Porting Base—A testbed system that allows Pxpl5 software to be simulated on a UNIX system. This system became functional during the past year. Problems with synchronization were corrected, and enhancements were made to improve significantly the speed and accuracy of the hardware simulation.
- Ring Operating System—was written and tested. This is the lowest level of software, primarily handling message passing among the hardware components: Host, Graphics Processors, Renderers, and Frame Buffer. The Porting Base system was used as a test environment. No significant changes were made since the last reporting period (ending in April '89). Some maintenance changes were needed to track changes to the porting base, and these have been made.
- Render Control—This system was designed in detail, and a simplified version was coded and tested. This software component manages the rendering process by coordinating the GPs and Renderers during the rendering of a frame. The simplified version does not attempt to overlap rendering of multiple frames. Since April this system has been upgraded to add some new functions: antialiasing, refinement, and multipass transparency.
- Rendering Library—A set of subroutines for rendering specific graphical objects. During the first part of FY88-89, the routines for generic polygons, spheres, and triangle strips were coded in the C language and tested. Since April, enhancements were made to perform antialiasing, multipass transparency, and a more elaborate shading model. Multiple colored lights and Phong shading are now supported. Code was added to sort primitives into bins corresponding to screen regions.
- PPHIGS—During the past year, a subset of the Pxpl PHIGS-compatible library was written and tested. This software is the primary programming interface for Pxpl users. Since April, most of the functions of PPHIGS have been completed. Improved distribution of the database to the GPs is now working.
- Textures—Algorithms were developed for rendering procedural and image textures. An implementation plan for including textures in the integrated software system was produced and reviewed.
- Integration of the Software—All the software was integrated to create a complete rendering pipeline. A number of fairly complex images and some film loops were created to test the pipeline. The integrated system does have some bugs that cause occasional failures when running concurrently on several UNIX systems.
- Intel i860 System—An i860 development system was acquired from Intel to write and test microcode for the graphics processors. Some small test programs were developed in order to help learn how to program this processor.
- Technical Reports—Two technical reports by members of the Pixel-Planes team are in progress:
  - Tebbs, Neumann, Turk, and Ellsworth. "Using Deferred Shading to Accelerate High-Quality Rendering."
  - Ellsworth, Good, and Tebbs. "Distributing Display Lists on a Multicomputer."

Pixel-Planes 4

Pixel-Planes 4 continues to serve as the principal display device for most of the interactive 3D projects in our Graphics Lab—Head-Mounted Display, Walkthrough project, etc—and applications programs are now being written by members of those teams. The hardware is being maintained by Graphics Lab personnel. To date, only about 8-to-10 memory chips have had to be replaced. A board to allow stereo display by two separate video streams (for use in head-mounted display) has been designed by Ulrich Neumann and built by David Harrison, a Graphics Lab staff member. This board is currently being debugged.

Although the project research assistants now devote most of their time to development of the Pixel-Planes 5 software, some work is still being done on software for Pixel-Planes 4. During this reporting period, this system was upgraded to run the X11 windows system, and the front-end display program (XFront) was upgraded to operate with X11. Several minor bug fixes and enhancements were made in support of application users in the Department.

Other

Grant proposal preparation—Vernon Chi, Henry Fuchs, and Julian Rosenman (joint appointments in the Departments of Radiation Oncology and Computer Science) are working on a grant proposal jointly with Bell Northern Research, the Microelectronics Center of North Carolina (MCNC), GTE, and Bell South to demonstrate an application of Pxpl5 using gigabit networking. A site visit including representatives from the National Science Foundation took place in October 1989.

Plans for next reporting period:

Hardware

- We are attempting to accelerate our production schedule so that a system with frame buffer and graphics processors running on a ring will be operational by early January 1990 and a full system will be operational by late March 1990.

Software

- Textures will be implemented and integrated into the rendering pipeline using the Porting Base. Both procedural (Gardner) and image textures will be supported.
- Multipass transparency will be integrated into the software system.
- Improvements to the database distribution in PPHIGS will be made.
- The rendering software will be ported to the Pixel-Planes 5 hardware, and the time-critical parts of the system will be microcoded. This includes primarily the Rendering Library routines and display list traverser. In all, about five percent of the C code will be converted to microcode. The software will be tuned to achieve the performance goals of the project.

Related publications and technical reports of this reporting period:

Ellsworth, David. "Pixel-Planes 5 Rendering Control," technical report TR89-003, Department of Computer Science, UNC at Chapel Hill (in press).

Fuchs, Henry, John Poulton, John Eyles, Trey Greer, Jack Goldfeather, David Ellsworth, Steve Molnar, Greg Turk, Brice Tebbs, and Laura Israel. "Pixel-Planes 5: A Heterogeneous Multiprocessor Graphics System Using Processor-Enhanced Memories," *Proc. SIGGRAPH '89*, Boston, MA, 31 July - 4 Aug. 1989; in *Computer Graphics*, 23(3), Aug. 1989, New York: ACM SIGGRAPH, 1989, 79-88. (See TR89-005)

Fuchs, Henry, John Poulton, John Eyles, Trey Greer, Jack Goldfeather, David Ellsworth, Steve Molnar, Greg Turk, Brice Tebbs, and Laura Israel. "Pixel-Planes 5: A Heterogeneous Multiprocessor Graphics System Using Processor-Enhanced Memories," *Proc. SIGGRAPH '89*, Boston, MA, 31 July - 4 Aug. 1989; in *Computer Graphics*, 23(3), Aug. 1989, New York: ACM Siggraph, 1989, 79-88.. (See TR89-005)

Goldfeather, Jack, Steven Molnar, Greg Turk, and Henry Fuchs. "Near Real-Time CSG Rendering Using Tree Normalization and Geometric Pruning," *IEEE Computer Graphics and Applications*, 9(3), May 1989, 20-28. (See TR88-006)

Goldfeather, Jack. "Progressive Radiosity Using Hemispheres," technical report TR89-002, Department of Computer Science, UNC at Chapel Hill, Feb. 1989.

Levoy, Marc. "Rendering Mixtures of Geometric and Volumetric Data," technical report TR88-052, Department of Computer Science, UNC at Chapel Hill, Dec. 1988.

Molnar, S., and H. Fuchs. "Advanced Graphics Architecture," to appear as Chapter 18 in *Computer Graphics: Principles and Practice*, Foley, J., A. van Dam, S. Feiner, and J. Hughes, Addison-Wesley, Reading, MA, 1990.

Molnar, Steven and Mark C. Surles. "A Microprogramming Support Tool for Pipelined Architectures," *MICRO 21: Proc. 21st Annual International Workshop on Microprogramming and Microarchitecture*, San Diego, CA, 2 Dec. 1988, 108-110.

Molnar, Steven. "Combining Z-buffer Engines for Higher-Speed Rendering," *Proc. Eurographics '88 3rd Workshop on Graphics Hardware*, Nice, France, Sept. 1988.

Tuck, Russ. "An Optimally Portable SIMD Programming Language," *Proc. Frontiers '88: 2nd Symposium on the Frontiers of Massively Parallel Computation*, George Mason University, Fairfax, VA, Oct. 1988, IEEE Computer Society Press, Feb. 1989, 617-624. (See also TR88-048)

Tuck, Russ. "Porta-SIMD User's Manual," technical report TR89-006, Department of Computer Science, UNC at Chapel Hill, Jan. 1989 (revised March 1989).

Related presentations in this reporting period:

By: Henry Fuchs
Topic: "An Interactive Display for the 21st Century: Beyond the Desktop Metaphor."
Event: Keynote address at the Computer Graphics International '89 conference
Place: Leeds, UK
Date: 27-30 June 1989

By: Steven Molnar
Topic: Combining Z-buffer Engines for Higher-Speed Rendering
Event: Eurographics '88 Third Workshop on Graphics Hardware
Place: Nice, France
Date: Sept. 1988

By: John Poulton
Topic: "Pixel-Planes 5: A Heterogeneous Multiprocessor Graphics System Using Processor-Enhanced Memories"
Event: SIGGRAPH '89 conference
Place: Boston, MA
Date: 31 July - 4 August 1989

By: Mark C. Surles
Topic: A Microprogramming Support Tool for Pipelined Architectures
Event: 21st Annual Workshop on Microprogramming and Microarchitecture
Place: San Diego, CA
Date: Nov. 1988

By: Russ Tuck
Topic: An Optimally Portable SIMD Programming Language
Event: Frontiers '88 Second Symposium on the Frontiers of Massively Parallel Computation, jointly sponsored by NASA/Goddard Space Flight Center and the IEEE Computer Society
Place: George Mason University, Fairfax, VA
Date: 10-12 Oct. 1989

(See also Appendix I)

3.2.2 Compiling Data-Parallel Languages for SIMD Execution (Jan F. Prins, coordinator)

Other participants:
RAs: John A. Smith, D. Poirier (Merit Assistantship)

Objective:
To identify the components of a high-level programming language that promote the expression of data-parallelism and to investigate their compilation for efficient execution on massively-parallel SIMD architectures.

Significant progress during reporting period:
- Acquisition and installation of two second-generation data-parallel programming languages: Q'Nial and APL*PLUS.
- Analysis of BLITZEN (prototype SIMD machine) architecture and data-movement techniques.
- Detailed description of project aims and proposed work submitted to ONR for consideration as a separate contract. (see below)
- Identification of a subset of data-parallel operations that can be compiled to use efficient data-movement operations in execution.

Plans for next reporting period (through March 1990):
- Description of a data-parallel programming language (DPPL) and subset language (DPSL).
- Movement generator for DPSL on torus-connected SIMD machine.
- DPPL development of Bitonic Sort Algorithm for SIMD execution.

Related presentation in this reporting period:
By: Jan Prins
Topic: Compiling Programs for Parallel Execution
Event: Department research colloquium
Place: Department of Computer Science, UNC-Chapel Hill
Date: 9 Nov. 1988

This project was presented to the Office of Naval Research as a candidate for support independent of the URI grant in a proposal dated December 1988. The proposal was approved for the period 3/15/89 - 3/14/90 and is supported under ONR contract N00014-89-J-1873; a project report is included here because it was started under URI support and falls under the more general umbrella of ONR-sponsored research at UNC-Chapel Hill.

(See also Appendix I)

3.2.3 CLOCS—Computer for Low Context Switch Time (Donald F. Stanat, coordinator; report by Mark Davis, ONR fellow)

Other participants:
Faculty: Frederick P. Brooks, Jr., advisor

Objective:
The Computer for Low Context Switch Time (CLOCS) project will design a computer architecture that can support applications needing many independent, rapidly switching tasks. To achieve fast context switching, the CLOCS architecture eliminates some levels of memory hierarchy, including registers and cache. As a result, all instructions are memory to memory. The CLOCS architecture supports modern operating systems and virtual memory in order to provide a reasonable development platform for systems. Otherwise, the architecture is quite simple to ease the task of demonstrating the capabilities of the concept. This architecture is well suited for hard-real-time applications.

Significant progress during reporting period:
- CLOCS architecture simulator completed.
- Architecture definition modified to improve performance of selected benchmarks (see Appendix I).
- Previous C Language Compiler discarded because of inefficient optimization.

- GNU C Language Compiler ported to CLOCS architecture.
- Improvements to GNU C Compiler accepted by Compiler authors.
- Assembler and simulator modified for architecture changes.
- Simulator reimplemented to improve performance.

Plans for next reporting period:

- Run benchmark programs.
- Analyze project results.

Related presentation in this reporting period:

By: Mark Davis
Topic: 1) The Penalty of Context Switch Time in Distributed Computing;
2) The Computer for Low Context Switch Time
Place: Communications Products Division, IBM, Research Triangle Park, NC
Date: 21 July 1989
Note: Mention was made of ONR's support of this research through his fellowship.

(See also Appendix I)

3.3 Database Technologies

3.3.1 Temporal Database—Final Report (Richard Snodgrass, coordinator)

Other participants:

RAs: Debashish Chatterjee (NCR Assistantship), Robert Stam

Objective:

A temporal database management system (TDBMS) by definition must support both transaction and valid time. This project involves developing a formal model of temporal information and implementing a prototype TDBMS to investigate issues of performance and functionality. Now that the formal model is in good shape, we have during the past year started focusing on the substantial implementation issues.

Significant progress during reporting period:

- TQuel prototype based on Version 8 Ingres is now fairly complete. It executes on Sun-3's and Vaxes (the original version of the prototype ran only on Vaxes). This prototype will provide a valuable baseline with which to compare functionality and performance of our new system, now under development.
- The second prototype, being built to explore incremental maintenance of materialized temporal views, is coming along nicely. We have completed lexical, syntactic, semantic analysis, and code generator phases for a significant subset of TQuel. The phases make heavy use of the Interface Description Language Toolkit, a programming environment developed during the past five years at UNC-Chapel Hill by Richard Snodgrass and students. The interpreter now executes the append, retrieve, and delete statements incrementally. A small set of queries/updates has been run through the entire system. View support is under development (interestingly, the interpreter is farther along than the rest of the phases). This prototype supports a main-memory database; the next prototype, termed TempIS, will be much larger, but will support disk-based data. We hope to build TempIS on top of an extensible DBMS such as Exodus or Genesis.
- The architecture for TempIS has been designed, and research issues concerning each component have been identified. We plan to focus on temporal partitioning and incremental view materialization to increase the performance of temporal queries. Both of these techniques involve fairly fundamental changes to the basic DBMS architecture, and thus require rethinking of many of the design decisions.

Plans for next reporting period:

There are no plans to continue this project under the ONR contract; Richard Snodgrass resigned from the Department to accept a position this fall in Computer Science at the University of Arizona at Tucson.

Related publications and technical reports of this reporting period:

Ahn, Ilsoo and Richard Snodgrass. "Performance Analysis of Temporal Queries," to appear in *Information Sciences: An International Journal*, (49)1, Oct. 1989, 44 pp.

Ahn, Ilsoo and Richard Snodgrass. "Partitioned Storage Structures for Temporal Databases," *Information Systems*, 13(4), Dec. 1988, 369-391.

McKenzie, E. and R. Snodgrass. "Schema Evolution and the Relational Algebra," to appear in *Information Systems*, 1989, 52 pp. (See TR87-003)

McKenzie, Leslie Edwin, Jr. "An Algebraic Language for Query and Update of Temporal Queries," Ph.D. Dissertation, UNC at Chapel Hill, Sept. 1988.

Stam, Robert B. and Richard Snodgrass. "A Bibliography on Temporal Databases," *Data Engineering*, 11(4), Dec. 1988, 53-61. (See TempIS Doc. No. 23)

Valiente, Juan A. "The Temporal Query Language TQuel: A Tutorial," TempIS Document No. 22, Department of Computer Science, UNC at Chapel Hill, 15 Dec. 1988.

(See also Appendix I)

3.3.2 Full-Text Retrieval: An Expert System for Searching in Full-Text (John B. Smith, coordinator; report by Susan Gauch, ONR fellow, fall 1988)

Objective:

The main focus of the full-text retrieval project is the development of an on-line search assistant using expert systems technology. Increasingly, information is available on-line in the form of full-text documents. However, people's abilities to search full-text databases vary greatly. The goal of this project is to provide an expert system so that users will need less training to find the information they seek.

Goals:

- Develop an expert system for query reformulation.
- Demonstrate that the query reformulation system improves search effectiveness for novice searchers.
- Demonstrate that the query reformulation system improves the efficiency for novice searchers.
- Demonstrate that the system can rank retrieved passages in decreasing order of relevance.

Significant progress during reporting period:

- Addition of the production rules for passage ranking to the expert system.
- Formatting of retrieved text.
- Completion of interactive and independent modes.
- Completion and testing of the expert system.
- Evaluation experiment with 12 subjects run.

Results:

- *Search effectiveness:* all three systems retrieved comparable numbers and produced comparable precision. No significant difference in effectiveness for the human user working alone, with the thesaurus, or with the expert system.
- *Search efficiency:* the expert system improved search efficiency in half the number of queries.
- *Ranking passages:* the expert system ranked relevant passages more highly than would be predicted by randomness.

Plans for next reporting period:

- Analyze experimental data.
- Write dissertation.

Gauch defended her dissertation in November 1989, and expects to complete the Ph.D. degree in December. The support she received through December 1988 allowed her to build the system and to make good progress toward the completion of her dissertation.

Related publications of this reporting period:

Gauch, Susan and John B. Smith. "An Expert System for Searching in Full-Text," o appear in *Information Processing and Management*, 1989.

Gauch, Susan and John B. Smith. "Query Reformulation Strategies for an Intelligent Search Intermediary," *Proc. Annual AI Systems in Government Conference*, Washington, DC, March 1989.

Related presentation in this reporting period:

By: Susan Gauch
Topic: Query Reformulation Strategies for an Intelligent Search Intermediary
Event: The Annual AI Systems in Government Conference
Place: Washington, DC
Date: 27-31 March 1989

(See also Appendix I)

3.4 Display and Interaction

3.4.1 Head-Mounted Display (Frederick P. Brooks, Jr., coordinator)

Other participants:

Faculty: Henry Fuchs, Vernon L. Chi
Staff: Warren Robinett (project leader since 1 September 1989), John Hughes (research associate)
RAs: Ron Azuma, William Brown, James Chung, Michael Kelley, Daniel Palmer, Jih-Fang Wang
Other: Michael Pique (collaborator, Scripps Institute)

Objective:

Dynamic interaction with a virtual world seen in stereo from a view based on user's head position.

Significant progress during reporting period:

- The new fiberglass head-mounted display came from the Air Force Institute of Technology. A third display came from VPL as a gift.

Plans for next reporting period:

- Rationalize the software and put under the Revision Control System.
- Set up tandard demos.
- Standardize the virtual world software base and data structure.
- Create several specific interesting or useful virtual worlds.
- Explore input devices and associated interaction techniques.
- Install sound, triggered by events in virtual world.

Related publication of this reporting period:

Chung, James C., Mark R. Harris, F. P. Brooks, Jr., Henry Fuchs, and Michael T. Kelley, John Hughes, Ming Ouh-young, Clement Cheung, Richard L. Holloway, and Michael Pique. "Exploring Virtual Worlds with Head-Mounted Displays," *Proc. SPIE Conference, Nonholographic True Three-Dimensional Display Technologies*, 1083, Los Angeles, CA, Jan. 1989. (Same as TR89-009)

Related presentation in this reporting period:

By: J. C. Chung
Topic: Exploring Virtual Worlds with Head-Mounted Displays
Event: Conference on Non-Holographic True Three-Dimensional Displays
Date: Los Angeles, CA
Place: 15-20 Jan. 1989

(See also Appendix I)

3.4.2 A Real-time 3D Position Tracker for Head-Mounted Display Systems (Henry Fuchs, coordinator)

Other participants:

Faculty: Vernon L. Chi, Gary Bishop, John Eyles, John Halton
RAs: Ron Azuma, Jih-Fang Wang

Objective:

Design and build a new real-time three-dimensional position and orientation tracking device for head-mounted display systems. The goal of this project is to come up with a product that provides a fast update rate (≥ 30 Hz), a large working volume (≥ 12' x 12'), high accuracy in the reported position and orientation, and immunity to environmentally induced disturbances. Furthermore, the tracker should be constructed from off-the-shelf components so that it can be easily duplicated.

The tracking system will consist of a cluster of three tiny cameras mounted on top of the helmet and a grid of hundreds or thousands of infrared LEDs mounted in the ceiling. Real-time position and orientation of the helmet is determined from the position on each camera's image plane of a flashed LED whose ceiling position is known.

Significant progress during reporting period:

Hardware:

- A proof-of-concept prototype was constructed. This prototype consists of three cameras, each using a lateral effect photodiode as the recording surface. A signal processing circuit was built to control the data acquisition and to filter out noises from the cameras. A parallel interface connects the prototype to a general-purpose computer for data analysis.
- A panel of a 4x4 grid of red LEDs was built. Address decoding circuitry was constructed to verify the ability of the system to select a particular LED.
- An optical mounting device was designed and built to position the prototype. Experiments were carried out to measure the accuracy of the prototype.

Software:

- A simulation program was developed to emulate the behavior of the system. Important design decisions were then made based on the simulation results.
- A device driver was written to allow the host computer to control the hardware functions.
- A novel method that calibrates automatically the positions of LEDs were designed and tested.
- A control program was written to direct the action of the prototype, and to integrate the whole system together.

Plans for next reporting period:

Hardware:

- Design LED circuitry. Since hundreds or even thousands of LEDs will be used in the final working system, how to place and address them efficiently is critical. We are currently planning to design 2'x2' circuit boards to mount the LEDs. The circuit boards can then replace the drop-in ceiling tiles.
- Design filter and lens assembly for outward-looking views. We plan to replace the current three-camera prototype with only one or two cameras, each with a multi-view port holographic lens. Such a lens can look into several widely separated directions simultaneously and reduce significantly the weight of the system.
- Rebuild the signal processing circuitry on a printed circuit board.

Software:

- Port the whole system to a faster workstation. Redesign the interface with the Pixel-Planes machine.
- Motion prediction.

(See also Appendix I)

3.4.3 Walkthrough (Frederick P. Brooks, Jr., coordinator)

Other participants:

Staff: John Hughes (research associate), David Lines (editorial assistant)
RAs: John Alspaugh, John Airey, Randall Brown, Curtis Hill, Penny Rheingans, John Rohlf

Objective:

Real-time, interactive graphics system for prototyping building architectures and similar structures. Hand controls and a steerable treadmill enable user to navigate within the structure; the image is updated in real time.

Significant progress during reporting period:

- Update rate:
  - Automatic partitioning with automatic visibility-set calculations yields correct images and an average 30-fold speed over naive use of Pixel-Planes 4. The current system now gives better than 15 updates/sec.
- Interface—flexible interface testbed:
  - joysticks—free and restricted
  - big screen—4 X 6 feet
  - treadmill
  - head-mounted display
- Radiosity lighting model:
  - seven-fold speed improvement over published algorithms through the use of adaptive sampling methods
  - development of an algorithm to filter finite-elements for smoother image
  - individual real-time control of lights
  - system adaptively refines from flat lighting to radiosity
- Model building:
  - AutoCad for building and importing models
  - model translator from AutoCad
  - model editing (for example, to reverse mal-oriented polygons)
  - furniture
  - lighting specifications

Plans for next reporting period:

- Update rate:
  - begin coding for PxPl5
- Interface:
  - interface comparison study with head-mounted display
  - dynamic objects: lights, doors, etc.
- Radiosity lighting model:
  - improve image quality/polygon ratio
  - incorporate specular reflection, mirrors
- Model building:
  - working with collaborating architects and start on a third building model

Related presentation in this reporting period:

By: Frederick P. Brooks, Jr.
Topic: "UNC Walkthrough," Course Notes for Course 29, *Implementing and Interacting with Real-Time Microworlds* (copy of slides in Appendix I)
Event: SIGGRAPH '89
Place: Boston, MA
Date: 31 July 1989

Related technical reports of this reporting period:

Airey, John M. and F. P. Brooks, Jr. "Walkthrough—Exploring Virtual Worlds: Second Annual Report," TR89-012, Department of Computer Science, UNC at Chapel Hill, Feb. 1989 (accompanying VHS videotape mailed to Ralph F. Wachter on 29 March 1989).

Airey, John, John Rohlf, and Penny Rheingans. Videotape: "The Virtual Lobby," *SIGGRAPH '89* Videonight, Boston, MA (sent to Ralph F. Wachter, Oct. 1989).

(See also Appendix I)

3.4.4 **Protocol Analysis Tools** [Newly funded project for FY89-90] (John B. Smith and Stephen F. Weiss, coordinators)

Other participants:

Faculty: Marcy Lansman (visiting research assistant professor)
Staff: Gordon Ferguson (research associate)
RAs: Murray Anderegg, Rick Hawkes

Objective:

Develop tools for understanding decision-making by individuals and groups working in a computer environment.

Plans for next reporting period:

- Develop tools for integrating machine-recorded protocols with think-aloud protocols.
- Develop tools for integrating protocols from individuals to form a protocol for the group.
- Develop tools for displaying, analyzing, and understanding integrated protocols.

(See also Appendix I)

4 MANAGEMENT, PERSONNEL, TRAVEL, EQUIPMENT

4.1 Management

Jeannie M. Walsh, administrative coordinator of the contract, continues to report to the Executive Committee (see below) and perform the necessary personnel, financial management, coordinating, and reporting duties. Laboratory and facilities management is the responsibility of the laboratory directors who report to Ralph A. Mason, associate chairman for administration.

4.1.1 ONR-URI Executive Committee

Stephen F. Weiss, appointed chairman of the Department as of 1 January 1989, has replaced J. Nievergelt as co-PI and will serve as committee chairman during FY89-90. Nievergelt has resigned from UNC-Chapel Hill, and is no longer associated with the contract. Henry Fuchs joined the committee during January 1989, while Frederick P. Brooks, Jr., Donald F. Stanat, and Ralph A. Mason continue to serve as members.

4.2 Personnel

4.2.1 Director of SoftLab

Susanna Schwab came aboard in June 1989 as research assistant professor and Director of SoftLab. Since 1 July, 10 percent of her salary has been paid by ONR funds. Please refer to Section 5.1 for a description of SoftLab's contribution to the project, and to the Department as a whole.

Dr. Schwab served as an assistant professor of computer science at the Illinois Institute of Technology, Chicago, and since 1978 has accrued additional experience as a technical manager and scientific staff member, switching systems, at AT&T Bell Laboratories. Among her many responsibilities at AT&T Bell Labs, Naperville, Illinois. Dr. Schwab managed a group of ten engineers responsible for the design and integration of test data for the system lab testing of the software to control the latest AT&T digital telephone switch; was responsible for quality certification and change control of successive official versions of software during entire development cycles; scheduled introduction of new software development tools; coordinated software packaging and helped coordinate problem resolution during site tests; and conceived, designed, and developed an automated system to facilitate parallel development of software releases. Dr. Schwab earned a Ph.D. degree in Math/Computer Science in 1976 at the University of Chicago.

4.2.2 Technical Liaison

We are pleased to announce that Warren Robinett, research associate and project leader, GRIP and Head-Mounted Display projects, has agreed to serve as technical liaison to ONR during FY89-90. Warren arrived at UNC-Chapel Hill on 1 September of this year. During his successful career as a software engineer/research scientist, he has conceived and implemented several commercially successful software products, and has 12 years of experience using C and Assembler to develop software products and design user interfaces based upon real-time interactive graphics. At the NASA-Ames Research Center, he designed and implemented the software for a head-mounted display system; designed a gestural language for an instrumented glove; and built a prototype head-mounted display using miniature CRTs. Warren holds an M.S. degree in computer science from Berkeley.

4.2.3 Fellows

Susan Gauch, ONR fellow during fall 1988, defended her dissertation in November 1989 (see Section 3.3.2). The vacancy created by her departure was offered to and accepted by David Ellsworth, a Ph.D. student working with Henry Fuchs on the Pixel-Planes project. Ellsworth continues as fellow during FY89-90.

Ph.D. student Mark Davis (a former naval officer) also continues as fellow during this academic year to work on the CLOCS project (see Section 3.2.3) under the supervision of Donald F. Stanat.

4.2.4 ONR Participants

Appendix III lists all participants during this reporting period.

4.3 Travel

Appendix IV provides a travel summary and supporting documents (see below) for this reporting period.

4.3.1 Interaction with the Navy

- NRL Project Review. On 13 October 1989, Frederick P. Brooks, Jr. was invited to attend the Review of Projects at the Human-Computer Interface Lab, Information Technology Division, NRL.

- Trip/Visit reports are included in Appendix IV for the following visitations:

  - 25 May 1989: Cdr. Rob Carter, Constance Heitmeyer, and Preston Mullen of the Information Technology Division of NRL visited the Graphics and Image Laboratory, Department of Computer Science, UNC-Chapel Hill.
  - 27-29 June 1989: Stephen F. Weiss attended the 1989 Joint Directors of Laboratories Symposium on Command and Control (C^2) Research at the National Defense University, Washington, DC.
  - 10-11 July, 1989: Donald F. Stanat attended the ONR-SEI Computer Science Workshop at Carnegie-Mellon University.

- Invitations extended during annual site visit on 31 August-1 September 1989 (*Status: pending*):

  - Ralph Wachter and Stanley Wilson of ONR and NRL, respectively, invited members of our Department to present their research at the NRL colloquia series, held at various Navy labs. Appendix IV includes four abstracts submitted (to date) to NRL on 2 October 1989.
  - Wachter and Wilson also invited interested graduate students to spend the summer of 1990 doing research at various Navy laboratories. Electronic news was posted in early October.
  - Members of the ONR-URI Executive Committee invited Ralph Wachter to solicit Navy personnel who might be interested in spending perhaps a semester working with our researchers on site here at UNC-Chapel Hill. Wachter indicated he would review applications and make a selection.
  - Richard Miller, Chief Scientist of the Mechanics Division, ONR, was unable to attend the site visit due to illness. Copies of materials distributed during the visit were mailed to him, and an invitation was extended to visit our facility at his convenience.

4.4 Equipment Report

Equipment reports for the first three years of the contract, along with a summary report, is attached as Appendix V.

5 DEPARTMENT INFRASTRUCTURE

5.1 SoftLab Software Systems Laboratory (Susanna Schwab, director)

Other participants:

Staff: Pamela Payne (secretary and SoftLab coordinator); Arie Trinker (research associate)
RAs: David Becker, Heng Chu, Charles Clark, Steve Tell, Chin Ho Yeh

Purpose:

SoftLab Software Systems Laboratory is an organization that provides the UNC-Chapel Hill Computer Science Department with software systems and manufacturing support services similar to those typically found in industry. As such, SoftLab serves as a software development resource for the Department and as an agent of technology transfer to other universities and to industry.

In addition, SoftLab facilitates rapid prototyping of novel architectures by developing drivers and interface software, by importing and integrating commercial software development tools, and by supporting an object-oriented programming environment.

Finally, SoftLab pursues an educational mission with emphasis in the areas of software engineering and development of software tools for laboratory use in computer architecture and operating system courses.

Significant progress: (Since January 1989--the inception of SoftLab)

- SoftLab has packaged and distributed the following products since it began operation in January of 1989:

	Purchased Licenses (or *Inquiries/Committed Customers)*		
PRODUCT	ACADEMIC	COMMERCIAL	Total Customers or *inquiries*
RSPACE (Reciprocal SPACE Modeling Tool)	27	17	44
IDL (Interface Description Language	33	24	57
COOL (Comprehensive Object-Oriented Library)	*17*	*29*	*46**
MAXL (Microcode Assembler for Weitek XL chip)	*0*	*2*	*2***

* *Customer inquiries (new product)*
***Committed customers (new product)*

- SoftLab has developed the following software products:
  - Device drivers for BLITZEN, a massively parallel, single instruction, multiple data machine being developed jointly between MCNC, UNC, NC State and DUKE University.
  - RCSM (Revision Control System Manager) , an enhancement to the UNIX configuration management tool RCS (Revision Control System) that increases its version management and status tracking capabilities.
  - MOSEL I (Modular Operating System Experimentation Laboratory), the first in a family of architecture and operating system experimentation tool sets that includes a hardware simulator and basic modular operating system. Later versions of MOSEL will include uni- and multi-processing operating systems and experimentation tools for monitoring and analyzing architecture and operating systems experiments. MOSEL can be used in a classroom setting or for rapid prototyping.
- As a secondary effect of the COOL productizing effort, SoftLab member Greg Bollella and faculty member James Coggins developed and published a novel way to manage large C++ libraries efficiently.
- Finally, SoftLab has acquired the following commercial tools:
  - Compiler construction: GLA, Lex, Flex, Alex, Yacc, Bison, Ayacc, GAG, CPS, ACK, GNU
  - Programming Tools: Eiffel

Plans for next reporting period:

- The following software is currently being productized:
  - WE (Writing Environment): A TextLab hypertext system for authors written in Smalltalk. It, together with MICROARRAS, a possible candidate for later productization, with form the basis for a full text retrieval system.
  - /usr/image: A graphics library for medical imaging.
  - /volume/rendering: Another library of graphics routines.
- We are also defining and implementing a procedure to productize data sets as well as programs. This procedure will be used to package and distribute the Volume Rendering data sets shown by Brooks at the Volume Visualization Workshop.
- SoftLab is developing the following software products:
  - OP860 - this is a microcode assembler for the Intel 860 chip. Pixel Planes is upgrading from the Weitek XL chip and OP860 will then replace MAXL. This tool will increase the efficiency of microcoding the I860 (a state of the art floating point chip) for graphics applications.
  - OAI UNIX Driver - OAI (Open Applications Interface) is a new feature for the Intecom telephone switch that serves the Computer Science Department. OAI will allow applications programs running on a host with a data link to the Intecom switch to interact with the switch. At present, Intecom supports the OAI feature only for VAX/VMS and IBM PC hosts. SoftLab will extend OAI features to a UNIX host in order to make the Intecom switch an effective test bed for department research in networking and telecommunications.
  - BLITZEN drivers - SoftLab will complete testing of BLITZEN device driver software and will begin work on applications programs.
  - MOSEL (Modular Operating System Experimentation Laboratory) - SoftLab will continue work on the MOSEL family. In particular, final debugging of the multiprocessing operating system will be done and work will start on the monitoring and analysis tools.
- Finally, SoftLab will continue work on establishing integration and support procedures for privately acquired but publicly used tools that lie beyond the scope of Facilities support. Currently, these tools include object oriented programming tools and text formatting software.
- SoftLab will begin planning work on interface software development for rapid prototyping. The VIEW project is an immediate customer for such interface software.

(See also Appendix I)

5.2 Computer Services (William Howell, director)

Significant progress during reporting period:

During this period, the computing requirements of our research work expanded beyond the capabilities of our 1- to 3-MIPS workstations (Sun-2, Sun-3, DEC GPX). In order to meet the needs of our research, it became necessary to acquire more powerful machines. During the first quarter, we acquired three RISC-based Sun-4 computers for specific research projects, including the Pixel-Planes front end, and the Molecular Modeling force-feedback control engine. In the second quarter, we conducted an extensive evaluation of the emerging breed of more powerful workstations; and in the third and fourth quarters, we ordered, received, and installed these new workstations.

Our evaluation resulted in the acquisition of 40 RISC workstations, primarily the DECstation 3100 and a few Sun SPARCstation-1 machines. These new RISC workstations all boast greater than 10 MIPS of performance, at least 12 megabytes of memory, a local 100 megabyte swap and temporary storage disk, and a color monitor. This configuration is a significant advance over our earlier workstations. We saw significant improvement in our computing productivity when we acquired our first workstations in 1984. We anticipate seeing as large an improvement in 1989 and 1990 with these second-generation machines.

We have ordered a DECsystem 5820 dual processor RISC-based machine that will act as our primary file and boot server for our fleet of DECstation 3100 workstations. The 5820 boasts nearly 40 MIPS of performance and has a high-speed I/O bus to support the large amount of disk space that we have on-line in support of our 3100 workstations. Until the 5820 arrives in early 1990, we are serving the 3100 workstations with a small number of DECserver 3100s that will later be converted to workstations and compute servers for specific applications.

The addition of some 30 Macintosh-II systems during this period brings our operating fleet of these personal workstations to over 100. Approximately 25 percent of the systems are used in educational laboratories, 25 percent in research laboratories, and the remaining 50 percent in supporting research roles, including drafting, design, project management, and document preparation. We have installed a Sun-3/280 file server, which will be upgraded to a 3/480 later this year, to support our fleet of Macintosh systems. We completed the hardware and software installation of this server and have centralized the accounts of our primary Macintosh users onto this machine. TOPS networking software is installed, and we are beginning to offer the ability to access all of our NFS-mounted file systems from the Macintosh workstations. A significant task remaining is to develop and deploy a backup mechanism for the Macintosh systems, as there are nearly 5 gigabytes of disk space across those systems.

With the addition of the RISC, UNIX, and Macintosh workstations, we were for the first time able to provide a workstation to every student who has passed the doctoral written examination. We predict that having convenient and consistent access to a personal machine will significantly increase the productivity of these key researchers and assist them to earlier completion of their degrees. We anticipate that over the next two-to-three years, we will be able to achieve a 1:1 ratio of workstations to students as we continue to bring in higher-end equipment and the older machines trickle down through the ranks.

A number of UNIX operating system upgrades were completed across our computing platforms, including the latest user interface offerings and a number of recent language releases. In order to utilize the latest enhancements and features in these foundation software products in our research, it is necessary to stay current with these releases. This is a significant undertaking requiring considerable man-hours of support staff, but it has proven beneficial in many areas of our research with payback far exceeding the costs of the upgrade work. In addition, we work closely with several vendors in the early stages of their development and are a frequent beta site, which gives us early opportunity to use many of the upcoming features and products.

The primary vision of our computing environment is to provide a fully integrated distributed computing environment. The advantages of distributed computing are widely known. It is now critical to reconnect those systems in an fully integrated fashion to realize the benefits of centralized computing layered across a distributed environment. These connections are accomplished at all levels, including networking, application software, and system software. During this period, we have undertaken a major expansion of our fiber-based Ethernet network. We are also actively evaluating high-speed bridging and routing equipment to span our many Ethernet subLANs. Included in this work is investigation into the use of FDDI as a backbone and high-speed communication network for our faster machines. We are moving forward to place larger numbers of Macintosh systems on the Ethernet network where they are capable of achieving higher performance. We have interconnected at a system software level, transparent to the researchers, all of our output devices so that it is now possible to get to virtually any output device from any of our computing systems. We are now acquiring software products that will help to harness the computing power of our workstations in a loosely coupled way for the distribution of processes to any available machine.

Plans for next reporting period:

During the next year, we will pursue five primary thrusts: 1) Continuation of our efforts to provide a consistent integrated computing environment across our distributed systems. 2) The addition of a massively parallel computing system to foster our research efforts in the development and application of such machines. 3) The investigation into optical storage technologies and how they can be implemented in our environment. 4) A continued expansion of our workstation fleet. 5) Implementation of higher-speed Ethernet subLAN bridging and routing.

5.3 Communications (Norman A. Vogel, director)

Other participants:

Staff: Steven Ornat (Televideo Communications Technician)
RA: John Menges

Significant progress during reporting period:

The InteCom Voice/Data switch and fiber optics-based Ethernet have been in continuous operation since "cut-over" on June 16, 1987. There have been no catastrophic failures; however, some parts of the system have had to be re-engineered because of the high performance requirement of our applications. The "soak test" was completed during April, 1988. We have acquired an Excelan Lanalyzer system used to monitor traffic on our Ethernet network and to assist in the location and diagnosis of problems on the network.

A Farallon AppleTalk/PhoneNet system that networks all Macintosh terminals and related laser printers has been operating extremely well. Three Kinetics bridges successfully interconnect PhoneNet to the Sitterson Hall Ethernet system. The installation of a twelve-channel Scientific Atlanta mid-split broadband system has been completed and is operating successfully. A three-meter Channel Master K_u/C Band satellite earth station and off-the-air antennas have been installed on the roof and coupled to the broadband system. Six stations of a twelve-station Token-Ring system have been installed. A Barco data video projection system has been installed on the ceiling of two classrooms, and another unit has been installed in rear-projection mode in our graphics lab. A FAX machine was installed in the Department and is operational 24 hours per day. Documents are received when sent to 919-962-1799.

Installations of a four-camera video classroom and an eight-camera teleconference facility are complete. A 10x20 RGBS (four cable per path) Dynair Switching system is being installed.

PC's have been equipped with TOPS cards and software and are attached to the Farallon PhoneNet system (Macintosh); we have attained fairly complete interconnectibility of all workstations in the building.

An Internet name server has been installed on our 4.3bsd VAXes and Suns, which allows smooth and efficient interconnection of our Department Ethernet with the rest of the Internet. Our software has been reconfigured to utilize the nameserver to its fullest. Nameserver applications have been expanded to Department Macintoshes.

During spring semester 1989, Fred Brooks conducted a three-credit-hour class entitled "Advanced Computer Architecture," which was carried not only to the usual MCNC microwave-supported sites but also to eight students at IBM via Instructional Television Fixed Service (ITFS) omnidirectional microwave.

A new software release for the Sitterson InteCom IBX switch brings with it an Open Application Interface (OAI) that will support direct attachment of external hosts to the call processing system of the IBX.

9600-bps modem service is now available for access to Sitterson Hall.

ANNUAL LETTER REPORT
FOR FISCAL YEAR 1987-88

Y2

The Infrastructure of Command Information Systems

Submitted to

Office of Naval Research
Arlington, Virginia 22217-5000

Submitted by

Department of Computer Science
The University of North Carolina at Chapel Hill
Sitterson Hall
Chapel Hill, North Carolina 27599-3175

Principal Investigators:

Frederick P. Brooks, Jr.
Jay Nievergelt
Donald F. Stanat

SEPTEMBER 1988

Contract No. N00014-86-K-0680

TABLE OF CONTENTS

1 Contract Title 1

2 Contract Number 1

3 Scientific Officer 1

4 Introduction 1

5 Scientific Goals, Significant Results, and Plans 1

5.1 Head-Mounted Display 2

5.2 Walkthrough 2

5.3 Pixel-Planes 5 Prototype 2

5.4 Temporal Databases 3

5.5 Full-text Retrieval 3

5.6 Tracking Machine 3

5.7 Expression Languages 3

6 Participants during FY 87-88 4

7 Other Sponsored Research 4

8 Electronic Mail Addresses: 4

Appendix I: Other Contracts and Grants during FY 87-88

Appendix II: List of Publications/Reports/Presentations

Appendix III: List of Awards

Appendix IV: Publications/Patents/Presentations/Honors Report

Appendix V: Four-part Foil and Project Foils, with Narrative

ANNUAL LETTER REPORT FY 87-88
ONR CONTRACT INFORMATION

1 Contract Title The Infrastructure of Command Information Systems

2 Contract Number N00014-86-K-0680

3 Scientific Officer Dr. Ralph F. Wachter, Computer Science Division, Office of Naval Research, 800 N. Quincy Street, Arlington, VA 22217-5000

4 Introduction

The ONR contract at the University of North Carolina is aimed at investigating fundamental issues in technologies associated with Command Information Systems. We are interested not in automatic systems, but systems in which the human decision-maker is a crucial part. Humans still excel in three kinds of processing:

- . pattern recognition
- . association of facts over a large context
- . judgments

while computers excel in:

- . data reduction
- . numerical calculation
- . high-volume data storage with precision

Good decisions require the use of both capabilities.

Research at the University of North Carolina in real-time interactive graphics is the basis for much of the work for the ONR contract. Three flagship projects of the Department have, with ONR support, progressed substantially and continue to show exceptional progress:

- . Head-Mounted Display
- . Walkthrough
- . Pixel-Planes

Additional research concentrates on providing suitable databases and retrieval systems for decision support, and in the area of parallel computing and languages:

- . Temporal Databases
- . Full-text Retrieval System
- . Tracking Machine
- . Expression Languages

5 Scientific Goals, Significant Results during FY 87-88, and Plans for FY 88-89:

Overall goal: To investigate fundamental issues in technologies of Command Information Systems, particularly:

- . human-computer interfaces
- . text and temporal databases
- . computer languages and architectures

5.1 Head-Mounted Display:

Objective:

Dynamic interaction with a virtual world seen in stereo from a view based on user's head position.

Significant progress in the past year:

Improvements in speed, image quality, and user-control.
Integrated with Pixel-Planes graphics engine.
Integrated with Walkthrough prototype.

Plans for next year's research:

Increase tracking reliability.
Implement tracking in large spaces.
Improve usability and user-interface.
Further improve speed, image quality, and update lag.
Integrate with data glove.

5.2 Walkthrough

Objective:

Real-time, interactive graphics system for prototyping building architectures and similar structures. Controls enable user to navigate within the structure; image is updated in real time.

Significant progress in the past year:

Integrated with Pixel-Planes to increase update rate to 15 fps.
Integrated Head-Mounted Display with treadmill interface.
Converted model-building and model-maintenance systems to Autocad.
Developed a double-wall model of Sitterson Hall
Developed a double-wall model of a second building.

Plans for next year's research:

Develop other user interfaces, e.g., bicycle.
Develop radiosity and texture models for improved images.
Implement cellular model to improve speed.
Model a third building.

5.3 Pixel-Planes 5 Prototype

Objective:

Development of massively parallel high-speed graphics engine using smart memory chips and small-grain VLSI.

Significant progress in the past year:

Integration of Pixel-Planes 4 with Walkthrough and Head-Mounted Display prototypes.
Detailed design of Pixel-Planes 5.

Plans for next year's research:

Completion of Pixel-Planes 5 with 20X speedup using modified SIMD architecture with some MIMD capability for increased algorithm generality..
Develop algorithms for solid volume rendering.
Improve usability.

5.4 Temporal Databases

Objective:

Development of database system capable of handling queries for various time concepts, including temporal indeterminacy.

Significant progress in the past year:

Completion and evaluation of the initial implementation of TempIS (Temporal Information System) and its graphical user interface.

Plans for next year's research:

Implement second generation TempIS based on a newly designed incremental architecture.

5.5 Full-text Retrieval

Objective:

Integration of an expert system and field-specific thesaurus to permit economical searches of full-text databases by unsophisticated users.

Significant progress in the past year:

Prototype expert system is complete.
Initial development of search strategies.

Plans for next year's research:

Refinement of search strategies.
Develop ranking system for responses.
Test system.

5.6 Tracking Machine

Objective:

Analysis of a tree architecture for tracking objects in multidimensional space.

Significant progress in the past year:

Simulation implementation on ADAS.

Plans for next year's research:

Refinement and testing of model.

5.7 Expression Languages

Objective:

Study of the linguistic basis for supporting scalable parallel architectures.

Significant progress in the past year:

Formulation of basic issues and concepts. Exploration of control vs. data parallelism.

Plans for next year's research:

Investigation of problems that can be programmed in a data-parallel language. Formulation of language constructs to support data parallelism.

6 Participants during FY 87-88:

ONR-URI Executive Committee:
Frederick P. Brooks*, Jr., Committee Chairman
Donald F. Stanat*, Technical Director
Jay Nievergelt*
Ralph Mason*

Other Faculty:
J. Dean Brock
Vernon L. Chi*
Peter Calingaert
James Coggins
Henry Fuchs*
Bharat Jayaraman
Gyula A. Mago'
David A. Plaisted
John Poulton*
Jan Prins*
John B. Smith
Richard T. Snodgrass*
Yuki Watanabe
Stephen F. Weiss

Vis. Faculty:
Hussein Abdel-Wahab

Staff:
Graham Gash, Software Manager*
Fred Jordan*, Electronics Technician
John Menges*, Communications Software Engineer
Steven Ornat*, Communications Hardware Technician
Raj Singh*, Project Management Engineer
Norman A. Vogel*, Director of Communications Research
Jeannie M. Walsh*, Administrative Coordinator
Sharon Walters*, Secretary (half-time)

RAs:
John Airey*
Edoardo Biagioni
Paulette Bush+
James Chung*+
Mark Davis* (Fellow FY 87-88, 88-89)
William Gallmeister+
Susan Gauch* (Fellow FY 88-89)
William Gibson+
Michael Kelley*
Marc Levoy (Fellow FY 87-88)
Richard Potter+
Penny Rheingans*
Frank Silbermann*
Robert Stam
Mark Surles
James Symon
Douglass Turner+

* *currently participating during FY 88-89*
\+ *M.S. Degree granted during FY 87-88*

7 Other Sponsored Research:

Other contracts and grants received by ONR participants during FY 87-88 are listed in Appendix I.

8 Electronic Mail Addresses:

Frederick P. Brooks, Jr.	brooks@cs.unc.edu
Donald F. Stanat	stanat@cs.unc.edu
Jeannie M. Walsh	walsh@cs.unc.edu

Research Overview

Background:

The ONR contract at the University of North Carolina is aimed at investigating fundamental issues in technologies associated with Command Information Systems. We are interested not in automatic systems, but systems in which the human decision-maker is a crucial part. Humans still excel in three kinds of processing:

pattern recognition,
association of facts over a large context, and
judgments

while computers excel in:

data reduction,
numerical calculation, and
high-volume data storage with precision

Good decisions require the use of both capabilities.

Scientific Goals:

To investigate fundamental issues in technologies of Command Information Systems, particularly:

- human-computer interfaces
- text and temporal data bases
- computer languages and architectures

Projects:

Research at the University of North Carolina in real-time interactive graphics is the basis for much of the work for the ONR contract. Three flagship projects of the Department have, with ONR support, progressed substantially and continue to show exceptional progress:

Headmounted Display
Walkthrough
Pixel-Planes

Additional research concentrates on providing suitable data bases and retrieval systems for decision support, and in the area of parallel computing and languages:

Temporal Data Bases
Full-text Retrieval System
Tracking Machine
Expression Languages

The University of North Carolina at Chapel Hill

The Infrastructure of Command Information Systems

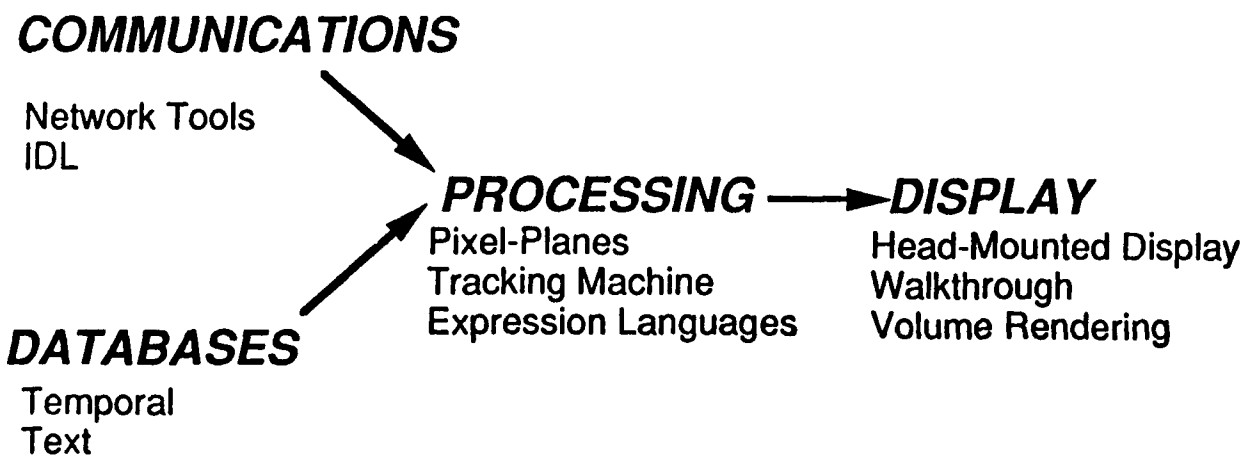
Scientific Goals:

To investigate fundamental issues in technologies of Command Information Systems, particularly:

- **human-computer interfaces**
- **text and temporal databases**
- **computer languages and architectures**

Information Display for Decision Making

The University of North Carolina at Chapel Hill



OBJECTIVE:

Interactive and real-time 2- and 3-D graphic displays of information for the support of decision making.

APPROACH:

Development of generalizable techniques in the context of vertically integrated application-driven projects, tested by real users on real problems.

'87 - '88 ACCOMPLISHMENTS:

Prototypes
- Head-Mounted Display
- Walkthrough System
- Pixel-Planes 5
- TempIS Temporal Database
- Full-text Retrieval System

Department Infrastructure
- CS Building Communications Networks

Tools Built
- IDL Programming Environment
- Volume Rendering Graphic Algorithms
- Object-oriented Image Processing Language

Head-Mounted Display

A head-mounted display (HMD) is a helmet-like device worn by the explorer of a virtual world. A 3-dimensional image is presented to the user using two screens built into the helmet. A similar system under development at NASA-Ames encloses the wearer's head so that he cannot see the real world. We feel that superimposing the virtual image on the real world makes using the device much less claustrophobic and also provides a real frame of reference for the virtual scene. (We might be wrong as to the best method, however, so we plan to try some tests to compare the approaches.)

One of our major goals is to incorporate the system into a molecular-modeling package that has been developed here, so that a chemist will be able to move about inside a room-filling molecule, grasp a piece of molecule with a data-glove, and manipulate the virtual structure as if it were a solid model.

This year's accomplishments:

This year we improved the head-mounted display system in image quality, function, and speed. Image quality was improved by

switching to a 320 x 220 resolution color screen,

developing an interface to the Pixel-Planes raster graphics system, and

algorithm refinement.

Currently the illusion suffers from a perceptible lag between when the head is moved and when the image is updated. This makes virtual objects swim about in space when they should appear to stay still. Even in this condition, the display appears to be useful, but update rate and lag remain the most difficult problems with the fidelity of the virtual-object illusion.

Plans for next year:

With the recent improvements in performance, we can at last begin application to virtual molecules, hung in space, that can be pointed to with a wand-controlled cursor. The cursor will be drug-shaped to simulate docking of molecules.

The tracking problem is by far the most serious of our technical problems. We will initiate work on optical trackers, and perhaps accelerometers, as alternates or supplements to the magnetic tracking used today. We are investigating schemes that may make tracking feasible in very large spaces rather than the cubic meter presently usable.

User interaction will be improved by the use of a data-glove sensor with its gesture libraries, and by harnessing our Votan spoken-command recognition system.

Head-Mounted Display:

Objective:

Dynamic interaction with a virtual world seen in stereo from a view based on user's head position.

Significant Progress in the past year:

1. Improvements in speed, image quality and user-control.
2. Integrated with Pixel-Planes graphics engine.
3. Integrated with Walkthrough prototype.

Plans for next year's research:

Increase reliability of tracking.

Implement tracking in large spaces.

Improve usability and user interface.

Improve speed and image quality.

Integrate with data glove.

Walkthrough - Exploring Virtual Structures

A virtual world computer graphics system allows real-time interaction with a 3-dimensional model world. The first versions of Walkthrough have as their goal a system for architects and clients to explore bulidings before they are built, so as to iteratively refine their specifications.

Most previous virtual world research at Chapel Hill has concentrated on molecular structure or anatomy. In neither of these applications do we know how the virtual world should appear to the viewer. In Walkthrough, on the other hand, the researcher can easily judge how closely the virtual world matches the real one in the ways that matter.

Any virtual world project must strive to improve in four aspects:

- Speed of image update
- Better appearance
- Providing an intuitive user interface
- Tools for building the model

We have accumulated a modest but adequate set of tools for building models of buildings; these are based on commercially available CAD software.

This year's accomplishments:

1. Integrated the system with Pixel-Planes to increase the image update rate to 15 cps. (Still much too slow, but a vast improvement over our first version.).

2. Improved the appearance by going from a 2-dimensional screen display to the stereo images available with the Head-Mounted Display.

3. Improved the user interface by integrating the system with a treadmill that allows the user to 'walk around' inside a building. This interface is not perfect ... steering is by an auxilliary device, and the user must walk straight ahead even while changing direction ... but it provides an added dimension of realism.

Plans for next year:

1. Exploring other user interfaces, such as a bicycle,
2. Getting better looking images by incorporating radiosity and texture information, and
3. Implementing a cellular model of space to reduce the information processed with each image.

Walkthrough:

Objective:

Real-time, interactive graphics system for prototyping building architectures and similar structures. Controls enable user to navigate structure; image is updated in real time.

Significant Progress in the past year:

1. Integrated with Pixel-Planes to increase update rate to 15 fps.

2. Integrated Head-Mounted Display for stereo image.

3. Integrated treadmill interface for navigation with Head-Mounted Display.

Plans for next year's research:

Develop other user interfaces, e.g., bicycle.

Develop radiosity and texture models for improved images.

Implement cellular model to improve speed.

PIXEL-PLANES: A Parallel Architecture for Raster Graphics

Pixel-Planes is a raster graphics system for high-speed rendering of 3D objects and scenes. It features a 'frame buffer' composed of custom logic-enhanced memory chips that can be programmed to perform most of the time-consuming pixel-oriented tasks in parallel at each pixel. The novel feature of this approach is a unified mathematical formulation for these tasks and an efficient tree-structured computation unit that calculates inside each chip the proper values for every pixel in parallel. The current system, Pixel-Planes 4 (Pxpl4), contains 512 x 512 pixels x 72 bits/pixel, implemented with 2,048 custom 3-micron nMOS chips (63,000 transistors in each, operating at 8 million micro-instructions per second). Algorithms for rendering spheres (for molecular modeling), for adding shadows, for enhancing medical images, and for rendering objects described by constructive solid geometry (CSG) directly from the CSG description have been devised by various individuals within and also outside our research group. The Pxpl4 system is in daily use in our department's Computer Graphics Laboratory, where applications in molecular modeling, medical imaging, and building architecture are being developed.

Accomplishments this year:

1. Pixel-Planes 4 has been integrated into the ongoing research projects of the Department, including Walkthrough and Head-Mounted Display.

2. Detailed design of the next Pixel-Planes machine was completed. This design promises greater speed and architectural enhancements that will allow, among other things, direct rendering of some curved surfaces.

Plans for next year:

Completion of Pixel-Planes 5, with perhaps 20x improvement in speed and various architectural enhancements that will allow, among other things, direct rendering of some curved surfaces.

Develop algorithms for solid volume rendering, a computation-intensive approach that makes it possible for the same scan data to provide a variety of views of the same object.

Improve the usability of the architecture so that it can be incorporated in a project by someone not familiar with the architectural details of the machine.

Pixel-Planes 5 Prototype:

Objective:

Development of massively parallel high-speed graphics engine using smart memory chips and small-grain VLSI.

Significant Progress in the past year:

1. Integration of Pixel-Planes 4 with Walkthrough and Head-Mounted Display prototypes.

2. Detailed design of Pixel-Planes 5.

Plans for next year's research:

Completion of Pixel-Planes 5 with 20X Speedup using modified SIMD architecture with some MIMD capability for increased algorithm generality.

Develop algorithms for solid volume rendering.

Improve usability.

Annual Report to the
Office of Naval Research
Arlington, Virginia 22217-5000
September 15, 1986 through September 14, 1987

Y1

The Infrastructure of Command Information Systems

Submitted by
Department of Computer Science
The University of North Carolina at Chapel Hill
Campus Box 3175, Sitterson Hall
Chapel Hill, North Carolina 27599

Principal Investigators:
Frederick P. Brooks, Jr.
Jay Nievergelt
Donald F. Stanat

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Table of Contents

1. Introduction 2

Table 1. Organisation of Clusters 2
Table 2. Principal Affiliations by Cluster 2
Table 3. Projects by Cluster 3

2. User Interfaces and Graphics Cluster 5

2.1 PIXAR Image Computer Development 5
2.2 Integrated Object-Oriented Environment for Image Pattern Recognition and Computer Graphics (COOL) 6
2.3 Symbolic Graphical Display 7
2.4 Walk-Through 7
2.5 Head-Mounted Display (Project Planned for Year 2) 8

3. Communications Cluster 8

3.1 Research Projects 8
3.1.1 Remotely Shared Workspaces for Distributed Collaborative Writing 8
3.1.2 Hypertext '87 Workshop 9
3.1.3 Systems Support for Remotely Shared Workspaces 10
3.1.4 Distributed Temporal Database 10
3.2 Education Projects 11
3.2.1 Tutorial on Communications Software, UNC-Chapel Hill, October 19-20, 1987 11
3.2.2 Softlab: An Educational Environment for Distributed Systems Implementation 12
3.2.3 Comp 243 — Projects Course on Distributed Systems 12
3.3 Infrastructure Projects 13
3.3.1 Installation and Tuning of an Advanced In-house Communications System 13
3.3.2 An Internet Name Server 13

4. Decision Support Cluster 13

4.1 Architectures 14
4.1.1 A Prototype FFP Machine 14
4.1.2 Fuzzy Logic Inference Engine 15
4.1.3 Computer with LO Context Switch time (CLOCS) 15
4.2 Languages 16
4.2.1 Declarative Languages and Implementations 16

Table of Contents

1. Introduction 2

Table 1. Organisation of Clusters 2
Table 2. Principal Affiliations by Cluster 2
Table 3. Projects by Cluster 3

2. User Interfaces and Graphics Cluster 5

2.1 PIXAR Image Computer Development 5
2.2 Integrated Object-Oriented Environment for Image Pattern Recognition and Computer Graphics (COOL) 6
2.3 Symbolic Graphical Display 7
2.4 Walk-Through 7
2.5 Head-Mounted Display (Project Planned for Year 2) 8

3. Communications Cluster 8

3.1 Research Projects 8
3.1.1 Remotely Shared Workspaces for Distributed Collaborative Writing 8
3.1.2 Hypertext '87 Workshop 9
3.1.3 Systems Support for Remotely Shared Workspaces 10
3.1.4 Distributed Temporal Database 10
3.2 Education Projects 11
3.2.1 Tutorial on Communications Software, UNC-Chapel Hill, October 19-20, 1987 11
3.2.2 Softlab: An Educational Environment for Distributed Systems Implementation 12
3.2.3 Comp 243 — Projects Course on Distributed Systems 12
3.3 Infrastructure Projects 13
3.3.1 Installation and Tuning of an Advanced In-house Communications System 13
3.3.2 An Internet Name Server 13

4. Decision Support Cluster 13

4.1 Architectures 14
4.1.1 A Prototype FFP Machine 14
4.1.2 Fuzzy Logic Inference Engine 15
4.1.3 Computer with LO Context Switch time (CLOCS) 15
4.2 Languages 16
4.2.1 Declarative Languages and Implementations 16

1 Introduction

The ONR-supported research project on Command Information Systems calls upon faculty, staff, and resources of the entire Department. In order to reacquaint the reader with the organisational management of research and support activities, we include Tables 1 and 2 (amended) from the semi-annual report.

Table 1. Organization of Clusters	
Clusters	Executive Committee
User Interfaces and Graphics	Frederick P. Brooks, Jr.
Communications	Jay Nievergelt
Decision Support	Donald F. Stanat
Management, Facilities, Laboratories	Ralph A. Mason

A "cluster" is defined as a set of interrelated research and/or support projects and is managed by one of the four members of the Executive Committee.

Table 2. Principal Affiliations by Cluster
User Interfaces and Graphics: Beard, Brooks, Coggins, Eyles, Fuchs, Piser Adjunct: Whitted
Communications: Calingaert, Menges, Nievergelt, Ornat, Smith, Snodgrass, Weiss, Vogel Adjuncts/Visiting: Abdel-Wahab, Marsland, Pitt
Decision Support: Brock, Halton, Hedlund, Jayaraman, Magó, Plaisted, Prins, Stanat, Tyagi, Watanabe
Management, Facilities, Laboratories: Chi, Core, Gash, Howell, Kusminski, Mason, Poulton, Singh, Walsh

Sections 2 through 5 describe the research, education, and infrastructure projects, organised by cluster, as well as the organisational and administrative activities of the first year of this grant (see Table 3). Please refer to the appendices for project narratives and for copies of related publications and reports.

Section 6 gives an overview of this year's site visits. Section 7 proposes members of the Program Advisory Panel to the Executive Committee, addresses mutual cooperation with NRL, and mentions our graphics lab open house.

Table 3. Projects by Cluster

User Interfaces and Graphics

- Pixar (Coggins, Brooks, Piser)
- COOL (Coggins)
- Symbolic Graphical Display (Snodgrass, Magó)
- Walk-Through (Brooks)
- Head-Mounted Display–Year 2 (Brooks)

Communications

- Research
  - Remotely Shared Workspaces for Distributed Collaboration (Smith, Weiss)
  - Hypertext '87 Workshop (Smith)
  - Systems Support for Remotely Shared Workspaces (Nievergelt, Abdel-Wahab)
  - Distributed Temporal Database (Snodgrass)
- Education
  - Conferences on Communications Software (Calingaert, Nievergelt)
  - Softlab: An Educational Environment for Distributed Systems Implementation (Snodgrass)
  - Projects Course on Distributed Systems (Brock)
- Infrastructure
  - Installation and Tuning of an Advanced In-house Communications System (Vogel)
  - An Internet Name Server (Menges)

Decision Support

- Architectures
  - A Prototype FFP Machine (Mago)
  - Fuzzy Logic Inference Engine (Watanabe)
  - Computer with LO Context Switch Time (Stanat)
- Languages
  - Equational Languages (Jayaraman, Plaisted)

Management, Facilities, and Laboratories

- Management
  - Financial Accounting
  - Personnel and Payroll Accounting
  - Equipment Purchases
  - Contract Negotiations
  - Patents and Copyrights
- Facilities
  - Computer Installation and Maintenance
  - Communications
  - Software Installation and Maintenance
  - Facilities Coordination
- Laboratories
  - Graphics and Imaging
  - Microelectronics Design
  - Microelectronic Systems
  - Communications
  - Natural Language and Text Processing
  - Software Systems

2 User Interfaces and Graphics Cluster

The Graphics Cluster has several projects in graphics and image processing. A unifying theme is that we test new ideas and technology by using them in systems for real applications, tested by real users. Most of our work emphasises real-time processing, and most is concerned with 3-D graphics.

The first project is concerned with installing, mastering, supporting, and exploiting a very powerful off-the-shelf image and graphics engine, the Pixar, loaned to us by Phillips Medical Systems, Inc. This gives us a powerful enhancement to our graphics infrastructure.

Professor Coggins has been overseeing the Pixar project and developing an object-oriented library to serve as a base for image pattern recognition research.

Professor Snodgrass has been exploring 2-D graphics for showing subtle relationships among abstract concepts, and for the contents of temporal databases.

Professor Brooks has a 3-D interactive system aimed at the rapid prototyping of buildings while still under design. This is almost up to the level necessary for testing with real architects. Its real-time nature pushes hard against many present boundaries in the graphics technology.

2.1 PIXAR Image Computer Development

Coordinator: James M. Coggins

Participants: Frederick P. Brooks, Jr., Stephen M. Piser

RA Participants: Russell Tuck, Robert Stam

Key Words: Pixar, SIMD architecture, image processing, graphics.

Objective: To develop software to incorporate the Pixar Image Computer into the graphics lab facilities; to teach potential users about the Pixar and its use.

Results to Date: *Machine administration.* The Pixar and its host Sun have been incorporated into the Department's network. *Product testing.* We are a beta test site for the Pixar Chap C compiler. *Data compatibility.* We have developed routines for converting image data produced elsewhere in the lab for use on the Pixar. *Software development.* COLORTOOL, a color design and matching tool, has been completed. Real-time 2-D Fast Fourier Transforms have been encapsulated and used in research software. An interface module between Chap C and microcode has been developed. *Education.* Two seminars on Pixar usage were held, resulting in increased usage of the system.

Expected Results: Further integration of Pixar into Department network; development of software to make Pixar a display server on the network. Software for object definition research involving continuous blurring. Development of medical imaging applications over next six months.

Related Presentations:

By: James Coggins
Topic: Object-Oriented Programming,
Computer Science Department
Place: Furman University, Greenville, SC
Date: October 16, 1987

By: James Coggins
Topic: Pixar Development Objectives
Event: First Pegasus Users Group Meeting
Place: Philips Medical Systems, Inc., Shelton, CT
Date: July 6-7, 1987

By: Russell Tuck
Topic: Pixar Development Progress
Event: Second Pegasus Users Group Meeting
Place: Philips Medical Systems, Inc., Shelton, CT
Date: October 6-7, 1987

By: James Coggins
Topic: Integrated Class Structures for Image Pattern Recognition and Computer Graphics
Event: First USENIX C++ Workshop
Place: Sante Fe, NM
Date: November 8-11, 1987

By: James Coggins
Topic: A Summary of C++ Applications Under Development at UNC-Chapel Hill
Event: First USENIX C++ Workshop
Place: Sante Fe, NM
Date: November 8-11, 1987

By: James Coggins
Topic: Object-Oriented Programming in C++
Event: IEEE Software Technology Conference
Place: Atlanta, GA
Date: November 12-13, 1987

2.2 Integrated Object-Oriented Environment for Image Pattern Recognition and Computer Graphics (COOL)

Coordinator: James M. Coggins

RA Participants: Bryce Tebbs, John Rohlf, Muru Palaniappan

Key Words: Image pattern recognition, software engineering.

Objective: Dr. Coggins joined the faculty one year ago. He has been supported by the ONR grant to reestablish his software tools for pursuing research in image pattern recognition.

The main objective has been to develop an object-oriented implementation of image pattern recognition strategies and simple computer graphcis tools.

Results to Date: The initial phase of tool development work is nearing completion; tools for image analysis, statistical pattern recognition, and simple computer graphics are now available in an integrated object-oriented environment in the C++ programming language.

Expected Results: With the object-oriented tools now available, Dr. Coggins' main research into object definition strategies has begun again. Experiments are under way to determine how objects in images can be represented and identified. In addition, investigation into the feasibility of object-oriented redesign of other tools in the Graphics Cluster are underway.

Related Presentations: please see Section 2.1.

2.3 Symbolic Graphical Display

Coordinators: Richard T. Snodgrass and Gyula A. Mag6

RA Participants: Tai-sook Han (summer, 1987)

Key Words: Temporal database, graphical objects, Interface Description Language.

Objective: This project involves two separate activities that intersect in providing support for displaying, in a graphical fashion, symbolic information which has no inherent graphical aspects. The first activity concerns the graphical display of temporal databases. The second concerns graphical display of IDL instances during programming environment development.

Results to Date: Only the first activity was pursued during the first year. We completed a prototype temporal database displayer and experimented with various representations of a temporal database containing information on the dynamic behavior of a simulator for the Mag6 FFP machine.

2.4 Walk-Through

Coordinator: Frederick P. Brooks, Jr.

RA Participants: John Airey, Curtis Hill (Sept. 1987 only), Penny Rheingans, Douglas Turner

Key Words: Interactive 3-D graphics, virtual worlds, building architecture, rapid prototyping.

Objective: To develop the real-time, interactive 3-D graphics techniques necessary to make a *rapid-prototyping system for building architecture*. The architect and his client use interactive controls to navigate, in real time, over a floor plan of a planned building. On a raster screen, they see a continuously updated shaded, lighted, perspective view of the building as viewed in the specified direction from the currently specified spot.

Results to Date:

1. We can now automatically partition building models into chunks that are mostly invisible from each other.
2. A 6-degree of freedom "Eyeball" control allows the user to control his viewing position and direction dynamically and naturally.
3. We can walk with 9-frames/second update—almost real time, using the UNC Pixel-planes graphics engine.
4. We can project the view on a 4' X 6' screen, with great improvement in naturalism.
5. We have installed Autocad on the Sun and are using it for building models.

Expected Results:

1. Twenty frames/second.
2. New interactive devices—treadmill or exercycle.
3. More buildings in database.
4. More realistic scenes.

Related Publication (see appendix):

Brooks, Frederick P., Jr., "Walkthough–A Dynamic Graphics System for Simulating Virtual Buildings," *Proceedings of the SIGGRAPH-NSF Workshop of 3-D Interactive Graphics*, 1986.

2.5 Head-Mounted Display (Project Planned for Year 2)

Coordinator: Dr. Frederick P. Brooks, Jr.

Participants: Henry Fuchs, Mark Harris, John Hughes, Michael Pique, Helga Thorvalsdottir

RA Participants: Jim Chung, Ouh-young Ming

Key Words: Head-mounted display.

Objective: To create a display and interaction system in which the scene from a virtual world is projected in stereo in the user's field of view, and the user's own movements control the display. We are concentrating in this project on the user's head movements; the display shows the view of the virtual world based on the position and orientation of the user's head.

This project will be the main thrust of this cluster's research during the next year.

Expected Results: Real-time motion (at least 20 updates per second) in stereo views of the virtual world. At present, we manipulate wire mesh models only; we hope to incorporate Pixel-planes to render more complex models as quickly. We intend to experiment with different interaction devices and methods, including a bicycle interface to move the viewpoint with head-mounted sensors for view orientation. We want the interaction to feel real and look real.

3 Communications Cluster

In 1985, the Department of Computer Science initiated a major new research area in the fields of in-house communications, communications software, and distributed systems. As an integral part of our new building, Sitterson Hall, we designed and installed an advanced voice/data and video communications plant. With support from ONR, we initiated major thrusts in research and graduate education to take advantage of the unique infrastructure we now have installed.

Our research focuses on systems support for real-time remote collaboration, and applications thereof, in particular to distributed temporal databases and team writing.

Our educational activities have resulted in starting an annual series of tutorial conferences in communications software, in conjunction with universities and industrial research labs in the Research Triangle. The first conference was held in October 1987 (see Section 3.2.1); the next one will be organised by North Carolina State University's Center for Research on Signal Processing. We have also developed a Projects Course on Distributed Systems, taught this fall 1987 semester by J. D. Brock. (See Section 3.2.3).

Further developments of the communications infrastructure in Sitterson Hall focus on video communication and interconnection of heterogeneous local area networks.

3.1 Research Projects

3.1.1 Remotely Shared Workspaces for Distributed Collaborative Writing

Coordinator: John B. Smith

Participants: Stephen F. Weiss, Gordon J. Ferguson

RA Participant: Yen-Ping Shan, Paulette Bush

Key Words: Collaborative writing, distributed systems.

Objective: Our long-term objective is to develop a system that supports collaborative writing by a group of widely distributed users. The system would then be used to study the collaborative process.

Doing this requires, first, that we extend the current, single-user writing system to accommodate a group of users. Second, we must design the remotely shared workspace, data structures, and communi-

cation techniques needed to support the collaboration. We must also develop a collaborative paradigm to manage the collaboration. And once the system is in operation, we must design and carry out experiments to evaluate system performance and, more importantly, to investigate the collaboration process.

Results to Date: We have developed, with support from NSF, ARI, and IBM, a prototype, single-user writing support system (called WE for Writing Environment). Under ONR support, we are extending WE toward our goal of a system to support remote collaboration. The first step is to translate WE from the prototype language Smalltalk to Objective C. So far, we have translated the underlying support functions and two of the four user modes. We expect to finish by early 1988.

Expected Results: We are just beginning to explore the shared visual space needed to support simultaneous collaborative writing. We expect to begin design of the support functions for both simultaneous and non-simultaneous collaboration next spring. ONR support will provide both equipment and personnel for this work.

Related Publications, Technical Reports (see appendix):

Smith, John B., Weiss, Stephen F., Ferguson, Gordon F. "A Hypertext Writing Environment and its Cognitive Basis," Technical Report TR87-033, University of North Carolina, Chapel Hill, October 1987.

Smith, John B., Weiss, Stephen F., Ferguson, Gordon J., Bolter, Jay D., Lansman, Marcy, Beard, David V. "WE: A Writing Environment for Professionals," Technical Report TR86-025, University of North Carolina, Chapel Hill, August 1986.

Related Presentations:

By: John B. Smith
Topic: Writing Environment
Event: National Computer Conference
Place: Chicago, IL
Date: June 15-18, 1987

By: John B. Smith
Topic: A Hypertext Writing Environment and its Cognitive Basis
Event: Hypertext '87 Workshop
Place: UNC-Chapel Hill
Date: November 13-15, 1987

3.1.2 Hypertext '87 Workshop

Coordinator: John B. Smith, workshop co-chairman

Participants: Stephen Weiss, program committee co-chairman; Jay Nievergelt, summariser; Frederick P. Brooks, Jr., invited speaker; Sandra Cunningham and Rebecca Highsmith, administrative assistants; with assistance from departmental support groups, as well as workshop assistance from several RAs.

Key Words: Hypertext, electronic document, multimedia systems.

Objective: To bring system developers, people interested in applications, and individuals concerned about issues raised by Hypertext from around the world to discuss common interests. (See Appendix I for information sheet.)

Results to Date: ONR support was used in planning the Hypertext '87 Workshop that will take place in Chapel Hill, November 13-15. The workshop has generated a great deal of interest and enthusiasm. More than 80 technical papers were submitted, and more people applied to attend than we could possibly accommodate.

3.1.3 Systems Support for Remotely Shared Workspaces

Coordinator: Jay Nievergelt

Participants: Hussein Abdel-Wahab

RA Participant: Sheng-uei Guan

Key Words: Remote real-time collaboration, interprocess communication.

Objective: Computer networks have been used mainly for file transfer and electronic mail—applications which are not subject to real-time constraints.

There is now increased research interest in remote collaboration where users at different locations operate on shared objects in "what you see is what I see" mode. In contrast to other work which focuses on special-purpose systems, we wish to show that remotely shared workspaces can be implemented efficiently on existing hardware and software systems.

Results to Date: A software package has been implemented using the UNIX Interprocess Communication facilities that turns any interactive single-user application into a multi-user tool.

Expected Results: Develop techniques for efficient implementation of remotely shared workspaces in heterogeneous networks. Demonstrate and test in prototype implementations.

Related Publications, Technical Reports (see appendix):

Abdel-Wahab, Hussein M., Guan, Sheng-Uei, Nievergelt, J. "Shared Workspaces for Real-time Collaboration in Distributed Networks: Concepts, Techniques, Problems," submitted for publication.

Abdel-Wahab, Hussein M., Guan, Sheng-Uei, Nievergelt, J. "A Prototype for Remotely Shared Textual Workspaces," submitted for publication.

Abdel-Wahab, Hussein M., "Experience with Berkeley UNIX Interprocess Communications," submitted for publication.

Staunstrup, Jorgen, Nievergelt, J. "The Behavior of Shared Objects: Concepts, Pitfalls, and a New Model," submitted for publication.

Related Presentations:

By: Hussein Abdel-Wahab
Topic: Remotely Shared Workspaces
Event: Communications Software Conference
Place: UNC-Chapel Hill
Date: October 19, 1987

3.1.4 Distributed Temporal Database

Coordinator: Richard Snodgrass

Key Words: Historical database, Quel, relational model, rollback database, temporal database, transaction time, valid time, concurrency control, recovery.

Objective: A temporal database management system (TDBMS) by definition must support both transaction and valid time. This project involves developing a formal model of temporal information and implementing a prototype TDBMS to investigate issues of performance and functionality.

Results to Date: See publications, listed below.

Related Publications, Technical Reports (see appendix):

Ahn, Ilsoo, Snodgrass, Richard. "The TempIS Project: Performance Analysis of Temporal Queries," TempIS Document No. 17, Department of Computer Science, University of North Carolina, Chapel Hill, August 11, 1987.

McKenzie, Edwin, Snodgrass, Richard. "An Evaluation of Historical Algebras," Technical Report 87-020, Department of Computer Science, University of North Carolina, Chapel Hill, October, 1987.

McKenzie, Edwin, Snodgrass, Richard. "Supporting Valid Time: An Historical Algebra," Technical Report TR87-008, Department of Computer Science, University of North Carolina, Chapel Hill, August 1987.

Snodgrass, Richard. "The TempIS Project: Current Status," TempIS Document No. 15, University of North Carolina, Chapel Hill, June 19, 1987.

Snodgrass, Richard, Gomes, Santiago, McKenzie, Edwin. "The TempIS Project: Aggregates in the Temporal Query Language TQuel," TempIS Document No. 16, Department of Computer Science, University of North Carolina, Chapel Hill, July 27, 1987.

Related Presentations:

By: Richard Snodgrass
Topic: Adding Transaction Time to the Relational Algebra
Event: ACM-SIGMod International Conference on Management of Data
Place: San Francisco, CA
Date: May, 1987

3.2 Education Projects

3.2.1 Tutorial on Communications Software, UNC-Chapel Hill, October 19-20, 1987

Coordinator: Peter Calingaert

Key Words: Communications software, tutorial. Message passing: design options, implementation. Remote procedure calls: design options, implementation, security. Communication system design principles, non-OSI architectures. Reliable group communication. Virtual shared memory as a communication paradigm.

Participants: Organized jointly with UNC-CH, North Carolina State University, Duke University, and IBM. Supported in part by ONR; co-sponsored by the IBM Corporation.

Objective: To increase awareness of and knowledge about fundamental issues in communications software design. (See Appendix I for information sheet.)

Presenters: F. Donelson Smith (senior programmer, IBM) on networking at Carnegie-Mellon University; J. Dean Brock (professor, UNC-CH) on distributed systems architecture; Robert B. Bailey (product manager, IBM) on networking management; Hussein Abdel-Wahab (professor, NCSU) on remote shared workspaces; T. Anthony Marsland (professor, University of Alberta) on distributed computation; James P. Gray (IBM Fellow) on SNA's distributed systems; Norman Vogel (director of communications, Comp. Science, UNC-CH) on the Sitterson Hall network; James Jones (system engineer, Southern Bell) on its installation; technical tour.

Results to Date: Approximately 100 participants from universities and practicing software engineers in the Research Triangle were in attendance.

3.2.2 Softlab: An Educational Environment for Distributed Systems Implementation

Coordinator: Richard T. Snodgrass

RA Participant: Vikram Biyani (fall 1987–spring 1988)

Key Words: Hardware simulation, compiler generation, intermediate representation, Interface Description Language.

Objective: SoftLab is a laboratory for software engineering education. It offers a collection of tools that support experimentation in software systems, specifically operating systems, programming environments, and database systems. The tools are programs that construct, manipulate, test, simulate, and display portions of a particular software system.

When completed, the laboratory will include tools to automate the construction of compilers. We are investigating these issues in the context of the Interface Description Language (IDL).

Another major tool of SoftLab is the reconfigurable hardware simulator, consisting of a collection of device simulators interacting through message passing.

Results to Date: We released Version 3.0 of the IDL Toolkit in March, 1987. This version is organised around an internal description of IDL called Candle. Naturally, Candle is also specified in IDL.

We have completed a Modula-2 compiler that generates Mcode, an Mcode linker, a program that produces core images for bootstrapping, and a CPU device module that executes Mcode.

Expected Results: We are working on adapting the implementation of an assertion checker to use Candle, and on adding Pascal support to the IDL translator.

We are debugging the CPU device module with a simple operating system written in Modula-2.

3.2.3 Comp 243 – Projects Course on Distributed Systems

Coordinator: J. Dean Brock

Participant: Sailesh Chutani

Participated in the Course: 35 students, as follows:

- 28 full-time graduate students in our Department
- 2 part-time graduate students in our Department, but also working in communications at IBM
- 5 "evening-college" (unadmitted) students:
  - 3 employed by MCNC
  - 1 employed by Data General
  - 1 employed by IBM (in communications)

Key Words: Distributed systems, communications education.

Objective: Comp 243 is a graduate-level course in distributed systems. Students are introduced to the protocols used in widely-used computer networks and then shown how computer operating systems can support these networks. Common paradigms for inter-machine communications, such as remote procedure calls, and important distributed applications, such as network file systems, are studied.

Expected Results: The students in Comp 243 are working on twelve communications-related projects. Among the projects are:

- An investigation of extensions to Modula/II to support inter-processor communication.
- A study of the contributions of the hardware and software of Sitterson Hall to inter-processor response time.
- Searching number spaces using a network of computers.

— A distributed scheduler to support parallel processing of a single task across several networked Suns.

In addition to providing some useful applications, the projects are also developing a great deal of local expertise in the construction of distributed applications.

Class projects will be presented at the end of the semester.

3.3 Infrastructure Projects

3.3.1 Installation and Tuning of an Advanced In-house Communications System

Coordinator: Norman A. Vogel

Participants: John Menges, Steven Ornat

Key Words: Network, integration voice/data communications, broadband, Ethernet, satellite communications, gateway, bridge, AppleTalk, PhoneNet, video conferencing, teleclassing.

Objective: To provide the communication systems infrastructure required for computer science graduate training and research.

Results to Date: The telecommunication construction contract with Southern Bell Advanced Systems, Inc., achieved "cut-over" on June 16, 1987. The installed communications system is in full use during the six month long "soak test". The target date for final acceptance is December 16, 1987. The InteCom Data-Voice switch and the fiber-optics based Ethernet systems are fully operational.

Expected Results: Additional network capability is being installed by University personnel. An AppleTalk/PhoneNet system which ties together all MacIntosh terminals and Laser Printers has been fully installed. A Kinetics bridge/gateway which internetworks PhoneNet and the building Ethernet system is being installed. A twelve video channel mid-split broadband system, an eight-station IBM token ring system, and a voice-directed eight-camera video conference facility are being installed. Sitterson Hall networks have been interconnected to the University of North Carolina's broadband system and the MCNC statewide microwave network.

3.3.2 An Internet Name Server

Coordinator: John Menges

Key Words: Nameserver, Arpanet.

Objective: To link to Arpanet via TUCC, the Triangle Universities Computer Center; the Arpanet name server will insure smooth and efficient interconnection of our Ethernet with Arpanet.

Results to Date: The implementation of a local name server for the Internet is nearly complete. There are still a few minor problems that we want to resolve before we are ready to take over the name server function for our local domain.

Expected Results: We expect to complete this project by December 1987.

4 Decision Support Cluster

The Decision Support cluster emphasizes research in areas that will support the computational aspects of decision making. This includes special- and general-purpose languages and machines. It is our belief that successful architectures of the future will be language-based; that is, they will be designed to exploit and

accommodate features of a language that is itself chosen to make programming (either general or special purpose) more tractable.

Our special emphasis has been on declarative languages and parallel architectures that will support them. A secondary emphasis is that of more modest but novel architectures, such as ones to support rule-based systems using fuzzy logic, and an architecture for fast context-switching.

The language aspects of our work include a number of deep mathematical areas, such as theorem proving, programming with sets, and logic programming, all of which are particularly amenable to parallel processing if suitable computational paradigms are developed. We are pursuing a spectrum of topics in this area, ranging from theoretical investigations to the implementation of a new general-purpose language.

We are actively working on the design and implementation of several machines. The Microelectronics Center of North Carolina, located in the nearby Research Triangle Park, provides an excellent environment and support for the VLSI design aspects of the architectures on which we are working, and the Microelectronic Systems Laboratory, one of our departmental facilities, is actively participating in the design and construction of two of these machines.

4.1 Architectures

4.1.1 A Prototype FFP Machine

Coordinator: Gyula A. Magó

RA Participants: Will Partain, William Gibson, Eduoardo Biagioni

Key Words: Small grain parallel architectures, declarative programming.

Objective: To develop a small grain asynchronous parallel machine that uses a high-level declarative machine language.

Results to Date: A small grain parallel machine has been designed. It uses Backus's FFP language as its machine language. The machine consists of a binary tree of processors of two types. In cooperation with the Institute of Biomedical Computing of Washington University, we are in the process of developing the specifications for the two processors. Because the machine is inherently asynchronous, the specifications must be given with great care. The design has been supported by ONR and various other sources. Major funding was received from NSF late last summer to get the machine implementation started.

Expected Results: After specifications are complete and have been approved by Washington University, we will proceed with designing VLSI implementations of the two processor types and the chips that will hold them.

Related Publications (see appendix):

Magó, G. A., Stanat, D. F. The FFP Machine. A chapter of a forthcoming book: *High Level Language Computer Architectures*, edited by V.M. Milutinovic, to be published by Computer Science Press.

Magó, G. A., Partain, W. "Implementing dynamic arrays: a challenge for high-performance machines." *Proceedings of the Second International Conference on Supercomputing*, Santa Clara, CA, May 3-8, 1987.

Magó, G. A., Middleton, D. "The FFP Machine—A Progress Report." *International Workshop on High-Level Computer Architecture 84* (Los Angeles, California, May 23-25, 1984). (Reprinted in *Dataflow and reduction architecture* by S.S. Thakkar, IEEE Computer Society Press, 1987, and in *Computer architecture* by D.D. Gajski, V.M. Milutinovic, H.J. Siegel, and B.P. Furht, IEEE Computer Society Press, 1986, pp. 456-468.)

Magó, G. A. "Making parallel computation simple: the FFP machine." Digest of Papers, *IEEE Computer Society COMPCON* (Spring 1985), pp. 424-428. (Reprinted in *Computers for artificial inteiligence applications* by Benjamin Wah and G.J. Li, IEEE Computer Society Press, 1986, pp. 324-328.)

Magó, G. A. "A cellular computer architecture for functional programming." Digest of Papers, *IEEE Computer Society COMPCON* (Spring 1980), pp. 179-187.

Magó, G. A. "A network of microprocessors to execute reduction languages." Two parts. *International Journal of Computer and Information Sciences* 8, 5 (1979), pp. 349-385, 8, 6 (1979), pp. 435-471.

4.1.2 Fuzzy Logic Inference Engine

Coordinator: Hiroyuki Watanabe

Participants: Wayne Dettloff (Microelectronics Center of North Carolina–MCNC)

RA Participant: James Symon

Key Words: Fuzzy logic, VLSI, expert system, process control

Results to Date: The CMOS full custom design of the inference machine is almost complete. The VLSI chip is designed for MCNC 1 micron n-well CMOS technology and consists of approximately 614,000 transistors. A single chip can store and execute up to 102 control rules. Operational speed is expected to be 40MHz and 645,000 fuzzy inference per second. We are testing correctness of design by simulation, and we are developing a software support system for testing our chip after fabrication. This software is also useful as a base for development environment for control rule set.

Expected Results: The chip will be integrated on a single board system with a standard bus interface to an available personal computer (IBM PC/AT) or a workstation (Sun). The chip, a host computer, and software support system together constitute a general-purpose fuzzy controller for real-time application.

Related Publication (see appendix):

Watanabe, Hiroyuki, "Fuzzy Logic Inference Processor for Real Time Control: A Second Generation Full Custom Design," to appear in *Proceedings of IEEE 21st Annual Asilomar Conference on Signals, Systems, and Computers*, November 2-4, 1987 (Co-sponsored by IEEE and Naval Postgraduate School).

Related Presentations:

By: Hiroyuki Watanabe
Topic: Fuzzy Logic
Event: MCNC VLSI Design Seminar Series,
Place: MCNC, Research Triangle Park, NC
Date: March 1986.

By: Hiroyuki Watanabe
Topic: Fuzzy Logic
Place: Department of Information Science, University of
Tokyo, Japan
Date: June 11, 1987

By: Hiroyuki Watanabe
Topic: Fuzzy Logic
Place: Ricoh Central Research and Development Laboratory, Yokohama, Japan
Date: June 22, 1987

4.1.3 Computer with LO Context Switch time (CLOCS)

Coordinator: Donald F. Stanat

RA Participants: Mark C. Davis, Bill O. Gallmeister

Key Words: Microprocessor, real time, general purpose.

Objective: The CLOCS project will design a computer architecture and operating system that will switch context (change executing tasks) up to 10,000 times faster that current designs.

Results to Date: Progress to date includes forming two research teams of graduate students. The main team consists of Davis and Gallmeister who are working on the computer's architecture and design of the operating system to run on it. The second team consists of three unsupported students in an advanced compiler course who are writing a C language compiler for the computer.

Expected Results: Simulations of the CLOCS architecture and operating system will show the ability of CLOCS to support many applications that current design computers cannot run.

4.2 Languages

4.2.1 Declarative Languages and Implementations

Coordinators: Bharat Jayaraman and David A. Plaisted

RA Participants: Gopal Gupta, Amos Omondi, Frank Silbermann

Key Words: Functional and logic programming, equations, sets, sequential and parallel execution.

Objective: To develop a practical, declarative language suitable for symbolic computation and multiprocessor execution. Existing languages, such as LISP and Prolog, have too many imperative features to be considered 'declarative'; furthermore, they cannot fully take advantage of the parallelism offered by multiprocessor systems. We seek to combine the capabilities of LISP and Prolog in a declarative language based on equations and sets.

Results to Date: We have developed a language called EqL which provides the capabilities of first-order functional and Horn-logic programming. The declarative semantics of EqL is based on the notion of complete set of solutions, and the computational paradigm of EqL is equation-solving. We completed a sequential interpreter for EqL in May 1987 and will soon distribute it to a number of sites. (Our first user was Prof. Valdes Bersins at the Naval Postgraduate School) Our first version, which was not specially fine-tuned, runs about half as fast as C-Prolog on Vaxes and Suns.

We have also been developing a language called SEL (Set-Equation Language) which allows David Turner's set-abstraction construct to be specified more declaratively. A SEL program is a collection of equation and subset assertions. In SEL, we can also declaratively specify many programming paradigms of Prolog, including uses of the 'cut' and 'setof' constructs. We are at present implementing a sequential interpreter for SEL.

Expected Results: Our next step is to integrate the capabilities of EqL and SEL. We would like to define sets as the collection of solutions arising from EqL-like equation-solving, and also support higher-order functions. The net result would be a declarative language with good expressiveness, yet retaining potential for highly efficient implementation.

One of the benefits of SEL is that and- and or-parallelism is much more tractable than for Prolog. Also, formulating problems in terms of sets rather than lists gives more parallelism, because elements of the set can be produced in parallel. We would like to demonstrate these benefits through an actual parallel implementation. We have already started developing conceptual techniques for the parallel implementation of SEL and EqL.

Related Publications, Technical Reports (see appendix):

Jayaraman, B. "Semantics of EqL," Invited paper for a special issue of *IEEE Transactions on Software Engineering*, to appear, March 1988.

Jayaraman, B., Gupta, G. "EqL: the language and its implementation," submitted to *IEEE Transactions of Software Engineering*, September 1987, 32 pages.

Jayaraman, B., Plaisted, D. "Functional Programming with Sets," *Third International Conference on Functional Programming Languages and Computer Architecture*, Portland, OR, September 1987, pp. 194–210.

Jayaraman, B., Gupta, G. "EqL User's Guide," Technical Report TR87-010, Department of Computer Science, University of North Carolina, Chapel Hill, May 1987 (revised September 1987).

Jayaraman, B. Gupta, G. "Parallel Execution of an Equational Language," *1986 Graph Reduction Workshop*, Santa Fe, proceedings published by Springer-Verlag, October 1986, LNCS Vol. 279.

Jayaraman, B., Silbermann, F. S. K., Gupta, G. "Equational Programming: a Unifying Approach to Functional and Logic Programming," *Proceedings of the 1986 International Conference on Computer Languages*,, Miami Beach, October 1986, pp. 47-57.

Jayaraman, B., Silbermann, F.S.K. "Equations, Sets, and Reduction Semantics for Functional and Logic Programming," In *Proceedings of 1986 ACM Conference on LISP and Functional Programming*, M. I. T., August 1986, pp. 320-331. Magó, G. A. "A network of microprocessors to execute reduction languages." Two parts. *International Journal of Computer and Information Sciences* 8, 5 (1979), 349-385, 8, 6 (1979), 435-471.

Related Presentations:

By: Bharat Jayaraman
Topic: Parallel Execution of an Equational Language
Event: Graph Reduction Workshop
Place: Santa Fe, NM
Date: September 28 - October 2, 1986

By: Bharat Jayaraman
Topic: Equational Programming: A Unifying Approach to
Functional and Logic Programming
Event: International Conference of Computer Languages
Place: Miami Beach, FL
Date: October 26-28, 1986

By: Bharat Jayaraman
Topic: Functional Programming with Sets
Event: 3rd International Conference on Functional Programming
Languages and Computer Architecture
Place: Portland, OR
Date: September 14-16, 1987

5 Management, Facilities, and Laboratories Cluster

The contract with the Office of Naval Research demands full-time management of both personnel and facilities to insure optimization of existing resources. Mrs. Jeannie Walsh is the administrative assistant to the Executive Committee and as such performs the necessary personnel and financial management duties. Laboratory and facilities management is the responsibility of the laboratory directors who report to Ralph Mason for overall coordination.

5.1 Management

5.1.1 Personnel

Eight new positions were created during the first year (see p. 1, Semi-annual Report, January 1987). Since January, two additional vacancies were filled: Sharon Core filled the half-time position of Secretary IV, and Raj Singh was hired as Project Management Engineer.

The Department is fortunate to have hired two additional faculty members (funded by the State)—bringing our total full-time faculty to 22. Jan Prins brings to us the experience in program specification and correctness which he gained at Cornell and Wisconsin; Akhilesh Tyagi from the University of Washington adds to our expertise in VLSI and computer architecture.

Table 4 below lists the names of research assistants supported by ONR during the first year.

Table 4.
Research Assistants Supported by ONR During Year 1

J. Airey	H. Lander	J. Symon
E. Biagioni	M. Levoy	M. Surles
P. Bush	S. Molnar	B. Tebbs
K. Clapp	R. Potter	R. Tuck
M. Davis	P. Rheingans	G. Turk
D. Ellsworth	D. Schiff	D. Turner
W. Gallmeister	K. Shannon	L. Westover
W. Gibson	F. Silbermann	B. White
E. Grant	S. Southard	M. Winslett
R. Holloway	R. Stam	

5.1.2 Travel

Appendix IV includes all travel funded (fully or partially) by the Office of Naval Research during the first year.

5.2 Facilities

5.2.1 New Building

The Department's physical resources have changed significantly since it moved into its new home, J. Carlyle Sitterson Hall, during July 1987. The new $10 million, 74,000 square foot building, dedicated on University Day, October 12, was designed to provide sophisticated communication support for the Department's research programs. The building provides space for offices, two teleclassrooms, several conference areas, and devotes nearly 10,000 square feet to its six major laboratories (see Section 5.3 below). The building is equipped to switch video and integrated voice-data signals and is wired with fiber optic and coaxial cables, in addition to the cooper plant, to provide state-of-the-art communications. All of the Department's major computing resources are accessible from anywhere in the building through six separate local area networks that are themselves connected by a high-speed digital switch.

The Department's general computing facilities include one 16-MB VAX-11/785, one 4-MB VAX-11/780, one 8-MB VAX-11/750, one 10-MB DG-MV/10000, a Sun-4 compute server, eight Sun file servers, more than 60 Sun Microsystems workstations with the Network File System (NSF), and more than 50 other workstations and personal computers. These machines are supported by over 13 gigabytes of on-line disk storage, and an assortment of high-speed dot matrix printers through typeset quality laser printers.

5.2.2 Equipment Report

Please refer to Appendix III for the report of equipment purchased during the first year, 15 September 86 through 14 September 87.

5.2.3 Software Installation and Maintenance

At the time of this report, all Sun workstations have been upgraded to the Sun Version 3.3 UNIX Operating System. The Department VAXES are presently being upgraded to Berkeley 4.3 UNIX with the Sun Network File System (NFS). The Department has been a beta test site for MAC II software and is currently beta testing the MAC II A/UX, an Apple UNIX product.

5.3 Laboratories

5.3.1 Graphics and Imaging Laboratory

Specialized image-generating systems include the unique UNC Pixel-planes machine (27,000 rendered polygons/second), a 4-processor Pixar, an Evans and Sutherland PS-300 color vector system, a Vector-General 3300 vector display, a varifocal mirror true-3D display, and two Adage Ikonas 3000's, each with a high-precision Tektronix 690 SR monitor. Each display, including projected video, can be viewed in stereo via Tektronix liquid-crystal shutters.

The image-generators are hosted and supported by a dedicated Vax-11/780, a Sun-4 file server, a color Sun-3, three monochrome Sun-3's, two color Masscomp 5500 workstations, and more than four gigabytes of disk storage. All raster display and some vector display can be converted to NTSC for recording or display on a Barcodata precision video projector.

5.3.2 Microelectronics Design Laboratory

The Microelectronics Design Laboratory (MDL) is a facility for the design and simulation of MOS integrated circuits. The laboratory contains four VAXstation GPX color workstations and two color Sun-3 workstations. All workstations have 8-MB of main memory and floating point accelerators. Additional equipment includes a Sun-4 file server, a Vax-11/750, more than three gigabytes of disk storage, and a Hewlett Packard plotter. MDL is networked via a high speed microwave link to two Convex mini-supercomputers at the Microelectronics Center of North Carolina. Each Convex has 64-MB of main memory, and they are used for design simulation and testing.

5.3.3 Microelectronic Systems Laboratory

The Microelectronic Systems Laboratory (MSL) provides facilities for the rapid prototyping of large scale, high-performance VLSI systems. It supports architectural research by fabrication of prototypes based on custom designed VLSI chips. A full-time staff of ten enables the laboratory to implement functioning systems of significant size and complexity, containing hundreds or thousands of custom VLSI circuits designed in-house.

State-of-the-art equipment allows in-circuit real-time diagnostic probing of IC's using SEM E-beam technology, fabrication of dense, high-performance thick-film mutilayer hybrid circuit modules, and integration of chip, module, and board design. Coordinated design and test tools as well as computer controlled fabrication equipment provide the ability to produce prototypes of entire systems with extremely fast turn-around.

The MSL has nearly $2M of major capital equipment as well as an extensive inventory of engineering stock, hand tools, and plant facilities such as plant air, vacuum, and chemical fume hood.

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5.3.6 Software Systems Laboratory

SoftLab is a software laboratory, similar in concept to a physics or chemistry laboratory. This laboratory consists of a collection of tools that support experimentation in software systems, specifically operating systems, programming environments, and database systems. The tools are programs that construct, manipulate, test, simulate, and display portions of a particular software system.

6 Site Visits

6.1 May 27, 1987

The following individuals from the Office of Naval Research visited the Computer Science Department on May 27: Dr. A. F. Norcio, Computer Scientist, Computer Science & Systems Branch, NRL, and Scientific Advisor, Computer Science Division, ONR; Dr. Ralph Wachter, Program Manager, Computer Science Division, ONR; Mr. Stanley H. Wilson, Head, Computer Science & Systems Branch, Information Technology Division, NRL.

Each member of the ONR Executive Committee gave an overview of his respective cluster; cluster participants presented their project reports; demonstrations were provided where appropriate; and guests were taken for a tour of the new Computer Science building. Please see Appendix V for complete agenda.

Finally, members of the ONR site visit team:

- provided positive feedback relating to the Computer Science Department's research efforts;
- discussed their need for software engineering security systems;
- invited a group of our faculty/students to their facility this fall and the A7 Project class next spring;
- discussed the June 18-19 meetings of URI Principal Investigators in Washington, DC;
- stated their desire for mutual cooperation between NRL and the Computer Science Department on human-factors research (please see Section 7.2);
- suggested that the Department establish a videoconference link with NRL;
- invited the Department to suggest possible members of the Program Advisory Panel (see Section 7.1).

Jay Nievergelt invited NRL members to provide the Department with specific applications with regard to the remote graphical workspace project, along with some of their current technologies (see Section 7.2).

6.2 July 8, 1987

Dr. Charles Holland, Science Officer, Office of Naval Research, visited the Department on July 8. He was provided with detailed information required for financial reporting purposes (Walsh); heard progress reports from each Principal Investigator (Executive Committee); listened to presentations about the new communications plant (Vogel) as well as the distributed temporal database project (Snodgrass) and the COOL project (Coggins); observed a demonstration of the remotely shared textual workspace project (Abdel-Wahab) and various Graphics demonstrations; and was given a tour of the new building.

Dr. Holland also suggested the implementation of an ONR fellowship program for our outstanding Ph.D. students. We have chosen two advanced Ph.D. students as departmental ONR fellows:

> Mark Davis (Decision Support Cluster): His Ph.D. thesis, supervised by F. P. Brooks, Jr., involves the design of CLOCS, a computer with low context-switching time.
>
> Marc Levoy (Graphics Cluster): His Ph.D. thesis, supervised by H. Fuchs, is on rendering volume elements without imposing any surface artifacts.

The next site visit is planned for Spring 1988.

7 External Contacts

7.1 Program Advisory Panel

The following individuals have agreed to serve on the Program Advisory Panel to the Executive Committee. They will be invited to participate at the next site visit, subject to the approval of Dr. Charles Holland.

All clusters:

Mr. Stanley Wilson
Head, Computer Science & Systems Branch
Information Technology Division
Naval Research Lab
Code 5590
4555 Overlook Avenue, SW
Washington, DC 20375-5000

User Interfaces and Graphics:

Dr. Andries Van Dam
Department of Computer Science
Brown University
Providence, RI 02912

Communications:

Dr. Edward H. Sussenguth
IBM
P. O. Box 12195
Research Triangle Park, NC 27709

Decision Support:

Dr. Bruce MacLennan
Department of Computer Science
University of Tennessee
Knoxville, TN 37996

7.2 Mutual Cooperation with NRL

Some NRL researchers will participate at the UNC Hypertext Conference (see Section 3.1.2) and explore possible cooperation with our TextLab researchers.

NRL plans to bring us into contact with some avionics software experts so that Dr. James Coggins might use this topic as a case study in his software engineering course during spring 1988.

7.3 Graphics Open House

The Department plans to host demonstrations in its new graphics laboratory during an open house to be held immediately after the 1988 SIGGRAPH Conference in Atlanta next summer.

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User Interfaces and Graphics Cluster

Faculty Research Initiation Support

Dr. Coggins, an expert in image pattern recognition, joined the UNC faculty in the fall of 1986. Dr. Coggins brought with him a research methodology and software tools developed over the last ten years. Unfortunately, the software was incompatible with the UNC computing environment. Thus, Dr. Coggins faced a massive rewriting effort to make his tools available for further research. About the same time that he arrived at UNC, the Department obtained a compiler for the recently-developed object-oriented programming language C++. Dr. Coggins worked on learning C++ and led efforts by several graduate students to develop an object-oriented implementation of his image pattern recognition strategies. This effort is nearing completion, and tools for image analysis, statistical pattern recognition, and simple computer graphics are now available in an integrated object-oriented environment.

With the object-oriented tools now available, Dr. Coggins' main research into object definition strategies has begun again. Experiments are under way to determine how objects in images can be represented and identified. Several preliminary problems of increasing complexity are driving this effort. The easiest driving problem is recognition of certain geometrical shapes. Further problems in increasing difficulty are recognition of printed English characters, recognition of printed Tamil characters (Tamil is an Indian dialect with a large, highly structured alphabet), identification of cells in a microscope image, and identification of organs in a computed tomography image.

Dr. Coggins has also established contacts in the Departments of Opthalmology and Pathology where other kinds of image analysis problems are waiting to be solved. These problems include 3-D modelling of the surface of the cornea, stereo image analysis and subsequent measurement of the optic disk, and automatic segmentation of 2-D and 3-D electron microscope images.

Dr. Coggins has also guided the development of the Pixar Image Computer as a research tool. This work is described in another section.

PIXAR Image Computer Development

The Pixar Image Computer and its host, a Sun-3 workstation, were installed in the Department's graphics lab in mid-May. A team consisting of Dr. James Coggins, a faculty member, and Robert Stam and Russell Tuck, graduate students, began work immediately to explore the Pixar's capabilities and make them available to other members of the Department. Two members of this team had previously traveled to Pixar's headquarters for a three-day course on programming the Pixar.

This team's work can be divided roughly into six categories. These include: machine administration, product testing, data compatibility, software development, education, and research.

Machine administration included integrating the host into the departmental network, which provides disk and printer sharing, electronic mail, and daily disk backups. Software from Pixar and CEMAX was installed, as were subsequent updates to that software. The host had inadequate disk space, so some software and data were migrated to another machine and are now accessed through the network. Access permission to proprietary Pixar and CEMAX software was restricted to authorised users in accordance with our obligations to those companies. Continuing tasks include adding users, installing software updates, and making weekly backup copies of disk storage.

In order to improve our software development productivity, we applied for and were granted status as a beta test site for Pixar's Chap C compiler. As part of this arrangement, we have found, reported, and in some cases fixed problems in this compiler and related libraries.

Image and graphics data in the Department are stored in two data formats. An important early task was to make it possible to use the Pixar on data stored in these formats. We wrote a program to load data from one of these formats into the Pixar, and one of the first users we trained in Pixar programming wrote a similar program for the other image format. These conversion programs make it possible for existing Pixar software to operate on our data. The Pixar demonstration software was augmented to use local data.

The team has developed other software in addition to these conversion programs. An interactive program called "cclortool" was written in microcode (before the C compiler was available) to allow users to explore easily the vast selection of colors (more than 8 billion) representable on the Pixar. A variety of color models

are supported, and the host window system and Pixar processor and display are closely integrated. This tool has been used by other projects in the Graphics Cluster to select realistic colors for rendering a variety of objects.

Another software development effort involved the real-time 2-dimensional Discrete Fourier Transform microcode inside one of the Pixar demonstration programs. This code can also do filtering and convolution in real time. These operations are important to image processing research in the Graphics Cluster and take minutes to compute on other available machines, rather than a fraction of a second. In order to make this code accessible to researchers, code was written in microcode and C to encapsulate the important operations performed by the demonstration program. The result of this work is that programs written in C and running on the host or the Pixar can invoke these operations with a simple subroutine call.

An important role of the team has been to educate users in the Graphics Cluster. One focus has been to demonstrate the Pixar's capabilities, so users whose needs can be met by the Pixar are aware of this. Self-guided demonstrations have been made available to all users in the Graphics Cluster, and the team has given many narrated demonstrations and descriptions of the Pixar's capabilities. The second, complimentary function has been to teach interested people how to use existing software and how to program the Pixar to do new things. Early users were taught individually. A four-hour mini course which is just finishing has given twenty individuals an introduction to Pixar software and programming. The team will continue to be available to answer questions and provide additional guidance to these users.

Work with the Pixar is part of ongoing research projects. Dr. James Coggins' work in image processing will utilize the real-time filtering and convolution software described above. Russell Tuck expects to use the Pixar as a test case in his work on programming machines with SIMD parallel architectures. Bobby Stam plans to make some of the Pixar's capabilities available from any machine on the network. The team has also communicated with other researchers. We received software from Mallinckrodt Institute through direct interaction with their researchers. A team member participates in each Philips Pegasus Project users group meeting, where ideas, experiences, and software are exchanged.

Head-Mounted Display (Year 2)

Ming, Hughes, and Pique fabricated a prototype using two Casio tiny TV's, half-silvered mirrors, the Polhemus sensor, and the PS300 as an image-generator. Pique and Thorvaldsdottir took the head unit prototype to the May meeting of the Molecular Graphics Society in France.

Work has concentrated on calibration and on speeding up the Polhemus sensing loop. We are getting 4-10 updates/second and must achieve 20 updates/second to achieve steady, realistic virtual objects. Getting to 20 updates/second requires meticulous, detail-by-detail engineering of the whole system. We are getting closer month by month by switching from ASCII to binary transmission, moving calculation of matrices downstream to the faster machine, using faster PS300 GSR subroutines, etc. The next effort is to get 19,200 baud transmission working.

Meanwhile, we have started fabricating a second-generation display, using Seiko color TV's with about two times the former resolution.

Decision Support Cluster

Computer with LO Context Switch Time (CLOCS)

Many applications need computers that can switch tasks quickly. Real-time systems require physical events to be serviced rapidly before the next event. General-purpose operating systems need many processes to handle a multitude of background activities. Current computer architecture emphasize throughput at the expense of response time for context switching. Our project will design a microprocessor that will switch context fast enough for the applications mentioned in the main report, and the design will have throughput performance comparable to current designs.