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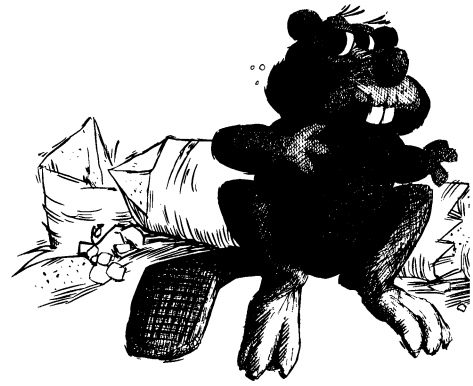

Project ARIES
A Network for Convenient Computing in Education

D. D. Cowan
T. M. Stepien

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A Network

for

Convenient Computing in Education

D.D. Cowan and T.M. Stepien

Computer Science Department
and
Computer Systems Group
University of Waterloo
Waterloo Ontario Canada
N2L 3G1
Telephone D.D. Cowan 1-519-888-4467

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DRAFT

ABSTRACT

Microcomputers have become a significant component in the educational toolkit used by students in post-secondary institutions. As computer applications in education continue to grow, we should expect to find microcomputers installed in classrooms, laboratories, libraries, and residences throughout the university. This level of convenience and accessibility implies a campus-wide "integrated" computing and communications system, an obvious duplication of facilities, and significant costs for universities.

Project ARIES - the University of Waterloo Portable Computing Project- involves the development of an experimental computing and communications system for education in which we attempt to address these issues within the bounds of today's university budgets.

Groups of students are now being equipped on an experimental basis with portable computers which can be carried easily between classes. Students can fill their portable computers with software and data from Transaction Ports on a campus-wide local area network, and then do their computing wherever and whenever it is convenient. It is expected in the future that this mode of computing will handle a large percentage of the computing tasks normally encountered in an undergraduate program.

A description of the uses of microcomputers in education, the rationale behind Project ARIES, the underlying local area network structure, and the current experiments with portable computers are described.

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INTRODUCTION

Computers have become a significant component in the educational toolkit used by students in post-secondary institutions, and microcomputers especially are starting to rival the book, the pencil, and the calculator in importance. As computer applications in education continue to grow, the microcomputer will need to be as convenient to use as these other essential tools, and as a consequence we should expect to find microcomputers installed in classrooms, laboratories, libraries, and residences throughout the university.

This level of convenience and accessibility implies a campus-wide "integrated" computing and communications system, and an obvious duplication of facilities, so that faculty, staff and students may use a computer whenever and wherever such use is appropriate, a situation which might be called "computing on demand".

Such exciting prospects for growth and integration raise many interesting questions:

- Where will schools obtain resources to finance the purchase of all the necessary computing equipment, and to replace it as technology advances?
- Where will space be found to house the equipment?
- How will schools support all the ancillary services associated with computers such as maintenance, communications and air conditioning?

This paper describes Project ARIES - the University of Waterloo Portable Computing Project. Project ARIES involves the development of an experimental computing and communications system for education, in which we attempt to address the previous questions within the bounds of today's university budgets. In order to motivate the rationale behind Project ARIES a brief survey of some of the current uses of the microcomputer in education is also presented.

RATIONALE - MICROCOMPUTERS IN EDUCATION

Microcomputer technology is changing rapidly and so any notion of the microcomputer's role in education should be viewed as being evolutionary. Microcomputers provide certain capabilities which will expand as the power, capacity and capability of the microcomputer increase and its size and price decrease. Hence any discussion of the role of the microcomputer in education must be viewed in the context of the current technology [1].

Almost any characterization of the functions of the microcomputer in education is certainly not mutually exclusive, furthermore it represents only one way of categorizing this topic. Thus in the educational process, microcomputers currently could be viewed as filling the following roles:

i) as a productivity tool for both students and teachers,

ii) as a device for communication and sharing information,

iii) and as an object of study.

The first two uses of the microcomputer shown in the list are ones that might be found in most academic units of the University and probably represent a large percentage of microcomputer usage. The third role

can be viewed in two contexts: the first in the perspective of social science as an object which has impact on society and the individual during work and leisure; the second in the perspective of the fields of Computer Science and Computer Engineering. The first two uses will generate most of the microcomputer applications in the university and determine the infrastructure needed to support these activities.

In the following sub-sections we discuss briefly each of these educational functions of the microcomputer. In this way we continue to develop the thesis that microcomputers are a very important educational tool, and thus we motivate the need for a computer and communications system as exemplified by Project ARIES.

Microcomputers as Productivity Tools

It appears to be well accepted that the microcomputer is an excellent general-purpose productivity tool for both teachers preparing educational materials and students doing the resulting assignments. There are numerous contemporary generic software programs including writing aids such as word processors and text formatters, spelling checkers, and thesauri; calculation aids such as spreadsheets, statistical packages and charting programs; and information management tools such as data-base systems and application development packages; and design and drawing packages which can assist the student in undertaking a range of academic tasks.

Writing Tools: The use of computer-based writing aids enables the student to concentrate on the content rather than devoting energy to the appearance of the finished document.

Calculation Tools: Because of their automatic calculation capability many packages such as spreadsheets make excellent tools for simulating experiments and for checking postulates (so-called "what-if" questions). The ability to make complex statistical calculations rapidly enables a student to concentrate upon the meaning of the data rather than constantly checking for arithmetic errors.

Information Management Tools: Information management tools allow the student to develop personal information systems and to analyze data created by the student or provided by the teacher. These programs can also be used by students to prepare and maintain bibliographic and biographic information which can be used in conjunction with written reports and essays. Such programs also enable students to maintain, organize and retrieve course notes, literature abstracts, and a variety of informational materials.

Graphics Software: Microcomputer design and drawing packages enable students to have access to a host of graphic tools for preparation of assignments which require graphic presentation in such areas as fine arts, architecture, and engineering. Concepts which do not lend themselves easily to textual forms may be represented in a graphic format.

Discipline-related Software: A substantial amount of discipline-related software is also available including: music editors, poetry parsers, molecular modelling programs, and anatomical analysis programs to name a few examples.

Microcomputers as a Communications Devices

The microcomputer in conjunction with modem communications technology provided by both campus networks and the common carriers is an effective communications mechanism. It is intended that the network support provided by Project ARIES will further enhance this capability.

Electronic Distribution Systems and File Transfer: Teachers may send assignments, lecture and laboratory notes, data bases and many other types of teaching materials to students by depositing these materials in a central file-server. These "notes" may be made generally available to a class or sent to a restricted group. The students may then make electronic and/or printed copies of these notes for their personal use. Such mechanisms are often called bulletin boards or electronic distribution systems.

Students may reverse the process described in the previous paragraph and send assignments to the teacher electronically for detailed criticism, discussion and marking. Such electronic transmission minimizes the time needed to return such documents to the student.

Electronic Mail: Electronic mail systems are a special version of the electronic distribution systems just described. These systems allow private communication between individuals and between individuals and groups.

Conferencing Systems: Conferencing systems are another effective means of group communication using the computer. All messages sent to a conferencing system are time-stamped and displayed on an electronic bulletin board in different categories, and messages placed on the board can never be removed. Users of the conferencing system can scan the board for information and/or place their own queries and responses on the board.

Access to Other Computers: Finally, the microcomputer can be programmed to act as a terminal thus allowing the student or teacher to "communicate" directly with another computer such as a large mainframe. Such communication will allow access to large-scale software which may not be available on current models of microcomputers.

Microcomputers as Objects of Study

The microcomputer can also be an object of study in its own right. Students can study the many different application programs now available, and thus become more knowledgeable users of the computer. They can also study Computer Science, the implementation and analysis of algorithms.

The microcomputer can also serve as the subject of social, psychological, and philosophical study for students in various disciplines as they observe the impact of microcomputers on society and the individual in different geopolitical and socioeconomic situations.

PROJECT ARIES - THE PORTABLE COMPUTING PROJECT

Background

Recent advances in computing technology have produced lap portable computers which can easily be carried by the student and used almost anywhere. These portable computers are approximately the same price and have the same power and capacity as the desktop microcomputer, but are much smaller and lighter. With the same capability as the desktop microcomputer, the portable can support many of the applications found in most undergraduate programs, thus making Alan Kay's Dynabook at least a partial reality [10] [11]. Rooms full of workstations and microcomputers throughout the campus may not be necessary; students could carry their own computer between classes thus eliminating the need to duplicate many of the computer facilities on campus.

Availability of portable computers raises some further interesting questions:

- How are machine-readable materials such as applications software, data, and assignments distributed to students?
- How do students obtain access to different types of output devices such as laser printers?
- How do students and teachers communicate with each other, and obtain access to mainframe computers which may house large data bases, the library catalog, or extensive teaching software?

In other words, ***"Can portable microcomputers be turned into fully functional portable workstations and be effectively integrated into existing and future campus communications and computer systems?"***

Project ARIES - The University of Waterloo Portable Computing Project - has been created to examine this and related questions [8]. There is currently a network at the University of Waterloo which allows students to use portable computers as functioning portable workstations. Students plug their portable computer into one of several Transaction Ports on the network, and then transfer software and data to their computer, print files, send and receive mail, or store their work on file-servers. Once these transactions are complete, and the students have any new mail, assignments, and applications software, they disconnect and do their computing at any convenient time or location.

Soon the Project ARIES network will be connected to the university's other networks and the public data network, to provide access to all university computing resources from locations both on and off-campus.

Of course, the ultimate goal is to make "computing on demand" as convenient as possible. Students will not be constrained by a wired network but will be able to use wireless technology. Initial research indicates that experiments with wireless data communications on the Waterloo campus may be only two or three years in the future.

The remainder of this section describes the current Project ARIES network, some future plans for expansion, and the experiences with the network and the portable computers.

A Network for Portable Computers

Experiments with networks and network services for portable computers have been conducted at the University of Waterloo since 1984. The next sub-sections provide details of the computers being used, the user interface and services provided, the current network, and future plans for the network. A diagram depicting the current network configuration is shown in Figure 1. As the network evolves it is expected to support a wide-ranging heterogeneous educational computing environment.

Since the portable computers are supported by network services, they can more accurately be described as portable workstations and this term will be used in the rest of this paper.

The Portable Workstations: The current experiment is using 310 Hewlett Packard Portable Plus Computers and 40 IBM PC Convertibles which are distributed to various student groups around the University.

The Hewlett Packard Computers have 512K bytes of memory, a 25 by 80 monochrome screen, and weigh about 4.5 kilograms. The operating system is MS/DOS 2.1. These computers do not have a built-in diskette drive, and so usually half the memory is configured as an electronic disk. This computer also has two communication interfaces, an asynchronous communications port and an HPIL interface. The HPIL interface is similar to a serialized version of the GPIB or IEEE 488 protocol [9]. and can transmit and receive data at about 10K bytes per second.

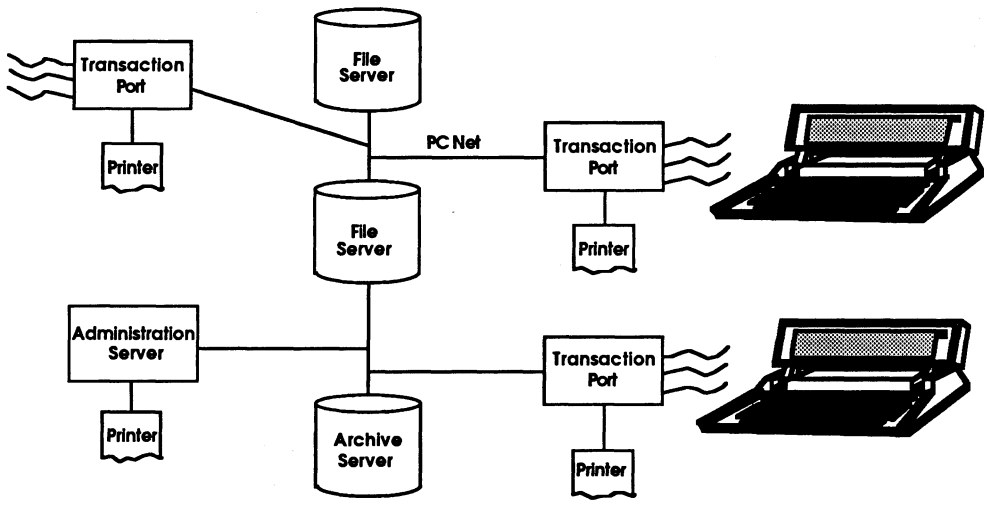

Figure 1. Project ARIES Network Configuration

The IBM Convertibles have 512K bytes of memory, a 25 by 80 monochrome screen, 2 720K-byte, 3.5-inch built-in diskette drives, and weigh about 5 kilograms. PC/DOS 3.2 is the operating system. This computer also has an asynchronous communications port as its communication interface and by suitable programming the interface can transmit and receive data at about 10K bytes per second.

The User Hardware Interface: There are currently nine (9) Transaction Ports on the University of Waterloo campus where users can obtain services. These Ports are at widely distributed points around the campus within an area of approximately 150 acres (61 hectares).

Each Transaction Port consists of a complete microcomputer with a keyboard, a screen, a printer, and a system unit containing 512K bytes of memory, an Intel 80286 CPU and both a 5.25 and 3.5 inch diskette drive. As well, the system unit contains an adapter card for a network connection and a number of adapter cards with attached cables for both asynchronous (RS232) and HPIL communications.

Users may take their portable computers to a Transaction Port to transfer data between the Port and the computer. This data may then be either transferred into the network or displayed on the printer attached to the Port. Users who have computers which are not portable may bring a diskette to the Port and obtain the same services.

A user approaches the Port, and either attaches the portable computer to the adapter cards using the cables, or inserts a diskette into the diskette drive. Services are then obtained by using the keyboard and screen attached to the Port. From the user's perspective the Transaction Port is similar to a banking machine; the user plugs in the portable computer, provides identification, and obtains a number of services.

Data enters the Transaction Port from the network at an effective rate of 50K bytes per second and is transferred to the portable through the HPIL or asynchronous interface at 10K bytes per second. This speed is comparable to the transfer rate of a 5.25 inch diskette drive and has been found by the users to be reasonably satisfactory.

The next section describes the services currently available to the user through the user interface.

The User Software Interface and User Services: After connecting the portable computer or inserting a diskette, the user obtains services by activating commands which appear as menus on the screen at the Transaction Port. These menus define the services that are currently available from the network. These services include: authentication and authorization, file transfer (including electronic mail and printing a file), directory access and maintenance, and tailoring the user interface to the user's computer and operating system. A description of some of these services is presented in the next few paragraphs.

The authentication service is similar to the logon procedure on any shared-resource computer system. Execution of a logon command with a userid and password authenticates the identity of the user, authorizes access to the user's file space, and presents a menu appropriate to the user's portable computer. Once access to the personal file space is permitted, other services such as accessing other file spaces, become available. These additional services may also require a second level of authorization.

The current file space provided to the user is identical in appearance to any MS/DOS or PC/DOS file system. A user has access to a number of directories (usually labelled A:, B:, C:, D:, E:, F:, G: and H:, although more directories can be created), each one of which supports a tree-structured file system; these directories emulate the diskette structure of the DOS file system. Even though the underlying file system is totally tree-structured, the extra level of structure is imposed to provide transparency to the users of the current portable computers. In effect the file system has facilities which have goals similar to NFS [22].

There is also an archive system which provides for file backups. Periodically the archive system checks all file spaces and copies any files which have been changed since the last archiving operation. The archiving system thus allows recovery from either a system failure or a user error.

The mail system must provide for the fact that the portable workstation is not always connected to the network. All outgoing mail is placed in an out-basket in the workstation's local file-space, and when the workstation is connected to the network the mail in the out-basket is sent, and any incoming mail is placed in the workstation's in-basket. This system allows the user to process mail while disconnected from the network.

Administering the Network: One workstation is permanently attached to the network as an administrative-server. Functions such as the operation of the archive-server, and the creation, deletion, or renaming of accounts and directories are usually performed from the administrative-server. All these activities can be performed while the network is fully operational. The administrative software is only available in the administrator's file space, and requires authorization through a password before use.

The Current Underlying Network: The current Project ARIES network consists of nine Transaction Ports, two file-servers with a total of 80M bytes of disk storage, an archive-server, and an administrative-server. The Ports and the servers are interconnected with Physical and Data-Link Layers consisting of PC Network running on a broad-band cable. The network can also contain gateways which allow the interconnection of several LANs, although no gateways are installed at present. The remainder of the description of the Project ARIES network is loosely based on the Open System Interconnection (OSI) Model [18], [21].

PC Network is a broadband network using a carrier-sense multiple-access collision-detection protocol (CSMA/CD) [15]. The interface between the Network and Data-Link Layers is designed so that the Network Layer is independent of the Data-Link Layer. This independence feature allows different Data-Link Layers to be used in the Project ARIES network without affecting any of the software running in the upper five layers of the network (Network, Transport, Session, Presentation and Application). Although the Project ARIES network is currently using PC Network for the Physical and Data-Link Layers, other network types such as Token-Ring [16], and the IBM PC Network Baseband [13], have been substituted on an experimental basis and have operated quite successfully.

The Network Operating System: It was our intention in designing the Network Operating System to use existing software wherever possible. Such a design has a number of advantages:

i) minimal manpower is needed to develop and maintain the network software,

ii) the network can be easily kept current with the the latest advances in operating systems,

iii) most of the network operating system is commercially available and hence could be easily adopted by current users.

Each Transaction Port, server and gateway runs the most current available version of MS/DOS or PC/DOS. This base operating system is modified with a kernel containing a real-time scheduler which provides fast context-switching so that the software on these computers may be process-based. The processes communicate by passing messages and use a model similar to the one used in Thoth [3], [5], MINIX [19], or V kernel [4].

A process-based operating system permits processes to be loosely coupled thus allowing the network to be expanded or contracted easily. New Ports, servers and gateways have been added to the network in less than an hour as long as cabling for the network was accessible. Although the network currently in operation at Waterloo is campus-wide, it can be configured to any size. Even a single machine version of the network has been constructed for demonstration purposes.

The next few paragraphs describe how a message is sent between a sending and receiving process.

For a sending process S to send a message to a receiving process R, S must know the entire address of R, and R must be running on a computer in the network. The address could be either obtained through a name-server or could be a fixed value on a given LAN. The address of a process follows the conventions used in the IEEE 802.2 Logical Link Control address format [14], and consists of the route, destination and source addresses and the destination and source service access points. The route represents the addresses of the LANs interconnected by gateways, the destination and source addresses represent the addresses of a workstation or server in a LAN, and the destination and source service access points are the addresses of the sending and receiving process in a workstation or server. Normally, a sending process S in the Application Layer communicates with a receiving process R in two steps:

i) the sending process S spawns a Transport Layer process P_1,

ii) and S sends a message to the receiving process R by a procedure call with three parameters, namely the name of P_1, the address of R and the text of the message.

Since R is running and expecting messages, it will have spawned a Transport Layer process called P_2 (similar to P_1) which will receive messages sent from S, and any other processes communicating with R.

As messages are sent to P_1 in the Transport Layer, they are divided into packets, the packets are sequence-numbered, the address of the receiving process is appended to each packet, and the packets are then sent to the Network Layer. Upon reception at P_2 in the receiving Transport Layer, the packets are reassembled in the correct sequence, the address is removed, and the entire message is passed to the receiving process. The network currently implements a datagram service, since the Transport Layer is responsible for packetizing and re-assembling, as well as re-transmission and acknowledgement of messages.

The Network Layer has a switch process which incorporates IEEE 802.2 dynamic routing. The switch communicates with a process which passes information to the Data-Link Layer for transmission over the network. A single workstation or file server would only have one such process, while a gateway would have one process for each connected LAN. The process which connects the Network Layer and the Data-Link Layer adds any information needed to send the message over the network, and is the process which must be replaced when a different Data-Link Layer is installed.

Expansion of the Network Services

Since this is a research project on heterogeneous computing environments to support convenient educational computing, there are still many services and network functions which need to be explored. The next few paragraphs present some of the future direction for the Project ARIES network.

Users of text-processing software are beginning to expect high-quality laser-printed output whenever they print a document. For this reason it will be necessary to provide laser printers at each Transaction Port. However, the cost of laser printing is too expensive to be absorbed in a university budget, and so mechanisms must be in place for users to prepay for printing on unattended laser printers. Experiments are being conducted with various techniques such as debit cards, and bar-code readers to provide users with a method of authorizing the release of their printing and the charging of their "accounts".

Currently, users of portable workstations only have access to the facilities of the Project Aries network. The University of Waterloo has many other networks such as TCP/IP, DECNET, Localnet 20, and RSCS which provide access to most of the other computing facilities on campus. In turn, these other networks are connected to various wide-area networks which provide access to world-wide communication facilities. Research needs to be conducted in providing uniform portable interfaces between the Project Aries network and these other networks. At present we are implementing file-transfer capabilities between the Project ARIES network and DECNET, and also bisynchronous communication to RSCS.

At the present time, users can only access the Project Aries network on the campus of the University of Waterloo. This is a serious shortcoming, since a large number of the students do not live on campus, and the University also supports a very large distance-education program. The Project Aries network will be expanded to support off-campus computing uses; students will be able to access the network through the Canadian Datapac system using such services as iNet 2000 [20]. Students in the distance-education program will also have access to a conferencing system to provide better communication between the faculty and their fellow students.

Experience With Portable Computing

Experiments with the use of portable computers in education were initiated at the University of Waterloo in September 1985. The portable computers have been used in over 30 courses including ones in Biology; Chemical, Civil, Mechanical, and Systems Engineering; Chemistry; Computer Science; Environmental Studies; Leisure Studies; and Physics. Varied activities have been undertaken particularly in the area of simulation, text processing, data bases, numerical analysis, programming and logic programming. Translators for languages such as Basic [12], Fortran-77 [7], Pascal [2], and Prolog [6], have been used as well as applications software for text processing [17], and data bases [23], design packages and spreadsheets.

The response from the faculty and students using the portable computers and the network has been quite enthusiastic. Assessment of the system is determined by random in-depth interviews with the students and faculty and by a detailed questionnaire which is completed by each student at the end of the term in which they participated in the experiment.

These experiments with a network for portable computers solve many of the problems of duplication of facilities and communication with the users. But the university will still have to purchase the portable computers initially and replace them as they become obsolete. If students perceive that the network services to support the computers are adequate, then they may purchase a portable for the convenience of having their own computer.

The capital cost of computing will be transferred to the student, the consumer of education. Obsolescence of this type computing equipment will no longer be an issue, since the University will not have the responsibility of replacement.

Experience with the Project ARIES Network

The initial network configuration developed and installed at the University of Waterloo has been a success, but there are a number of issues which must be addressed in the continuing development of the system. Some of the more important issues are briefly examined in the remainder of this section.

As the network and user base expand we must be constantly aware of the need for new applications, user services, and network technologies . For example, our current limited experience has already caused us to use three different strategies for network technology and forced a complete redesign of the user interface. These significant changes had to be made so as to minimize the interference with the users.

Network management and administration have been continuing issues which must be addressed. We have had to institute daily operational policies which provide the services for the user and these will continue to evolve as the user community continues to grow. Also planning for development and installation of new and extended services is a serious problem. Developing satisfactory methods for interconnecting with other networks and converting the Project ARIES network to new network technologies must also be addressed.

The Project ARIES network is an experiment but in order to address the issues properly we must work with a large community of active users with all the attendant problems. Every indication is that the experiment has been well received and that the network will become a standard production service in the near future, but we will continue to do research on the issues already mentioned.

SUMMARY

A brief description of the use of microcomputers in education is given at the beginning of this paper. In the second half of the paper Project ARIES - the University of Waterloo Portable Computing Project - is described in which it is planned to build networks and software so that students at the University of Waterloo may use powerful portable microcomputers (sometimes called lap portables) anywhere on or off the campus and yet have access to extensive software and data, high-speed and high-quality printers, and centralized personal file-storage.

The primary function of the network will be to allow students to obtain software and data, to put their completed work into permanent mass storage or onto "hard-copy output devices, and to communicate with their peers and the faculty. The project will initially use wired local- and wide-area networks but as the project progresses it is anticipated that many of the functions will be provided through various types of wireless communication. The combination of portable computers and easy access to various computing services through networks will allow students to use the computer whenever and wherever it would be a suitable tool.

In the near future, a different model of educational computing may appear. Students will provide their own portable computer to perform many of the computing tasks needed in a modern undergraduate program, while the university will provide the specialized computational resources such as large mainframes and design stations, and the network to interconnect both these computing resources and the fully functional portable workstations.

BIBLIOGRAPHY

1. Avedon, E. et al. *Student-Owned Microcomputers - Issues and Implications.* Waterloo Ontario Canada: University of Waterloo, 1987

2. Boswell, F.D. Grove, T.R. Mackie E.W. *WATCOM Pascal Primer and Reference Manual.* Waterloo Ontario Canada: WATCOM Publications, 1985 ISBN 0-919884-84-9

3. Cheriton, D.R. *Multi-Process Structuring and the Thoth Operating System* Waterloo Ontario: Computer Science Department University of Waterloo, 1979.

4. Cheriton, D.R. *The V Kernel: A Software Base for Distributed Systems* IEEE Software, April 1984, pp 19-42.

5. Cheriton, D.R. Malcolm, M.A. Melen, L.S. and Sager, G.R. *Thoth, A Portable Real-Time Operating System* Communications of the ACM Vol. 22, No. 2, February 1979, pp 105-115.

6. Clark, K.L. McCabe, F.G. *micro-PROLOG Programming in Logic.* Englewood Cliffs, New Jersey: Prentice Hall, 1984 ISBN 0-135812-64-X

7. Coschi, G. Schueler, J.B. *WATFOR-77 Language Reference Manual.* Waterloo Ontario Canada: WATCOM Publications, 1984 ISBN 0-919884-90-6

8. Cowan D.D., Fenton S., Graham J.W., Stepien T.M. *Networks for Education at the University of Waterloo,* Computer Systems Group University of Waterloo, Waterloo Ontario Canada: June 1987. "Submitted to Computer Networks and ISDN Systems"

9. Fisher, E. and Jensen, C.W. *PET and the IEEE 488 Bus (GPIB).* Berkeley California: OSBORNE/McGraw-Hill, 1980 ISBN 0-931988-31-4

10. Goldberg, Adele *Educational Uses of a Dynabook* Computers in Education Vol. 3, Great Britain: Pergamon Press Ltd, 1979, pp 247-266.

11. Goldberg, Adele *Introducing the Smalltalk-80 System* Byte Vol. 6, No. 8, August 1981, pp 14-26.

12. Graham, J.W. McPhee, K.I. Welch, J.W *WATCOM BASIC Primer and Reference Manual.* Waterloo Ontario Canada: WATCOM Publications, 1983 ISBN 0-919884-18-0

13. IBM *PC Network Baseband Adapter Technical Reference.* IBM Corp., 1987

14. IEEE *ANSI/IEEE Std 802.2-1985 ISO/DIS 8802/2.* 345 East 47th Street New York NY 10017: IEEE, 1985 ISBN 0-471-82748-7

15. IEEE *ANSI/IEEE Std 802.3-1985 ISO/DP 8802/3.* 345 East 47th Street New York NY 10017: IEEE, 1985 ISBN 0-471827-49-5

16. IEEE *ANSI/IEEE Std 802.5-1985 ISO/DP 8802/5.* 345 East 47th Street New York NY 10017: IEEE, 1985 ISBN 0-471829-96-X

17. Mackie, E.W. *Waterloo Word Processor User's Guide for the IBM PC.* Waterloo Ontario Canada: WATCOM Publications, 1986 ISBN 0-919884-65-2

18. Tanenbaum, Andrew S. *Computer Networks.* Englewood Cliffs, New Jersey: Prentice Hall, 1981 ISBN 0-131651-83-8

19. Tanenbaum, Andrew S. *Operating Systems Design and Implementation.* Englewood Cliffs, New Jersey: Prentice Hall, 1987 ISBN 0-13-637406-9

20. Telecom Canada *The Solution to Information Management iNet 2000 The Intelligent Network.* Telecom Canada 1985

21. Voelcker, J. *Helping computers communicate.* IEEE Spectrum March 1986, pp61-70, IEEE, 1986

22. West, Anthony *The Sun Network File System - Business Overview.* Mountain View California: Sun Microsystems Inc.,

23. Wilkinson, Terry *WATFILE/Plus Data Manipulation System Tutorial and Reference.* Waterloo Ontario Canada: WATCOM Publications, 1986 ISBN 0-919884-59-8