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Research Reports 1988 (May to August)

CS-88-22 - MODELS AND ALGORITHMS FOR RACE ANALYSIS IN ASYNCHRONOUS CIRCUITS

ABSTRACT:

This thesis addresses the problem of analyzing asynchronous sequential circuits. Our first contribution is a unified mathematical framework which enables us to derive a theory applicable to gate circuits, as well as to the more modern MOS circuits. We then study the behaviour of asynchronous circuits using the abstract framework together with several different delay and race models.

The first race model developed is the "extended multiple winner" (XMW) model in which each logic component has an arbitrary finite delay. For this model we prove that the set of state variables used to analyze a circuit can be reduced to a minimal set of feedback variables, without any loss of state transition and hazard information. (This contrasts sharply with previously known models.) Secondly, we prove that ternary simulation (which is very efficient) yields the same results as the XMW analysis (which is intractable).

The XMW model is closely related to delay-independent circuits, i.e. to circuits that operate correctly, no matter what the component delays are. Using the XMW theory, it is shown that the class of delay-independent circuits is quite small, and that many common sequential behaviors cannot be realized delay-independently. The main reason for this is the unrealistic assumption that component delays can be arbitrary.

To overcome the limitations of the XMW model, we derive two race models that are more realistic. The "almost-equal-delay" model makes the somewhat idealized assumption that all component delays are approximately equal. The "extended bounded-delay" model assumes that each delay is bounded by a lower and an upper limit. These intuitive notions are formalized, and practical algorithms are developed for race analyses using these models.

Finally, we derive a number of complexity results for the race analysis problem using different delay models.

AUTHOR: Carl-Johan Henry Seger

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CS-88-23 - PATTERN MATCHING IN TREES

ABSTRACT:

This thesis examines a tree automata approach to tree matching problems. This approach is motivated by the finite automata approach which has been very successful in designing string matching algorithms. In particular, we show how the KMP algorithm can be generalized to give tree matching algorithms which preprocess the pattern tree. We also define structures for trees which are analogous to suffix tries and DAWGs for strings and show how they can be used for tree pattern matching. Additionally, we explore some other approaches to tree matching problems.

AUTHOR: Peng Li

PRICE:$5.00

CS-88-24 - CONSISTENCY AND SATISFIABILITY OF WAVEFORM TIMING SPECIFICATIONS

ABSTRACT:

Manufacturers often use digital waveforms to specify critical device timing. In this paper we study two problems related to the use of such specifications. First, we are interested in verifying that the timing information is consistent to begin with. Second, given waveform specifications of two devices which are to be linked, we wish to know whether one satisfies the other's timing requirements. We construct a model of the timing information conveyed by the waveform convention, and show how both problems can be solved efficiently with optimization techniques. To illustrate our arguments, we compare the write cycle timing of a typical CPU with that of a RAM device.

AUTHORS: J. A. Brzozowski, T. Gahlinger, F. Mavaddat

PRICE:$2.00

CS-88-25 - THE ThUMS PROJECT: IMPLEMENTING USER SPECIFIC RESPONSES TO AN EDUCATIONAL DIAGNOSIS SYSTEM

ABSTRACT:

This report describes how the capability to support user specific responses was added to an expert system constructed to diagnose a student's learning disabilities.

Our task was to develop a prototype implementation of the Computer Guided Diagnosis (CGD) expert system which could combine information on a user's goals and background in the generation of a response. Our solution involves an architecture which separates the expert system and user modelling components, and a control algorithm which co-ordinates the information from both components in order to prepare a response. In addition, we suggest a particular implementation of the user model using Theorist, a system for diagnosis and default reasoning being developed at the University of Waterloo.

AUTHORS: A. Sanmugasunderam, B. Spencer, R. Cohen

PRICE:$2.00

CS-88-26 - SPACE BOUNDS FOR SELECTION

ABSTRACT:

We present several algorithms for selecting the kth smallest element from a multiset of n elements in linear time using only a constant amount of additional space. In particular, we show that $8.8256n + o(n)$ comparisons are sufficient to perform the selection if all elements are distinct, $9.3884n + o(n)$ comparisons are sufficient if elements can appear at most a constant number of times, and $10.8696n$ comparisons are sufficient in the general case. We also present an application of our implicit selection algorithms in the maintenance of implicitly represented k-d trees, and give insertion and deletions algorithms that run in $O(n \log n)$ time in the worst case.

AUTHOR: Tony W. Lai

PRICE: $2.00

CS-88-27 - DIVERSITY, ACCESSIBILITY AND ADAPTABILITY

DATA COMMUNICATION NEEDS FOR HIGHER EDUCATION

THE UNIVERSITY OF WATERLOO EXPERIENCE (REVISED)

ABSTRACT:

Diversity, Accessibility and Adaptability are three key-words which help to characterize computing requirements in higher education. Diversity in the number and type of computers needed both now and in the future, in the audience to be served, and in the breadth of computing services required. Accessibility in that computing services should be available to the user community for whom they were intended, wherever and whenever needs arise. Adaptability since the computing and communications system in a university should be able to cope with the changing and diverse computing needs and equipment of the user community.

This paper will explore the implications of these key-words for data communications from the perspective and experience of both users and network managers in one university. The paper concludes by suggesting that university computing facilities will develop as an Extended LAN which will consist of several LANs interconnected by multiple paths via gateways. These gateways contain facilities which will provide the user with a high degree of transparency and the network manager with tools for measurement and control.

AUTHORS: D.D. Cowan, S.L. Fenton, T.M. Stepien, A. Pittman

PRICE: $2.00

CS-88-28 - NETWORKS FOR EDUCATION

AT THE UNIVERSITY OF WATERLOO (REVISED)

ABSTRACT:

Students and faculty members at the University of Waterloo have been using powerful microcomputer workstations connected to local area networks (LANs) since 1981.

Project ARIES has been started to investigate further refinements of this computing concept. Some groups of students are now being equipped on an experimental basis with portable computers with 512K of memory; these computers can be carried easily between classes. Students can fill their portable computers with software and data from Transaction Ports on a campus-wide LAN and then do their computing whenever and wherever 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. Initial experiments with Project ARIES indicate wide acceptance of this concept.

This paper describes Waterloo JANET, a workstation and LAN system, which was developed to form part of the backbone of the educational computing networks at the University of Waterloo. Reference is also made to the economic and academic advantages of microcomputer workstations connected by LANs. The rationale behind Project ARIES, the current experiments with lap portable computers, and the underlying LAN structure are also described.

AUTHORS: D.D. Cowan, S.L. Fenton, J.W. Graham, T.M. Stepien

PRICE: $2.00

CS-88-29 - PORTABLE COMPUTERS AND DISTANCE EDUCATION

ABSTRACT:

Experiments are being conducted at the University of Waterloo with an integrated computer and communications system for students in distance-education programs. Distance students will be able to use the data communications capability of the telephone system in conjuction with microcomputers to communicate with their teachers on the Waterloo campus and their fellow students.

This system should also allow distance students to have immediate access to teaching materials such as lecture notes, laboratory sessions, and assignments, and to many of the computer-based tools and information sources which are commonly available to on-campus students. Electronic submission and return of assignments should also be possible.

With this new ability to use computers and communications, students enrolled in distance education programmes will have many of the advantages of on-campus students. Microcomputers will not be a substitute for the teacher, but will act as a useful learning tool and facilitate communication with on-campus teachers and other distance students, and provide access to many of the accumulated resources of the university.

AUTHORS: J.P. Black, D.D. Cowan, V.A. Dyck, S.L. Fenton

C.K. Knapper, T.M. Stepien

PRICE: $2.00

CS-88-30 - CONCURRENCY IN *C* ++

ABSTRACT:

C ++ already supports many programming paradigms: procedural programming, data hiding, data abstraction, and object-oriented programming. All of these are subdivisions (though not necessarily disjoint) of the imperative programming style. A paradigm that is not supported by *C* ++ is *multi-process structuring*, where a program is designed as a set of processes that cooperate to solve a problem. This paper considers several ways to add support for concurrency to *C* ++. A number of alternative concurrency models are considered because of the number of programming paradigms available in *C* ++, any of which could be adapted to provide multiple processes. A type safe model is suggested that is similar to that in Ada with the extension that a process can respond to requests in arbitrary order making it as powerful as the send/receive/reply model. As well, the model continues to support object oriented facilities like subtyping and inheritance.

AUTHORS: P.A. Buhr, G.J. Ditchfield, C.R. Zarnke

PRICE: $2.00

CS-88-31 - REPRESENTING AND REASONING WITH PROBABILISTIC KNOWLEDGE

ABSTRACT:

A logic, called Lp, is developed which can express a large variety of probabilistic knowledge of a statistical nature. This logic takes a novel approach to the problem of mixing probabilities with ordinary first order logic. In the logic there is a probability distribution over the domain of discourse, while in previous work, e.g., Nilsson's probability logic, the probability distribution is over the set of possible worlds. It is shown how logics with a probability distribution over the set of possible worlds are incapable of expressing statistical knowledge, e.g., "The majority of birds can fly", whereas, the logic developed here can. It is shown how this statistical knowledge can be used to induce a degree of belief in sentences. This degree of belief is generated through a simple and intuitive inductive assumption. The induced degrees of belief display non-monotonic properties and provide an alternative formalism for expressing and reasoning with notions of statistical typicality. The formalism has the advantage of possessing a transparent semantics, based on sets and probabilities of those sets, as well as a sound and complete syntactic proof theory.

AUTHOR: Fahiem Bacchus

PRICE: $5.00

CS-88-32 - IMPLICIT SELECTION

ABSTRACT:

We consider the problem of selecting the kth smallest element of a multiset of n elements using only a constant amount of additional space, the *implicit selection problem*. We demonstrate that this problem can be solved in $O(n)$ time in the worst case. Moreover, we prove that $6.4217n + o(n)$ comparisons are sufficient if all elements are distinct, $6.4514n + o(n)$ comparisons are sufficient in the general case, and $24.8388n + o(n)$ data movements are sufficient in either case.

AUTHORS: T.W. Lai, D. Wood

PRICE: $2.00

UNIVERSITY OF WATERLOO COMPUTER SCIENCE DEPARTMENT

Portable Computers and Distance Education

J.P. Black
D.D. Cowan
V.A. Dyck
S.L. Fenton
C.K. Knapper
T.M. Stepien

Research Report
CS-88-29

July, 1988

UNIVERSITY OF WATERLOO COMPUTER SCIENCE DEPARTMENT

Portable Computers

and

Distance Education

J.P. Black, D.D. Cowan, V.A. Dyck,
S.L. Fenton, C.K. Knapper, T.M. Stepien

Computer Science Department
and
Computer Systems Group
University of Waterloo
Waterloo Ontario Canada
N2L 3G1

July 1988

DRAFT

ABSTRACT

Experiments are being conducted at the University of Waterloo with an integrated computer and communications system for students in distance-education programs. Distance students will be able to use the data communications capability of the telephone system in conjunction with microcomputers to communicate with their teachers on the Waterloo campus and their fellow students.

This system should also allow distance students to have immediate access to teaching materials such as lecture notes, laboratory sessions, and assignments, and to many of the computer-based tools and information sources which are commonly available to on-campus students. Electronic submission and return of assignments should also be possible.

With this new ability to use computers and communications students enrolled in distance education programmes will have many of the advantages of on-campus students. Microcomputers will not be a substitute for the teacher, but will act as a useful learning tool and facilitate communication with on-campus teachers and other distance students, and provide access to many of the accumulated resources of the university.

Research described in this paper has been supported by the University Research Incentive Fund of the Ontario Government, the Natural Sciences and Engineering Research Council of Canada, Bell Canada, Hewlett Packard (Canada), IBM Canada, Toshiba of Canada, and the WATCOM Group.

INTRODUCTION

Students who take their academic programs on the campus of a university or college, or at a secondary or primary school have a number of significant advantages over their peers who must acquire their education through correspondence or distance education programs. Students who can "attend school" have constant contact with the teachers and their fellow students and these contacts are an important component in the learning process. Also, these students have access to all of the accumulated resources of the school and surrounding community such as the libraries and laboratories.

Although students learning through distance education programs will always be at some disadvantage, it is possible to minimize these disadvantages through the use of inexpensive communications and microcomputer technology.

At the University of Waterloo we are constructing an integrated computer system which will allow all students on the campus to use microcomputers in their academic program, wherever and whenever such use is appropriate. We are now expanding this integrated system to the distance education program. Students in such programs will be able to use the data communications capability of the telephone system in conjunction with microcomputers:

i) to communicate with their teachers and fellow students,

ii) to have immediate access to teaching materials such as lecture notes, laboratory sessions, and assignments,

iii) to have access to the tools which are commonly made available to on-campus students,

iv) and to have access to many of the information sources easily accessible to on-campus students.

The remainder of this document describes:

i) the scope and general approach of the current distance education program at the University of Waterloo,

ii) the expanding role of the microcomputer in education,

iii) the current integrated system at the University of Waterloo,

iv) the plans to expand the integrated system to include correspondence and distance education programs.

THE DISTANCE EDUCATION PROGRAM AT WATERLOO

Teaching by correspondence began at the University of Waterloo in 1968 with an initial offering of four Physics courses. Many of the early students were teachers wishing to upgrade their qualifications without the necessity of taking a leave of absence from their position. Waterloo now offers over 300 different courses in some 50 different disciplines, and three degrees (in Arts, Science, and Environmental Studies) can be earned entirely by distance study.

There have been over 190,000 registrations in correspondence courses since the inception of the program, and the University of Waterloo has one of the largest university credit distance education programs in

North America. Current annual course registrations are about 20,000, which represents about a fifth of the total university enrolment.

Although Waterloo has a reputation for "high tech", especially in computer science and engineering, its distance program has not reflected this emphasis, either in the type of courses offered (which are mainly in Arts), or in the instructional approach adopted. Distance courses comprise audio-tapes, a variety of print materials (course notes, textbooks), video cassettes and special kits where necessary. There is also a set of from four to six assignments which must be returned for marking at regular intervals throughout the term. A major difficulty arises from the slow "turn-around" time for assignments and the resulting lack of timely feedback to students on their progress in the course.

THE MICROCOMPUTER IN EDUCATION

Microcomputers play an ever-expanding role in the educational process. The computer is used in a variety of ways:

i) as a communications device and a mechanism for delivering educational materials,

ii) as a productivity tool,

iii) as a base for developing specialized learning tools,

iv) and finally as an object of study.

The Microcomputer - A Communications Device

The microcomputer in conjunction with modem communications technology provided by the common carriers is an effective communications mechanism.

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 electronically to the teacher for detailed criticism, discussion and marking. Such electronic transmission minimizes the time needed to effect communication between students and instructor.

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. Facilities also exist for immediate simple reply to a message, forwarding mail, registered mail and other functions similar to those offered by conventional mail 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 a conferencing system can scan the board for information and/or place their own queries and responses on the board.

municate with their peers or teachers. This network is being enhanced to provide other services essential to the long-term success of this project.

EXTENSION TO DISTANCE-EDUCATION PROGRAMMES.

Introduction

We are planning to extend the portable computing concepts of Project ARIES beyond the campus of the University of Waterloo. In this way we can service distance education programs and hence provide the distance education student with an educational setting which is closer to that experienced by students on the campus. Any modifications created for distance education will be integrated into the current system developed for Project ARIES, so that the faculty and students will not have to learn to use two network systems. Such integration should make the faculty more productive in the development and distribution of teaching materials to both local and distance education students.

The services that will be provided for distance education students will be somewhat different than those for students on or near the campus. We expect to provide the following facilities to support those services:

i) an ability to handle a large number of simultaneous calls from remote computers through a public data network,

ii) a conferencing system so that students can communicate in an informal way with their peers and teachers,

iii) an electronic mail system for private communication,

iv) a file transfer system so that students can submit electronic copies of assignments and receive new educational materials.

Research Overview

In order to provide the environment necessary for effective use of portable computers in distance education a number of different activities must be completed successfully. The next few paragraphs identify and describe these activities.

Courses will have to be identified which will be amenable to "computerization", and arrangements will have to be made with faculty members to prepare or modify these courses. Such courses could be from the distance education program at the University of Waterloo or other universities or colleges. The first course offerings will originate at Waterloo as this will minimize the logistics problems in establishing the portable computing environment. Initially, CS100 a course in microcomputer applications will be chosen, since it has a high degree of computer content and is likely to be quite popular. CS100 is described in more detail in [1]. This course should provide a thorough test of the remote portable computing environment.

A number of portable computers will have to be obtained for distribution to distance education students. Since this is an experiment we should not expect these students to purchase their own computer. Desktop models of microcomputers could be purchased for this project but portable computers offer several advantages:

i) most portables today have capabilities comparable to those of a desktop model and are quite adequate for this project,

ii) shipping a portable computer to a student is much easier,

iii) because the computer is portable, students will be able to be more mobile and even learn while on vacation or moving between jobs,

iv) and because of the portability factor, students will be able to use the computer in a large variety of learning situations, even outside their course.

The campus network for Project ARIES will have to be modified to handle long-distance data communication using Datapac and the value-added iNet 2000 Service [5]. Datapac is the Canadian public data network which allows long-distance data communication between computers at 300, 1200 and 2400 baud over the telephone system. Datapac is an X.25 network and is similar to Tymnet and Telenet in the U.S.A, Transpac in France, and P.S.S in the U.K. The iNet 2000 service has been added to Datapac to provide appropriate user interfaces and connect users to various service providers. This service permits data communication over Datapac from any telephone in Canada.

The feasibility of providing this service has already been proven but extensive work needs to be performed to make it function in combination with a local area network environment.

Various communication systems such as electronic mail, bulletin boards, and conferencing systems will need to be identified and installed on the network so that students can communicate with each other and with the faculty.

Manuals and software will need to be prepared so that users of the system who will be isolated from any direct help can learn enough to function and use the basic features of the computer and the network system without reference to other users or to personnel at the University of Waterloo.

Although manuals will be prepared for the students it will be necessary to have a telephone hotline service available during the day for students who have difficulty communicating with the network system by computer. As more experience with the system is acquired and as the manuals improve, the need for such a hotline will likely diminish. There will always need to be a telephone number that students can call in case of operational difficulties or equipment malfunction, although this can probably be restricted to normal working hours after a suitable time period.

There will also be a need for a staff member to monitor the electronic mail and conferencing systems. Since there is no experience with how students will interact with the faculty and their peers, it will be necessary to oversee the use of the electronic communication systems to determine the usage patterns.

CONCLUSIONS

Although there has been much hope held out for the transformation of distance education by technology, so far most distance education is "low-tech" (print, audio cassettes). Computers have been used, but mostly in experimental settings since cost, logistics and lack of standards in software and hardware created problems for larger-scale programs. Recently costs of appropriate microcomputers have dropped substantially and reasonable standards have started to emerge, thus making this new round of experiments feasible.

The innovation described here is one of the first by a large successful distance education program in a large established university. It will be interesting to look back at the next ICDE conference in 1991 to see see what impact this trial has had on the practice of distance education at the University of Waterloo.

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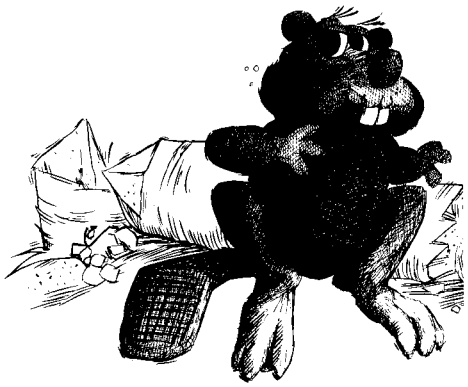

Portable Computers and Distance Education

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ABSTRACT

Experiments are being conducted at the University of Waterloo with an integrated computer and communications system for students in distance-education programs. Distance students will be able to use the data communications capability of the telephone system in conjunction with microcomputers to communicate with their teachers on the Waterloo campus and their fellow students.

This system should also allow distance students to have immediate access to teaching materials such as lecture notes, laboratory sessions, and assignments, and to many of the computer-based tools and information sources which are commonly available to on-campus students. Electronic submission and return of assignments should also be possible.

With this new ability to use computers and communications students enrolled in distance education programmes will have many of the advantages of on-campus students. Microcomputers will not be a substitute for the teacher, but will act as a useful learning tool and facilitate communication with on-campus teachers and other distance students, and provide access to many of the accumulated resources of the university.

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INTRODUCTION

Students who take their academic programs on the campus of a university or college, or at a secondary or primary school have a number of significant advantages over their peers who must acquire their education through correspondence or distance education programs. Students who can "attend school" have constant contact with the teachers and their fellow students and these contacts are an important component in the learning process. Also, these students have access to all of the accumulated resources of the school and surrounding community such as the libraries and laboratories.

Although students learning through distance education programs will always be at some disadvantage, it is possible to minimize these disadvantages through the use of inexpensive communications and microcomputer technology.

At the University of Waterloo we are constructing an integrated computer system which will allow all students on the campus to use microcomputers in their academic program, wherever and whenever such use is appropriate. We are now expanding this integrated system to the distance education program. Students in such programs will be able to use the data communications capability of the telephone system in conjunction with microcomputers:

i) to communicate with their teachers and fellow students,

ii) to have immediate access to teaching materials such as lecture notes, laboratory sessions, and assignments,

iii) to have access to the tools which are commonly made available to on-campus students,

iv) and to have access to many of the information sources easily accessible to on-campus students.

The remainder of this document describes:

i) the scope and general approach of the current distance education program at the University of Waterloo,

ii) the expanding role of the microcomputer in education,

iii) the current integrated system at the University of Waterloo,

iv) the plans to expand the integrated system to include correspondence and distance education programs.

THE DISTANCE EDUCATION PROGRAM AT WATERLOO

Teaching by correspondence began at the University of Waterloo in 1968 with an initial offering of four Physics courses. Many of the early students were teachers wishing to upgrade their qualifications without the necessity of taking a leave of absence from their position. Waterloo now offers over 300 different courses in some 50 different disciplines, and three degrees (in Arts, Science, and Environmental Studies) can be earned entirely by distance study.

There have been over 190,000 registrations in correspondence courses since the inception of the program, and the University of Waterloo has one of the largest university credit distance education programs in

North America. Current annual course registrations are about 20,000, which represents about a fifth of the total university enrolment.

Although Waterloo has a reputation for "high tech", especially in computer science and engineering, its distance program has not reflected this emphasis, either in the type of courses offered (which are mainly in Arts), or in the instructional approach adopted. Distance courses comprise audio-tapes, a variety of print materials (course notes, textbooks), video cassettes and special kits where necessary. There is also a set of from four to six assignments which must be returned for marking at regular intervals throughout the term. A major difficulty arises from the slow "turn-around" time for assignments and the resulting lack of timely feedback to students on their progress in the course.

THE MICROCOMPUTER IN EDUCATION

Microcomputers play an ever-expanding role in the educational process. The computer is used in a variety of ways:

i) as a communications device and a mechanism for delivering educational materials,

ii) as a productivity tool,

iii) as a base for developing specialized learning tools,

iv) and finally as an object of study.

The Microcomputer - A Communications Device

The microcomputer in conjunction with modem communications technology provided by the common carriers is an effective communications mechanism.

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 electronically to the teacher for detailed criticism, discussion and marking. Such electronic transmission minimizes the time needed to effect communication between students and instructor.

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. Facilities also exist for immediate simple reply to a message, forwarding mail, registered mail and other functions similar to those offered by conventional mail 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 a conferencing system can scan the board for information and/or place their own queries and responses on the board.

The Microcomputer - A Productivity Tool

The microcomputer is an excellent general-purpose productivity tool. There are now many software programs including writing aids such as word processors and text formatters, spelling checkers, and thesauri; calculation aids such as spreadsheets; and information management tools such as data-base systems to assist the student.

Students can use the writing aids to make the preparation of reports and essays a more pleasant task and can concentrate on the content rather than the appearance of the finished document.

Aids such as spreadsheets are extremely useful in almost all courses which require various tabular calculations. Because of their automatic calculation capability they make excellent tools for simulating experiments and for checking postulates (so-called "what-if" questions).

Information management tools allow the student to develop personal information systems and to analyze data created by the student or provided by the teacher.

The Microcomputer - Developing Educational Materials

Educational materials can be developed using the tools described in the previous section. Students can then use these tools to explore these educational materials.

Word processors can be used to prepare materials for distribution, students can often use the same word processor to return modified materials to the teacher.

Spreadsheets have been found by many teachers to be excellent simulation tools allowing the student to explore the consequences of changing the parameters of a problem.

Teachers can purchase or create data bases and thus allow students to make extensive analyses. Students will not need to be guided to a preconceived set of conclusions but may gain significant insights.

As well, many specialized educational software systems for historical simulations, and simulations of natural disasters and laboratory experiments which are too expensive or inaccessible, may be developed. Such simulations are very important for distance education students who do not have access to laboratory facilities.

The Microcomputer - An Object 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 INTEGRATED SYSTEM AT THE UNIVERSITY OF WATERLOO

Introduction

At the University of Waterloo we are conducting a research project into the use of portable computers in education; this project is called Project ARIES - the University of Waterloo Portable Computing Project [2], [3], and [4]. As part of this activity we are developing 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. It is anticipated that the primary function of the network will be to allow students to "fill" their computer with software or data, to "dump" their finished work onto printers or plotters or into permanent mass storage, and to communicate with the faculty and their peers.

As this project develops it is expected that more and more students may wish to obtain lap portables and use them whenever and wherever a computer would be a suitable tool. Computers will become common tools in all courses not just a requirement of specific courses; we will be moving from course-oriented to effective personal or student-oriented computing.

Our hope for the long-term is that students will carry a fully functional lap portable computer which will:

i) be light-weight,

ii) operate from solar cells,

iii) be as compact as a regular-size three-ring binder,

iv) and be able to store and retrieve all software and data using a wireless network.

Although this is only a hope at the moment, we believe that such a time is not far away. For example, the electronic calculator has evolved from a $1,000 desk-top model the size of a typewriter to a $5 model the size and weight of a credit card in just 15 years. Several manufacturers are producing portable computers which come fairly close to providing the capability we have already described at the beginning of this paragraph.

If we are to use computers in this mode of operation, then it is necessary to provide an infrastructure that will support both wired and wireless high-speed, high-volume data communication; this is one of the goals of this research project. Of course if this portable computational power becomes commonly available, then the way in which we use computers in education and business could and will change dramatically.

Current Status of Project ARIES

Currently we have 350 lap portable computers which are distributed to students in various courses in the different faculties. The students use the computers in their courses and help us to evaluate the concept of portable computing in a university setting.

In order to provide file storage, printing, and communication facilities for these portable computers, we have installed a computer communications network across campus. Students can go to ten widely dispersed points on campus (called Aries Service Centres) to fill their microcomputer with software and educational materials or to dump accumulated data into more permanent file storage, onto printers or to com-

municate with their peers or teachers. This network is being enhanced to provide other services essential to the long-term success of this project.

EXTENSION TO DISTANCE-EDUCATION PROGRAMMES.

Introduction

We are planning to extend the portable computing concepts of Project ARIES beyond the campus of the University of Waterloo. In this way we can service distance education programs and hence provide the distance education student with an educational setting which is closer to that experienced by students on the campus. Any modifications created for distance education will be integrated into the current system developed for Project ARIES, so that the faculty and students will not have to learn to use two network systems. Such integration should make the faculty more productive in the development and distribution of teaching materials to both local and distance education students.

The services that will be provided for distance education students will be somewhat different than those for students on or near the campus. We expect to provide the following facilities to support those services:

i) an ability to handle a large number of simultaneous calls from remote computers through a public data network,

ii) a conferencing system so that students can communicate in an informal way with their peers and teachers,

iii) an electronic mail system for private communication,

iv) a file transfer system so that students can submit electronic copies of assignments and receive new educational materials.

Research Overview

In order to provide the environment necessary for effective use of portable computers in distance education a number of different activities must be completed successfully. The next few paragraphs identify and describe these activities.

Courses will have to be identified which will be amenable to "computerization", and arrangements will have to be made with faculty members to prepare or modify these courses. Such courses could be from the distance education program at the University of Waterloo or other universities or colleges. The first course offerings will originate at Waterloo as this will minimize the logistics problems in establishing the portable computing environment. Initially, CS100 a course in microcomputer applications will be chosen, since it has a high degree of computer content and is likely to be quite popular. CS100 is described in more detail in [1]. This course should provide a thorough test of the remote portable computing environment.

A number of portable computers will have to be obtained for distribution to distance education students. Since this is an experiment we should not expect these students to purchase their own computer. Desktop models of microcomputers could be purchased for this project but portable computers offer several advantages:

i) most portables today have capabilities comparable to those of a desktop model and are quite adequate for this project,

ii) shipping a portable computer to a student is much easier,

iii) because the computer is portable, students will be able to be more mobile and even learn while on vacation or moving between jobs,

iv) and because of the portability factor, students will be able to use the computer in a large variety of learning situations, even outside their course.

The campus network for Project ARIES will have to be modified to handle long-distance data communication using Datapac and the value-added iNet 2000 Service [5]. Datapac is the Canadian public data network which allows long-distance data communication between computers at 300, 1200 and 2400 baud over the telephone system. Datapac is an X.25 network and is similar to Tymnet and Telenet in the U.S.A, Transpac in France, and P.S.S in the U.K. The iNet 2000 service has been added to Datapac to provide appropriate user interfaces and connect users to various service providers. This service permits data communication over Datapac from any telephone in Canada.

The feasibility of providing this service has already been proven but extensive work needs to be performed to make it function in combination with a local area network environment.

Various communication systems such as electronic mail, bulletin boards, and conferencing systems will need to be identified and installed on the network so that students can communicate with each other and with the faculty.

Manuals and software will need to be prepared so that users of the system who will be isolated from any direct help can learn enough to function and use the basic features of the computer and the network system without reference to other users or to personnel at the University of Waterloo.

Although manuals will be prepared for the students it will be necessary to have a telephone hotline service available during the day for students who have difficulty communicating with the network system by computer. As more experience with the system is acquired and as the manuals improve, the need for such a hotline will likely diminish. There will always need to be a telephone number that students can call in case of operational difficulties or equipment malfunction, although this can probably be restricted to normal working hours after a suitable time period.

There will also be a need for a staff member to monitor the electronic mail and conferencing systems. Since there is no experience with how students will interact with the faculty and their peers, it will be necessary to oversee the use of the electronic communication systems to determine the usage patterns.

CONCLUSIONS

Although there has been much hope held out for the transformation of distance education by technology, so far most distance education is "low-tech" (print, audio cassettes). Computers have been used, but mostly in experimental settings since cost, logistics and lack of standards in software and hardware created problems for larger-scale programs. Recently costs of appropriate microcomputers have dropped substantially and reasonable standards have started to emerge, thus making this new round of experiments feasible.

The innovation described here is one of the first by a large successful distance education program in a large established university. It will be interesting to look back at the next ICDE conference in 1991 to see see what impact this trial has had on the practice of distance education at the University of Waterloo.

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