THE
UNIVERSITY
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Manpower and funding in Canadian University Computing and Information Science: the crisis continues

by

David R. Hill

Research Report 82/90/9
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DEPARTMENT OF
COMPUTER SCIENCE

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Prepared for the NSERC Grant Selection Committee
for Computing and Information Science

CONTENTS

Summary

The NSERC Computing and Information Sciences (CIS) Grant Selection Committee has continued to study the problems of manpower and funding in CIS since the Vaucher report two years ago. The crisis has deepened, though not as badly as it might have if the NSERC, backed by the federal government, had not taken a number of steps to cope with some of the most outstanding problems within their control. This report represents a personal view by this year's committee chairman, based on discussions within the committee and with visitors, as well as a study of the continuing flood of documentation concerning the situation and needs in computer science, on the international as well as a national scene. The conclusions are that the NSERC could further assist CIS by taking the following steps:

1. Accelerate programs intended to make the research environment at universities more attractive. The chief mechanism is through equipment and infrastructure support. The estimated budget provision needed to meet the real needs in these areas is \$3.5M on equipment on average each year for the next three years, and \$4.4M rising to \$5.8M on infrastructure over the same period. The fact the budget is set for this year makes action all that more necessary for next year, as there will be further catch-up, but whatever flexibility still remains this year should be fully utilised. Specific detailed recommendations are made herein, including a recommendation for early publicity for any major new initiative in this direction.
2. Increase the operating grant budget for CIS in such a way that it would have yielded at least \$7.3M in 1982 (in 1982 dollars), instead of the current \$5.0M to meet the individual and team grant holders' operating costs plus infrastructure. Even ignoring inflation, an annual 15% increase in the numbers of grantees is predicted. This will lead to a further necessary increase in the budget. Using other forecasting models, the desirable 1982 operating and infrastructure provision could have been up to double this year's maximum possible of \$5.0M. If actually implemented for next year, such an increase would require the 15% growth factor plus heavy publicity to gear up potential grantees.
3. Provide a new program of research fellowships for established faculty at their home institutions, and for visitors.
4. Change the title and subcategories for the committee for Strategic Grants in Communication to include Computing and Information Science topics explicitly.
5. Avoid restrictions on the number of post-doctoral years expected for research associates in computing and information science.
6. Encourage universities to allow the combination of full grant and full teaching support for graduate students in recognition of the new NSERC policy in this area.

The benefits to be expected from these measures are summarised as follows:

1. Increased quality and quantity of faculty and graduate students to man programs in CIS.

2. Increased quality and quantity in the supply of highly trained manpower at all levels within this economically and socially vital field.
3. More technology transfer.
4. The creation of new jobs at all levels, in many fields.
5. Reduced dependence on imported CIS, and increased exports in all areas, with consequent benefit to national security as well as the balance of trade.

The committee stresses that action cannot be long delayed or much reduced in scale if it is to be effective.

1. Context

This document is an attempt to capture the essence of the continuing crisis in Computing and Information Science (CIS) as it relates to the funding of research in the area at Canadian Universities. It is a personal view by the chairman of the Grant Selection Committee for Computing and Information Sciences following both formal and informal meetings of the committee, including some visitors. In February 1982. Some of the steps taken, or proposed for alleviating the worst aspects of the crisis, by the committee and NSERC, are noted. Reference is also made to matters which concern the NSERC *ad hoc* committee on research computing, chaired by Dr. Sutherland of Dalhousie.

It is not so much an update of the Vaucher report, produced two years ago by the same committee with largely different membership, as another view of the same area, two years later.

The point that we only address problems within the university context is still valid. Clearly, an important part of the problems faced by industry relates to the supply of highly skilled manpower and long-term research results that are supplied by universities. For this reason, study of the problems in CIS research and manpower (or other areas) as seen from an industrial viewpoint would be illuminating. It should be noted that the committee still has two representatives from industry amongst its members who provide input.

2. Introduction

In the last two years, the crisis in Computer Science has deepened. In response to the perceived needs and opportunities in our society, student enrolments have doubled in some Computer Science departments. At others enrolment limitations have been imposed, while the demand for graduates continues to increase. An increasing number of areas of economic performance are becoming dependent on the use of computer power to remain competitive and innovative in a national and international context. There is a growing need for the highly trained manpower available from graduate schools. In this context. Universities have been increasingly unable to meet even the need for B.Sc. level manpower. There are several reasons for this, and they are inter-related. This report is primarily intended to view matters of concern to the Natural Sciences and Engineering Research Council, but the view, and the problems, are of much wider import. All levels of departments at universities should be very concerned, and should take urgent action to help deal with a crisis that threatens to throttle both the economic performance and the generation of new jobs in almost every sector of industry for at least the next two decades. These levels range from university boards of governors to the federal cabinet. Responsible people who ignore what is happening will have to account for their lack of action when the inevitable results become apparent to the public, as they must if action is delayed. The problems will not just go away. Action is required on a massive scale that may be hard to believe, yet it must be taken now.

3. Manpower

One strand in the web of crisis is the continuing shortage of manpower in computer science research, especially experimental research, in universities. Low production of suitably trained people, lack of facilities and equipment, low salaries relative to industry, and exceptional pressure from teaching loads combine to reduce the flow of faculty appointees at universities. The teaching pressure is partly due to vastly increased enrolments which have quadrupled in seven years (doubled in the last two) at some places; is partly due to the contingent nature of what must be taught -- in a rapidly changing and expanding technological environment; and is partly a vicious circle effect as faculty leave, or decline to sign up, due to deteriorating conditions for teaching and research. Faculty and graduate students are lured away (to industry, or south of the border), and replacing them is very difficult. The loss of even one key person can be devastating in the Canadian context which has few real centres of excellence at present and desperately needs to sustain those it has and to create new ones. Thus the recent loss of C. from UBC to a US university due to shortage of equipment is far more significant than the loss of one person. It represents a loss of perhaps 10% of our next generation of centres of excellence because such outstanding individuals provide the academic leadership and focus to develop the required centres of excellence. Several medium sized groups, such as the newly burgeoning group at Calgary, may dissipate if not soon provided with the reasonable research facilities that are currently so conspicuously absent and desperately needed.

At Waterloo (one of the top two departments in Canada), after advertising heavily last year, and a succession of 40 interviews and 15 offers of employment. 5 new faculty were recruited. But 3 others left, so there was a net gain of two faculty, for an investment of 2 man-years of recruiting effort by senior faculty. Thus, even with prodigious efforts, the best schools can only just meet their commitments. Others remain with open positions, and would have more if there were real hope of filling them. The problem is not helped when, despite a known inability of the country to produce anywhere near enough suitably qualified manpower, all academic advertising is required to bear a statement to the effect that only Canadians and others legally entitled to work in Canada at the time of application, need apply -- at least in first round advertising. Because of the various stages in the process of recruiting, by the time the first round has been completed, it is often too late to do anything in time for the next academic year, even if there are still people available elsewhere.

Denning (1981) described a process called ‘eating our seed corn’, where industry and government take the doctoral graduates needed for the urgently required expansion of post-secondary education capacity in computer science at all levels. A further problem is that good people are leaving the smaller struggling departments and going to the larger, better equipped schools. For example. Waterloo has three (possibly four) such cases this year, which has helped keep them level. This is a form of cannibalism that complements the seed-corn eating. Both processes will tend to destroy first the smaller schools and then the larger ones. Ultimately all national institutions will suffer.

Competition is so fierce in this area of skilled manpower recruitment that commercially backed research laboratories have been moved wholesale to more attractive locations in an attempt to keep existing staff and attract new staff. Thus GTE and others moved to the Arizona sun-belt in the States while Hewlett-Packard moved their research lab from a big city to Chico, an attractive location in California. The scale of the problem for Canada is well documented in the report prepared by a subcommittee of the Canadian Heads of Departments committee that meets annually (Oren, *et al.* 1982). The conclusions in that report are in consonance with those reached in this report.

The NSERC can do little about teaching loads and salaries (which are worse than might appear from the unadorned figures, because of the rate at which the discipline is evolving, and the rate at which enrolments are and should be increasing). However, the NSERC could (if given the required government funding) make departments of computer science more attractive and, at the same time, provide for increased productivity on the part of those who are attracted. Much of the rest of this report bears directly on this extremely urgent matter.

4. What distinguishes computer science from other disciplines

It may well be asked: "Why is computer science in a situation different from other disciplines?" The question is especially relevant at a time when Dr. R. E. Bell, at McGill (who is Canada's NATO Science committee representative) reports NATO-recommended measures for science-in-a-time-of-financial-stringency that amount to accepting zero growth in scientific research, with all that implies. The clue lies in the paragraph numbered 3 on page one of the document circulated by Dr. Bell (1982). Referring to science in general, it states:

> 3. As regards personnel problems, the most striking feature is the concentration of a large proportion of researchers in the 35-50 year age bracket the reason for this is the rapid takeoff around 1960 and the no less sudden halt in the early 70s.

It goes on to say that as a result, renewal of the science laboratory population is very slow, with little prospect of recruiting new young researchers for 15 years.

This is quite the reverse of the situation in computer science. This year, for example, there were over 65 posts open in Canada for computer science faculty (a tally taken at the June Heads of Departments meeting at Waterloo) and in the current NSERC grant competition 50 new applicants applied for grant funds -- an increase of 17.5% in the total number of individuals seeking or receiving individual support from our committee, and more than double the equally surprising number of new applicants last year. The only reason there were not more is because of recruiting difficulties -- many posts were still vacant, or filled with temporary or under-qualified start as the 81-82 academic year began. Thus, the age profile suggests that more than half the new applicants were middle-aged returns or re-treads, so that, despite the opportunities for young blood, there is inadequate supply.

In fact, when other well established disciplines were setting up in the affluent '60s, computer science was hardly recognised as a separate discipline. The majority of departments in Canada were formed very late in the '60s, or during the lean '70s. Others have still been unable to crystalize and differentiate themselves from their departments of origin in EE and Math. Thus, just when the new discipline started its exponential growth, scientific research as a whole was entering a freeze, and universities were being squeezed very hard -- a process which continues with increasing ferocity today. With well-established disciplines, well staffed and well equipped, competing for dwindling resources, computer science received a highly geared "kick" – i.e. nothing to help with development – just when growth was occurring. Thus one university grew by 5% in enrolment between 1975 and 1980, but received only 3% real increase in dollars: the science faculty at that university grew by 8% (computer scientists and geologists) but was cut back 6% in real dollars: and, at the highly geared end, computer science enrolments doubled, but the operating budget increased by only 8% in real dollars. A similar picture emerges for other budgetting classes and, while teaching loads in the declining sciences lightened as their enrolments decreased, computer science suffered from loading and a lack of facilities that still persists. This threatens to destroy what research capability exists at all but the largest schools, and stifles many possibilities of new strength growing.

Coupled with the lack of budget provision has been the emergence of computer science as an experimental discipline. In the UK, 1982 has been officially marked as the year of Information Technology, with Kenneth Baker as Minister. Information Technology has been defined as:

> The use of computers, microelectronics and telecommunications to help us produce, store and obtain and send information in the form of pictures, words or numbers, more reliably, quickly and economically. (Sturridge 1982).

The major technological component of the systems which include office automation, inventory systems, educational materials, intelligent point-of-sale terminals, automobile control systems, and the like, is the software component, and that is based on computer science research and innovation. The hardware is certainly important to society at large. However, it is only one component, namely the foundation on which the new structures of programs and data sit and operate. The current revolution is widely billed as a 'microelectronics revolution' and, to the extent that absence of the silicon foundation would leave nothing on which to build, this is fair. However, the major costs and future problems lie in the software – the programs and data, and the liveware – the people who need to use the systems, with their need for sophisticated communications interfaces to the machine components of systems. The solution of tomorrow's problems, the innovation, and the chance for high 'value added' or wealth-creating industry, lies in these areas, both of which are solidly based in computing and information science. The point is made very strongly in an article by Manchester (1982) in the British Computer Society newspaper Computing". He says:

> It is commonly held that we have now entered a new era of the computing industry. It is an era where the solution to a problem is more important than the method used to solve it and that the key to solving problems lies in producing the right software, not a flashy piece of hardware.
>
> Observers of IBM, for instance, are adamant that IBM's survival depends on being able to switch its major source of revenue from hardware 'sales' to 'service' sales.
>
> Michael Hunt, head of the software package giant Management Science of America, remarked that he could see a time not too far in the future when computers would be given away together with the software packages.

It is worth making two further observations. In most experimental disciplines, it is customary to find the best equipped laboratories for basic research located in the universities, and certain government or international research institutes. In computer science these well equipped laboratories are, in industry, bent (with only a few exceptions) to the needs and problems of short-term interest. This would be unfortunate in itself. But the fact is that the hardware needed for computer science is really one level more basic to any experiment than the physicist's cyclotron or the chemist's mass spectrometer. In computing and information science, the hardware is more like the foundations needed to support the cyclotron, since the objects – expensive objects at that – which the computing and information scientist creates or experiments with, are the programs and data embodying new ways of doing things; or new structures for storing and retrieving things; or new approaches to organizing systems; or new and useful formulations of knowledge; to mention only the first few that come to mind. The computer, for CIS, is not just a means of manipulating data, as for research in other disciplines. It is the very foundation of the experimental apparatus with which the researcher experiments.

Universities have a primary responsibility, not only for the longer-term basic research on which future economic activity and Nobel prizes are based, but also for the training of the highly-skilled manpower needed for industrial research and innovation. Yet many departments of computer science lack even reasonable foundations for the objects of their experimental research. That is, they lack computers, and related equipment and support.

A Science Council of Canada report (July 1981) is entitled *The impact of the microelectronics revolution on the Canadian Electronics Industry*. It is probably fair to say that, without the systems design capability (and that means primarily software), and adequate understanding of the needs of the liveware and how to meet them, the impact of the microelectronic revolution could possibly be to eliminate the Canadian electronics industry! It is essential that, whatever effort is put into building a Canadian chip supply capability, an equal or preferably greater effort is put into the new software and systems industry that builds these, at high value-added, into world exports. This is one strategy being pursued in the UK, and was proposed as a strategy worth pursuing in the BBC documentary *Now the chips are down* (1979), a film that is credited with radically changing the policies of the British government in respect to computers and software. But even if Canada concentrated at first on domestic systems, rather than exports, the cumulative effect on the trade figures over the next decade could be vital for the economy, since less money would be spent on expensive imported CIS technology. In either case, there will be a tidal-wave demand for computer-skilled manpower (CSM), as well as for new information technology, as a basis for performance in all sectors of the economy. Many existing products will incorporate the chips, quite apart from the new products and services that will become possible. Success will depend on systems and software skills, a major point made by British government NEDC report "Computer Manpower in the ‘80s”. It is worth quoting from the conclusions to that report (NEDC 1980, p 201):

> Before discussing detailed conclusions, we must put them firmly and simply into context The overwhelming current constraint on the adoption of computer technology is a massive shortage of computer-related manpower, before which all other constraints pale into insignificance. The problem has three principal, interrelated dimensions.
>
> (1) A marked shortage of “computing” type skills. These are suffered principally by computer users. They are complemented (and partly caused) by:
>
> (2) Serious shortages of “engineering/systems/software-type skills. These principally affect computer suppliers, of both hardware and services. They are in turn strongly re-inforced by
>
> (3) Limitations in software technology where evolution -- let alone revolution -- has been slow and confused.

Thus computer science is special because the future of the economy is likely to depend on its success as a discipline and field of research, yet it is the Cinderella of the scientific and engineering disciplines due to the circumstances and timing of its growth. Although the other disciplines may not be ugly sisters, computer science needs more than rags and a pumpkin to overcome its unfortunate history and fulfil its vital role in society.

5. What is being and should be done

5.1 Experimentalists, theoreticians and excellence;

The Vaucher report (1980), attached as an appendix to this report, outlined the situation in computer science as it was seen two years ago. Many of its points are still completely up-to-date, but some action has been taken. Included in the

Vaucher report as appendices are two papers referring to ‘experimental’ computer science. A quotation from the Feldman paper gives some idea of what is meant by ‘experimental’ when attached to computer science.

> Experimental computer research requires the testing of new ideas. Often these tests – to achieve an appropriate scale – require many users, many systems, much development, and much programming. These tests are correspondingly expensive. Consider, by analogy, the problems in scale of testing a new air traffic control feature in the nation or a new aircraft maintenance strategy in an entire fleet. Similarly, many experiments in time-sharing and networking of computers have been very expensive and extensive. Nevertheless, academic institutions have had, and can continue to have, a role in this experimentation, and that role is essential to their continued health as educational institutions in the art and science of computing. Without a significant research role the universities lose their cadre of excellent people, and the inevitable deterioration results that affects the quality of faculty and graduates.
>
> Computer systems experimentation and invention occurs in an environment of a researcher’s assumptions and expectations. Getting this environment right critically affects the quality and extent of creative work. Computing research is tackling problems of increasing complexity which often cannot be theoretically modeled, necessitating an experimental approach that requires adequate equipment. A quick study shows that a few leading industrial research activities in computer science are capitalized in the range of $40-60K per research professional. A very few major university experimental systems are capitalized in the range of $1S-25K per professional. The vast bulk of other university efforts in computer experimentation have well below $10K of capital equipment per researcher, making their efforts marginally viable. The current pace of technological change is so rapid as to make a large portion of this capital equipment obsolete every few years.

The above figures (which are US dollars) have certainly inflated since 1979, when they were written.

In the Vaucher report it was noted that the Computing and Information Sciences Grant Selection Committee was really funding two areas: theoretical CIS and what the report called Computing Systems Engineering (CSE). It is in this latter area (CSE) that our ‘experlmentailsts’ are working, and if they need more and more modern equipment, they also need the maintenance and technical staff (or infrastructure) to support it and work with it. We shall return to this topic in sections 5.2 and 6.2. It was also pointed out that funding levels were generally low and that the more practical systems engineering side was particularly badly hit by this. Subsequent analysis of grant statistics has confirmed that roughly 50% of our grantees and applicants are ‘experimental’ and has revealed that, within the constraints of its budget, the committee has begun to favour this group with larger grants than the theoreticians -- at least for the outstanding researchers from each category. The following table shows the average dollar amounts requested and awarded, for four categories of grantees, with the percentage extra associated with experimentalists.

Grantee type		**Av. grant $’s Requested 81** Ex/Th x 100%	**Av. grant $’s Awarded 81** Ex/Th x 100%
Excellent young researchers	Th	18437	9854
	Ex	23759 (+29%)	15682 (+59%)
Outstanding seniors	Th	27157	19266
	Ex	35006 (+29%’)	22748(+18%)

Except for the top left difference of 29%, all the differences were significant at the 1% level or better. It was interesting to note that CIS grants overall were $12,500 on average as opposed to the average over all committees of $15,770. This situation is almost Identical to that at the time of the Vaucher report (which is surprising) and would require an overall 26% boost in CIS grants to bring them in line. Not every discipline can equal or exceed the average, of course, but given the current situation, and the high cost of working in, and of training highly skilled manpower in, this important new discipline (as documented below) there is every reason to suppose that even more should be done.

Our response, this year, working within the guidelines set by the NSERC, was to recognise the difference between experimentalists and theoreticians at the starter level (which we had not done before). We continued to provide for the special needs of experimentalists, though without special budget provision. Finally, we recognised special merit in our outstanding researchers, using the funds allocated for this purpose, thereby achieving close to a 40% boost for outstanding grantees at all levels. Because of existing differentials, this recognises to some extent the extra need of experimentalists, whilst keeping to NSERC guidelines.

5.2 Infrastructure grants:

For the first time this year, new rules were in place for core grants which were renamed 'infrastructure grants'. The changes were seen by our committee as a direct response to the Vaucher report recommendations, following the committee's decision to abandon a trial policy on the original core grants that threatened to distort the whole structure of our grant allocations.

In computer science, unlike other disciplines, it is difficult to fund the required 'infrastructure' for research (programmers, technicians, specialised maintenance, …) from a levy on user fees for several reasons. There are, of course, genuine centres of excellence with specialised facilities, provision for visitors, and the like that fall into the spirit of the original core grant policies. But, at other places, though support is needed, the minimum active mass of senior grantees required to provide continuity of substantial support does not exist. Being young, very fast growing, subject to the squeeze of the '70s, and having been seriously misunderstood by levels of government right down to university budget committees, computer science has not the support from other sources, the maturity, or the numbers, to put things on a proper footing. There is also no reasonable mechanism, within the incremental grant structure, to provide a 'bonus' grant to all members at an institution that needs support for some reason. Furthermore, the committee wishes to make the best use of the limited funds that may currently be available by encouraging coalescence of the support facilities for computer science research, at a given institute, until a clear need for separately funded groups has been demonstrated.

Thus we are using the new infrastructure program as a major form of funding technical support for computing and information science research on a group basis. In some cases this follows the previous 'unique centre' Idea, and in other cases it is on a profiled start-up basis. The latter type we refer to as type 'A' and certain components of the support (though not necessarily all) may be reduced as a newly viable department builds up its research, and hence its individual grants, and can provide some portion of the continuing support by a levy on researchers' grants. The committee also considered the possibility that a particular group might prefer the support to continue through a central infrastructure, in which case the committee would (in effect) impose the levy on behalf of the group by continuing infrastructure support and reducing the amount of increase in individual operating grants. No policy was formed on this, but it was felt that it was somewhat contrary to the principle of allowing individual researchers to have freedom in their research spending. The advantages may outweigh the disadvantages for a time and input to the committee would be useful.

The 'unique facility' type of infrastructure grant was called type 'B'. It was envisaged that some type 'A' grants would progress to type 'B'. It was also considered that all such grants would initially be awarded for a 3 year period, if at all, and a review would be taken after two years to give a year's notice of any change in the status of the grant after the third year.

Because of the high rate of growth in computing and information science, and the need to put new equipment in place as fast as Is practical, the committee recognises that additional infrastructure support may become necessary during the tenure of an award by any group. The committee recommends a mechanism whereby holders of and existing infrastructure grant may apply for "Conditional early termination" of their grant, concurrently with an application for a new grant. The old grant would be terminated only if the new grant were awarded. Such new grants would be awarded in a normal competition and on the basis of documented significant change in circumstances at an institution (such as the acquisition of a major piece of new equipment).

Since infrastructure support was felt to benefit the experimentalist more than the theoretician, the committee believes the new program may be a further recognition of the needs of experimental computer science that will reduce but not eliminate the need for differentials between grants for experimentalists and theoreticians, once it is fully in place.

5.3 Equipment:

The committee was concerned about the shortages of equipment in the discipline. Funding formulae, and previous experience with applications and success rates, had suggested that the most urgent problem was to encourage well-justified, well-documented proposals. It was expected that a continuation of previous levels of support would then suffice for the current year whilst further planning was done for next year. This year, in fact, budgetary constraints, changes in the funding formulae, and the large increase in good equipment requests, have left some worthwhile proposals unfunded. This problem requires a stable approach to funding to encourage researchers to do their part in getting the right equipment in place on the basis of identified need, and to ensure that the funds are available to meet the demand that is created by publicity. Unlike other disciplines that are, according to the 5-year plan, using increasingly obsolete equipment, there is not much equipment to replace in CIS. The need is for initial placement of equipment for research. At present, many researchers are not simply using obsolete equipment. At worst, they are using no equipment. At best, with a few notable exceptions, they are using unsuitable equipment or even equipment borrowed from the physicists and engineers -- either alternative being likely to distort and curtail research programs due to constraints and/or conflicts in use. Remarks concerning research use of computers in general are relevant here (see below, this section). There is an unfortunate chicken and egg problem in preparing proposals for equipment for CIS research in the present circumstances. Namely, without facilities one cannot do research, but without research output, one cannot justify much equipment.

A major problem in the discipline is the cost of equipment. Provision of equipment adequate to the needs of researchers is very costly for a number of reasons. Quite apart from the high initial cost, and the high cost ratio between capital and manpower needs compared to many conventional areas, there is a high rate of technology turnover. What equipment there is needs to be replaced more often, especially since computer science research is heavily concerned with the information technology problems created by, or suggested by new hardware. Typical provision for overheads associated with computing, on top of the normal loaded rates for workers in industry, is $20-40K per software designer per year, with a capitalisation for equipment of $40-60K each (Feldman 1979 and recent information from industrial contacts). For research, at the leading edge of technology, at universities, one cannot expect the costs to be lower, except by reason of the part-time nature of university research. However, an active faculty member typically supports 4 graduate students who work full-time. Many organisations have recognised the need to provide better computer access for information users, and are planning to provide fairly sophisticated work stations for them. For example, Ontario Hydro plans to spend $75M over the next several years on personal work stations, each one costing about $10K over and above shared computer resources and communications. To the extent that equipment is provided, programming and technical support is required. However, it should be noted that such facilities are intended for all information users, not just CIS professionals. The needs of the latter are certainly more specialised and expensive, as well as the basis for the planned growth in the provision of such services.

Figures for 1974-81 produced by Vaucher (1982) show a total equipment spending on computer science of $1.65M, or 2.8% of the total for all disciplines. This does not include major grants made during the past 12 months amounting to roughly $1M. Chemistry and Physics received around $22M (37.5%) in the same period, which was one of financial restraint. The numbers of individuals receiving grants in these disciplines as of February 1982 (taking Physics as Main-line Physics and including team members) were roughly 280. 544 and 422 respectively based on individual and team grants that were active. If CIS grantees had similar capitalisation to Chemists and Physicists in 1981/82, based not on 3 years, but on 7 (i.e. from 1974-81) the total might have been expected to be $5.4M – over 3 times the rate. There is no hard reason to make assumptions about parity. Nevertheless, it is interesting that the figure reached by a different route (see section 6 on levels of funding) tends to support the need for this kind of major increase in capitalisation in CIS.

During the February meetings, the committee met with Dr. Sutherland, chairman of the *ad hoc* committee on research computing. He noted that there had been a great deal of hostility from the research community towards the interim policy to the extent that it had prevented researchers not in computer science research from obtaining their own computing equipment. The CIS committee was generally sympathetic towards the needs of other researchers. It felt that the need for such dedicated equipment reflected, in many cases, a real need which mirrored the growing importance of computing in all areas of endeavour, including research. The trend also reflects the falling costs and increasing power of general purpose computers, and the development of new system architectures in which many powerful but independent computers are connected together using local and long distance networks. Two suggestions were forthcoming. One was a rewording of the policy, the other suggested that, as networks come to dominate the provision of computer power, the need for distinguishing policies may become irrelevant, since adding more power to a centrally controlled distributed system, by adding a new processor, may well best be satisfied by placing that processor in an end-user location, regardless of the intended use, with access to files, special equipment, and the like taking place via the shared network, or locally, depending on particular circumstances. The general trend in the provision of computing power is to make systems more accessible to users, and less dependent on specialist help. Research on networks themselves would be another matter, and would fall in category C below.

The rewording of the categories (and also re-ordering, to try and avoid the assumption that the new policy is identical to the interim policy) was suggested as follows. The headings reflect the orientation of the user to what must be provided.

A **Buying computer 'power':**
Use of the computer as a facility. Computer power may be provided in various ways, including time-shared access to central sites or bureaux, but it may still be cost effective for some reason to have a machine dedicated to the user if the use is heavy, the system specialised, or whatever, and if the research justifies the cost.

B **Controlling the hardware:**
The use of the computer to manage an experimental set-up involving variable local connections to apparatus. Regardless of the software or activities involved, the degree of dedication, the need for real-time performance, and the special connections mean that such a computer is often only practical if it is under the direct control of the user. Such a system may still be connected to a network, or central facility, to gain access to number-crunching, file storage, etc.

C **Controlling the software:**
The use of the computer when, regardless of the hardware needed (and it may be a single machine, or a distributed system: it may be involved in real time control or in providing time-shared access), the user needs control over the software, and the software and/or system configuration are liable to change. The system, including the software, is usually the research.

The committee felt that computer science research would predominate in category C., but a need for control over the software may be essential even if CIS research is not involved (e.g. when an operating system not acceptable to others is essential to the research). The committee also felt that, while funding for computer science research needs must have very high priority (whatever the category, for reasons already noted), other disciplines are likely to have legitimate needs that are best satisfied by individually owned equipment, even in category A. The basic fact is that the use of computers for just about anything is dramatically on the increase. Class C computing tends to pave the way for other classes 5-10 years down the road.

Possible criteria for an individual computer system being provided under class A might include:

(a) Cost-benefit compared to buying 'time';

(b) Need for guaranteed fast response for interactive problem solving, especially where much computing is involved (e.g. computer aided circuit design, or graphics and image processing);

(c) Physical isolation (hooking into a 'site' etc. is difficult);

(d) Central 'site' is a network system;

(e) Special software packages are used that are essential, but not available on the central facility. (This is different from the need to control the software); or

(f) A need for security/prlvacy.

6. Levels of funding

6.1 Background and equipment needs

In the 1980 Vaucher report, the author was wisely circumspect with respect to recommending levels of funding. Such estimates tend to be crystal ball affairs in the current flux. However, if the capitalisation and operation of people performing similar work in industry is any guide, provision per researcher should be of the order of \$50K for capital, and \$30K per year per worker for infrastructure (over and above normal operating costs), with a three-year write-off period on equipment, because of the technology turn-over problem. If we assume that NSERC supplies roughly half the funding for equipment, as in the past (NSERC 5-year Plan), and that a 15% annual growth of grantees continues over the next three years, the total equipment funding by NSERC to ensure adequate capitalisation of researchers in 1985/6 would be (based on 280 1982/3 grantees):

280 x (1.15**3) x \$50000/2 ≈ \$10.6m

This \$10.6M becomes an average annual expenditure on capital equipment in the universities of \$3.5M in 1982 dollars, based on the 3-year write-off period.

If it were assumed that theoreticians need no computing equipment, this could be halved. However, this is not a realistic assumption as theoreticians are likely to need at least class A computing (using the above classification), as equipment requests by symbolic mathematics groups confirm.

6.2 Infrastructure needs:

Average costs would be \$30K per experimentalist for infrastructure support in 1982 dollars, giving a desirable total infrastructure support cost of \$4.4m in 1982/3 rising to \$5.8M, in 1982 dollars, in 1984/5. Clearly for 1982/3 we are far short of this figure, the committee having recommended around \$0.4M of infrastructure support (both types I and II), not all of which may be funded. There is an order of magnitude discrepancy which may well be an important cause of the relatively low rate of publication in practical areas, quite apart from the character of the activities. The real problem is that anybody running a substantial experimental research project in computer science today must spend enormous amounts of time doing various jobs that could and should be done by support people (i.e. infrastructure). For example, such jobs include: the evaluation, purchasing, expediting, installation, and commissioning of new equipment; administrative management; hardware maintenance; the operation of a laboratory on a day-to-day basis; construction and testing of special equipment. The point is that there are many time consuming, but necessary activities which do not require the skills of a highly trained research worker, except in a general supervisory role.

6.3 Operating grant needs:

The actual total funding this year is still uncertain, as not all decisions have been made. If all the amount recommended, but within this year's NSERC guidelines, were funded, then the total for individual, team, and infrastructure support would be roughly \$5.0M, in 1982 dollars. (**Model 0**).

In November 1981 a study of individual operating grant needs was made. It covered the needs of our best researchers, both theoretical and experimental, at both ends of the maturity curve, as well as starters, based on minimum and ideal funding for the support of graduate students, small items of equipment, travel, supplies, research associates, technical support and computing costs. Assuming that technical support costs and computing costs are reduced by an overall 50%.

because of the provision of Infrastructure, the figures produced then may be summarised as follows:

Class: (Assumed age)	Starter (30)	Excellent younger (38)	Outstanding senior (55)
Type			
Theoretician Min	9.7	20	39
Theoretician Ideal	14.8	40.2	61
Experimentalist Min	13.1 (11.1)	24.8 (17.8)	39.4 (29.1)
Experimentalist Ideal	23.8 (20)	54.2 (39)	69.8 (48.8)

(Thousands of dollars annual operating)

The bracketed figures for experimentalists in the above table shows the effect of denying all technical support and computing on the assumption that infrastructure were to be fully funded everywhere.

Making cost estimates based on these figures is less easy without knowing the detailed age/ability distribution for our grantees. There are currently 280 CIS grantees, of whom roughly half are theoretical and half experimental. Let us assume that the average age of our grantees is 35, that the maturity curves are reasonably approximated as linear (which they are not, in general), and that 17% of our grantees are outstanding (based on this year's judgements for extra merit adjustments -- probably low as second and third year instalments likely contain proportionately more). Let us also assume that what is minimum for an outstanding researcher should be average for a normal one (which, given the way the figures were derived is not unreasonable); and that outstanding researchers should deviate at least halfway towards their ideal funding, on average, from the mean normal grant. By interpolating the recommended maturity curves for age 35 we can make a rough estimate of the total dollars needed to fund CIS operating grants adequately. The amounts derived in what follows are what would have been required this year based on the forecasts of November 1981 adjusted for inflation to 1982 dollars.

Normal theoreticians	280 x 0.5 x $16K x 1.123 K 0.83 +
Outstanding	280 x 0.5 x $23.5K x 1.123 K 0.17 +
Normal experimentalists	280 x 0.5 x $20K x 1.123 x 0.83 +
Outstanding	280 x 0.5 x $32.5K x 1.123 K 0.17 =

Total $6.2M

Thus about $6.2M would be reasonable, giving an average grant over all grantees of around $22.1K. Infrastructure support would add a further $4.4M to this figure giving a total of $10.8M. (**Model 1**).

If it is assumed that experimentalists need no technical support or computing on an individual basis if infrastructure is fully funded everywhere (and this is a rather dubious assumption that goes against the NSERC idea of reasonable individual freedom), then, using the bracketed figures as the basis of maturity curves, and making the same assumptions, the total required for all grantees falls to $5.5M, giving an average grant over all grantees of $19.6K. Adding the suggested infrastructure puts the total support needed in 1982 dollars to support individual grantees at $5.5M + $4.4M = $9.9M In 1982/83. (**Model 2**).

On the other hand, if the figures are re-done on the assumption that no separate infrastructure support is to be provided, so that experimentalists require the full technical and computing support recommended in November 81 then the amount required to fund operating grants for 1982/3 to meet the recommendations rises to $7.3M in 1982 dollars. (**Model 3**).

The following table summarises the above figures (all amounts being shown In 1982 dollars):

Maximum actual award for 1982/3 (Model 0, including all infrastructure)	$5.0M
Amount suggested by model 1	$9.9M
Amount suggested by model 2	$10.8M
Amount suggested by model 3	$7.3M

Model 0 represents the most that will be done this year in terms of operating grants and infrastructure support. Model 1 assumes that, in addition to the overheads special to CIS research provided for by infrastructure, experimentallsts still need some individual support in these areas. Model 2 assumes that experimentalists need no individual support for technical and computing costs because everything is provided by infrastructure. Model 3 assumes that all the support for CIS generally, and for experimentalists in particular, is provided through individual operating grants, and that there are no infrastructure grants.

These are simple models, with obvious flaws. For example. Model I seems to be an overestimate, since some of the needs of experimentalists appear to be covered twice. But it should be noted that this group has little provision for scholarly visitors, compared to theoreticians, and equivalent visitors who contribute to the practical goals of projects may not readily be fundable from totally committed infrastructure allocated to a group, so failure to provide some funds under individual control could involve considerable loss of research freedom. At the same time, the funding levels for infrastructure could not be much reduced and still be effective. One would expect the quality and quantity of research to be highest under Model 1, which approaches the ideal. Another kind of constraint is illustrated by the fact that Model 3, involving total freedom for individuals, certainly flies against the whole principle of efficiently providing the infrastructure support that is badly needed and that was strongly endorsed by the committee. However, the models do allow a feel to be gained for the range of support for CIS that might be reasonable. It is clear that, compared to any reasonable assumptions and models, CIS is currently underfunded. The factor is somewhere in the range between 1.5 and 2.1 to 1. This accords well with the guesstimate in the Vaucher report (1980).

6.4. Errors:

The error bounds on the suggestions for equipment and infrastructure support are probably rather large -- around +/- 30%, on the basis of the range reported for industrial settings. The levels for individual operating grant support are probably much more precise, because they are based on a careful recent study of detailed (Itemized) needs, and are not subject to so many unpredictable factors. Those estimates are probably within 10%.

6.5. Concluding remarks:

The actual amount provided for operating costs, assuming that type II infrastructure recommendations are funded, and counting the 75% NSERC funding of type I grants, for 1982/3 is $5.0M. This is at least $2.3M on the low side, and may be as little as half what is required. The equipment allocation is also low compared to what reasonable planning for the future requires. Roughly $0.5M was provided for equipment but, due to greater awareness in the community, coupled with greater need together with encouragement by committee members by personal contact and during site visits, we could have usefully funded nearly double this amount. To meet the needs 3 years down the road, we ought to have considered spending 7 times this amount ($3.5M). However, that would have required considerable advance planning and notice to allow grantee groups an individuals to prepare enough worthy applications to merit such heavy spending. The committee recommended that, for this year, some way be found to extend the reserve list on minor equipment (to a total $ amount of about $0.836M), instead of limiting it to the 50% of requests as planned. The needs are urgent, and many more applications merited support. The committee were hopeful that major equipment and major installation requests judged at higher levels would be treated generously, in accordance with the perceived needs, expressed on a number of occasions. The committee also recommended a major new initiative, with adequate funding and advance notice to all potential applicants, to upgrade the equipment provision for CIS over the next three years and to maintain It at an appropriate level thereafter.

7. In conclusion

7.1 Good things so far:

(a) Grantees are almost unanimous in their praise of the flexibility and freedom allowed in the use of grant funds. Indeed, this does, to some extent offset the worst effects of low grants, since it Is possible to take advantage of opportunities, as the technology changes. Even NSF is modifying its rigid approach to budgetting now.

(b) The predictability of grants allows some degree of continuity, even for fairly small operating grants. Reaction has been very favourable to the system of warnings that offsets the slow rise of grants and allows for fluctuations in productivity. At the same time it is felt that some kinds of work produce few regular refereed journal publications while other work may take a long time to produce any results. More weight should be given to the quality of the work independently of the formal publications, whilst avoiding an 'old boy network'.

(c) Seed money has been given by NSERC and has blossomed well. CSRG at Toronto is an outstanding example.

(d) The change in the infrastructure grant rules is likely to prove crucial to computer science. If adequately funded and matched by appropriate equipment funding, it will go a long way towards alleviating the current crisis.

(e) The change in the visa student regulations that allows payment of graduate students from operating grant funds helps to improve the research environment, especially at the smaller schools, and indirectly benefits the program to produce needed highly skilled manpower because of the teaching contribution made by these students.

7.2. What more might NSERC be able to do ?

There are some things that NSERC cannot do, at least, not directly. Most notable among these are improvement of salaries, and reduction of teaching loads. Given this, the most important steps that NSERC may take to help computing and information science research in Canada seem to be as follows:

(a) Accelerate programs intended to make the research environment at universities more attractive. This is not something that may be spread over the next few years: action is urgently needed this year, on a massive scale, before nascent centres dissipate, and existing centres lose key personnel. The chief mechanism is through equipment and infrastructure support. The scale is of the order of \$3.5M a year for the next 3 years on equipment, and a 1982/3 figure of \$4.4M rising to \$5.8M by 1984/5 on infrastructure, both in 1982 dollars. It is clearly too late to implement this recommendation fully in 1982/3 but what action can be taken should be. The committee was conscious of the loss of control of priorities implicit in the splitting of these categories of grant into minor and major, when the major awards were unknown at the time of deciding other grants of all types. The committee felt that, with adequate prior commitment In the areas of equipment and infrastructure, more excellent applications could be received and funded. Given the pressures on researchers, it is hard to put the considerable time needed in to the preparation of submissions. If the chances of success are perceived as small. Group proposals typically involve man-months of effort and are competing with some very high priority activities (such as recruiting and research) at a time when the pressure is very great, and individual research projects offer their own compensations.

(b) Provide increased operating grant funds to CIS grantees. The figures are presented above, but a minimum increase would be \$2.3M in 1982 dollars if the current year were refunded – an increase of 46%. The full increase required could amount to doubling, depending on how infrastructure grants are handled, and how they are thought to relate to operating grants.

(c) Provide research fellowships tenable by Canadian-based faculty at their home institutions and for visiting research associates. This would probably involve the consequent employment (by the university) of some less well qualified staff for teaching but the benefit is expected to outweigh the cost.

(d) Change the title and subcategories for the Strategic Grants Committee concerned with communications. This is to be discussed further with that committee, but the title Computing and Communications was suggested. At present, although many computer projects seem allowable, project design is distorted and some areas are not ostensibly covered (e.g. Data Bases – unless distributed). Potential applicants are unlikely to apply if they feel computing is of lower priority than communications, whatever the informal intent of the committee.

(e) Avoid restrictions on required years of post-doctoral experience for research associates In CIS. Once such personnel go elsewhere, they seldom return to university, and post-doctoral salaries will not keep them in place.

(f) NSERC could pressure universities to accept the spirit of the new regulations on payment to graduate students, so that more realistic salaries can be offered by a combination of sources of income. At present, although NSERC regulations permit combinations, many universities assume that payments from grants involve a time commitment from students that is not related to thesis work. They allow only partial research grants and partial teaching support to be combined on the grounds that this limits the time commitment devoted to non-thesis work. In fact research grant support is very often directly intended to support thesis research because it falls into the general plan, and this should be recognised where appropriate.

7.3. What benefits may be expected ?

(a) It will be easier to attract and retain high quality faculty and graduate students to man research programs and keep departments alive.

(b) As a consequence of 7.3 (a), not only will the supply of highly skilled manpower at all levels in computing and information science be secured and increased, but also research activity will be increased in an area that has become fundamental to overall performance in many areas. These consequences are vital to the future health of the economy.

(c) Faculty will gain more time for technology transfer activities.

(d) New jobs will be created at all levels due to the enhanced supply of highly skilled manpower in this critical area of CIS. These jobs will be outside CIS as well as inside due to increased activity in many industries.

(e) A longer term benefit will be to reduce dependence on imported systems, and increase exports. This is important for national security, as well as the balance of trade.

8. Acknowledgements

The report is for general circulation. However, it should not be taken as official NSERC policy, nor even an official GSC document. It is intended to inform, to provoke discussion, and to provide a starting point which can be corrected. Any mistakes are the responsibility of the author, but preparation of the document would have been impossible without the willing cooperation of all CIS GSC members, including the Permanent Secretary, and the Group Chairperson. It remains, however, a personal view.

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d.r. hill march 1982

REPORT ON THE FUNDING OF

COMPUTING AND INFORMATION SCIENCE

IN CANADA

[THE VAUCHER REPORT]

NSERC Grant Selection Committee
Computing and Information Science

April 1980

1. INTRODUCTION

Over the last two years, our committee has discussed at length the type and level of funding required to stimulate effective Canadian university research in the area of Computing and Information Science. This discussion was sparked by President MacNabb's request in 1979. It was further stimulated by NSERC's 5-year Plan and the publication of American reports to the National Science Foundation on the need to rejuvenate Experimental Computer Science.

Our main conclusion is that Computing and Information Science (CIS) is unique amongst other scientific disciplines in its speed of growth and evolution and in its present and foreseeable impact on society. As a result, the funding of CIS should receive special attention from NSERC.

A second conclusion is that the classification of our discipline as a Science overlooks the important engineering component of the research done by over half of our grantees. In a sense we are funding two equal areas: theoretical CIS and an area which might be termed Computing Systems Engineering. Considering that the origins of CIS lie in both Mathematics and Electrical Engineering this duality is natural but, whereas the present type and level of NSERC funding is reasonable for the theoretical area, it is totally inadequate for the engineering side: on the basis of average grant size, CIS ranks third worst amongst the disciplines supported by NSERC.

In what follows, we present evidence to support our claim that CIS Is special. Then, we examine problems specific to research in the area and make propositions to remedy them. Our committee is aware that many of the problems we raise have ben identified in NSERC's 5-year Plan as applying to Canadian research in general, but the very success and dynamism of CIS makes them much more acute in our case.

Before proceeding, we should point out that our report makes definite proposals on the type of funding required but is much less precise with respect to levels of funding. We believe it is essential to establish need and form of remedial action first. Only once these points are recognised can our commiittee and NSERC proceed constructively. However, as a rough estimate, we believe that effective stimulation of CIS university research requires doubling of our committee's budget. As a final point, our report deals exclusively with university research but it should be apparent that full benefits to the Canadian economy will occur only if industrial research and development are also the target of a similar effort.

Statistics used in the report have been drawn from many sources including NSERC's published grant figures, its 5-year Plan and a recent (Jan. 1980) CIPS Review issue devoted to the impact of technology on employment. Two other recent and pertinent reports, The "Feldman" report and the companion "McCracken" report, are included as annexes.

2. GROWTH AND IMPORTANCE.

The evolution of Computing and Information Science is directly linked to the spread of computers and the growth of the industry. Accordingly, CIS is a relatively young discipline appearing about 30 years ago with its major growth beginning in the 1960s. The importance of CIS can be gaged by considering the rapid increase of computer installations and computer professionals as well as the forecasted impact of computer automation in employment patterns.

In 1960, there were roughly 10,000 large and medium scale computers in North America. In 1970, the number reached 100,000 and presently, in 1980, these computers number 800,000 at an average cost of $200K each ($1K = $1,000). Currently, with pocket calculators having the same power as the first million dollar computers, there is a problem in defining exactly what is a computer but the trend is clear and forecasts for Canada indicate a further growth in the number of installed computers by a factor of ten over the next ten years.

Consider next the number of jobs involved. Between 1969 and 1978, the number of computer professionals in Canada increased from 2,000 to 11,000. A recent study foresees a further 50,000 job openings in Canada over the next 5 years and warns that many of the openings will have to be filled through immigration due to a shortage of native trained manpower. The situation, however, is the same in other countries: in the US, it is estimated that there will be 5 times as many computer jobs in 1985 as in 1977 and it is forecast that demand will be twice the supply. An indicator of this situation is the employment register at the Annual ACM Computer Science Conference. In 1977, openings listed outnumbered applicants by a factor of three. In 1978, the ratio of jobs to candidates was 10 to 1 and in 1979 it reached 12 to 1.

Although computerisation is responsible for the creation of some jobs, it is also displacing many others. The most vulnerable job category is that of secretaries and office workers where office automation based on microcomputer word processors is expected to have a profound effect. Recent pessimistic studies forecast displacement of 5 million such jobs in France by 1985, 2 million jobs in Germany by 1990 and 4 million jobs by 1995 in England. The jobs that remain will make more and more use of computer derived information and it is predicted that by 1985 half of the US working population will be using computer technology daily.

These numbers illustrate clearly that, by its impact, Computing and Information Science is unique amongst scientific disciplines and should be treated as an area of national concern.

3. PROBLEMS.

The very success of the industry leads to special problems in its supporting science and research. Briefly, the problems confronting Computing and Information Science in Canada are the following:

1) a shortage of qualified manpower,

2) inadequate facilities and rapid obsolescence of those which are adequate now.

3) underestimation of the engineering component in our research and

4) the absence of concentrated applied research.

3.1. Shortage of qualified manpower.

We .previously noted a forecast 2 to 1 ratio of jobs to candidates in the computer industry. The situation is even worse at the Ph.D. level. The CIS Ph.D. production in the US is about 200/year and it is estimated that only one quarter (50) of these will find their way into universities. Yet a recent issue of the Communications of the ACM (Association for Computing Machinery) listed over 160 open faculty positions. The specialities most in demand were in the Computing Systems Engineering area: operating systems, software methodology, data bases and networks.

In its 5-year Plan, NSERC noted a balance between supply and demand in the physical sciences and mathematics and a 50-100% deficit in the applied sciences and engineering. In CIS, at the Ph.D. level, the discrepancy is even greater and a 4 to 1 ratio of openings to applicants is forecast for 1985.

It is ironic that postgraduate production is in steady decline whereas undergraduate enrolment keeps on increasing, approximately doubling in the last two years. In Canada in 1977, we produced 161 M.Sc. and 20 Ph.D. graduates in CIS. These figures were in decline by 6% and 26% respectively compared to 1974 levels. In the US, between 1975 and 1978, a similar 17% decrease at the Ph.D. level was observed.

What is happening is that research in general and the Universities in particular are losing out to industry. Starting salaries in the industry are quite attractive, in the range of $18K for the B.Sc. graduate and $25-30K for the Ph.D.. Comparing these figures to NSERC's stipends and scholarships, we note a 2 or 3 to 1 differential in favour of industry, and it is quite evident to students that research does not pay. Even the increases outlined by NSERC in its 5-year plan will not materially change the situation. In particular, the basic salary proposed for Research Associates is much too low and the requirement of 2 years post-doctorate experience is unacceptable.

One might expect that low remuneration might be offset by providing an attractive environment for research. Yet, this is not so! Let us consider NSERC funding in general; the next section will deal with the special problems of equipment. Analysis of grant figures over the last 6 years shows that CIS grants are consistently 17% below the general average for all disciplines. For the last competition (1980), grouping all categories (operating, team, equipment, etc. ...) the average grant was $15.7K; in CIS the average grant was $12.6K, 20% below the general average. Our committee is aware that there may be several good reasons for this: CIS being a young discipline, the average experience of applicants may be less than elsewhere and many of our applicants do research in areas close to mathematics where grants are lowest of all. Nevertheless, the fact remains that in spite of the unique character and impact of our discipline, we are one of the three worst funded areas.

3.2. Inadequate facilities

Stimulated by the needs of the industry, the leading edge research areas evolve and shift rapidly. In the recent past, we have seen the appearance of the following new areas at the rate of roughly one per year:

- microprogramming
- portable systems software
- image analysis and remote sensing
- data bases
- networking and telecommunication protocols
- structured language design
- multiple microprocessor specialised architectures
- personal computing
- text handling and software tools
- electronic mail
- office automation

These are areas were research has a definite spin-off to industry and these are the areas which provide the type of challenge and relevance which attract students and retain Ph.D.s . Unfortunately, these are also the applied areas where research requires extensive modern equipment and support facilities lacking in our universities.

The Feldman report notes that leading industrial research laboratories in experimental computer science are capitalized in the range of $40-60K of equipment per research professional whereas in the vast bulk of universities the level is well below $10K per researcher. Furthermore, sheer value -is a poor indicator of capability. The problem of obsolescence noted in NSERC's 5-year Plan is nowhere more acute than in the computer field. In laboratories such as XEROX PARC, Stanford and MIT, researchers use individual personal computers costing around $20-30K each which have a power equivalent to that of data centers of a few years ago (execution at one million instructions per second, 256K bytes of main memory and 10Mbytes of disc storage). Can our universities compare?

Equipment by itself is not enough. To keep equipment useable for research requires software (bought or leased), hardware and software maintenance, and operators. In other words, equipment acquisition entails a yearly recurring operating cost for the life of the system. NSERC's 5-year Plan noted that this expense can reach 60% of the initial investment per year and the Feldman report suggested a support commitment of 10% of the capital cost yearly for a life of 5 years. Except for very minor equipment, this recurring expense is usually outside the possibilities of individual operating grants.

In the crucial area of equipment, our allocation over the past 6 years was 22% below the general average. We are aware and grateful that over the last two competitions NSERC has shown willingness to improve the situation ($287K in 1930 and $161K in 1979). What is disturbing, however, is the contrast to the amounts of $15K in 1978 and $22K in 1975. It is a fact that researchers tend to apply for what is known to be available, and the spate of applications this year is a direct result of the previous year's relatively generous allowance. Continuing clear evidence of a will to support equipment at a reasonable level is a necessity.

What is also necessary is provision of a granting mechanism to provide for maintenance and support activities so that potential benefits of equipment are fully realised. In the past, aware of the critical need for this type of support, our committee has used the CORE grant mechanism in three instances although the equipment in question was not within the strict interpretation of the Awards Guide's definition as “very special research facilities not otherwise viable in Canada ... accessible to scientists from several institutions or departments”. Last year, we informed NSERC of this dilemma. This year, after lengthy discussion, it became obvious that a continuation of our policy would eventually divert a large part of our budget to maintenance and impact substantially operating grants. We therefore tuned down a similar application and we foresee that the existing CORE grants will not be renewed.

We believe that equipment grants in the present sense are unsuitable to the discipline and that they should be replaced by grants for special computing “facilities” including both purchase and continuing support.

3.3. Engineering content of CIS research.

This concern with computing facilities is in line with the important engineering component of the research funded by our committee. Many of our applicants do experimental research in that they are designing and building new kinds of hardware and software systems or measuring and testing both algorithms and systems. Others draw their problems from areas of concern to the industry and concentrate on tools and methodology and several list industrial contracts. Analysis of proposal content and field codes indicate that roughly 55% of the applications to our committee are in the computing systems engineering area.

The committee regards applied research as vital and 2 of our 9 members are representatives from industry. We also feel that, because of the expense involved, this type of research should be generally supported at a higher level than theoretical research. However, traditional criteria for evaluating proposals are hard to apply because it is quite normal for a good applicant on the practical side to produce 1 paper per year whereas the theoretician may produce 4 per year.

It would be useful to us if NSERC’s intent regarding engineering content and industrial contacts could be clarified. We have often hesitated between regarding these items as a positive indication of relevance and considering them as evidence that the work was too practical to be funded as research. We suspect that applicants may be hesitant to describe their true activities for the same reasons. We believe that, for engineering proposals, more weight should be placed on evidence of dissemination of results other than strict publications in refereed journals or conferences. It would be helpful to our committee if the application form layout and the awards guide would encourage the applicant to list and expand on:

- industrial activity
- distribution of software products
- patents
- graduate students and their topics

Note that, although some of our applicants have patents, because of the difficulty in patenting software, this measure is not generally applicable.

3.4. Lack of concentrated applied research.

We believe that computing systems engineering should be strongly supported and that there should be special granting mechanisms for funding concentrated applied research. In Canada, we have no situations where large complex computer system development projects can be initiated and sustained in a university environment. This is unfortunate since the graduate students involved, the basic knowledge gained and specific results achieved could have a considerable impact on the Canadian economy. The Feldman report emphasizes the important contribution of university teams to the development of the first computers, the first time-sharing systems and the first data networks. The key points with regards to this type of activity are provision of “critical mass” teams and stability of funding. Examples of the type of affirmative action NSERC could undertake in this area are given in the next section.

4. SOLUTIONS.

Solutions to the first three problems follow directly from our analysis.

To attract and retain researchers, scholarships and stipends in the CIS area must be increased.

Increased “facilities” funding is also necessary to maintain existing equipment and replace obsolete machinery.

NSERC should indicate clearly its willingness to support computing engineering research and modify current documents and forms to allow presentation of appropriate evidence of “productivity”.

Finally, to counter the absence of concentrated applied research, we make three proposals.

First we repeat the suggestion made last year in our answer to President MacNabb’s request. We proposed the creation of a small number of “Centres of Excellence” with annual funding in the order of $2,000,000 per year. A possible model for such a centre would comprise 25 positions with 7 or 8 full time Ph.D. researchers, 12 research assistants and 5 visiting positions. This is in line with the critical mass noted by Feldman as ranging between 20-50 full time positions and budgets between $2-3,000,000. This kind of organization would be suitable for projects in the $100-$200,000 range and, once established, the “centres” should attract industry interest and funding. This sort of action parallels NSERC’s proposal for a research associate program. However, in our discipline, we believe these associates should be regrouped and concentrated on applied research. It should also be apparent that due to recruitment difficulties, long term policies are necessary and it may take some time to staff such centers to the required levels.

Secondly, we propose that the Strategic Grants programme should be expanded to include a category for Computing Systems. We recognize that this area of concern is not particular to Canada as might be others such as energy or communications. On the other hand, it is a major area of concern to all industrialised countries and should be treated as such.

Finally, we propose the creation of a Canadian research computer network as a means to achieve critical mass effects without physical proximity. In the American ARPA network, users can collaborate using electronic mail, exchange files and use each others' facilities. In Canada, the DATAPAC network facility exists enabling users to communicate at an average cost of $1.00/hour (cheaper than long distance phone or even mail). However, the mechanics of communication are enough to discourage all but the most persistent. Sending a message requires the preliminary setting up of a special account in the recipient computer and knowledge of 4 computer languages and 3 different account and network numbers. It is quite feasible, however, to consider a standard mail interface to DATAPAC coupled with a directory of CIS grantees and their research interests so that a researcher could locate and communicate with others in the same area. The design and implementation of such a network could be funded through strategic grants in the Computing Systems category or carried out in a centre of excellence.

5. CONCLUSIONS.

We have demonstrated that Computing and Information Science is unique with respect to its growth and impact on society. We have also underlined the large engineering component of the research we presently support. Although the present funding mechanisms appear satisfactory for maintaining a solid base for theoretical research, they are totally inadequate for the type of engineering research carried out by the majority of our grantees and that type of research most relevant to our industry.

Therefore we propose NSERC increase its support of Computing Systems engineering by:

1) increasing amounts of scholarships and stipends in the CIS area and at least removing the post-doctoral experience requirement for Research Associates,

2) increasing equipment grants and coupling these with provision for maintenance and support,

3) recognising the special criteria of "engineering" to research and modifying its Awards Guide and Applications forms accordingly,

4) recognising Computing Systems as an area of national concern and adding that category to the Strategic Grants Program,

5) creating a small numbers of applied Centers of Excellence, and

6) sponsoring and funding the design, creation and operation of a CIS research network.

7. MCCRACKEN REPORT: CRISIS IN EXPERIMENTAL CS

An ACM Executive Committee Position on the Crisis in Experimental Computer Science

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The following is the text of a letter commenting on the Feldman Report sent to Dr. Richard C. Atkinson. Director of the National Science Foundation, and other Administration and Congressional officials.

We write about the so-called Feldman Report, addressed to the National Science Foundation and others, entitled "Rejuvenating Experimental Computer Science." This report argues that there is a crisis in experimental computer. We agree. The report proposes remedial directions for academia, industry, and government. We agree with some of those proposals.

There is indeed a crisis in experimental computer science, both in academic and in industrial research centers. The crisis is manifested mostly as a severe shortage of computer scientists engaged in, or qualified for, experimental research in computer science. (By "experimental research" we mean not only the construction of new kinds of computers and software systems, but also the measurement and testing of computing algorithms and systems.) This shortage is aggravated by strong demand in the computing industry at all levels for systems-oriented personnel. The demand is so great that holders of bachelors degrees in computer science normally start their careers with salaries in excess of $16K while those with Ph.D. degrees command at least $25K. High salaries in industry attract qualified systems-oriented faculty from universities; they entice qualified students from graduate school. The result is fewer systems-oriented faculty supervising fewer systems-oriented students. This further worsens the underproduction of qualified systems-oriented computer scientists.

We have a special vantage point for viewing the widening gap between supply and demand of systems-oriented computer scientists. Each spring the Association for Computing Machinery's Computer Science Conference sponsors an employment register that helps bring together prospective employers and employees. In 1979 employers registered 12 times as many jobs as there were candidates; in 1978 the ratio was only 10:1; in 1977 it was closer to 3: 1. Although it is not wise to draw precise conclusions from our employment register, there is a definite and alarming trend.

This problem is recognized by some components of government. The President's Federal ADP Reorganization Study (FADPRS) emphasized findings remarkably similar to the Feldman Report. It reported that shortages of computer science personnel may actually impede technological advance in this country. The Council on Wage and Price Stability (COWPS) has ruled that (in certain instances) Computer Scientists (not systems analysts or programmers) are an "endangered species" and, therefore, can be excluded from the President's Wage and Price guidelines. A recent Rome Air Development Center/State University of New York Symposium on Command, Control, and Communications predicted that, by 1985, over half the total U.S. work force will use computing technology daily—and that we face an imminent defense crisis because we will be unable to attract scarce computer science resources to defense problems.

The Feldman Report focuses on academic computer science, which has, over the years, provided much of the research thrust and has trained most of the computing personnel. By pointing out that good faculty and graduate students are being recruited away from universities, the report intends to highlight the danger in continuing the shortage of those who train the new generations of computer scientists and who help bring new research ideas to the entire community. Presumably the decay of academic computer science will propagate to other sectors, affecting our economic and military strength in an area where now we enjoy the strongest international position. As the Feldman Report suggests, we concur that the focus of the solution must be in the Ph.D. programs of the academic sector. These programs are the primary source of trained researchers and of new faculty to teach computer scientists at all levels. Making these programs more attractive is an essential element of the solution of the current crisis.

The Feldman Report also focuses on obsolescent computing equipment as a primary cause of the decline of academic computer science. The report argues that the better experimental computing facilities in industry entice the experimental computer scientists from the academic community. The report suggests that an ambitious equipment program—large grants to a select few universities that have a "critical mass" of research faculty—would go a long way toward relieving the crisis.

While we agree that academic experimental computing facilities tend toward obsolescence, we have serious doubts that huge grants to the so-called "centers of excellence" would achieve the desired objective. The' Feldman Report envisions up to 25 centers being started .over a five-year period. However, there are now 62 universities in the United States that cram Ph.D's in computer science. We believe that the embittered feelings of, and the drain-off of resources from, the institutions not favored by this program would severely divide the community just when unity and common programs are most important. We believe that the community is best helped by providing that all available research funds, whether from existing sources or from new ones, be available equally to all qualified computer science research groups.

We believe that the National Science Foundation can, and should, take the lead in reversing the crisis in experimental computer science. We endorse three concepts discussed by the Advisory Panel for the Computer Science Section at its meeting in late May, 1979: traineeship programs, capital equipment programs, and a computer network for computer science research.

Traineeship Programs. We believe that a good method for relieving the personnel shortage is to encourage more students to take up experimental computer science. Some years ago, the NSF responded to a shortage of mathematicians by earmarking fellowships for that discipline. The infusion of money led to an increase in the production of needed mathematicians. Present estimates put the supply of Ph.D. computer scientists at one-fourth of the need. Thus a program of traineeships with attractive stipends would serve as a strong inducement to students to stay for doctoral programs. After one or two years of support on a traineeship, such students would be sufficiently involved in research to be supported from Research Assistantships on other grants. Further, traineeships are preferable to pure fellowships because traineeships distribute the qualified student manpower over a large number of institutions, rather than concentrating it at the few best endowed ones.

It is sometimes argued that more support funds would merely lower the quality of those supported, because "all good students find support." However, we believe the evidence shows that there is a large pool of excellent students who bypass Ph.D. programs because they perceive better opportunities in industry. An attractive traineeship program would draw from this presently untapped pool of good students.

Capital Equipment Grants. The NSF computer equipment grant program may have mitigated the current. manpower crisis. Through this program, many university Computer Science departments acquired modern computing facilities, now used solely for research. This reversed the trend toward obsolescence in those places.

NSF can meet the Feldman Report's recommendation to upgrade capital equipment by expanding its computing equipment grant program. We believe this is a better program than the "centers of excellence" concept not only because the existing program permits everyone to partake of the available funds, but because it is a tried-and-tested program with proven success.

The Feldman Report focused on computing equipment at universities. We note, however, that the FADPRS observed many instances of obsolescent equipment throughout government, Defense in particular. Although we believe that you should upgrade your support of the university computing equipment program, we also encourage you to support efforts to achieve a balanced program to strengthen the nation's overall position in computing.

We also encourage you to support government policies that give incentives to industry to donate equipment and funds to universities. Federal policies over the past decade have discouraged such donations, which were once common.

Research Computer Network. The principle realized in the ARPAnet computer network has proved of considerable benefit to its users. These scientists are able to collaborate by electronic mall; they can exchange files, data sets, and software modules; and they can use each other's computing facilities. The ARPAnet realizes most of the benefits of resource-sharing of large centralized facilities, within a distributed system; it enables a critical research mass without requiring physical proximity.

The NSF can take the lead, or cooperate with ARPA, EDUCOM, or other agencies, in developing a computer network open to all members of the computer science research community. Modem minicomputer technology and common carrier data networks can be combined to permit research groups to connect at modest costs that are well within the reach of an equipment grant program. We encourage you to support such a network. We note that supporting a network in today's technology does not preclude upgrading to better technologies when they are available.

Summary. There are other aspects of the Feldman Report on which we have taken no position. We have focused here on what we believe to be the essential elements of the report—the ones on which the NSF can have the greatest influence. We hope that you will find these comments useful, and that they will help you as you work to preserve our national expertise in computing technology.

8. FELDMAN REPORT: REJUVENATING EXPERIMENTAL CS

Rejuvenating Experimental Computer Science

A Report to the National Science Foundation and Others

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This report is based on the results of an NSF sponsored workshop held in Washington, D.C. on November 2, 1978. The co-authors of the report are: Gordon Bell, Digital Equipment Corporation; Bernard A. Galler, University of Michigan; Patricia Goldberg, IBM Corporation; John Hamblen, University of Missouri at Rolla; Elliot Pinson, Bell Telephone Laboratories; and Ivan Sutherland, California Institute of Technology. Also participating in the workshop were representatives of NSF and other government agencies. In addition to the authors, a number of other people have contributed to the contents of this report. In preparation for the original workshop, all doctorate-granting computer science departments in the nation were asked for comments and suggestions on the problems of experimental computer science. A version of the current report dated January 15 was circulated to these departments and to a number of industrial and government groups for criticism. The editors and authors of this final version gratefully acknowledge the contribution of a large number of other people at all, stages in the preparation of the report. [Note: Following this presentation of the report, there is a position paper on the crisis in experimental computer science written by the ACM Executive Committee.)

Summary

Computation is a large and growing component of the intellectual, economic, and military strength of the nation and constitutes an area where the United States has the strongest international position.

Academic computer science provides much of the research thrust and trains most of the professional manpower for this sector.

The confluence of major advances in microelectronics, communications, and software technology has brought about a greatly expanded need for experimentation in computing.

Many of the best faculty, staff, and graduate students are being recruited away from universities.

To improve university experimental computer science requires an immediate investment in capital equipment.

Recommended courses of action by various sectors include the following:

Universities

- Recognize the special resource needs of experimental computer science.
- Use appropriate criteria in evaluating experimental computer science programs and faculty.
- Encourage cooperative programs.

Industry

- Exchange and share people and technology with universities.
- Provide funds and equipment, possibly through a private foundation.

Government

- Reconsider tax incentives, patent policy, and consent decrees.
- Develop funding of adequate scale and time horizon for experimental computer science. A model program is suggested in Section II.
- Designate a lead agency responsible for the national future in computing.

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1. The Importance of Computer Science

Computation and communication form a large and growing component of the economic, intellectual, and military strength of the nation. The fundamental resource, technological, and societal conditions driving this expansion should continue to hold for the foreseeable future. The widespread introduction of computation and information processing approaches have led to major new developments in almost every field of intellectual endeavor. In the social and behavioral sciences, computer technology provides the major set of new tools. The role of communication and advanced computation in the nation's military posture has also been growing rapidly [1].

Academic institutions have played a major role at every stage in the development of the information processing sector. In addition to providing the great bulk of trained people at all levels, universities have led in research, development, and deployment of many of the hardware and software concepts which form the backbone of commercial, scientific, and military information processing. Universities have provided the most broadly based environment for research and advanced development in experimental computer science, but can continue to do so only with substantial help from industry and government.

There are a number of ways to measure the contributions of experimental computer systems efforts at universities to the current state of computer technology. We shall look at some important uses of computers and detail the unique university contributions, as well as the synergistic effects that university systems research has had on industrial research and development. We shall consider some of the largest, most mundane applications and how they have benefited from academic discoveries. The relationship in more advanced applications such as image analysis and industrial automation is obvious enough to require no exegesis.

Large Management Systems. Large database systems are today crucial to many organizations. They are employed, for example, not only by insurance companies for policy management, but by large engineering projects for design control and parts management. Complex inventory control systems and management information systems are the order of the day. What do these systems consist of? A typical system controls scores of terminals updating multiple files, which are frequently of large size. The central machine is multiprogrammed (to give appropriate terminal response), and the software consists of a combination of vendor (or software house) -supplied operating system and database management software, together with user written code for database access and transaction processing.

Many of the key techniques employed in the vendor-supplied software (and in the hardware to support it) have origins in the timeshared operating systems developed at universities. For example, virtual memory and the associated storage management techniques, which were developed for timesharing, are almost universally used to accomplish the required multiprogramming. Similarly, the file protection mechanisms so important in this environment have their origins in early university attempts to achieve user protection with selective sharing.

In addition, dynamic storage management and reclamation, which were first explored in the context of LISP and other early list processing languages, have become standard in such systems. These are used not only for managing main memory, but are employed in secondary storage management as well. Not only have the software and hardware technologies used in early university systems been exported, but there is a growing trend to develop business applications (which will ultimately run in a batch environment) on a timesharing system—using the editors, interpreters, and file systems that have evolved from the original university technology.

Currently we see university systems groups anticipating the need for distributed database systems. There is a high probability that this work will influence the commercial database systems of the next decade.

Office Automation. This application, which is in its infancy, has a tremendous potential impact on the economy. As currently conceived, office automation involves a marriage of hardware and software technologies from the areas of graphics, document preparation, database manipulation, timesharing, communications technology; and networking. Again, one can show that the origins of many of these technologies have been in the universities, either in the systems groups or in some of the activities of the artificial intelligence community.

In order to compose documents combining text with pictures, one needs a high resolution, all points addressable display, backed with appropriate software. Much of the experience with such systems comes from the academic artificial intelligence community. The document composing programs had their origin at MIT under CTSS. Improvements in interfaces for handling multiple fonts, exotic layouts, and mixing of text with graphics have come from several universities.

The universities' interest in networking, supported by DARPA, demonstrated the importance of networking in an office system, and developed the first protocols for accomplishing it. This work also led to university research activities in peer networks, which is an essential piece of the technology required to build communicating offices.

Killing the Goose that Laid size Golden Eggs. There are many other examples that follow the same pattern of small-scale university research, followed by a larger concept demonstration leading to major industrial exploitation. These developments came about because university researchers had excellent tools for early exploratory research and could marshall resources (often made available via government funding) needed for demonstrations of sufficient scale when necessary. This made the research-oriented universities very attractive as a career choice for talented computer scientists.

The current situation, in computer science research seems to us to be critical. We are involved in a rapidly developing and growing industry. Great impetus is provided by the integrated circuit technology that will provide continuing increases in performance with reduced cost of equipment for the next decade. The growing application of computing in a variety of fields is making heavy demands for skilled people. The universities should be increasing the size and quality of research and training programs in computer science and technology. In reality, the strength of university programs in this area is declining. There are currently over two hundred unfilled faculty positions in Computer Science. A few industrial laboratories, notably IBM Yorktown, Bell Laboratories, Xerox PARC, and General Motors, have achieved eminence by providing adequate equipment support for their computer researchers. By contrast, the experimental facilities at universities, remaining from timesharing and networking experiments, are largely obsolete and no adequate plan for their replacement is presently available. If the situation persists there will be an accelerating flight of good research people from universities to the industrial activities. Similarly, students who might otherwise stay on in universities for advanced work are finding the work in industrial laboratories more attractive.

There is universal agreement that the strength of academic computer science must be increased. Surveys [2,3] have shown a demand for computer personnel at all levels far in excess of the available supply. Even more disturbing is the indication that the number of doctorates in computer science has actually decreased for the last two years [3]. We have concluded that, because of its leverage in stimulating research, retaining faculty, and capturing the interest of superior students, the most important requirement is the establishment and maintenance of outstanding university research facilities. Section II of this report discusses the liabilities issue in more detail. Section III presents a number of specific recommendations for solving the facilities and other problems, organized by the sector which could take the lead role in each action,

II. Facilities and Equipment

Computing systems, both hardware and software, serve in two different roles. First, they serve as tools to manipulate information in a variety of technical disciplines. Physicists, engineers, chemists, business people, and social scientists all use computing in their research. A second role for computers, which is much more important to experimental computer science, is their role as objects of research experimentation. Just as transport aircraft serve a large segment of the population, so do computers. Just as the aircraft research community needs experimental aircraft, so the computer science research community needs experimental computers. Usually these must be different computers from those in general service not only because they are different in structure (the X-15 is different from the 747), but also because they are operated in a different regime. (The X-15 would not be as useful as an experimental machine if it also had to provide routine service.)

Experimental computer research requires testing of new ideas. Often these tests—to achieve an appropriate scale-require many users, many systems, much development, and much programming. These tests are correspondingly expensive. Consider, by analogy, the problems in scale of testing a new air traffic control feature in the nation or a new aircraft maintenance strategy in an entire fleet. Similarly, many experiments in timesharing and networking of computers have been very expensive and extensive. Nevertheless, academic institutions have had, and can continue to have, a role in this experimentation, and that role is essential to their continued health as educational institutions in the art and science of computing. Without a significant research role the universities lose their cadre of excellent people, and an inevitable deterioration results that affects the quality of faculty and graduates.

Computer systems experimentation and invention occurs in an environment of a researcher's assumptions and expectations. Getting this environment right critically affects the quality and extent of creative work. Computing research is tackling problems of increasing complexity which often cannot be theoretically modeled, necessitating an experimental approach that requires adequate equipment. A quick study shows that a few leading industrial research activities in experimental computer science are capitalized in the range of $40-60K per research professional. A very few major university experimental systems activities are capitalized in the range of $15-25K per professional. The vast bulk of other university efforts in computer experimentation have well below $10K of capital equipment per researcher, making their efforts marginally viable. The current pace of technological change is so rapid as to make a large portion of this capital equipment obsolete every few years.

We can easily identify a series of major systems ex-periments which have been undertaken successfully by universities and transferred to routine use. Let us review them here to see the pattern which emerges.

In the very early days of computing the universities made a major contribution to computation. Many early machines were built in universities, including Pennsylvania, Harvard, MIT, Illinois, Michigan, UCLA, and others. These machines not only provided a valuable base of university research which served to train a first generation of computer people, they also provided a counterpoint of architectural exploration which taught industry the fundamental architectural notions in use today. These efforts were mostly at a staff level of 20-50 FTE, which required the combined resources of several faculty members and their students with a base of technical support. In today's terms, these were each projects of about a million dollars per year.

This early period was followed by a major investment in computing equipment made by NSF. Over the period 1957-1972, NSF purchased $85 million worth of computing equipment for universities. Donations from manufacturors raised the total investment still higher. Although most of this equipment was for general campus use, it served as the research base of computing equipment on which the first computer software efforts in universities were founded. MIT, Carnegie, Berkeley, Stanford, Michigan, and many others used these facilities with great effect in establishing the teaching of software, as well as in major research contributions. The most advanced experimental computing faculties in universities also attracted imaginative workers from other disciplines and continue to do so where they exist.

A second round of major experimentation that began in the early 1960s centered around timesharing. The idea was that very rapid access to computing could multiply the effectiveness of researchers substantially. This idea was well supported by several sources, but mainly by the Defense Advanced Research Projects Agency (DARPA). Critical mass activities were established at MIT, Carnegie Tech, Berkeley, and SDC to spearhead this activity. These activities later saw realization as commercial products in the Digital Equipment Corporation PDP-l0, the SDS-940, and the GE Honeywell Multics system. Essentially all major computers sold in this country now have timesharing capabilities.

The critical mass for major systems work in time-sharing systems was somewhat larger than earlier projects required, because the systems were substantially more complex. Groups with 50 or so coordinated workers were typical with budgets in the range of one to three million dollars per year. The capital investment in a computer system for timesharing research often exceeded $1 million. This activity moved into commercial exploitation in its time, but the legacy of this period is still to be seen in many academic departments. Facilities built up during this period are still being expanded, though the technology to support them is over a decade old.

In the very early seventies another systems idea emerged which could provide focus for experimental computing activity. This was the notion of networking. If computers could communicate with each other automatically, then researchers at variety of locations could be coupled together just as timesharing systems had coupled the researchers in individual locations. This idea, again funded by DARPA, started another round of systems experimentation. The lead in making a working and reliable nationwide network system was taken by a commercial firm (BBN), but major contributions to theory and experiment were provided by a community of university researchers.

Because multiple computers and vast software systems were involved, the networking experiment critical mass was substantially larger than the timesharing critical mass. Networking could provide a cohesion between universities which has had an important multiplier effect on the computer science research community. It provided mobility to researchers because they could demonstrate and work on their programs anywhere via the network. In turn, the ideas behind this major experiment have moved into commercial exploitation. Telenet, SBS, and the recently announced Bell ACS systems can in part trace their origins to this major systems experiment. A major new national capability has been created.

This brings us to the present time. The era of the microcomputer has arrived because of advances in microcircuit technology. Computer science experimentalists are eager to explore the potential of large communicating clusters of microcomputers, and would willingly experiment except that adequate equipment is not available. Although one might think that microcomputer cxpcrimentation would be inexpensive, it is not, for the investment in software required is substantial and is only reasonable to generate for large groups of users. The problem is not how to get a single microcomputer, but how to get one or more for many researchers in a community and link them together. What is only one telephone? So, too, the microcomputer will be our digital communication device of the future. Thus the capitalization required for the upcoming generation of research, though less than that required for early networking, is still significant. For research on the design and synthesis of microcomputer elements themselves, the capitalization required is generally beyond the capacity of any university and some shared resources are required.

Another area of current experimental research is advanced applications of computers. Experimentalists are using the increased computing power now available to attack a whole range of problems, e.g. vitamin synthesis, speech recognition, algebraic computing, etc. This research requires large computing resources to write and run meaningful programs, but such resources are available at only a few institutions. For several lines of research, such as machine vision and robotics, a significant amount of special purpose hardware is also requited.

One conclusion to be drawn from the above is that adequate experimental facilities for computer systems research are at least a necessary condition for reversing the decline of university experimental computer research capabilities and ensuring an adequate output of trained computer system professionals. The experimental facilities must be provided within the following guidelines:

1. Principles of critical mass must be observed. Enough capital resources for each project are needed to put an experimental project into a mode where creative energy goes into solving problems and not on scrounging for survival. Fewer but larger grants are appropriate if no additional resources can be brought to bear on the problem.

2. Necessary capital resources are needed at the beginning of a project, and these resources should be under control of the research project without undue administrative interference.

3. Capital resource investments will be required on a continuing and recurring basis. The rapid pace of computer technology development makes obsolescence particularly critical for experimental systems research which almost by definition requires cutting edge facilities. The

rapid pace of obsolescence should be a recognized factor in the funding plans for computer science research.

For example, these principles could be implemented along the following lines: Each year there would be a national competition for five resource grants averaging $2 million capital expenditure each. Each grant would include maintenance support totaling 10 percent of the capital cost yearly for five years. A university could apply for a new award at the end of the five-ycar program. In five years, such a program could produce 25 well equipped university laboratories for a total cost of about $15 million yearly.

III. Courses of Action

Given that academic computer science is of national importance and that equipment is one of the core problems, what can be done? This section outlines a number of directly relevant solutions, organized by the sector which should initiate the action. Many of the recommended actions require cooperation between two or more sectors. In cooperation with the universities, private foundations could also play a major role in achieving the goals of this report.

A. Courses of Action by Universities

Universities can play a role in encouraging students and faculty to remain to study and carry on their research, just as government and industry can. In particular, it is necessary for universities to recognize the competitive market that exists today, and provide for adequate incentives to retain both faculty and graduate students as is currently done in fields like management and medicine. Support must be provided for university computer centers here the facilities and staff play an important role in creating an attractive environment for computer research. In addition, there must be recognition of the nature of research in the systems area, including the experimental aspects and the amount of time and energy needed to carry out such research. A problem often stated by junior faculty is that theoretical computer scientists can produce papers much faster and have an unfair advantage in the tenure race. If better hardware and software facilities were available, some of this experimental cost in time and energy could be reduced, but the quality of performance still cannot he assessed by counting publications.

Although the kind of funding needed to bring facilities to an attractive level is large, universities do have equipment budgets which could he used on a (not neces-sarily equal) matching basis to attract outside capital funds. This would require internal reallocation from the more established disciplines.

B. Courses of Action in Industry

There can be most effective coupling between universities and industry through the flow of money, equipment, ideas, joint research, and joint appointments. Government policy in the form of tax incentives could stimulate the flow.

Although some money is given to universities on an unrestricted basis, this is relatively rare. More commonly there is a flow of resources from industry in various forms, in exchange for university research. There are the usual problems in terms of whether there will he too much interference or direction. In some cases, universities are simply engaging in contract development. This may not be bad *per se*, particularly when universities are crying to bootstrap their way to the state-of-the-art. One way to achieve a broader channel of research flow would be through an independent private foundation sponsored by industry and responsive to general rather than specific needs.

Currently the flow of people is perceived to be only out of the university in the form of students at all levels, of faculty, and even of operational staff. A number of policies and attitudes can effect the flow. The possibilities include:

1. Graduate (master's level) study programs and Ph.D. fellowships. Bell Laboratories has been a leader in programs of this sort.
2. Exchange sabbaticals both at the university and in industry. Government or Foundation subsidies may be required to help cover salary differentials, but such programs cannot succeed if the universities are not adequately equipped.
3. Postdoctoral studies within industrial labs may be undertaken, but may require external funding.

Flow of Money, Equipment, and Services

There are many ways, besides outright cash gifts, by which industry might help universities. Some of the possibilities are:

1. Use of facilities. There is high cost equipment that could be made available. A somewhat more liberal tax program would stimulate this use. Most organizations have interactive computers that could be used on an off prime time basis. The use of semiconductor fabrication equipment is also possible; in fact, if universities are to be involved in any computer systems research in the future, it is essential that they engage in research on the design and fabrication of semiconductors. We know almost no universities that can afford the capital equipment necessary to make semiconductors.
2. Valuation of software, on a list price basis—or at least on a developmental cost basis. Under the current tax structure, gifts of software are only deducted at the pro rata manufacturing cost, which is essentially zero.
3. Hardware can be given outright, and the only tax allowance is the incremental manufacturing cost. A more liberal allowance would permit various costs associated with the particular product to be included in the deduction including development and service costs.
4. Service-oriented companies such as AT&T and Xerox could provide their services.
5. In order to build up hardware facilities, a federal loan program with insurance such as that of the student loan program could provide the mechanism to get facilities into existence quickly.
6. IBM special case. IBM contributed to university

computing in the late 1950s until the Consent Decree and subsequent antitrust activity made this infeasible.

Flow of Research

The most effective way to bring up the levels in both industry and education is through joint research. While one can argue about whether any work should be done on a *quid pro quo* basis by the university, the fact is that a *quid pro quo* arrangement solves the fundamental problem of technology and idea transfer, given that results arise from the research. The methods:

1. *Quid pro quo* using money, resources, and people furnished in exchange for research.
2. Consortia. There is currently a small number of research groups that are funded by a consortium of companies. The direction is set by the university, but there are meetings of the consortium members where results are presented and members express concern about direction. Federal patent policies have been a barrier to this kind of effort in a number of cases.
3. NSF-supported joint university-industry research projects. These are just starting and promise to be an effective way to both couple and support research. If equipment is an allowable form of payment by industry, then this can be even more effective in stimulating flow.

C. Courses of Action by Government

Government can assist in many ways to increase the personnel and resources available to universities for computer systems work.

Reassessment of Resource Allocation

The clear shortage of computer systems researchers and facilities calls for significant allocation of funds. Within NSF, the computer sciences should be organized as a distinct discipline. In addition to more total dollars being needed for computer science support, the current computer systems shortage could be helped by changing the split between support for theoretical and systems work. Unless the total resource available grows, support for some current programs will have to be cut to accommodate the high priority needs of Computer Systems work. A particular funding program is proposed and defended in Section II of this report.

Government Policy Reevaluation

Industry contributions to universities could be effectively multiplied by a revised interpretation of what donations qualify as deductible contributions. In particular, enabling equipment donations to be written off on the basis of a fraction of list price rather than internal cost would help. So would a revised view of the capital value of software. It is also time to reevaluate government antitrust actions for their effect on university education and research. Section III.B contains further discussion on the interplay of government and industrial actions.

Research Center Development Awards

NSF and other government agencies should consider Computer Systems Career Grants for young faculty. There is a very successful program of this kind sponsored by the National Institutes of Health to encourage physicians and medical scientists to pursue academic careers. These awards provide salary support for three to five years; there are currently about one thousand awards outstanding. One difficulty encountered in the NIH program is that the awards provide no facilities support.

Fellowships for Ph.D. study could be made available with obligation to continue in university teaching/research for some period beyond the completion of the Ph.D. degree. Faculty whose skills have become less current could be encouraged by grants to retrain and participate in ongoing research projects to become up-to-date.

Distinguished visitors to universities from industry should be encouraged. Financial support to universities to attract visiting industrial fellows should be available to bridge the gap between what universities can pay, what industry will contribute, and the salary level required by such visitors.

Lead Agency

It is important that a "lead agency" be designated to promote computer science. The departmental location of the activity is much less important than the generality of its charter. Much of the nation's current strength in computing resulted from farsightcd leadership from first ONR and NSF, and later DARPA. Although young as a discipline, the computer science community has an impressive record of providing the leadership for governmental activities of appropriate scope. A national commitment to the fundamental strength of experimental computer science is the most important recommendation of this report. We believe that the case for it is clear.

Conclusion

Computer technology and academic computer science have a large and growing role to play in the nation's future. Universities continue to attract many of our best minds because of their dedication to basic knowledge and because of the excitement of working with students. The situation in experimental computer science has slipped in recent years and should be improved. Resolute action by all parties, but particularly by the Federal Government, can help to correct the present serious situation. The Resource Grants Program described in Section II and Career Development awards are two suggestions which could be implemented in the near-term by NSF with considerable benefit to our national position in computer science.

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