Behavior Research Methods & Instrumentation
1978, Vol. 10 (4), 585-593

Microcomputers in Great Britain

Low-cost laboratory computing: Microcomputers in British psychology departments

DAVID HALE
Queen's University, Belfast, Northern Ireland

Over 25% of the 80 British psychology departments use microcomputers. This paper summarizes the types of processor, level of system integration, applications, and problems of these users. The Motorola 6800 is by far the most popular processor, but there is a growing number of Z-80 users. Useful microcomputers have been developed from chips, single-board evaluation kits, hobby products, and manufacturers' development systems. Applications include front-end processing, networking, and stand-alone uses for data logging, process control, and the development of intelligent laboratory tasks. Emphasis is placed on the need to match system packaging and support facilities to the application.

The first laboratory computer to be installed in a British psychology department was at Sheffield, in 1965. In the ensuing decade, almost all of the 80 psychology-based departments in British universities, polytechnics, and research units have acquired laboratory minicomputers. Indeed, the report by Hale (1977) from a survey of these departments made in September 1976 showed that well over 90% had computers, over 50% had at least two machines, and a large number had more than two. In many ways, 1976 was a very suitable year for such a survey, as it marked a turning point in the development of low-cost laboratory computers. Prior to 1976, the cost of minicomputers, while steadily declining, was still high. For example, almost none of the useful laboratory machines surveyed cost under £10,000, and some were costing upward of £50,000, with consequent yearly maintenance contract costs of £6,000.

Many strategies have been used to achieve low-cost computing: Some have purchased used equipment, some have used timesharing facilities on large computers (Green, 1972), some have kept old systems going (the first system at Sheffield is still in use after 12 years), and some have used alternative forms of local computation such as the programmable calculator (e.g., Bloch, 1978). However, the real breakthrough to low-cost computing came with the microprocessor.

Although microprocessors had been available since the early 1970s, it was not until middecade that basic microprocessor chips became available as usable microcomputers with appropriate support facilities. Many factors influenced the relatively sudden appearance of useful systems. Microprocessor manufacturers began to produce single-board computers, evaluation products, and prototyping systems. Cross-development software, particularly assemblers, became available on central, timesharing, or local minicomputers, allowing easier program development. The "personal" computer industry emerged in 1975 to innovate not only the packaging of small systems, but also the literature on microcomputers, both books and magazines. The hobby industry must be credited with demystifying microcomputing as well as offering a host of useful products (Brown & Deffenbacher, 1978). The year 1976 also saw the first articles on microcomputer use in psychological journals (e.g., Krausman, 1976; McKenzie, 1976). The year also saw, in the British survey, a single report of a working microcomputer, the Motorola 6800-based Control BASIC at Warwick, and one mention of a "potential development by the end of 1977," with a microprocessor-based intelligent keyboard from the Medical Research Council Social and Applied Psychology Research Unit at Sheffield.

PROBLEMS

Where can an interested researcher obtain advice on microcomputers? It is difficult enough to obtain coherent advice on minicomputing, despite the many years of experience in hundreds of laboratories. To both the neophyte and the expert, all is superficially a confusion of different systems and approaches. In many ways the potential problems associated with microcomputers are greater than those facing the minicomputer user. Those unfamiliar with microcomputers will find from Pavel (1968) that they are smaller, less expensive, and generally less powerful than existing minicomputers. They are also, with a few exceptions, entirely incompatible with existing minicomputer

This work was supported by a grant on low-cost computing in psychology from the British Social Science Research Council. Thanks are given to Veronica Sloan and Maggie Hale for assistance with the paper.

hardware and software. Consequently, potential users are forced to "reinvent the wheel," only this time with incredibly inexpensive hardware. Obviously, anyone considering the use of microcomputers must very carefully evaluate the many and complex tradeoffs involved in answering the most basic questions about their use. Should one use a microcomputer, or remain with a minicomputer until microcomputer technology has "settled down", or, should one use a microcomputer version of a mini, such as the DEC LSI-11? Should one use stand-alone microcomputers or incorporate them into a network involving a minicomputer? Which of the dozen types of microprocessor should one use? (See Osbourne, 1976, for a detailed review of types.) At what level of integration should one work: chips, single-board evaluation systems, development system, or hobby product? Should one build from kits or purchase ready-made? How should one develop software: hand code, resident assembler, cross-assembler, or some high-level language?

It seems likely that any information from existing microcomputer users might aid not only other existing users but also those contemplating use. It is, after all, more convenient to learn from the mistakes of others. Since 1976, how have British departments responded to the potential of the microcomputer? It is possible that the British experience might prove a microcosm of the larger United States experience, although there are important differences between the two countries. For example, Britain has no effective mini- or micro-computer industry, so most products and technology are imported. Consequently, they are available some time after their initial appearance in the U.S. Also, all imported products are subject to a price mark-up, often from 10% to as much as 70%, which, coupled with the absolute and relative economic poverty of Britain, means purchasers tend to choose less expensive products.

CONTENT

The information reported in this paper relates to the period of December 1977 to March 1978, and it was gathered in three ways. (1) A short questionnaire was distributed at the "Psychological Laboratory Computing Conference" (December 1977, in London) organized by the author for the Association of Psychology Technicians and the British Psychological Society. Over 75% of the British psychology departments were represented. (2) A shorter specialized request for information was sent in February 1978 to those departments thought to have microcomputing interests. (3) Telephone calls were made in March 1978 to clarify details. The responses show that well over 25% of the British departments have made some start into microcomputing. This paper attempts to summarize these uses. Papers describing detailed applications should appear in a later issue of this journal.

MICROS AND MINIS

To protect an existing investment in minicomputer software, it may be wise to use a microcomputer version of an existing mini: The DEC LSI-11 and Data General MicroNOVA are good examples. It might also be argued that they are the only sensible choice because of the existence of excellent, well developed software of all types. However, in terms of the application-level system (as opposed to the development system), such a solution may be too costly, too large physically, or too powerful. One use of "micro minis" is to replace main departmental laboratory computers as general-purpose workhorses. It is interesting that British grant-awarding bodies seem increasingly to be taking this approach when asked for funds for large minicomputers. A microcomputer version of the minicomputer is often suggested. For example, an LSI-11 with diskettes and appropriate laboratory peripherals can serve as a general-purpose machine. This approach has worked well at, for example, the University of Warwick, which uses an LSI-11 in conjunction with a QVEC graphics system. The University of Loughborough also has an LSI-11 in use for work-scheduling experiments in factories.

An alternative approach is to use the LSI-11 as a satellite to a larger, better configured machine. Oliver Braddick at Cambridge University has developed a QVEC graphics system he reported recently (Braddick, 1977) to work from an LSI-11, which is a satellite to a larger PDP-11 system. Roger Henry at Nottingham University has extended the satellite LSI-11 approach with a multiuser version of RT-11 that allows a central fully configured PDP-11/34 with disks and fast printer to be networked to a series of satellite LSI-11s. These can download RT-11 from the central machine and function as if they were independent RT-11 systems, accessing systems resource and existing languages such as PACER (Henry, 1976). However, despite the high cost of each satellite (around £2,000), there is little local intelligence until connected via cable to the central machine. A similar approach is anticipated by University College London and by Newcastle-upon-Tyne Polytechnic.

Another approach is to use a microcomputer so fully configured as to function as if it were a laboratory minicomputer. The Hearing Research Institute of the Medical Research Council at Nottingham hopes to follow this approach with an order for up to seven Cromemco Z-2s that are based on the Zilog Z-80 processor. While this system is based on the "hobby" S-100 bus, the Z-2 is professionally engineered. At Nottingham, the system will run with 32K memory, dual floppy disks offering a full disk operating system, utilities, BASIC and FORTRAN, a floating point processor, DECwriter, and visual display terminals. The reason the Z-2 was chosen over an equivalent LSI-11 was that the Z-2 system costs approximately £5,000; the LSI-11 system costs approximately £9,000.

Four of the Z-2s are intended to service outstations where patient record and test data will be transferred to floppy disk for processing on a large central computer. The other Z-2s will be equipped with laboratory peripherals and used for general research work. With a large PDP-11 as well, the Institute will keep open its options on a future networking scheme. The City of London Polytechnic (CLP) also has a Z-2 as a main laboratory machine.

It seems from a wide variety of sources that anyone looking for a well engineered S-100 bus computer should seriously consider the Cromemco Z-2. The only other diskette-based microcomputer in the report is a Zilog development system, an STC 80 costing around £6,000, in use at the National Physical Laboratory (NPL) to develop programs that can then be run on cheaper portable systems. Clearly, the cost of a fully configured version of this system would approach laboratory minicomputer prices. The lack of other large-scale microcomputers, such as those described by Crossman and Williams (1978) and by Santa and Streit (1978), perhaps reflects the higher costs in Britain. Both Sussex and Belfast may add minicomputer floppy diskettes to their SouthWest Technical Products (SWTP) MP68s, but this is for the future.

DISTRIBUTED PROCESSING

A glimpse into the future of distributed processing and networks is offered by Polson (1978) in his description of the ambitious CLIPRnet project in Colorado. Several British departments are working along similar, although perhaps more modest, lines. Already described is the Nottingham LSI-11 network, which is already running due to skillful development of existing PDP-11 software. The PDP-11, particularly with the central machine running the Bell Laboratories UNIX operating system, appears to be the most popular machine to lie at the center of a network. Alan Cleary at the University of Newcastle-upon-Tyne is developing an 11/34 network with terminals based on S-100 bus systems. This development began with an IMSAI 8080 chassis housing a Technical Design Laboratories Z-80 processor and memory. Each terminal also uses a local Teletype and connects via serial interface lines to the 11/34. Programs and data can be transmitted between host and satellite and Z-80 program development done via a cross-assembler on the 11/34. Development of system software is aided by UNIX, running the "C" language (see Gregg, 1977) and YACC (an acronym for "yet another compiler compiler"). Current developments at Newcastle involve the mass production of network node processors, again S-100 based, but constructed from bare boards and components from many different sources. Cleary hopes to give his terminals some local intelligence by developing the Cromemco Control BASIC. The Laboratory of Experimental Psychology at the University of Sussex is also running a large PDP-11 with UNIX and hopes to develop a network based on SWTP MP68 processors. They plan for a great deal of local intelligence, with minidiskette nodes, so that the terminals can function for long periods without the central machines and be used for autonomous program development using the 6800 assembler code or some appropriate interpreted or compiled Control BASIC. Other departments with tentative plans for networks include those already mentioned at University College London and Newcastle Polytechnic based on LSI-11s, and a PDP-8 at the University of Reading using Intersil 6100 PDP-8-compatible micros as terminals.

PROCESSOR TYPES

The Motorola 6800 is used in 18 British psychology departments, the Zilog Z-80 in 6, the National SC/MP in 3, and the MOS Technology 6500 and Intersil 6100 in 1 each. Some departments have more than one type. For example, CLP started with a 6800 and then added an SC/MP and Z-80. Reading, Oxford, and NPL all started with 6800s, and then the University of Reading acquired an SC/MP, and the University of Oxford and NPL acquired Z-80 systems. In terms of processor type, then, the Motorola product is the most popular by far. Why is this, and how different is it from the pattern of U.S. usage?

The recent National Conference on the Use of On-Line Computers in Psychology (November 1977) offered information on U.S. usage. Brown and Deffenbacher (1978) concluded that the Intel 8080 was best for hardware and software support, while the 6800 was easier to program. Crossman and Williams (1978) and Santa and Streit (1978) used diskette-based 8080 systems. A MOS 6500-based KIM-1 was used by Murray and Lawler (1978), and the same processor was used in the Commodore PET described by Durrett (1978). Only McKnight, Waters, and Lamos (1978) and Zilm, Durand, and Kaplan (1978) used the 6800 and, perhaps significantly, packaged their own systems from basic chips.

There are many possible reasons for the popularity of the Motorola 6800 in Britain. Most frequently mentioned by users is the superb documentation. For example, the applications manual (Motorola, 1975) offers over 600 pages on all aspects of the 6800, from a basic chip description to cross-development software, and includes many detailed examples. The 6800 does have an instruction set that is easy to program, logical, and cohesive, quite like that of the PDP-11. There is an easy availability of cross-development facilities either already in use on a University central computer or easily moved in FORTRAN to a departmental machine. There are many hard-science departments using the 6800 who can, potentially, rescue the psychologist with an errant system. The 6800 is available in a wide variety of packaged systems, yet is also quite easy to use at the single-chip level, with a low chip count and single 5-V power supply. Motorola offers a useful single-board development system, the D2, that allows operator communication via a hex keyboard and display and stores programs on audio cassette. The D2 can be made compatible with the range of larger paper-tape or diskette development systems and there is also a comprehensive range of single-board computers. Additionally, the 6800 is well supported by a range of distributors. Finally, in the form of the SWTP MP68, the 6800 was the first personal computer to be available in Britain at a realistic price and is still one of the least expensive, easily expandable, hobby products.

This eulogy perhaps explains why the 6800 is so popular and also summarizes some factors that might need to be considered when choosing a microprocessor. Some opposite arguments might explain why the 8080 has been bypassed completely in favor of the compatible but more powerful Z-80 (e.g., the first Altair systems in Britain suffered an amazing 90% price mark-up over U.S. retail prices). The SC/MP seems to have been purchased as a very low-cost starter system, perhaps just to "test the water" over microcomputing. Only a single 6500 is running, but this situation may change dramatically when PET becomes freely available.

Because processor type is currently the major factor in any potential exchange of programs or applications, the next section will attempt to summarize the state of use of microprocessors in Britain in terms of processor type and packaging.

INTERSIL 6100

The only Intersil 6100 reported is at University College London and is an Intercept Jr. with 1K of memory and the ability to execute PDP-8 instructions. The aim is to use it for testing in schools, where the CMOS components make battery operation easy. It was chosen largely because program development could be done on an existing PDP-12 in the department. At present, it has only been used for familiarization and still awaits interfacing and serious program development. Clearly, with such a system at under £200, one is not buying in any sense a usable PDP-8.

MOS 6500

The only KIM-1 is used at the University of Stirling on a joint project with the Department of Psychiatry at Edinburgh to study subnormal children, which involves logging the time of observer keypresses onto audio tape. At about the same price as the Intersil Intercept, KIM appears to offer a very much more usable evaluation product with Hex keyboard and display, Teletype and cassette interface, operating system in read-only memory (ROM), and 1K user memory. Program development is at present done by hand coding which, while hardly convenient, is possible for small programs and dedicated application. It is unfortunate that KIM has not until recently become available from British suppliers, as it has excellent documentation, a close similarity to the 6800 instruction set, and even availability of expansion adapters to allow S-100 boards to be used. The arrival of PET should result in a greater use of the 6500: Queen's University of Belfast has PET on order, and many other departments are expressing interest.

NATIONAL SC/MP

Three departments have purchased SC/MP evaluation systems. CLP and the University of Dundee have the Introkit with 256 bytes of random-access memory (RAM), a hex keyboard, light-emitting diode (LED) display, and monitor in ROM. Dundee intended to use it to test a series of eight alphanumeric displays that are normally connected to a large RDOS NOVA, so avoiding the need to use the NOVA for such routine testing. However, in practice, they have found that the development effort needed to make the SC/MP do this job is not justified, so it remains unused. CLP had a similar experience: Staff time limitations have prevented the development of the SC/MP as a low-cost process controller. In many ways, the SC/MP Introkit is attractive, with very low cost, good input-output (I/O) instructions, a useful programmed delay instruction, and space for extra circuitry on the board. In practice, however, it seems too basic and needs excessive work in order to work usefully. The University of Reading has a different SC/MP evaluation kit made by the Science of Cambridge Company that offers features similar to the Introkit, but for a price of only £40. They are building this into a simple experimental controller for use with operant experiments. Program development is by hand coding.

ZILOG Z-80

The Zilog Z-80 is a powerful processor found in six departments and in five different configurations. As mentioned earlier, both the MRC HRI at Nottingham University and CLP have Cromemco Z-2s configured to almost minicomputer status. NPL is using a Zilog diskette-based development system in the MAVIS project. MAVIS is a computer-based prosthetic or POSSUM for the disabled that is built into a portable suitcase, uses teletext for connection to standard television, and can act, via a keyboard, or special-purpose control adapted to the particular disability, as an information and control system to replace a whole series of separate devices. Development is proceeding in conjunction with the Ferranti Company and

Loughborough University. They hope to offer the system by late 1978, with 16K RAM, perhaps 100K of bubble memory, and minicassettes for around £2,000. Oxford University is running a 380Z built in Britain by Research Machines of Oxford. This personal computer offers 16K RAM, alphanumeric keyboard, TV display modulator, cassette interface, and ROM monitor at just over £1,000. The display uses its own refresh memory and offers 24 lines of 40 characters in the full ASCII character set or graphics on an 80 by 72 matrix. The 380Z is well engineered, expandable, and offers software from Technical Design Laboratories. However, at over £1,000, it compares unfavorably with PET, which at just over half the cost offers a self-contained display and cassette. The 380Z is to be used on a project involving business game simulations programmed in BASIC. It offers easy portability and dedicated freedom from timesharing or minicomputers. Oxford University has another 380Z on order, to be used for teaching.

The major United Kingdom psychology user of S-100 bus products is Alan Cleary, at the University of Newcastle-upon-Tyne. As one of the leading British instrumentation experts (see Cleary, 1977; Cleary, Mayes, & Packham, 1976), it is not too surprising that Cleary has assembled a conglomerate system from assorted sources. He has an IMSAI 8080 chassis with Z-80 CPU and many peripherals, such as the MERLIN video board and SPEECHLAB voice-recognition card. As discussed earlier, he is developing a network of home-constructed Z-80s around an 11/34 to service research laboratories whose work includes a study of Parkinsonism involving the measurement of limb movements using 8-bit analog facilities, a cognitive laboratory with Monsanto alphanumeric displays, and an animal laboratory. One eventual aim is the development of SKED for the Z-80. Finally, Loughborough University has another British hobby product, the NASCOM 1 from Lynx Electronics. For £200, this kit offers 2K of RAM, a ROM monitor, a Z-80 CPU, a full alphanumeric keyboard, cassette interface, and modulated display driver for connection to a domestic television. At Loughborough, the system has extra memory. The plan is to run BASIC for teaching and to develop a Control BASIC for human performance experiments.

MOTOROLA 6800

The Motorola D1 or D2 evaluation kit is in use by seven departments. Three departments are using Motorola development systems or single-board computers; three are using the EVK prototyping system from the 6800 second-source company, AMI (and incidentally, the same three departments are building their own machines from chips); and seven other departments have SWTP MP68 hobby computers.

The D1/D2 offers in basic form at about £200 a hex keyboard and LED display for operator communication, cassette program storage, .5K memory, and possibilities for expansion. The D1/D2 is popular, although one department, at the University of Aberdeen, has decided that the effort to develop it is not justified. They had intended it for portable blood pressure measurement but have been diverted from further development by the arrival of a new PDP-11/34. Aberdeen users were also slightly put off by the lack of local cross-development facilities. The Queen's University of Belfast has a D2, used to score an experiment that involves rotating Ames-style objects: The D2 records the angles of rotation where the subject reports subjective reversals of rotation. This experiment had previously tied up a large RDOS NOVA on-line or used audio-tape logging to replay data tapes that tied up the NOVA for slightly less time. The D2 is in a briefcase-sized portable package. The user sets the required number of rotations on the hex keyboard and, at the end of the run, interrogates memory via the keyboard to obtain on the hex display a readout of the number of reversals at particular angular rotations. This program was largely developed by hand coding, although cross-development facilities are available in Belfast. CLP has interfaced a D1 to an Analogic MP6812 and added an extra 2K of memory in order portably to log automobile-type vibration data. An accelerometer, located at the interface between the driver and his car seat, logs data at 50 Hz into the D1 memory. After each run the battery-powered D1 is left switched on, and the results are played directly into the central DECsystem 10, via a serial interface, for analysis. The University of Leeds is using a D2 as a portable reaction time tester. The D2 is also used to run an "interactive toy," consisting of a light box displaying different patterns of lights. The latter applications seem to represent the classic use of a microcomputer to replace hard-wired logic: The system developers at Leeds see the microcomputer only as a means of adding a little intelligence to instruments and devices. Preston Polytechnic also has a D2 with extra memory and analog facilities in use for a variety of experiments, including a project that studied changes in the two-flash threshold with body temperature, the generation of pursuit-tracking displays, and precisely controlled sine waves. Many of these tasks needed to be portable for use in hospitals. Reading University has a D1 with 2K memory that is being developed to complement existing programming modules to perform jobs at which the modules are poor, such as recording of interresponse times in operant studies. The D1 measures and stores these times, then dumps them onto a Teletype on demand. The Sheffield MRC Social and Applied Psychology Unit (SAPU) also has a D1 that was used for development until superseded by an AMI EVK.

Motorola offers the EXORciser as its major development system, which is a chassis to take a large variety of option boards. The University of Lancaster uses a Teletype paper-tape EXORciser for program development to program ROMs that implement running programs on the Motorola single-board computers. These have been used for field-based pilot-selection research and data logging, and they are to be used to control rat shuttleboxes and other laboratory equipment. A simpler and less expensive Motorola system is the Polyvalent Autonomous Development System, which offers a small display, keyboard, and terminal interface in a small package. The University of Manchester group uses this both to develop programs, again via paper-tape Teletype, and to run various experiments, including the control of multifield tachistoscopes with simultaneous collection of reaction time responses, and to run animal experiments. The University of Stirling is using Motorola stand-alone computer boards for data logging and experimental control after doing cross-assembly on a PDP-11.

Three departments have the AMI EVK 300 prototyping system: Warwick, Sheffield, and the Sheffield SAPU. The EVK 300 is an attractive package of 2K RAM, ROM monitor, terminal interface, and an EPROM programmer. It is more than coincidental that these three departments have also built their own computers from raw chips. The Sheffield psychology department is developing a front-end processor to their NOVA using 34K memory and intend it to control a picture scanning and reproducing apparatus. Pictures are first digitized, as a photocell mounted on a standard x-y plotter scans them under computer control (Brown, 1977), then they are input to the NOVA for digital processing (Mayhew, Frisby, & Gale, 1977), and finally, reproduced in processed form on a modified Muirhead facsimile receiver that can reproduce halftones. The 6800 front-end processor frees the NOVA from the relatively slow input and output of pictures and enables it to concentrate on digital processing. The SAPU at Sheffield has developed an intelligent keyboard, initially for use in a medical inquiry system. It consists of a matrix of LEDs and touch-sensitive switches that are overlaid with specific inquiry frames. The keyboard works as a terminal via a serial line to a host computer that sets up a variety of patterns of LEDs and interrogates the keyboard as to what responses have been made. The 6800 gives the keyboard enough intelligence to conduct a dialog with the user and to format a record of this for transmission to the host computer. The SAPU home-developed 6800 processor board will also be integrated into a variety of intelligent devices, including a graphics display.

One of the most generally useful 6800 programming systems has been developed by George Kiss at the University of Warwick. This is a Control BASIC developed from an integer BASIC to offer well developed digital I/O and timing that, with ingenious use of interrupts, allows 1-msec resolution, even with such a relatively slow microprocessor as the 6800. At present, a single 8-bit port is used for input and output with commands that turn ON specific bits, turn them OFF, SET or RESET bits according to their decimal equivalents, FLIP the states of specified bits, SENSE the inputs, AWAIT a specified input, or PULSE specified bits for a specified time. There is also a DELAY command and commands for memory examination and modification and for machine code routines. Millisecond timing is achieved via a 1-kHz interrupt clock, and BASIC variables are used to hold time values in milliseconds, seconds, and minutes. Accurate timing of external event occurrence can be achieved by connecting input transitions to an interrupt line. At Warwick, this BASIC is running from ROM on a home-built system, but it can be easily adapted to run from RAM on other configurations such as the SWTP MP68.

The MP68 is the final type of 6800 system widely used. The basic kit costs around £300, which purchases a chassis, power supply, backplane, processor, ROM monitor, 4K memory, and serial interface. As a kit it is fairly easy to build and offers considerable scope for expansion. The Queen's University of Belfast version of Control BASIC runs on the Mark 2 version of the MP68 from ROM into 8K of RAM with an 8-bit parallel port driving relays and detecting switch closures. Program and data storage is currently via audio cassette or paper tape, although the personnel at Belfast hope to develop EPROM for program storage. Another possibility is to develop the Control BASIC as part of a network to a NOVA minicomputer. Belfast has another MP68 used simply as a paper-tape editor in conjunction with NOVA ACT installation. ACT-N (see Mickey, 1976; Millenson, 1975) is limited to paper-tape program input and has no built-in program editing facilities. Consequently, to develop programs, one must either close down ACT and use the NOVA editor or use tedious and error-prone off-line Teletype editing. The MP68 uses a fairly sophisticated text editor from TSC that has been modified to use existing high-speed paper-tape peripherals from the NOVA. While such editing is a very simple use for the microcomputer, it is possible, just by adding more ROMs, to run BASIC for data processing and also the Control BASIC for those experiments at which ACT is poor, such as continuous data logging or activity analysis. The University of Sussex has an MP68 that is being developed as an intelligent terminal to a PDP-11. The Medical Research Council Applied Psychology Unit at Cambridge is developing the MP68 for data logging and the replay of data-logged information. The Institute of Psychiatry in London has an MP68 linked via a parallel interface to a LINC-8 that runs a 6800 cross-assembler. The personnel at the Institute have neatly repackaged the MP68 as a rack-mount unit, built an AC-30 cassette interface into a CT-1024 terminal, and added a car cassette player for program loading. This system is used essentially as a test bed for ideas for subsequent items of intelligent laboratory apparatus; for example, a simple programmed tachistoscope working from low-priced 8-bit digital-to-analog converters. Both Oxford and Leicester have MP68s, but the systems are still in an early development stage. Perhaps the major use of an MP68 comes from NPL, with its MICKIE interactive system for taking medical histories. This uses a 24K MP68 with dual 70-kbyte minicomputer floppy disks, an SWTP CT64 video terminal, and PR40 printer. It is programmed in BASIC and should be available from Computer Workshop in London or Southwest Technical Products Corporation in Texas for approximately £2,000.

PROBLEMS AND PROSPECTS

While the current uses of microcomputers and their immediate development are of interest, it should be worth noting the problems and queries raised by the departments, as these may identify areas where information is needed. Inevitably, many problems relate to hardware.

One major worry concerns the dangers of "jumping in" and trying to use microcomputers while hardware is changing so rapidly. One suggestion is that users wait until technology offers 32-bit machines with standard floating point processors. Clearly, if there is a need for a microcomputer in a project, whether because of cost or size limitations, then one should start to invest now before the first working systems are delivered. It is not hardware that is expensive, but human time and expertise for software development. A common plea in Great Britain is for greater standardization of hardware. This is unlikely to happen soon, given the likely spread of the 6500 processor in PET, which also uses another new interface system based on the IEEE/Hewlett-Packard system, and the TRS-80 with the Zilog-80 and yet another "standard" bus system. There are also other processors waiting to be used by psychologists; for example, the RCA Cosmac is reported to have many useful features and is available in an attractive evaluation kit with video graphic display and interactive "process control style" language. Indeed, the NPL group has already started using the Intel 8085 processor for a hand-held device called MUPPET. Most of the existing 8-bit microprocessor manufacturers will soon announce 16-bit devices that, hopefully, will be upward compatible with existing 8-bit software. One may also see more widespread use of the Texas 9900 16-bit microprocessor, following developments in Colorado (Polson, 1978). Many requests are being made for low-cost peripherals to match low processor prices. Computer users now need inexpensive printers, paper-tape punches, analog facilities, magnetic tape cartridges, plotters, and MOS memory with long-term battery back-up. Perhaps, though, the major requirement is for low-cost effective graphics.

The results of the surveys indicated a great need for a wider exchange of software for microprocessor applications. This was coupled with a plea for wider availability of cross-development facilities and high-level languages, particularly fast compiler languages, and for more system software development languages such as BCPL or "C." Several workers seem to be independently developing Control BASICs for a variety of processors, and George Kiss at the University of Warwick is developing a version of his Control BASIC for the 6800 that will cross-compile on the university's Burroughs system to generate machine code for fast execution. There is currently available both an interpreted and compiled BASIC for the 6800, so that program development can proceed interactively while production jobs can be done via the compiled version. Another interesting software development tool is MicroSIM, which is in use at NPL and acts as a combined interactive editor, assembler, and run-time emulator. Also available are high-level languages such as PL/M that produce compiled code for the 6800. The attraction of such a language is that versions are available for different mircoprocessors using the same high-level source code to produce object code specific for different processors. Wider use of such languages might allow easier portability of applications software across different hardware.

In terms of potential applications, by far the most common was data logging both in the laboratory and the field. It is clear that information about the types of systems reported by Sidowski (1977) has not yet become generally available in Britain. A large number of departments want to develop (or are developing) general-purpose experimental control systems for certain classes of experiments. Typical examples involve animal work, simple psychophysiology such as biofeedback, and replacements for the "student boxes" found in many undergraduate teaching laboratories. Among the more specific applications is the development of a stereoscopic display panel using matrices of LEDs for use in hospitals to detect stereoscopic vision anomalies. Another popular proposed development is for an inexpensive programmed tachistoscope with a television-style display. This requirement coincides with the general demand for low-cost graphics. Perhaps both applications are best served with a system that provides either dot-matrix alphanumerics for use in item-recognition paradigms or, perhaps, a 256 by 256 pixel dot-matrix display whereby every display point is mapped to a memory bit. Fast display changes can be made by merely switching the memory block accessed. The system would also be useful for much perception work, since it can display filled objects rather than the outline objects currently drawn by vector graphic techniques.

COMMERCIAL PRODUCTS

A few British manufacturers of psychological equipment are beginning to utilize microprocessor developments. BRD Electronics has a 6800-based data logger that records and replays time and event information for eight events onto audio tape at up to 100 bytes/sec. There is a variety of sampling rates, recording, and replay modes available for a cost of £450. The same firm will very likely offer a commercially packaged version of the Warwick University Control BASIC for about £500. Another audio-cassette derivative comes from Electronic Developments, which has a system for programming the operation of their tachistoscopes via a CUTS cassette system. Campden Instruments, the British suppliers of ACT-N, is proposing to develop a MicroACT that would be a ROM-based ACT subset running with a microprocessor powerful enough to service perhaps a pair of stations and also serve as a satellite to a minicomputer with two-way transfer of programs and data.

A British appliance computer to rival PET will soon be produced by the hobby company NewBear. This will be a 6800-based visual display with keyboard and serial interface. Among its attractive features will be the ability to emulate a standard visual display unit via its serial interface and to load and run programs from its own ROM via a single keystroke. Addresses of British companies are listed in Appendix A. Addresses of psychology departments and institutions are listed in Appendix B, along with the names of contact persons.

Britain now has its first personal computing magazine, *Personal Computer World*, and its availability should make more psychologists aware of the possibilities of microcomputing. Some psychologists are also members of the British Amateur Computer Club, which offers a useful information exchange with program libraries and data sheets for most of the popular processors. In addition, Academic Press plans to publish a book by Richard Bird of Newcastle-upon-Tyne Polytechnic entitled *Computer Control of Experiments in Psychology with PDP-8 Examples.*

CONCLUSION

With many of these systems still under active development, it may be premature to comment on their success or cost effectiveness. It is clear, however, that success does not depend merely on the type of processor. As with minicomputers, any of a dozen processor types can be used to solve most problems. Rather, success depends on an interaction between the type of application, type of system configuration, and level of support. If the application is simply to obtain a familiarization with microcomputing, then even the little used SC/MP and other systems might be successful.

It would be a pity, though, if potential users were prevented from further exploration just because of a bad initial choice of system or a lack of support. The most successful uses appear to be those that match a specific application, most frequently a fairly simple and well specified addition of intelligence, to an existing task, with a level of hardware integration not requiring a massive technical investment to interface to the task, and with adequate support facilities. Such support, too often neglected, can be vital and includes: documentation, training, local advice, cross-development facilities, and technical assistance. For many British users, the Motorola 6800 family seems best to meet these requirements, although this may change as other systems become more available and supported in Britain. For those who are using microcomputers as less expensive replacements for minicomputers, only time will tell whether the differences between micros and minis will vanish or become exaggerated further. Finally, and perhaps most importantly, all the present evidence demonstrates that large numbers of psychologists and their helpers are working away independently to solve very similar problems. Yet all feel a need for information, guidance, and communication with other workers.

Appendix A
British Companies

AMATEUR COMPUTER CLUB: 7 Dordells, Basildon, Essex.
BRD (ELECTRONICS) LTD: 32 Cottimore Lane, Walton-on-Thames, Surrey KT12 2BP.
CAMPDEN INSTRUMENTS LTD: 186 Campden Hill Road. London W8.
COMPUTER WORKSHOP: 174 Ifield Road. London SW10 9AG.
ELECTRONIC DEVELOPMENTS: Unit 37/e Platt's Eyot. Lower Sunbury Road. Hampton, Middlesex TW12 2HF.
LYNX ELECTRONICS (LONDON) LTD: 92 Broad Street. Chesham, Bucks.
NEWBEAR COMPUTING STORE: Bone Lane. Newbury, Berks RG14 5SH.
PERSONAL COMPUTER WORLD: 62a Westbourne Grove. London W2.
RESEARCH MACHINE LTD: P.O. Box 75. 209 Cowley Road, Oxford.
SCIENCE OF CAMBRIDGE LTD: 6 Kings Parade. Cambridge CB2 1SN.

Appendix B
Psychology Departments and Names of Possible Contact Persons

ABERDEEN: Roly Lishman. Psychology Department, University of Aberdeen. Aberdeen AB9 2UB.
BELFAST: David Hale. Psychology Department, Queen's University of Belfast. Lennoxvale, Belfast BT7 1NN. Northern Ireland.
CAMBRIDGE: Oliver Braddick. Psychology Laboratory. Downing Street, Cambridge CB2 3EB.
DUNDEE: Alan Kennedy. Psychology Department, University of Dundee. Dundee DD1 4HN.
KEELE: Stuart Forrest. Psychology Department, University of Keele. Keele, Staffs ST5 5BG.
LANCASTER: Jim Ridgeway. Psychology Department, University of Lancaster. Bailrigg, Lancaster LA1 4YF.
LEEDS: Kay Toon. Psychology Department, University of Leeds. Leeds LS2 9JT.

LEICESTER: Lawrence Hartley. Psychology Department, University of Leicester. Leicester LE1 7RH.
LONDON–CITY OF LONDON POLYTECHNIC (CLP): David Protheroe. Psychology Section, City of London Polytechnic. Whitechapel High Street, London E1 7FF.
LONDON–INSTITUTE OF PSYCHIATRY: Les Law. Psychology Department, Institute of Psychiatry. De Crespigny Park, London SE5 8AF.
LONDON–UNIVERSITY COLLEGE: Peter Livesley. Psychology Department, University College. Gower Street, London WC1E 6BT.
LOUGHBOROUGH: Robert Harding. Department of Human Sciences, University of Technology. Loughborough LE11 3TU.
MANCHESTER: Norman Hidden. Psychology Department, University of Manchester. Manchester M13 9PL.
MEDICAL RESEARCH COUNCIL–APPLIED PSYCHOLOGY UNIT (APU): Brian Styles. MRC APU. 15 Chaucer Road, Cambridge CB2 2EF.
MEDICAL RESEARCH COUNCIL–HEARING RESEARCH INSTITUTE (HRI): Graham Yates. MRC HRI Medical School, University of Nottingham. Nottingham NG7 2VH.
MEDICAL RESEARCH COUNCIL–SOCIAL AND APPLIED PSYCHOLOGY UNIT (SAPU): Clive Daly. MRC SAPU, University of Sheffield. Sheffield S10 2TN.
NOTTINGHAM: Roger Henry. Psychology Department, The University. Nottingham NG7 2RD.
NATIONAL PHYSICAL LABORATORIES (NPL): Chris Evans. Division of Computer Science, NPL. Teddington, Middlesex TW11 0LW.
NEWCASTLE: Alan Cleary. Department of Psychology, University of Newcastle-upon-Tyne. Claremont Place, Newcastle-upon-Tyne NE1 7RU.
OXFORD: Ivor Lloyd. Department of Experimental Psychology, University of Oxford. South Parks Road, Oxford OX1 3PS.
PRESTON: Mike Stone. Department of Psychology, Preston Polytechnic. Heatley Street, Preston PR1 2XR.
READING: Elizabeth Gaffan. Department of Psychology, University of Reading. Whiteknights, Reading RG6 2AL.
SHEFFIELD: Chris Brown. Department of Psychology, University of Sheffield. Sheffield S10 2TN.
STIRLING: Angus Annan. Department of Psychology, University of Stirling. Stirling FK9 4LA.
SUSSEX: Mick Burton. Laboratory of Experimental Psychology, University of Sussex. Falmer, Brighton BN1 9QN.
WARWICK: George Kiss. Department of Psychology, University of Warwick. Coventry CV4 7AL.

REFERENCES

Bloch, R. M. Aspects of programmable calculator stimulus control and data acquisition in a psychophysiology laboratory. *Behavior Research Methods & Instrumentation*, 1978, **10**, 246-248.

Braddick, O. Real-time generation of random-element motion displays. *Behavior Research Methods & Instrumentation*, 1977, **9**, 359-362.

Brown, C. A simple on-line device for scanning photographs. *Perception*, 1977, **6**, 479-481.

Brown, E., & Deffenbacher, K. Microcomputers big and little: Selecting a low-cost laboratory computer network. *Behavior Research Methods & Instrumentation*, 1978, **10**, 241-245.

Cleary, A. *Instrumentation for psychology*. New York: Wiley, 1977.

Cleary, A., Mayes, T., & Packham, D. *Educational technology: Implications for early and special education*. New York: Wiley, 1976.

Crossman, E. K., & Williams, J. G. Evolution of a multiuser on-line 8080 microcomputer system. *Behavior Research Methods & Instrumentation*, 1978, **10**, 254-258.

Durrett, H. J., Jr. A dream or reality? A real-time laboratory for under $1,000. *Behavior Research Methods & Instrumentation*, 1978, **10**, 345-351.

Green, B. F. The use of time-shared terminals in psychology. *Behavior Research Methods & Instrumentation*, 1972, **4**, 51-55.

Gregg, L. W. Maximizing the mini-uses of on-line computers. *Behavior Research Methods & Instrumentation*, 1977, **9**, 67-71.

Hale, D. Computer use in British psychology departments. *Bulletin of the British Psychological Society*, 1977, **30**, 410-413.

Henry, R. B. Implementation of experimental procedures in the PACER system of on-line control. *Behavior Research Methods & Instrumentation*, 1976, **8**, 508-512.

Krausman, D. T. The microcomputer kit: An excellent small system development tool. *Behavior Research Methods & Instrumentation*, 1976, **8**, 501-507.

Mayhew, J., Frisby, J., & Gale, P. Computation of stereo-disparity from rivalrous texture stereograms. *Perception*, 1977, **6**, 207-208.

McKenzie, K. A structured approach to microcomputer system design. *Behavior Research Methods & Instrumentation*, 1976, **8**, 123-128.

McKnight, L. R., Waters, B. K., & Lamos, J. P. Development and evaluation of a microcomputer testing terminal for testing and instruction. *Behavior Research Methods & Instrumentation*, 1978, **10**, 340-344.

Mickey, C. T. A brief history and comparison of several variants of the ACT language. *Behavior Research Methods & Instrumentation*, 1976, **8**, 252-256.

Millenson, J. R. System developments in the ACT language: Toward machine independence. *Behavior Research Methods & Instrumentation*, 1975, **7**, 165-173.

Motorola Corporation. *Motorola 6800 applications manual*. Phoenix: Author, 1975.

Murray, D. M., & Lawler, J. E. A KIM-1 microprocessor interface for aversive conditioning applications using multiple subjects. *Behavior Research Methods & Instrumentation*, 1978, **10**, 334-339.

Osbourne, A. *An introduction to microcomputers: Some real products* (Vol. 2). Berkeley, Calif: Osbourne, 1976.

Pavel, M. What is a microprocessor? *Behavior Research Methods & Instrumentation*, 1978, **10**, 238-240.

Polson, P. G. Microprocessors: Their impact on real-time computing in psychology. *Behavior Research Methods & Instrumentation*, 1978, **10**, 139-147.

Santa, J. L., & Streit, P. A microprocessor reaction time laboratory. *Behavior Research Methods & Instrumentation*, 1978, **10**, 352-355.

Sidowski, J. B. Observational research: Some instrumented systems for scoring and storing behavioral data. *Behavior Research Methods & Instrumentation*, 1977, **9**, 403-404.

Zilm, D. H., Durand, D., & Kaplan, H. L. A microprocessor-controlled clinical tremometer. *Behavior Research Methods & Instrumentation*, 1978, **10**, 177-181.

(Received for publication April 20, 1978;
revision accepted May 5, 1978.)