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Understanding Computers: A Modern Tool in Plant Pathology

Plant pathologists are using computers in numerous and diverse ways, including data analysis and graphics, simulation modeling, data collection, word processing, and information dissemination. Historically, data analysis has been the major use of computers in plant pathology. More recently, computer graphics has been developed into a sophisticated, yet easily implemented tool for data analysis and presentation of results. Plant pathologists interested in the systems approach to disease epidemiology use computers to simulate the temporal and spatial development of disease. Plant pathologists are taking increasing advantage of the potential to computerize electrically powered laboratory or field instruments used to collect data and of the communications options available with computers to send letters, text material, and data over the phone to distant locations. We used a computer to write this article. Clearly, computers have become an important and sometimes necessary tool for conducting research, extension, and teaching in plant pathology.

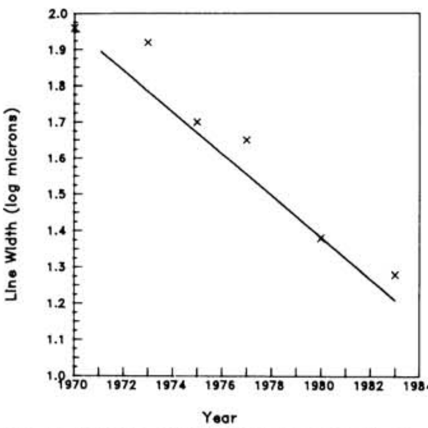

Fig. 1. Change in minimal line width of circuits embedded within integrated circuits (chips) vs. time (2).

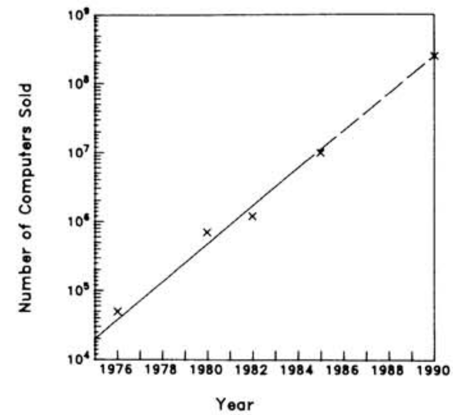

Fig. 2. Number of computers sold vs. time over the past 8 years, with projection to the year 1990 (6).

What Is a Digital Computer?

A computer is an electronic device that accepts information (input), manipulates it according to a set of rules, and produces results (output). Functionally, a digital computer must be capable of performing five operations: input data and/or instructions, store input data or results in memory, perform arithmetic or logical operations, control the sequence of events necessary to accomplish tasks specified by the user, and output results. Each of these functions requires electronic and/or mechanical hardware. In many cases, the electronic circuitry is packaged together so that it is not possible to physically separate each of the component functions of a computer.

Events within a computer are controlled in the central processing unit (CPU). Associated with the CPU is some amount of memory for the immediate use of the CPU. This space for storing data and programs is referred to as core memory. Core storage may consist of random-access memory (RAM) and/or read-only memory (ROM). ROM contains permanent sets of instructions used by the CPU and, as the name implies, cannot be changed, whereas RAM is used for temporary storage of instructions or input data. The size of a computer's memory is usually measured in terms of bytes, where a byte is an eight-place binary number. A single byte is used to represent a single alphanumeric character.

Hardware Technologies

Computers can be characterized by the speed with which the CPU performs arithmetic or logical calculations and the amount of storage space in ROM or RAM provided for program instructions and data. With respect to each of these characteristics, computer hardware technology has advanced with time while costs have decreased geometrically (7). Twenty-five years ago, computers were mammoth machines filling large rooms and using enough electrical power to supply a small city. With the development of the transistor and the integrated circuit (IC), computers began to increase in CPU speed and storage capacity and, concurrently, to decrease in physical size. Physically, an IC is a single piece of silicon (a chip) with circuits embedded in it. Integrated circuit technology has evolved from small-scale integrated circuits (SSI) to large-scale integrated circuits (LSI) and very large scale integrated circuits (VLSI). This is because the size of circuits embedded in the silicon chips making up ICs has decreased steadily (Fig. 1). Today, the multiple functions of computer control and arithmetic calculation can be placed on a single chip referred to as a microprocessor.

Microprocessors are characterized in part by the number of bytes of data they can process simultaneously. Until recently, microprocessors used in microcomputers sold commercially were able to process only a single byte (=eight bits) at a time and were referred to as eight-bit microprocessors. The reduction in size of individual circuits on the chip has allowed 16-bit and 32-bit microprocessors to be produced. Microcomputers with these microprocessors have considerably faster computation times.

As a result of this advancing technology, digital computers have become a pervasive part of society as well as a scientific tool. Four million computers

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were sold in the United States in 1983, bringing to 6 million the number in this country. On the average, computer production has doubled each year over the past 8 years (Fig. 2). It appears this trend will continue at least through the rest of this decade, resulting in a total computer population of over 250 million by 1990 (6).

The Kellogg Foundation has estimated that 75% of all mid-size farms in the United States will utilize computers by 1990 and that 90% of county extension offices will possess "intelligent" computer terminals by that time. An intelligent terminal has a microprocessor and can therefore perform the functions of a computer. There is already a rapidly expanding market for agricultural software to be used with on-farm computers. For example, a catalog of commercial agricultural software for the Apple computer lists over 200 programs (1).

Computer users in plant pathology are faced with several hardware modes: mainframe computers, minicomputers and microcomputers, hand-held computers (HHCs) or portable computers, and their associated peripheral devices. Ten years ago, most computer users relied almost entirely on mainframes, which are physically large and contain large (in terms of memory) and fast CPUs, allowing simultaneous interaction with many peripherals. Most mainframe users access the computer through remote job entry (RJE) sites, commonly work stations with a card reader or a terminal with screen referred to as a cathode-ray tube (CRT) or a video display unit (VDU), or a printer terminal. Many statistical analyses by plant pathologists are accomplished with a mainframe computer because these have a large amount of data storage capacity, are relatively inexpensive to access on most college campuses, and have "user friendly" statistical programs or programs whose use is taught in statistics classes. Additionally, there is usually a staff of consultants to provide guidance on the use of the mainframe system. As microcomputers become larger and larger in terms of memory, they will replace the mainframe computer as the primary statistical analysis tool. Before this will happen, however, much more sophisticated statistical programs will need to be developed for microcomputers.

Peripheral equipment. Peripherals are the auxiliary devices that may be placed under the control of the CPU. These include printers, modems, CRTs, mass-storage units, digitizers, and electronic laboratory and field equipment. Printers and CRTs are the most common peripherals encountered by plant pathologists, because they are used as terminals to communicate with the CPU. Microcomputers may be considered peripheral devices when connected to mainframe computers, minicomputers, or even other microcomputers and used as terminals.

A modem (MOdulator-DEModulator) allows the electronic signals from a terminal to be sent through telephone lines or coaxial cable to a computer, and vice versa. A modem is set to operate at a specific speed. Most routine access to computers is achieved at baud rates (bits per second) of 300 or 1,200, but faster communication is possible at 4,800 and 9,600 baud. Modems with autodialing and automatic answering capabilities are now available. Portable terminals with a modem have been used by pathologists to send survey data back to a computer through phone lines.

Mass-storage equipment includes disk drives and magnetic tape drives. With microcomputers, the 5¼-in. and 8-in. floppy disks are currently very popular for permanent storage of data and programs. Many microcomputers also allow storage of data on ordinary cassette tapes. The use of hard disk units with microcomputers is increasing in popularity because they provide convenient access to both large programs and data bases. Many portable computers and HHCs have nonvolatile memory, ie, the contents of memory are not lost when the machine is turned off.

In general, peripheral devices have been steadily declining in price while improving in quality owing to advances in IC technology. Mass-storage devices offer a good example. Until recently, hard disks were restricted to large mainframe computers but now they may be incorporated into microcomputer systems as Winchester-type disk drives. The 5¼-in. hard disk units are expected to reach 100 megabytes of data storage capacity by 1986, compared with their current capacity of 10–20 megabytes. CRTs, printers, and plotters are also improving in quality. Graphics terminals with high resolution are becoming available at prices compatible with the cost of some microcomputers.

A/D conversion. Microcomputers can be made to interface with many electronic devices by means of hardware that converts analog electronic signals into digital signals. The hardware that makes this conversion is referred to as an A/D converter. Such equipment as environmental measurement sensors, balances, and gas chromatographs can be connected to microcomputers. It is by means of A/D conversion that computers can be given eyes and ears. For example, the electronic signal from a video camera can be digitized and stored in a microcomputer. The camera senses each picture element (pixel) as a voltage that is converted to a number by the A/D converter. The computer can then analyze the picture. This technology has been used to assess plant disease (4), and we have used it to measure root length and assess bacterial growth. Computers can also be made to recognize speech. Again, an A/D converter is used to convert the electronic signal from a microphone into a series of numbers that are compared to sequences of numbers representing words stored in the computer. The ability to talk directly to a computer is being exploited as a means of entering research data for analysis as they are collected.

Videotext/teletext technology is a relatively new service commercially available to farmers. Although there are many versions and definitions, it commonly involves an on-line data base that can be accessed by phone to acquire information in a "screen-page" format. It has been described as a hybrid of the telephone, television, and computer (3). The Kentucky Green Thumb project is a pioneering example, having become operational in 1980. A user chooses the desired information from a given menu and sends the request to a computer by phone, the computer dumps the requested information into a memory unit in the user's home, and the telephone disconnects. The information is viewed as pages on a television screen. The Kentucky menu includes screens on plant diseases, eg, field control for blue mold.

Interfacing equipment. For peripheral devices to be compatible with a specific computer, certain rules have to be met to allow interfacing. The industry standard pertaining to most equipment used by plant pathologists is the RS 232 protocol, which defines, among other criteria, the baud rate and "handshaking" convention. This protocol further defines data terminal equipment (DTE) and data communications equipment (DCE); only DTE may "talk" to DCE, and vice versa. Modems are examples of DCEs, and CRTs and printers are examples of DTEs. When two devices are being interfaced, both must be set for the same baud rate, usually the highest that both can accommodate. For example, most microcomputers can interface with printers at 1,200–9,600 baud. When one device is receiving data too fast to process, "handshaking" has to be considered. A common situation is when a computer is sending data to a printer at 9,600 baud, but the printer can only print at 1,200 baud (120 characters per second). While printing at the slower speed, the printer stores the data arriving at the computer's rate in what is called a buffer. Eventually, the buffer space is filled and the printer sends a message back to the computer, on one of the 25 lines, to stop sending data.

In the near future, microcomputers with the capabilities of today's mainframes will be available. This has serious implications for the manner in which plant pathologists collect and analyze biological data. For example, it may not be necessary to scale down large computer simulations to fit a microcomputer, and many of the large epidemic simulation models will be implemented on microcomputers (5).

Software Technologies

Whereas hardware consists of the physical units that make up a computer system, software is the collection of instructions (programs) that allows a computer to perform defined tasks. Generally, software comprises system software and application software. System software is the resident set of instructions that internally run a computer and are commonly not modifiable by a user. In microcomputers, system software is frequently stored in ROM and is sometimes referred to as firmware.

System software includes the instructions that control the components of a computer system (the operating system) and programs that convert languages into a form the computer can understand (compilers, assemblers, or translators). Software that is frequently used by a computer and does not require changes may also be stored in programmable read-only memory (PROM) or in erasable programmable read-only memory (EPROM). Most application software is loaded into the RAM of computers each time it is needed; with microcomputers, the most common way of loading a program is from a disk by means of software in a disk-operating system (DOS).

Unfortunately, there is no universal operating system, and most computer users are faced with learning the system specific to the computer to which they have access. Knowledge of the operating system is necessary to allow the user to communicate instructions to the computer. With microcomputers, CP/M, MS.DOS, and Unix operating systems are gaining much acceptance by manufacturers, and software written for them generally can be used on computers that do not have them as native operating systems.

Computer languages. Computer languages enable the user to convey instructions to the CPU after they are converted into a machine language the computer can understand. The computer only understands a machine language based on numerical operation codes using the binary number system, and various ways have been devised to facilitate the conversion. Because machine language programs are tedious to write and difficult to decipher, higher level languages have been developed. The ones most familiar to plant pathologists are FORTRAN and BASIC, general-purpose languages suited to many scientific applications. The computer uses programs called compilers or translators to convert these languages to machine code. The process of converting a high-level language into machine language results in inefficiencies, however, and other languages have been developed that allow conversion with instructions nearer to machine language than the higher level languages. These are the assembly-level languages, each of which is specific to the microprocessor used in a computer. Programs for the common user are more difficult to write in assembly language than in the friendlier higher level languages, but they are more efficient to execute.

One question we commonly encounter from colleagues concerns which computer language to learn as a starter. We have no single recommendation. Up to about 5 years ago, most scientific programs used in plant pathology were written in FORTRAN. The increasing use of microcomputers, however, has resulted in a corresponding increase in the number of BASIC language programs available to plant pathologists. The full name from which BASIC is derived—Beginners All-Purpose Symbolic Instruction Code—suggests it is easier than FORTRAN to learn but also more limited for scientific applications programming. Other languages developed to improve user friendliness and efficiency of execution include PL1, APL, and PASCAL; PASCAL is gaining in popularity among scientific programmers. We have found that learning the first language, regardless of the one chosen, inevitably makes learning a second much easier.

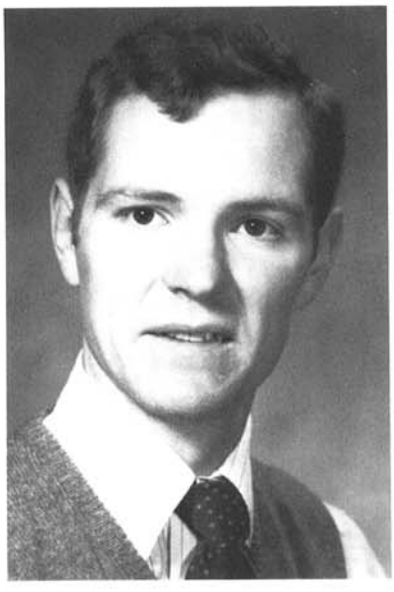
Specialized languages have evolved to meet the needs of users, eg, those involved with system simulation and modeling. CSMP (Continuous System Modeling Program), MIMIC, GASP-IV, and DYNAMO are some simulation languages that allow a user to develop a large simulation model of a biological system without too much knowledge of programming. These languages contain modules of code that enable a user to perform complex calculations by writing just a single instruction. A recent innovation is the preprogramming aid, software that converts logic documented in the English language into a higher level language such as FORTRAN. All these facilities lead to making the computer a less daunting machine to use.

Application packages. Software exists for a large number of applications in plant pathology. Among the best known are the statistics packages, including SPSS, BMDP, SAS, and Minitab. These packages offer many types of analysis besides the common ones such as analyses of variance, but our statistics training has been inadequate to allow us to use them. An example is nonlinear regression; software packages like SAS allow any researcher to fit nonlinear models as easily as doing one-way analysis of variance. One implication is that there is an increasing need for a subgroup of plant pathologists with special training in statistics who are also competent computer users. This is necessary to ensure that these new tools are quickly integrated into our science and are used properly. Because most statistical packages require large amounts of computer memory, SPSS, SAS, and the others are usually available only on mainframe computers, although statistical applications packages with nearly as much versatility are becoming available for some microcomputers. Apart from their use in analyses, most statistical packages allow simple x–y plots of data and also facilitate the management of large data bases through their filing options.

There are many other kinds of software packages of value to plant pathologists, including economic analysis, mathematics, and graphics software. Plant disease and crop loss surveys, which result in large amounts of data, usually require a data-base management system. Many of these are commercially available for use on mainframe computers, and some users have developed their own systems. In Minnesota, the central pest data base of a statewide crop loss survey is managed using SIR (Scientific Information Retrieval).

Software to enhance professional efficiency. Many plant pathologists have become seriously interested in microcomputers for the first time not because of their utility as a research tool but because they can increase the efficiency of office work. Word processing, bookkeeping (spread sheets), filing and address listing, data display/plotting, bibliographic files, and electronic mail services are all available through microcomputer hardware and software. For example, all popular microcomputers, such as the IBM PC and the APPLE II series, have word-processing packages, eg, WORDSTAR, APPLE WRITER II, and SCREENWRITER. These word processors are "user-friendly" and allow greater flexibility in composing and editing text than the best typewriters. Their ease of use makes them attractive to home computer owners; for example, the 11-year-old daughter of one of us (PST) became a competent user of APPLE WRITER IIe after only half an hour of instruction. Many spelling-check programs are available to complement the word-processing software, some containing up to 40,000 commonly used words that can be supplemented with specialized/personal dictionaries. There are moves in the computer software industry to develop grammar and context checks, and these may be available in the near future.

A logical development from word processing is electronic mail, in which text code created by word-processing software may be sent via phone lines to and from different microcomputers or mainframe computers. A modem is needed to do this. The U.S. Postal Service operates a nationwide electronic mail service, while on the local level, many companies and state agricultural extension services have designed their own. The North Central Computer Institute (667 WARF Building, Madison, WI 53705) has recently made available to its 12 member states an electronic bulletin board (BB) for posting messages of general or specific interest. In Minnesota, we have developed mailboxes for research into sugar beet and potato diseases and have the first identification of key pests conveyed to a central BB at St. Paul by cooperators as far away as Winnipeg, Canada, and Grand Forks, North Dakota. This has enabled us to test predictive programs on potato and sugar beet diseases and has also provided data for early warning in the control of Cercospora leaf spot on sugar beets. Electronic mailboxes also enable project



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leaders to communicate with their cooperators at all times of the day if the necessary equipment is available.

Computer spread sheets allow plant pathologists with several budgets to plan and program their expenditures efficiently. One such software package that is very popular with microcomputer owners is VISICALC, versions of which are available for most brands of microcomputers. The computer provides a convenient means for storing and accessing large amounts of data as FILES, and many programs use these files for such purposes as plotting graphs and histograms. Programs for handling references have been used to replace the traditional index-card system. At Minnesota we have a computerized bibliography with up to 10,000 entries from which a user can conduct searches by cross-indexed keywords. This system is implemented on an APPLE II Plus microcomputer with two disk drives.

Potentials and Problems

With the advances being made in digital electronic engineering, very powerful computer hardware is becoming available to the plant pathologist. Although lagging behind somewhat, software for making the computer even more easily accessible is also being developed. While there is great potential for the computer to advance the progress and quality of plant pathology research, there is also potential for misuse, eg, inappropriate statistical analysis and misinterpretation of results. Another potential problem is inaccessibility of a computer program written as part of a research project. Such programs are seldom if ever published, yet interpretation of research results may depend on their content. Software developed by a researcher for a specific purpose must be available to others. There is the danger, on the other hand, that a very large program, such as a crop growth or epidemic simulator, will be used by researchers who do not understand the contents. This could result in inappropriate use or perpetuation of mistakes made by the originator of the program. There is a clear need to increase the degree of computer knowledge within the plant pathology discipline even as computers become easier and easier to use.

Advances in digital electronics technology and software development make computers a research, teaching, and extension tool with which all plant pathologists should become familiar. It is imperative that the generation of plant pathologists being trained today be well versed in computer technology. We have an obligation to learn to use computers in our profession and to teach our students how to use computers as innovative tools for increasing research productivity and originality, communication, and professional efficiency.

Next month: How computer technology has enhanced development of such broad areas in plant pathology as environmental monitoring and equipment control, field data recording, computer modeling, data management, and information delivery systems.

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