

THE DEVELOPMENT OF DIGITAL COMPUTERS

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"How?" "Why?" These questions have probably given more spark and continued vitality to the growth of civilization than any other impetus. An urge to understand the "hows" and the "whys" of the world has caused men to constantly seek and find answers to their questions. Inventions have been created for their needs; and countless new products and discoveries have appeared. New ways to control the forces of nature have been discovered.

During the dawn of civilization, each man had to use his own imagination and knowledge in order to produce his few conveniences. Probably centuries passed before someone's insight led to a bow and arrow for hunting. Only after years was it perfected. All the inventions, discoveries, and insights have been accumulated over the centuries into a great storehouse of knowledge which man presently uses to stimulate his thinking and better his living.

With the growth of the fund of available knowledge, the rate of progress has been increasing at an astonishing pace. For example, the airplane has progressed from the hazardous mono-planes to the present modern jets within only fifty years. But how long have men been dreaming of sustained flight? Perhaps since the first man saw the first bird in flight. Greek mythology includes a story in which men attempted to fly by using large wings attached to their

arms. Leonardo da Vinci made plans for a machine that was supposed to fly. But da Vinci's plans were too far advanced for the state of knowledge and techniques of putting ideas into useful products. Man's imagination has always been several steps ahead of his technology.

The rapidity of the present rate of invention, improvement and development is astounding--almost as astounding as some of the products which are being created. The most promising tools recently developed are those used for processing the complex data of business, science, and other fields. The development of these machines is the result of research programs which utilize the knowledge which has been accumulating over the centuries.

Early in the development of civilization, communication was a great problem of men trying to gather together in groups. Sounds, movements, and signs--symbols representing ideas--were needed in order to pass on ideas and discoveries, and to convey their knowledge to their children. Language and written symbols came from refinements of these crude beginnings; and men were effectively able to communicate with each other and to permanently record their ideas.

Man began searching for means of expressing himself soon after he was able to satisfy his basic needs for shelter and food. The first "written" expressions were probably the picture symbols used to decorate the walls of his cave. Natural objects such as the sun and the moon were first and

frequent symbols in primitive art.

Man soon wanted to express "how many"--how many fish he had caught, how many children he had, and so forth. Terms such as "one", "several", and "many" appeared with his understanding of the basic concepts of quantity. He began to draw pictures to represent quantities, and soon one type of picture was taken to represent five or ten or any other specific quantity. Thus numbers were born. Here man began to think about exact quantities as abstract ideas, and the number language became a method for accurately counting and measuring.

Although many different languages are used in various parts of the world, there is one universal language-- the language of numbers. If I see a number, I can immediately recognize a definite quantity. There is no room for misinterpretation--it means the same to me as it meant to da Vinci or Galileo.

But men of ingenuity and imagination could not be satisfied with just counting. They looked for and found means to manipulate and apply numbers. These methods became important tools for exploring, measuring, and defining some of the mysteries of the world. These tools--mathematics--have grown and divided into many specialized branches of knowledge such as algebra, trigonometry, calculus, and statistics. Several of these branches are described in the following paragraphs.

Arithmetic began as a spoken language and later developed into a written system of notation for counting and measuring. As improvements such as multiplication and division were devised, arithmetic provided a very useful method for manipulating quantities.

Geometry includes some of man's earliest discoveries about the physical relationships around him. "The historical origin of geometry, which goes back to the Egyptians, supplies one of the many instances in which intellectual discoveries have grown from material needs. The annual floods of the Nile which fertilized the soil of Egypt brought trouble to landowners: the borderlines of their estates were destroyed every year and had to be reestablished by means of geometrical measurements. The geographical and social conditions of their country, therefore, compelled the Egyptians to invent the art of surveying."<sup>(1)</sup>\* Geometrical relationships among triangles and other figures led to tremendous developments in construction, art, and architecture.

Trigonometry is the study of the laws governing the relationships between the sides and angles of a triangle. It began with the study of the right triangle by Pythagoras, and was later extended to a variety of triangles. With a knowledge of trigonometry, surveyors can determine the heights and distances of inaccessible objects, and navigators

\*Numbers in parentheses refer to References at the end of paper.

can determine their location at sea.

Algebra is a technique which uses special symbols as well as numbers in representing quantities. Formulas or equations are used to express the relationships among quantities. Algebraic laws were devised and govern the use of these symbols and equations so that they will yield meaningful answers to a great number of problems.

Calculus was devised to handle many of the complex problems that cannot conveniently be manipulated by algebraic techniques. Essentially, calculus is concerned with studying the effect that a change in one variable has on other variables of an equation. Calculus is used to help answer questions about rates and curved motion such as the flight of a projectile. "Many major contributions to the basic principles of business machines have been made by calculus whose techniques can now be handled by the very machines they helped to make possible."(2)

The science of statistics applies mathematical techniques to a series of similar events in which there may be a trend or a "general conclusion", but in which all events will not be exactly the same. Data concerning the popularity of a TV program, or average height of a group of people may be collected and analyzed statistically. Although I do not have access to the reference, I understand that President-elect Kennedy used statistics concerning the attitudes of different sections of the country; and these along with other pertinent data were carefully analyzed with the aid

of a digital computer, and proved to be very beneficial in his campaign.

Logic is a relatively recent application of mathematics. Logic is concerned with expressing both qualitative and quantitative ideas in mathematical form. Mathematics techniques may be applied to logical expressions to produce methods for discovering truth. Complex symbolic logic is used in the design of digital computers. In this manner, electronic elements can be combined to perform very complicated operations.

The first device invented for aiding in working with numbers was the abacus, which appeared more than 5,000 years ago. At the beginning of the 17th century John Napier developed a system of numbering rods as an aid to multiplication, known as Napier's "bones". He also invented logarithms which led to the invention of the slide rule almost immediately.

A Frenchman, Blaise Pascal, built the first mechanical computer in 1642. It consisted of wheels with numbers around them, and it worked similarly to the modern revolution counter. Leibnitz improved his calculator by adding a system for multiplying numbers by successive additions. Burkhardt in Germany, Odhner in Sweden, and Burroughs in the United States were three important developers of mechanical calculators.

These machines, however, were not direct forerunners of the digital computer. The human operator was needed to supply them with figures, work the machinery, and to record the result of each step before going on to the next one.

Charles Babbage, a Cambridge mathematician, was the first to start a large computer based on the principles of modern computers. His plans for the Analytical Engine called for a system of sequential control over the arithmetic operations it was to perform. It was to be sequenced by the use of punched cards. His conception was never built due to financial difficulties and the limitations of the mechanical engineering of the time.

Dr. Herman Hollerith patented the Hollerith punched card in 1889, which is an example of the present application of punched cards. His equipment became the basis for the organization of the International Business Machines Corporation in 1911.

Dr. Howard Aiken of Harvard described a machine using Babbage's sequential control principle in the 1930's. It was called the Automatic Sequence Controlled Calculator and used electromagnetic relays; it used paper tape for sequence control. It was completed in 1944 by Harvard University and IBM and is still in use.

The development of electronic computers since 1945 had been nothing less than fantastic. A comprehensive coverage of the field is beyond the scope of this paper. A few of the fundamental aspects and some of the more interesting applications will be covered.

"Programming a problem for solution on a digital computer is basically a process of translating from the language convenient to human beings to the language convenient to the

computer. The language of the problems to be solved is mathematics or English statements of decisions to be made; the language of the computer is simple arithmetic and elementary choices, expressed in coded numerical form. By and large, we are at present required to present problems to the computer in its language."(3)

Digital computers are usually comprised of elements which perform five distinct functions. These are: input, memory, control, arithmetic, and output.

INPUT. Data can be entered into digital computers in the form of letters, numbers, and symbols. Input can consist of punched cards, punched paper tapes, magnetic tapes, or keyboards and switches. Most computers use a combination of several types of input.

MEMORY. The memory or storage element of a digital computer is the nerve center of the machine. All data must pass through it. All numbers have to be in memory before any arithmetic manipulations can be carried out. All instructions must be stored in memory before they can be used in the control section. The speed of arithmetic operations is largely dependent upon the access time--the time required to obtain data from memory and transfer it to other units of the system.

CONTROL. The control section of a computer interprets or decodes the instructions stored in memory and sends control signals to other elements telling them what to do. The control section can make certain logical decisions which are

based on intermediate results. For instance, if a calculation is being made to a certain percentage error, or to a particular number of decimal places, the computer will determine when the specified accuracy has been attained, and then go on to perform its other calculations.

**ARITHMETIC ELEMENT.** The arithmetic element performs the actual calculations in a digital computer. Digital computers can add, subtract, multiply, and divide, thereby performing any complex calculation, since complex calculations are always made up of these basic operations.

**OUTPUT.** After its calculations have been performed, the digital computer stores the results in memory or writes them out directly. The results may be punched into cards, recorded on magnetic tape, or printed out on paper. Printers are so much slower than computers that results are usually printed a line at a time.

Computer memories must be capable of storing binary digits, either a 1 or a 0. Certain magnetic devices are easily adapted to these requirements. These include tapes, drums, disks, cores, ferrite plates, twistors, and thin films. Most modern digital computers make use of one or more of these magnetic storage devices. Presently, of random-access computer memories, the most widely-used are memories made of ferrite cores which are driven by transistors. They have storage capacities which vary between  $10^4$  and  $10^6$  bits and their cycle access time is in the order of 10 microseconds. Some of the later memories have access

times of around 2 microseconds. Ferrite plate and twistor memories are now being used commercially; they have capacities of about  $10^5$  bits and cycle times of 3 to 5 microseconds.

In the past five years, the use of the superconductive effect at very low temperatures has been developed for computer components. In this time, extensive work has produced superconductive and cryoelectric techniques which have become prominent for computer logic and memory realizations. Logic gating by cryotrons is based on the control that a magnetic field has over the transition from superconductive to the normal state. Memory cells are obtained through the use of persistent superconductive currents or trapped flux. By inducing a current into a closed ring of zero resistance, it is possible to store either a positive or negative current; or to have an element in which there either is, or is not, a current flowing. The outlook for superconductive memory elements is good. Elements are small enough that they can be packed at least 100 to the <sup>cubic</sup> centimeter. Vacuum evaporation processes promise effective techniques for fabrication. "Results of efforts to implement memory potentialities have been reported in three areas: 1) greater understanding of the superconductive phenomena, particularly with regard to the transition between superconductive and normal states; 2) experiments with single and a few memory cells, demonstrating that all required properties for memory systems can be obtained and that the switching times can

be very short; and 3) suggestions on methods to make memory systems. No fundamental difficulties have been found. The problem seems to be chiefly one of technology."(10)

New uses for digital computers are appearing daily. Besides the usual "scientific" and "business" uses, there are many specialized applications. Computers have been used extensively to solve difficult mathematical problems which would take months or years of routine calculations normally. They have been programmed to play games such as bridge, checkers, and chess with amazing dexterity. Considerable research is being conducted in the field of "artificial intelligence". Computers are being used to develop theory and mechanizations to produce self-organizing machines.

A few of the more recent and interesting applications of digital computers are covered below. Many of these applications promise to show strong development in a very short time.

Although they are usually used in more precisely stated areas, computers are being used in literature and the arts. They are used in teaching, for instance. "...the computer directs the display of instructional material from slide projectors and determines sequences of diagnostic questions. The student can indicate answers by means of typewriter input, and the computer, in turn, can tell the student how correctly questions are answered. It is clear that teaching machines will come into greater use; the digital computer is obviously well suited to this application."(11) They have

been used in scheduling classes at Purdue University. Computers may some day be used in teaching "readin', 'ritin', and 'rithmetic". Computer programs have been prepared to correct spelling errors. Flight simulators have been used for some time, mostly controlled by analog computers. But digital computers are more flexible in the airplane models that may be simulated with one computer. They have been used facetiously to play tunes by amplifying some of the internal signals. They can analyze a musical score and write original compositions.

Digital computers are used extensively in business and government. The President could use a computer in the face of war to help him analyze the pertinent data in making his decision. Election forecasting is possible and may develop to the point that results in the East may affect the election outcome on the west coast due to the time differential. *an time ahead*  
This is easily foreseeable in the not too distant future. Many businesses use computers in their payroll calculations, but few, as yet, have reached the point of depending upon the computer for salary recommendations in an organization. This appears to the author to be a sensible application, yet one which might cause more turmoil than good. Too, there are certain qualities which at present are hard to judge other than subjectively. Personality certainly cannot be ruled out as a factor in wage determination.

Computers are used in many "on-line" applications in which they are tied directly to an activity and perform

work relating to demands occurring in real-time. The SAGE System was an early on-line application of digital computers. They are used for intelligence, attack warning, data processing and in the control and command of operations of the military. Machines controlled by computers for machine tooling are becoming rather common. A digital computer is used in Russia to control trains.

Digital computers are used by the Air Force for obtaining data from tracking stations and processing it in real-time during space probe shots. Data are processed and the current orbit and corrections for time and distances are transmitted to stations which cannot establish contact with the vehicle due to horizon limitations. These data are also used to fire retro-rockets and to put a vehicle into its proposed orbit.

"Although mostly in the experimental stage at this time, the compression of human speech by digital techniques is a new and important application. The process is essentially one of performing an analog-to-digital conversion of recorded speech sounds. Since the information content in human speech is low compared to the nominal information rate implied by the bandwidth used in human speech to produce the sounds, it is theoretically possible to compress the bandwidth through digital encoding. Following this compression, the resulting digital signal is sent over a less expensive communications facility, that is, one which handles the lower bandwidth. The signals are then reconstructed at the receiving end for

the formation of an analog speech pattern which can be recognized by the human ear."(11)

Digital computers are widely utilized to ameliorate traffic control problems. The mode of operation of traffic control signals can be changed from time to time, depending upon the current requirements of the signals due to the traffic demands.

Language translation by the use of digital computers is an application which shows promise of being developed. The present problems in this field seem to be largely those of cost. "First-rate professional translation by human beings can be bought at about 1.1¢ per word. Merely to key-punch input for computer translation costs about 2.3¢ per word. Thus, it is probable that machine translation can begin to match costs of human translation only with the development of a successful print reader. Such machines are under development by a number of companies."(11) There is a good market for translation of Russian technical material and this should provide good demand for future cost reduction of translational techniques.

Round-the-clock process control is possible with computers. The first process to be controlled by a digital computer on a large scale was oil refining. Human operators are not completely eliminated; in the event of a non-correctable off-scale reading, an alarm is sounded and information is printed out on a typewriter.

One of the most promising applications of the future

is in the field of medicine. "With the use of computers several mathematical techniques can be applied to aid certain aspects of medical diagnosis. However, much work remains to be accomplished in trying these methods under practical conditions. Although wide interest has been expressed, few studies have been reported in the literature. Among the potential advantages of computer aids are: making available to the physician quantitative methods in areas related to data analysis and differential diagnosis; assisting in the evaluation of the best alternative courses of action during stages of the diagnostic testing processes; and periodic recording and evaluating of individual physiologic norms for more sensitive determination of an individual's health trend relative to disease prevention. Communication between the physician or researcher and the computer is presently technically feasible but much research and planning are still required for realistic application!"(7)

Several thought-provoking implications may be drawn from this study. They are related principally to the possibilities that man-made automata may eventually attain the complexity required to cause human beings to let the "machines rule the earth". At present, the man-machine system is being replaced by machine-machine systems in more than a few instances. The use of computers is reaching higher levels in its applications to intelligence, data processing, and the command of troops. It seems to be a rather far-fetched idea to think that man would let himself

be ruled by a machine. But is it? It is happening to a greater extent every day! The alarming thought is that the digital computer is essentially only fifteen years old and the field is growing at an unimaginable rate. With only a little imaginative forethought, another fifteen years can be seen by this author to bring about a situation in which, whether he will admit it or not, man will be very nearly a slave to his own machines. ✓

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