Chapter 35

PILOT, the NBS multicomputer system[1]

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Summary PILOT, the new NBS system, possesses both powerful external control capabilities and versatile internal processing capabilities. It contains three independently operating computers. The primary and secondary computers each utilize only 16 basic types of instructions, thus providing a simple code structure; but because so many variations of the formats are possible, a wide variety of computing, data-processing, and information-retrieval operations can be performed with these instructions. The secondary computer is specially adapted for performing so-called "red-tape" operations, and both the secondary and the primary computers, acting co-operatively, can carry out special complex sorting or search operations. The third computer in the system, called the format controller, is specially adapted for performing editing, inspecting, and format modifying operations. The system is equipped to transfer information concurrently along several input-output trunks, though only two are planned for the near future. Using two such trunks, it is possible to maintain two continuous streams of data simultaneously flowing between any two external units and the internal memory, without interrupting the data-processing program. The system can operate with a wide variety of input-output devices, both digital and analog, either proximate or remotely located. The external control capabilities of the system enable the machine to supervise this wide family of external devices and, on an unscheduled basis, to interrupt or redirect its overall program automatically, in order to assist or manage them.

At the National Bureau of Standards (NBS) a new large-scale digital system has been designed for carrying out a wide range of experimental investigations that are of special importance to the Government. The system can be utilized for investigating new or stringent applications of these general types: (1) data-processing applications, in which the system can be used for performing accounting and information-retrieval operations for management purposes; (2) mathematical applications, in which the system can be used for performing mathematical calculations for scientific purposes, including scientific data-reduction; (3) control applications, in which the system can be used for performing real-time control and simulation operations, in conjunction with analog computer facilities or in conjunction with other instrument installations, remotely located if necessary; and (4) network applications, in which the system can be used in conjunction with other digital computer facilities, forming an interconnected communication network in which all the machines can work together collaboratively on large-scale problems that are beyond the reach of any single machine.

[1] *Proc. EJCC*, 71–75 (1958).

Because the system was designed for such varied uses (ranging from automatic search and interpretation of Patent Office records to real-time scheduling and control of commercial aircraft traffic), the system is characterized by a variety of features not ordinarily associated with a single installation, namely: a high computation rate, highly flexible control facilities for communicating with the outside world, and a wide repertoire of internal processing formats. The system contains three independently programmed computers, each of which is specially adapted for performing certain classes of operations that frequently occur in large-scale data-processing applications. These computers intercommunicate in a way that permits all three of them to work together concurrently on a common problem. The system thus provides a working model of an integrated multicomputer network.

System organization

Exclusive of data-storage and peripheral equipment, the central processing and control units of the over-all system contain approximately 7,000 vacuum tubes and 165,000 solid-state diodes. The basic component for these units is a modified version of the one megacycle package used in the NBS DYSEAC, which in turn was evolved from the hardware used in NBS Electronic Automatic Computer (SEAC). As a result of a more effective logical design and faster memory, however, the new NBS system will run more than 100 times faster than SEAC on programs involving only fixed-point operations; for programs involving floating-point manipulations, the advantage exceeds 1,000. The arithmetic speed of the new system derives in a large part from connecting a novel type of parallel adder to a diode-capacitor memory capable of providing one random access per microsecond.

The system contains seven major blocks, which are indicated in Fig. 1, namely: (1) the primary computer, in the lower center

Table 1 Arithmetic operation times
(including 4 random access times to last memory)

Operation	*Total time (microseconds)* Average	Minimum-maximum
Fixed-point Addition, Subtraction, Comparison	7.5	6–9
Fixed-point Multiplication	31	22–40
Fixed-point Division	73	72–74
Floating-point Addition, Subtraction†	20	19–21
Floating-point Multiplication	37	28–46

† For shift of 4 bits.

of the figure, (2) the primary storage, upper center; (3) the secondary computer and the secondary storage, right; (4) the input-output control, upper left; (5) the external storage units, upper far left; (6) the external input-output units such as readers, printers, and displays, lower far left; and (7) lower left, the external control containing the special features that facilitate communication with people and devices in the world outside the system which is remotely located if necessary. Interchanges of information between the system and the outside world can take place at any time, on a completely impromptu basis, at the instigation of either the system or the external world, or both acting jointly.

The primary computer, a high-speed general-purpose computer, contains both an arithmetic unit and a program control unit of considerable versatility. This computer can carry out a variety of high precision arithmetic and logical processing operations, in either binary or decimal code and in a wide variety of word lengths and formats. Its partner computer, the secondary computer, specializes in short-word operations, usually manipulations on address numbers or other "red-tape" information, which it supplies automatically as needed to the primary program. The third computer of the system, called the format controller (see input-output control in Fig. 1), is specially designed for carrying out editing, inspecting, and format-modifying operations on data that are flowing in or out of the internal memory via the peripheral external units of the system. All three computers, and all the external units of the system, share access privileges to the common high-speed internal memory, which is linked to the input-output and external storage units via independent trunks for effecting data-transfers. Transfers of data can take place between the external units, the memory units, and the computers concurrently without interrupting the progress of the computational program. Because of the flexibility of the format controller, incoming data can be accepted

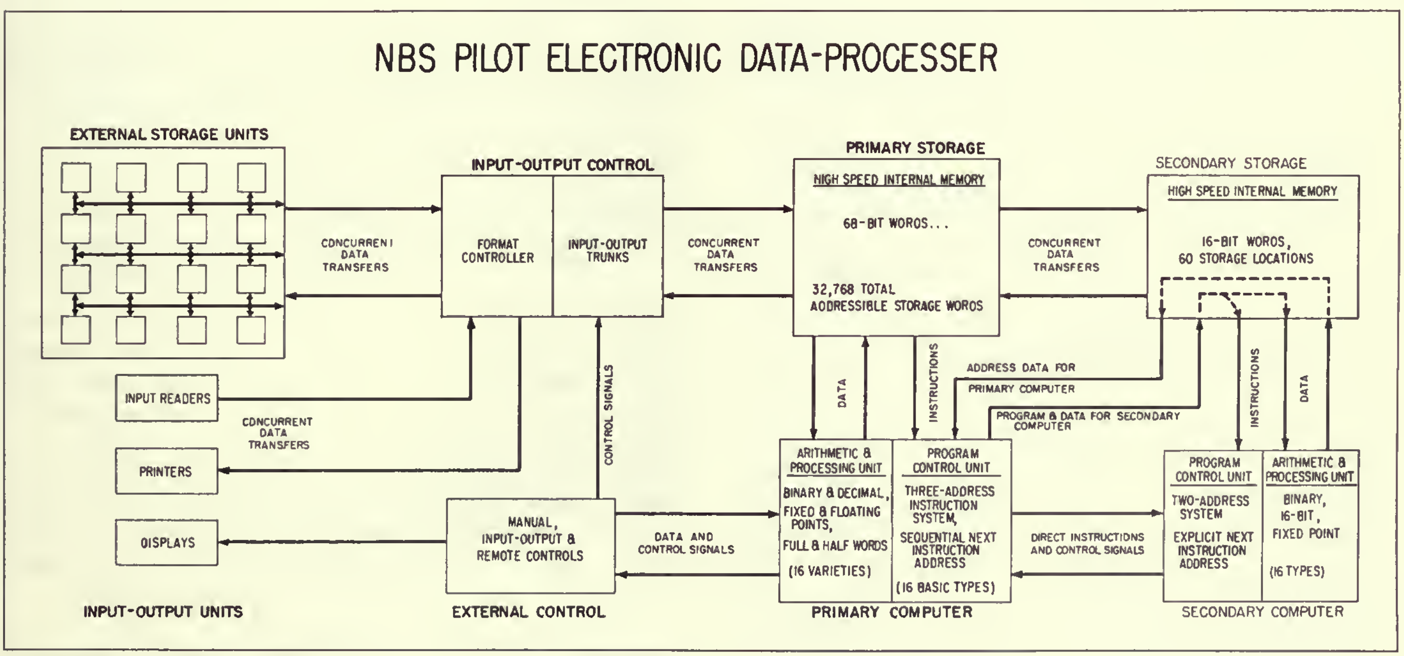

Fig. 1. Over-all block diagram for PILOT.

from a wide variety of external devices and in a wide variety of formats.

Functions of the major units

The specific functions of the major units can be described briefly as follows:

Primary computer

Arithmetic and processing unit. Using a 64-bit number word with algebraic sign, this unit carries out 7 different types of arithmetical operations, 5 types of choice (branch) operations, and 2 types of logical pattern-processing operations. See Table 2. Arithmetical operations can be performed in any of 16 possible formats. For example, arithmetic can be performed using either a pure binary or a binary-coded decimal number code, and in both fixed-point and floating-point notation. Fixed-point operations can also be carried out in a special half-word format in which two independently addressable half-words are stored in a single full-word storage location. These two half-words can be processed either separately, as independent words, or concurrently in duplex format. In duplex format, the respective lefthand and righthand halves of each double operand are processed simultaneously in a single instruction time, and the two independent half-word results are written back in the corresponding halves of the full-length result location.

Program control unit. The program control unit interprets and regulates the sequencing of instructions in the program. It operates with a 68-bit binary-coded 3-address instruction word. See Table 3. Each instruction word contains three 16-bit codes which specify the addresses of each of two operands, alpha and beta, and usually the address of the result of the operation, gamma, in the main memory. The memory location of the next instruction word is specified by a 16-bit address number contained in one of 16 possible base registers; a 4-bit code in the instruction word (*d*-digits) specifies which one of the base registers contains the desired word. Whenever a register is so used as a next-instruction address source, its contents are automatically increased by unity. Choice instructions, used for program branching, from time to time may cause a new alternative address number to be inserted in any one of the base registers. This register is then used as the source of the address number of the next instruction.

Table 2 Types of internal operations

Primary computer Name	*Abbreviation*
Arithmetic operations:	
Add	AD
Augment	AG
Subtract	SB
Multiply	MP
Divide	DV
Square-root	SQ
Shift	SH
Nonnumerical processing operations:	
Transplant Segment with Shift	TL
Generate Boolean Functions	GB
Choice operations:	
Compare, Algebraic	CA
Compare, Modulus	CM
Compare, Equality	CE
Check Scale	CS
Compare Boolean Functions	CB
Control operations:	
Transfer Between Storage Units	TS
Regulate Secondary Computer	RS

Secondary computer Name	*Abbreviation*
Clear add	ca
Hold add	ha
Store positive	sp
Transfer	tr
Increase	in
Decrease	de
Logical Multiply	lm
Compare, Zero	cz
Compare, Righthand Bit	cr
Compare, Lefthand Bit	cl
Compare, Negative	cn
Check Primary and Proceed	cp
Check Primary and Wait	cw
Regulate Primary Computer	rp
Replace Primary Instruction	ri
Secondary Take Input from Primary	si

Table 3 Contents of primary instruction word

Digits numbered 1 through 68																
68–65	64–61	60–57	56–53	52–49	48–45	44–41	40–37	36–33	32–29	28–25	24–21	20–17	16–13	12–9	8–5	4–1
Tags	Address alpha				Address beta				Address gamma				Next Instn.	Code for Operation		Mon. Break Point
000±	a-Digits				b-Digits				c-Digits				d-Digits	Parameter	Basic Type	e-Digits

Addresses alpha, beta, and gamma written in the instruction word are subject to automatic modification if desired by writing a 1-digit in a specified bit position. Such addresses are called relative addresses. Each of the three addresses (α, β, and γ) in each instruction word contains a 4-bit code group, called the *a*-, *b*-, and *c*-digits respectively, in which any base register identification number (0 through 15) may be written. When this is done, the address number to which the computer actually refers is equal to the sum (modulo 2^{16}) of the address number stored in the designated base register plus an address-modification constant, indicated in the remaining 12 bits of the 16-bit address segment of the instruction word.

Primary storage units

Fast access memory. Because of budget limitations, the initial installation of the system will contain only a relatively small section of internal memory of the diode-capacitor type. This diode-capacitor memory, originally developed at NBS in 1953, is very fast; i.e., capable of providing one random access per microsecond, but it has the disadvantage of relatively high cost per word of storage. This type of memory is available in modules of 256 words subdivided as follows:

Numerical information	64 bits
Algebraic signs and tags	4 bits
Parity check digits	4 bits
Total word length	72 bits

The over-all system is designed to accommodate up to 32,768 internally-accessible full-words, which may be held in storage units with access times ranging from 1 microsecond (μsec) to 32 μsec. Thus the minimum fast access memory can be backed up with a much larger and slower magnetic-core memory.

Inter-memory transfer trunk. Provision is made for transferring blocks of information between the various internal storage units in the system, concurrently with computation. The size of the block transferred may range from a single word to the entire contents of the memory, and the addresses between which the information is transferred are specified by a single programmed inter-memory transfer instruction. Automatic interlocks are provided to insure that all future references which the program may make to any memory positions involved in the inter-memory transfer operation are automatically made after the data have been shifted to the new locations.

Secondary computer

Arithmetic and processing unit. The secondary computer is a high-speed independently programmable general-purpose computer that operates in conjunction with the primary computer and can perform 16 distinct types of operations using 16-bit words. These operations include 6 arithmetic-processing operations, 4 choice operations, 1 nonnumerical processing operation, and 5 operations that transfer digital information or control-signals between the primary and the secondary computers. See Table 2. Operation times for the secondary computer average about 2 μsec.

Both computers operate concurrently and can transfer information back and forth between each other. One of the principal functions of the secondary computer is to carry out so-called "red-tape" operations, such as: (1) counting iterations, (2) systematically modifying the addresses of the operands and instructions referred to by the primary program, (3) monitoring the primary program, and (4) various special tasks. Through the use of special subroutines for the secondary computer, both computers acting co-operatively can be made to carry out a wide variety of complex operations without unduly complicating the writing of the primary computer programs. Examples of such operations are: (1) special types of sorting, (2) logarithmic search, (3) routines involving cross-referencing, or items selected according to an attached code, (4) error analyses, and (5) operations involving small numerical fields.

Secondary storage unit. Associated with the secondary computer is the secondary storage unit which consists of 60 storage locations containing 16-bit words. Sixteen of these locations can be used as base registers by the primary computer and may be selected by the primary computer according to the *a*-, *b*-, *c*-, and *d*-digits in the primary instruction word. The contents of the registers selected by the primary computer in this way are automatically added to the address numbers specified in the primary computer instruction word. The secondary storage unit is also capable of being addressed directly by the primary computer. The fifteen 4-word blocks of the secondary storage are identified by 15 special primary address numbers. Other addressable registers associated with the secondary storage hold the address numbers of current and next instruction words in the primary program.

Program control unit. The secondary computer program operates with a 2-address instruction system, the addresses referring to words in the secondary storage unit, including the base registers. See Table 4. From time to time the primary instruction program may order the insertion of a new instruction into the secondary instruction register or may order the transfer of data in either direction between the primary storage units and the secondary storage unit. The secondary computer program may also cause data to be transferred into the secondary storage unit from the primary instruction register and can also cause information to be transferred into the primary instruction register from a location in the main memory.

Using these facilities, the secondary computer can inspect each instruction word in the primary program as it is selected from the primary store and, acting upon specifications written into the secondary program, can cause the primary instruction either to be executed as written or to be replaced by a new instruction word from a memory location determined by the secondary. Other types of discrimination can be effected by the secondary that depend upon the result of a primary operation, such as an overflow, jump, etc. These features facilitate the use of interpretive programming methods.

Table 4 Contents of secondary instruction word

Digits numbered 1 through 16		
16....13	12....7	6....1
Operation code (0–15)	Address "g"	Address "h"

Input-output control

Concurrent input-output trunks. The concurrent input-output trunks have the function of controlling the transfer of information in either direction between the internal memory and the external storage units. All input-output transfers are initiated by a single internally programmed instruction, and are carried out by the trunk units with the aid of automatic interlocks similar to those used in the inter-memory transfer trunk for preventing interference with the progress of the computing program. The size of the block of data that is transferred may range from a single word to the entire contents of the memory and may be directed to any addresses. Using two such trunks, it is possible to maintain two continuous streams of data simultaneously flowing between the internal memory and any two external storage units without interrupting the progress of the computations.

Format controller. Data that are passing in and out of the internal storage system via the input-output trunks are subject to further concurrent processing by the format controller. The format controller is an independent internally-programmed data-processing unit specially designed for carrying out general-purpose editing, inspecting, and format-modifying operations on incoming or outgoing data. Programs for the format controller are stored on removable plugboards, and the primary computer program is able to direct the format controller to select whichever particular format program may be appropriate from among the small library of format programs contained on the boards currently attached to the machine. Among the typical kinds of programs that the format controller can carry out are: (1) searching of magnetic tapes for words bearing identifying addresses or other coded labels specified by the internal program, with selective input or output of data at these selected tape locations, (2) insertion of incoming data for the internal storage units of the system into address locations specified by the incoming data itself, (3) conversion and rearrangement of data that are stored on external units in formats not compatible with the formats used in the internal units; e.g., binary-decimal character conversion, adjustment of word-length modules, etc.

External storage

External storage in the initial installation of the system will consist mainly of magnetic tape units. Because of the flexibility of the format controller, it will be possible to supplement these tape units later with a wide variety of other types of external units without making any significant changes in the existing equipment.

Input-output units

The system is designed to operate with a wide variety of input-output devices, both digital and analog.

Input readers and printers. Flexowriter units and paper-tape readers and punches will be available in the initial installation. Punched card input readers and high-speed printers, along with their auxiliary controls, may be attached to the format controller in the manner indicated in the preceding paragraph.

Displays. Two types of displays are provided for: (1) pilot-light display of data and control information in the various registers and flip-flops throughout the system, in order to aid the rapid diagnosis of equipment malfunctions of programming faults, and (2) picture-tube display of real-time data stored in the internal memory of the system. This kinematic diagram type of display is very important when performing dynamic simulation operations which require visual presentation of the simulated data in real-time to the human operators.

External control

Manual-monitor control. The term "manual-monitor" was coined at NBS several years ago to describe certain types of control operations that are initiated either manually by the machine operator or by the machine itself under conditions which are specified by means of external switch settings. The former is referred to as a manual operation and the latter is called a monitor operation because the machine must monitor its internal program to determine precisely when the operation should be performed. The type of operation to be performed as well as the conditions under which it is to be performed are specified by means of external switch settings.

This feature provides for convenient communication between the data-processor and the operator, and allows the operator to monitor the progress of the program automatically, to insert new data and instructions, and to withdraw intermediate results conveniently, without need for advance preparation of special programs. This is particularly useful in debugging programs and in checking equipment malfunctions.

Monitor operations are performed by the machine whenever the conditions specified by the external switch settings occur in the course of the program; e.g., every time the program refers to a new instruction, any time the program refers to an instruction to which a special monitor breakpoint symbol (*e*-digits) is attached, any time an arithmetic overflow occurs, etc. By pairing a particular type of manual-monitor operation with a selected set of conditions, a variety of special composite operations can be performed.

Remote controls. Manual-monitor operations can be specified and initiated by external devices as well as by human operators. Since all of the external switch settings control only d-c voltages, the external devices can even be remote from the machine itself, and from a distance, via ordinary electrical transmission lines, they can exercise supervisory control over the internal program of the machine. This makes it possible to harness together two or more remotely located data-processing machines, and have them work together co-operatively on a common task. Each member of such an interconnected network of separate data processors is free at any time to initiate and dispatch special control orders to any of its partners in the system. As a consequence, the supervisory control over the common task may be shared among the various members of the system, and may be passed back and forth from one machine to the other as the need arises.

References

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