THE SCIENTIFIC COMPUTING NETWORK

THE CENTRAL LABORATORY

MEMORANDUM No. 1

CSIRO COMPUTING RESEARCH SECTION, OCTOBEI

THE SCIENTIFIC COMPUTING NETWORK:

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This is the first of a series of memoranda whose purpose is to inform potential users of the computing facilities that are becoming available.

1. Introduction.

Since the announcement on 19th June, 1963 that C.S.I.R.O. would let the main contract for the scientific computing network to Control Data Corporation, equipment to be installed has been determined. This memorandum deals only with the equipment and programming for the Control Data 3600 system to be installed at the Central Laboratory at Canberra. A smaller subsidiary computer will be placed in the same building and will be connected both directly, and via the peripheral units, to the 3600.

It is intended that the network be available for use by Universities, C.S.I.R.O. and Government Departments and Agencies involved in computations of a technical or 'scientific' type. So far as possible, the 'open shop' method of programming will be adopted although most of the actual operation of the equipment will, particularly at Canberra, be on a 'closed shop' basis. The staff of the Computing Research Section may be available for consultation. Data preparation services will be available for punched cards (IBM code) and 8-channel paper tape. In order to instruct intending users in programming it is expected that Control Data Corporation will, during the next few months, conduct suitable courses, for both the 3600 and subsidiary computers, in Canberra and at the various localities at which subsidiaries are to be placed. Subsequent courses will be provided as and when required by staff of the Section.

Documents on various aspects of the 3600 range of equipment will be made available in due course. At present such documents are in restricted supply. However, copies of the 3600 Preliminary Reference Manual have been, and later documents will be, supplied to the following C.S.I.R.O. libraries:

1. Chemical Research Laboratories, Melbourne.
2. National Standards Laboratories, Sydney.
3. Division of Mathematical Statistics, Adelaide.
4. Division of Plant Industry, Canberra.
5. Division of Tropical Pastures, Brisbane.
6. Regional Office, Perth.
7. Head Office, Melbourne.

Documents will in due course be supplied to prospective users outside C.S.I.R.O.

2. Features affecting choice of the Control Data 3600.

The Control Data 3600 was chosen for a number of technical reasons, among them being the following:

1. It possesses a fast execution rate comparable with the fastest of currently available computers.
2. It possesses a large expansion potential, by a factor of about 8 times in store and number of peripherals, up to 32 of the latter of which may operate simultaneously, so that the present configuration may later be expanded to accommodate larger programs by addition of equipment only.
3. Programs use the store economically. Most orders occupy only half a 48-bit word in store, thus allowing larger programs to be used than would be the case if orders always occupied a full word.
4. It possesses a comprehensive order code, not only for arithmetical operations, but also for data processing. It also possesses a word length giving a high precision.
5. It has comprehensive error checking features. Occurrence of a fault interrupts the sequence in a controlled manner.
6. It has a wide range of 'peripheral condition' interrupts such as are needed for true multiprogram operation, control of external devices and on-line communication.

3. Main equipment.

1. General Description.

The main equipment at Canberra will be a Control Data 3600 solid state, stored program, general purpose digital computing system, and some information about this system is given in the accompanying pamphlet, Attachment 1. A feature is that the system is composed of a number of separate modules, allowing considerable flexibility for future expansion of a basic system.

The computation module performs the arithmetical and logical operations required by the stored instructions, and also generates commands which initiate switching and counting actions of the communication module, which in turn acts as an access path between data channels and storage modules and the computer for input and output of data. The basic storage module consists of two independent units each containing 16,384 words (48 bits + 3 parity bits) which operate together during the execution of a program and are independently addressable. The system will initially include one such compound unit of 32,768 words, although it is capable of being expanded to a maximum of eight such units, a total of 262,144 words. During input or output the communication module sequentially examines the data channels for storage requests, increments storage addresses and performs parity operations. The data channels govern the input/output operations initiated by the computer,

and contain all controls and registers necessary to communicate between the external equipment and storage or the computer. Up to eight external equipments may be connected to each data channel, each of which may operate simultaneously on any one of the I/O units attached to each. The system will initially include one communication module and four data channels, but is capable of expansion to a maximum of four communication channels, each with up to eight data channels. The full degree of possible expansion is indicated in Attachment 1. A block diagram of the probable interconnections of the computer modules, the external equipments and the directly connected ("satellited") subsidiary computer is shown in Fig. 1.

2. 3600 Characteristics.

(a) Speed. The system has a high internal speed, effectively comparable with that of IBM "STRETCH" or of Ferranti "ATLAS". The store has a cycle time of 1.5 μ.sec. and an access time of 0.17 μ.sec. Average execution times for some typical instructions including access to instructions, are:-

Fixed point single precision, and logical operations		1-2 μ. sec.
" " " "	multiply	6 " "
Floating " " "	add/subtract	4.5 " "
" " " "	multiply	6.4 " "
" " " "	divide	13.0 " "
" " double "	add/subtract	5.6 " "
" " " "	multiply/divide	27.0 " "

(b) Precision. The storage word consists of 48 bits and the precision of arithmetical operations is as follows:-

Fixed point single precision - 15 decimal digits
Floating point " " - 11 decimal digits between 10^{-308} and 10^{+308}
Floating point double precision - 25 decimal digits between 10^{-308} and 10^{+308}

(c) Order Code. The storage space required for programs is used economically, most orders occupying only 24 bits, two being packed into a storage word. A few orders occupy 48 bits. There is a comprehensive vocabulary of over 100 instructions including single and double precision, fixed or floating point, normalized or unnormalized, rounded or unrounded arithmetic, and there are six indexing registers. Certain orders of unusual type are included, and are designed to enhance the operation of programs using closely compacted data. These include various searching operations (e.g. the equality search order searches a list of operands to find one that is equal to the current content of the accumulator), locate list element instruction (which will locate elements of a

list when the elements are scattered throughout the store), and variable data field operations (variable byte length operations, e.g. the bytes may be data characters).

(d) Interrupt system. A comprehensive automatic interrupt system provides for testing for a variety of conditions (internal or external) without having these tests in the main program. After executing each main program instruction, a test is made and, if the condition exists, an interrupt routine is initiated which takes the necessary action for the condition, and then jumps back to the main program. Three external interrupt conditions may be provided for each peripheral equipment, namely interrupt on read, on end of operation and on abnormal end of operation. Internal interrupts occur in case of various numerical conditions, overflow and parity failures, real time clock setting, 1604 mode, trace mode, bounds fault, illegal instruction and manual interrupt, all under programmed selection.

(e) 1604 Mode. The '1604 mode', which is part of the interrupt system, enables those few instructions whose codes are not identical in the 1604 and the 3600 to be "trapped" and executed by means of subroutines. This provision enables the 3600 system to simulate the operation of the earlier Control Data 1604 computer, and thus provides access to the bulk of the comprehensive 1604 program library. (See later for a further discussion of this.)

(f) Diagnostic features. A number of diagnostic aids provided by the SCOPE supervisory system (see section 6(a)) exploit certain interrupts, the bounds fault interrupt facilitates detection of illegal jumps to areas outside specified bounds, and the trace mode causes interrupt on jump instructions enabling jumps to be suitably listed for diagnosis. The central processing unit contains a real time clock which can be used for various auditing purposes, and also to limit the total time spent on one program.

4. Auxiliary Equipment.

1. Connected Peripherals.

A tentative schematic block diagram of the computer and peripheral interconnections accompanies this newsletter.

(a) Magnetic tape units. There will be ten Control Data Type 607 magnetic tape transports, any four of which may operate simultaneously. These units handle ½ inch tape using IBM seven channel format with variable record length. Three speeds are available, namely 800, 556 and 200 characters per

inch of tape corresponding to transfer rates of 120K, 83.4K and 30K characters per second respectively. The highest speed will be purely an internal mode, the other two speeds will enable tapes recorded on the Control Data Type 603 units (which will be used with the subsidiary computers) to be used with the 3600 system.

(b) Disc file. There will be a random access disc file store, of about 9 million words capacity, and an access time of the order of 200 milliseconds. It will be capable of variable block length transfers of data at speeds comparable to those obtained with magnetic tape units.

(c) Punched paper tape. The main input/output medium used by the Section will be one inch wide 8-channel punched paper tape. There will be three 110 character per second punches, two 1000 character per second readers and one 350 character per second reader, the slower reader and one of the punches being specifically associated with the satellite computer. The readers will also accept 5-channel (11/16") and 7-channel (7/8") paper tape.

(d) Punched cards. A Control Data Type 405 card reader which operates at 1200 cards per minute, and an IBM Type 523 card punch which operates at 250 cards per minute, will be available.

(e) Monitor typewriter. The console of the 3600 includes a character by character keyboard typewriter set for monitoring purposes; receiving directives from, and providing directives to the main operator.

(f) Line printers. Two line printers will be provided with speeds of up to 1000 lines per minute and up to 130 characters per line. An additional line printer will be specifically associated with the satellite computer, with a speed of between 150-600 lines per minute, depending on the character set used, and a line capacity up to 120 characters.

(g) Graph plotter. Two incremental graph plotters of the 'moving pen-moving paper' type will be provided, one with 30 inch wide paper and a speed of 300 plots per second. Another, with 12 inch wide paper and a similar speed, will be specifically associated with the satellite computer. Incremental precision of both will be 0.01 inch.

(h) High speed display. A double-tube cathode ray oscilloscope display unit will be provided for visual program control, to which photographic recording equipment may later be attached. It will be provided with its own internal storage device for con-

tinuous display for visual purposes without occupying computer time for continuous replenishment.

(i) Satellite. The local subsidiary computer will be connected directly to the 3600 via a 'coupler' unit, and will have access to all the peripheral I/O devices otherwise connected to the 3600 without having to pass through it.

2. Data Preparation Equipment.

Off-line data preparation equipment will allow for preparation on two media, 1 inch wide, 8-channel paper tape and 80-column punched cards, and will include:-

(a) Punched Cards

(i) Three keyboard duplicating and printing card punches.

(ii) Three punch card keyboard verifiers.

(iii) One card sorter, 1000 cards per minute.

(b) Paper Tape

Eight punched paper tape units, each comprising reader, punch, keyboard and type mechanism. Some of these units can be fitted with an extra reader and/or punch, and all will operate at 10 characters per second (if typing), and at 30 characters per second (if copying only). A comprehensive set of 89 characters will be provided (see Section 5).

(c) Chart Converter

In addition, an instrument for conversion of data recorded on graphs, charts or film frames to paper tape will probably be provided.

5. Character and Code Sets.

The character and code sets for punched cards will be the standard FORTRAN set used by IBM. Tentatively, in the case of paper tape, it is expected that a set of 89 characters will be adopted which, together with composite characters which may be constructed from this set, will cover the standard ALGOL 60 set as well as the standard FORTRAN set. The codes will be distributed so as to form a reasonably collatable set without extensive internal rearrangement of code. It will not be the standard Control Data tape code.

Character sets for the line printers are expected to constitute a distinguishable subset of the paper tape character set so that FORTRAN and ALGOL listings will be readily possible.

Final details of the codes and character sets will be a subject for a later memorandum.

6. The Programming and Operating System.

It is expected that the programming system available with the 3600 will allow it to accept programs from punched cards and 8-channel paper tape recorded in COMPASS, FORTRAN 63, or COBOL 61, and all processing of program translation and program running will be subject to control by a supervising routine.

(a) SCOPE

This is the supervisory system provided with the 3600 (Supervisory Control Of Program Execution) and it will be responsible for:

1. allocation and control of all peripheral equipment;
2. handling assembly and translation of all programs provided in COMPASS, FORTRAN 63, and COBOL 61;
3. dealing with coding and decoding of the data it passes to and from the peripherals;
4. scheduling and control of serial processing of runs;
5. communication with the operator by printing on and receiving directives from, the console typewriter;
6. dealing with unusual situations including system faults;
7. providing debugging aids using the 'trace' mode of operation together with dump and recovery procedures.

It will allow programs written for a 1604 to be operated on the 3600 by calling the '1604 mode' of operation into use.

At first SCOPE will handle a serial flow of programs through the 3600 system. It is expected that in due course it will be extended to allow for truly multiprogram operation and to accept for treatment programs in a number of additional source languages, e.g. ALGOL.

(b) FORTRAN 63

FORTRAN 63 is an improved form of the well known FORTRAN system designed especially for use as a programming tool for scientific types of computation. With this version which permits extension, it is now possible to perform detailed operations on strings and characters which were not readily possible before.

Its main features are as follows:-

1. Provision is made for an increased variety of types of data, namely,

(i) 'Integers', consisting of 48-bit binary numbers with a precision up to an equivalent of 15 decimal digits.

(ii) 'Real' numbers in floating point form, consisting of a fractional 37 bits including sign, and 11 bits of binary exponent including sign, giving an equivalent precision of about 11 decimal digits and magnitude variation between 10^{-308} and 10^{+308}.

(iii) 'Double-length' numbers in floating point form, consisting of a fractional 85 bits including sign, and an exponent of 11 bits as in case (ii). This gives a precision of about 25 decimal digits.

(iv) 'Complex' numbers, held in store as adjacent pairs in floating point form as for (ii) above. Operations on quantities of this type follow the arithmetical rules of complex numbers.

(v) 'Logical' quantities which can be only either TRUE or FALSE corresponding respectively to unity or zero.

Up to three additional modes of representing data, and operations on them, may be specified by the user either in FORTRAN or in the assembly language COMPASS. A typical additional type could, for instance, be the type 'CHARACTER' meaning strings of arbitrary length of 6-bit characters which may be defined to be operated upon in various ways, e.g. sorting substitution or removal of character groups and so on.

2. Undeclared variables are assumed to be of type 'real' unless, as usual with previous Fortran editions, the initial letters of their names are any one of I, J, K, L, M, or N.

3. Expressions may contain quantities of differing types, but the type of the variable computed will be that of the variable of highest order appearing in the expression, the order in ascending precedence being:

(i) integer
(ii) real
(iii) double
(iv) complex.

It is also possible in some cases to mix logical and arithmetical quantities.

4. Logical or relational statements may contain arithmetical and logical quantities but are distinguished from purely arithmetical statements by use of operator symbols consisting of mnemonic letter groups delimited on either side by a 'point' such as .EQ. for 'equal to', .LT. for 'less than' and so on. In cases of relational statements involving arithmetical expressions the arithmetical functions are always carried out first at run time.

5. A comprehensive set of input and output and format statements are allowed for control of peripheral equipments together with statements which can be used for the control of a program when parity faults occur and when working registers overflow.

6. A comprehensive set of functional routines is made available for inclusion into any FORTRAN program and may be called for use in the usual way by naming the routine in the statements which require them.

7. In certain cases some variables may be allotted parametric values chosen by the user and provided with the program, thus avoiding unnecessary input operations at run time.

8. Also, certain logical operations may be used in conjunction with integer and real values for 'masking' so that words may be treated as arbitrary byte strings for isolation, insertion of bytes within strings and for other similar manipulation.

(c) COMPASS

COMPASS (Comprehensive Program Assembler) is a machine-oriented language by means of which any basic function of the 3600 may be called into use. There are in general four parts to each COMPASS code word which usually corresponds to a single machine order after assembly. The four components consist of a 'label' name identifying the current point in the program, a mnemonic alphabetic group of 3 or 4 letters identifying the required operation, a numeric modifier group and a name representing the operand. Comments may follow each code word. Normally each order occupies half of a storage word and is 24-bits long, although some orders occupy a full storage word of 48 bits. In some cases a COMPASS code word may cause compilation of a number of orders placed consecutively in store.

There is, however, no need for the programmer to be concerned with the details of the magnitude of the assembled orders or where they are placed in store since COMPASS is completely 'relocatable' and is assembled in any part of the store as needed.

All variables are named, constants are written as literal quantities either decimal integers, decimal floating point numbers, octal integers or strings of 6-bit characters. All are written in their proper context. Entry points are identified by name and are called by name in COMPASS statements which control the course of the program.

Arrays of up to three dimensions may be included and, if necessary, various variables may occupy the same storage area at different times during a run.

COMPASS also provides facilities by which a program may be readily changed, e.g. for correction of logical errors and for 'patching in' additional statements.

(d) COBOL

COBOL is a programming language sponsored by the U.S. Department of Defense and accepted for implementation by a relatively large number of manufacturers, among them, Control Data Corporation. It is specifically intended for use by administrative organizations and is designed mainly for the manipulation of files of data, especially large files held on magnetic tape. In this regard it may well be used for 'scientific' data processing when file operations, e.g. extracting and inserting items, are involved.

In line with its intention to serve office functions, programs are expressed in an English narrative form, although simple formulae and named function routines may be used. Also, the defining committee (CODASYL) attempted to restrict aspects of programs which depend upon the detailed properties of the equipment upon which the programs are to be run, to as small an area as possible and to make the language implementable by many manufacturers so that, with little or no change, a program may be run on any of a possible number of different machines.

These requirements led to division of programs into four main parts:

1. 'Identification Division', consisting simply of naming the program, and is not dependent upon the computer on which the program is to be run;
2. 'Environment Division', in which is stated the features of the machine which is to run the program, and is entirely computer dependent;
3. 'Data Division', in which all input and output data and files are described, and is partly dependent upon the computer to run the program. It corresponds to many of the declarations distributed through a FORTRAN program;
4. 'Procedure Division', in which the processes to be carried out are specified, and is independent of the computer to run the program.

7. User's Organization - CO-OP.

CO-OP is an organization of users of large-scale Control Data equipment. It is intended as a vehicle for co-ordinating interchange of useful information on programming, equipment, techniques and procedures and

as a medium for communication between users and the manufacturer for recommendations concerning equipment modifications and standardization. C.S.I.R.O. has already applied for membership of CO-OP which currently has a membership of 51 organizations.

Benefits to all users of the computing network will be the availability of a large number of functional routines, programs, debugging routines and translating, scheduling and monitoring systems. Although the 3600 system is a newcomer to the computing market many routines and programs are already available. These arise from the past programming activities by users of machines of the Control Data 1604 type since the 3600 can accept and run them, at slight loss in speed, using the '1604 mode' of operation.

The CO-OP library, currently consisting of about 330 items of varying size, will be particularly useful to users of the network since Control Data have specialized in equipment for scientific computation which many large scientific research laboratories are operating.

The network will continue to benefit as more programs and routines are added and others become directed specifically to the 3600. It is hoped that, in due course, users of the network will contribute to the CO-OP library.

8. Building.

A special building to house both equipment and staff at Canberra is now being erected close to the existing C.S.I.R.O. area on Black Mountain, and it is expected to be occupied by April 1964. The 3600 equipment will be installed during June 1964.

The building will consist of two blocks, each of a single floor, placed on different levels and at rightangles to each other as will be seen from Fig. 2. The lower level block will be devoted almost entirely to equipment, power supply, and air conditioning. Air will be supplied via a false floor plenum although there will be no break in the floor level when entering the machine area. Heat removed by air conditioning will be about 300,000 BTU's per hour. The total equipment area, including that for data preparation, will be 3843 sq. ft.

The upper level will be devoted to offices for staff and visitors and will contain a lecture room, of 1320 sq. ft., for programming courses and symposia. The total office area, mostly on the upper floor, will be 4988 sq. ft., and a library of 650 sq. ft. and staff amenities of 500 sq. ft. will be included below. Fig. 3 shows the detailed plan.

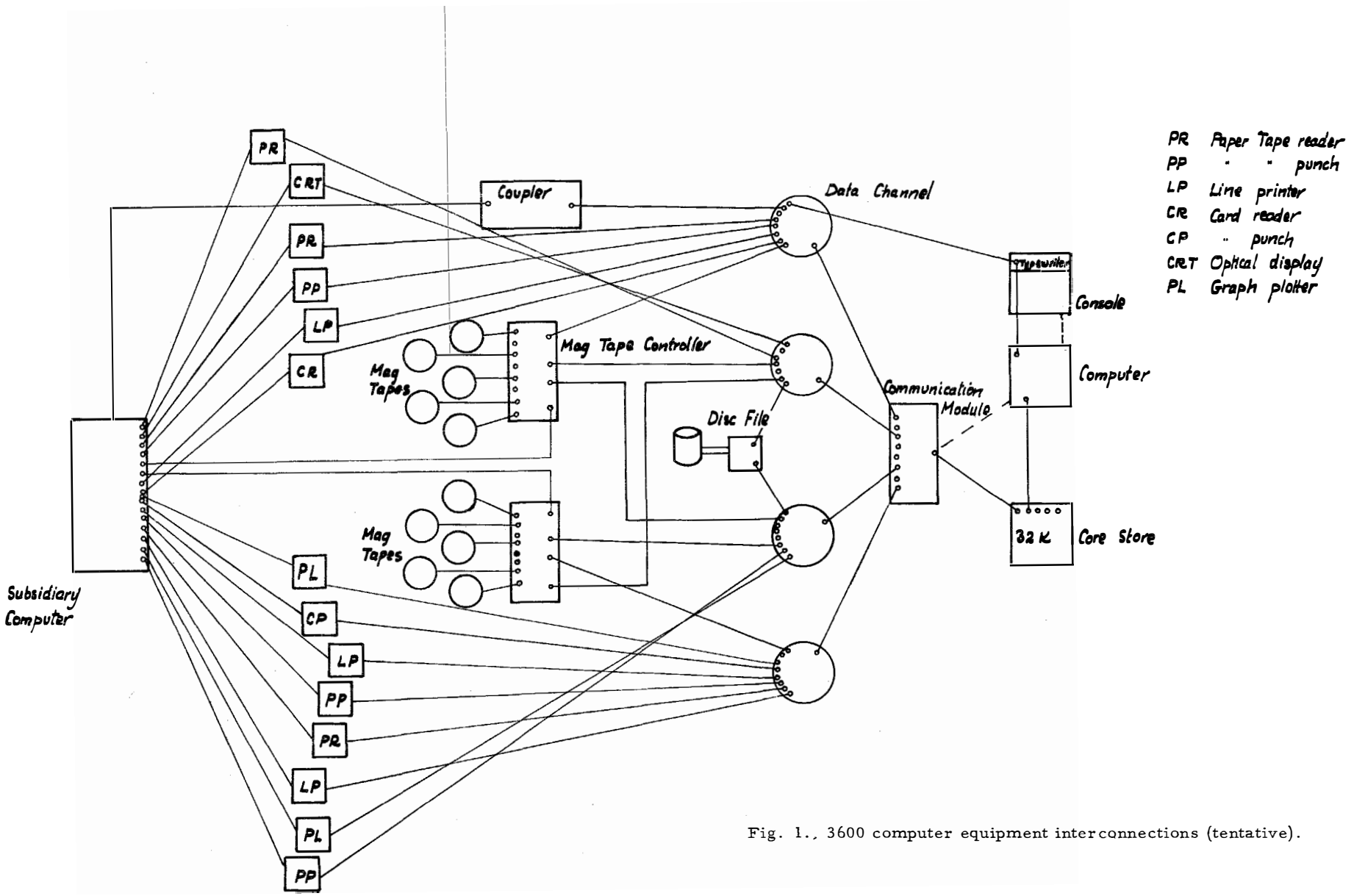


Fig. 1., 3600 computer equipment interconnections (tentative).

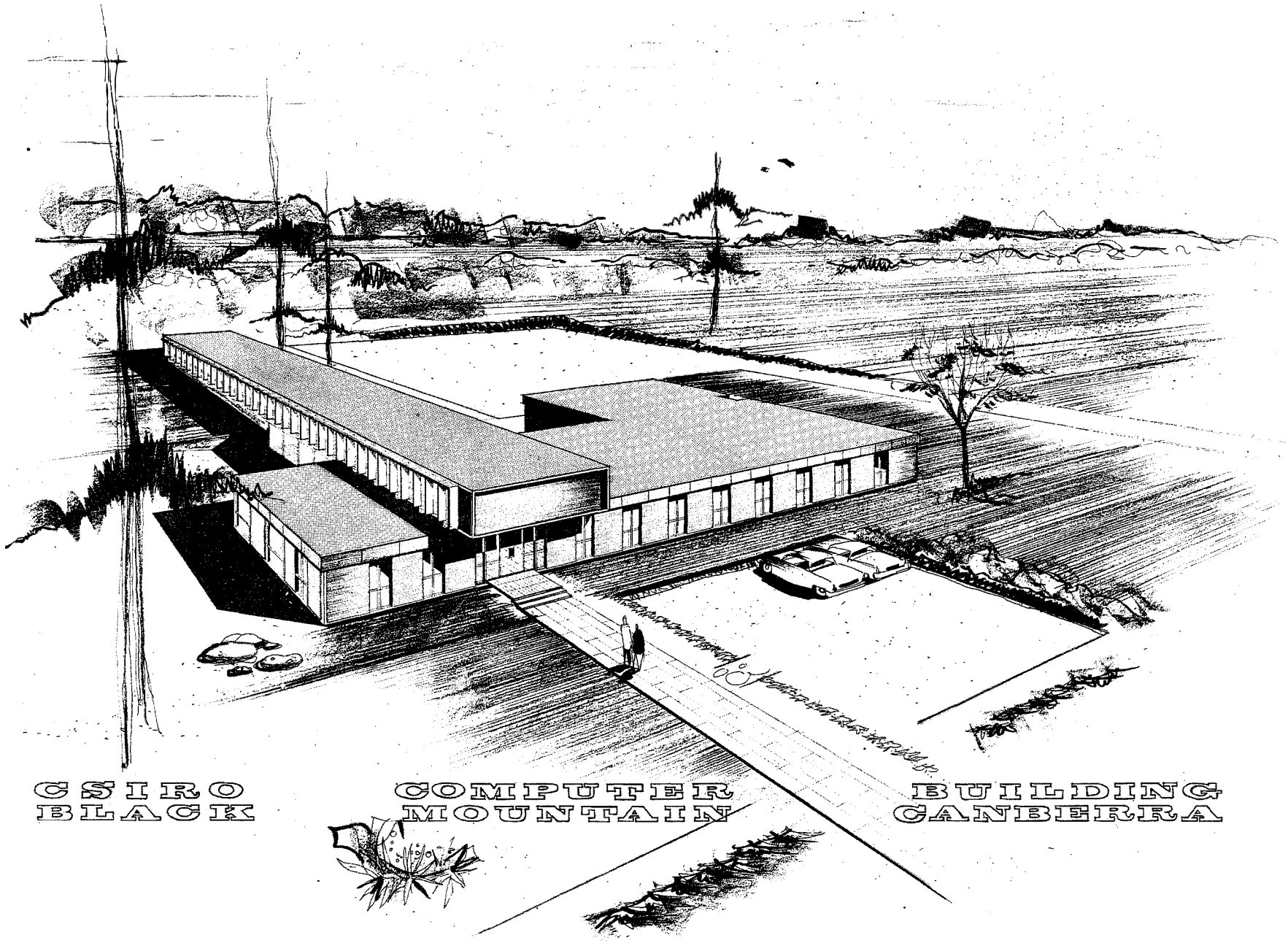


Fig. 2.

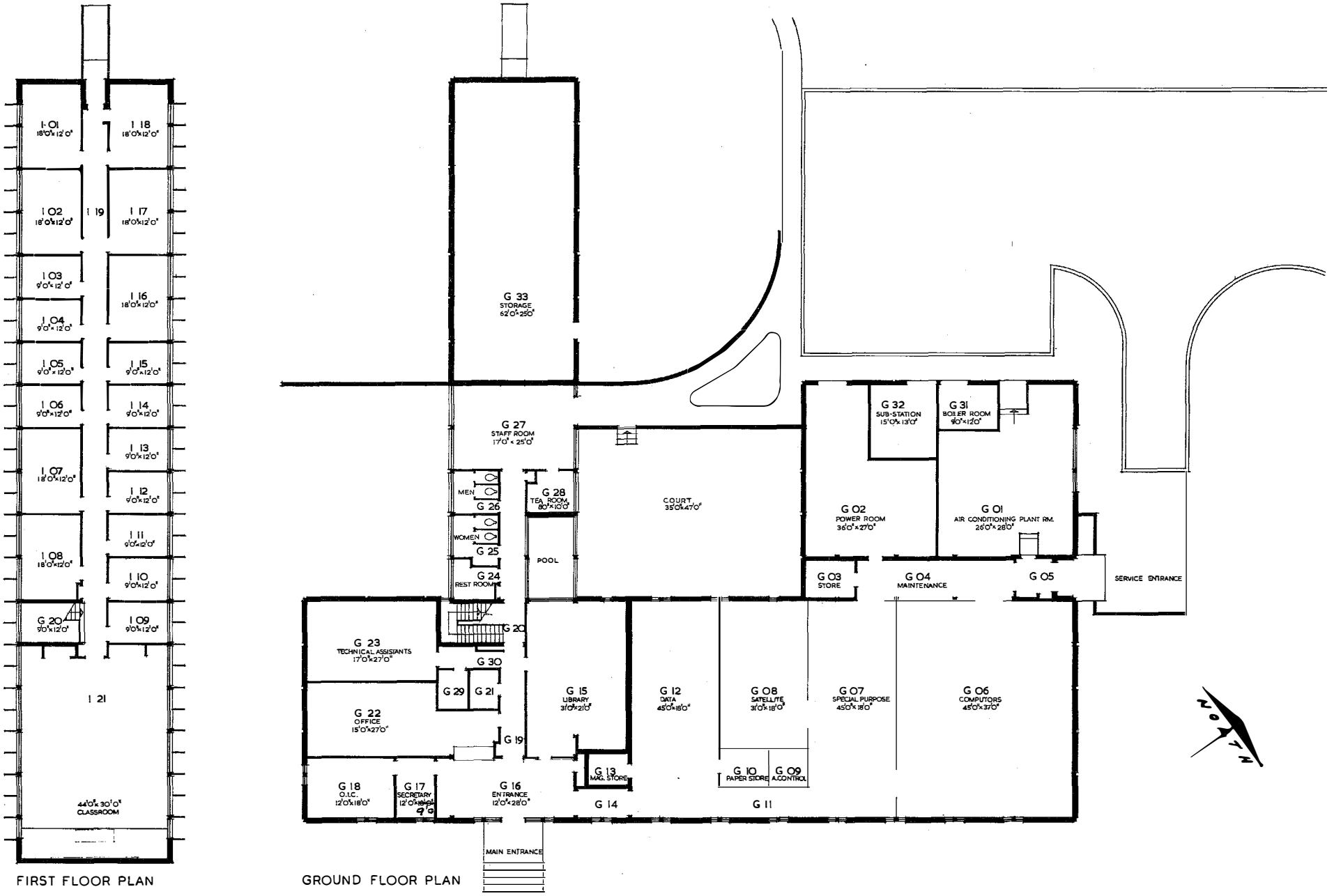
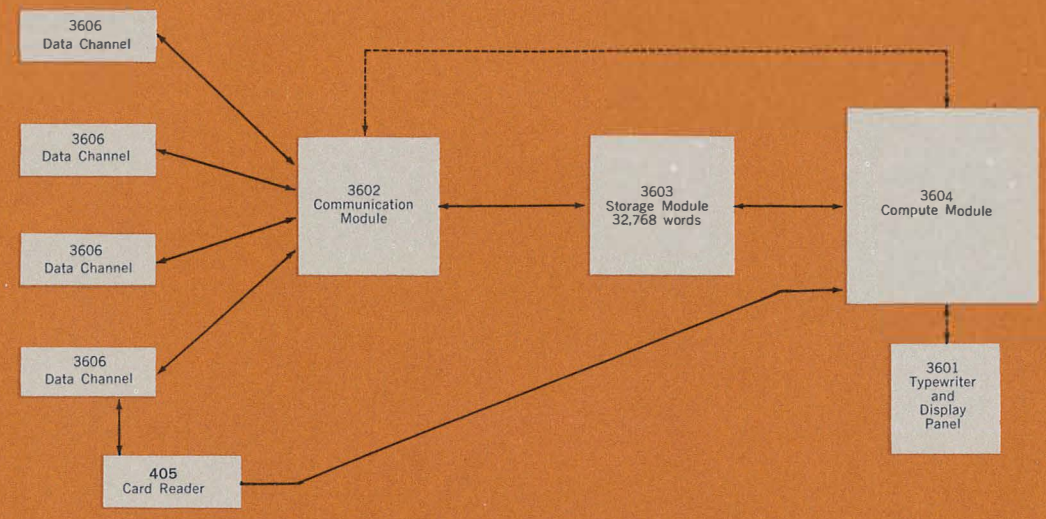


Fig. 3. Plan of CSIRO Computer Building, Black Mountain, Canberra.



CONTROL DATA® 3600 COMPUTER SYSTEM

INTRODUCTION

The **Control Data** 3600 is the latest addition to the line of advanced large-scale computers offered by Control Data Corporation. Again, Control Data is the first in the industry to offer a computer with the superior inherent speed, capacity, computing power, and machine characteristics of the 3600 at a price substantially less than other computers approaching the capabilities of the 3600 Computer.

The basic 3600 Computer is large by any industry standards. However, its modular design enables the user easily to add functional modules tailored to satisfy specific increased computing and data processing requirements as they arise.

3600 COMPUTER CHARACTERISTICS

Exceptionally suited for handling large-volume data processing and for solving large-scale scientific problems at very high speeds, the **Control Data** 3600 has the following machine characteristics:

- 48-bit word length plus 3 bits for parity checking.
- Storage Module of 32,768 48-bit words – expansible in 32,768-word modules up to 262,144 48-bit words:
  1.5 microseconds – memory cycle time
  .7 microseconds – access time
- Communication Module with 4 bi-directional data channels – expansible up to 8 bi-directional data channels. (Up to 8 control and/or peripheral devices can be attached to each bi-directional data channel.)
- Up to 3 additional Communication Modules may be added, with from 1 to 8 bi-directional data channels each.
- Execution times, including access:
  4 microseconds – Floating Point Add
  6 microseconds – Floating Point Multiply
  13 microseconds – Floating Point Divide
  27 microseconds – Double Precision Floating Point Multiply
- Code compatible with the **Control Data** 1604 Computer except for three 1604 I/O instructions.
- Byte-scan operation in which: 1) data of variable length within a word can be operated on by one operation or 2) high-speed scanning can be performed on computer storage in byte-size pieces.
- Special computing functions easily added to system via special channel in the Compute Module, e.g., trigonometric and exponential functions, etc.
- Double precision floating point commands – with mantissa of 84 bits plus sign.
- Results of all arithmetic operations normalized or un-normalized, rounded or unrounded . . . at programmer's option.
- Inter-register instructions.
- Two-way search instructions.
- Data transmission control performed by high-speed registers located in Communication Module – permitting I/O activity to proceed *independent and asynchronous* of main computer program.
- Universal bit-sensing instructions.
- Shifting time constant – regardless of number of positions shifted.
- Sophisticated interrupt capability.
- Auto-load button for selectable peripheral equipment.
- Direct typewriter entry into Arithmetic Register.
- Parity check on all I/O data transmission.
- Registers for memory lockout – under program control.
- Various special, high-speed circuits operating at 4 nanoseconds.

BASIC 3600 COMPUTER

Characteristic of the 3600 is the high degree of modularity achieved in this large-scale computer. Smooth expansion of the basic system is effected by the addition of functional modules. These can be added without the necessity of installing specialized interconnecting black boxes.

The basic 3600 Computer consists of three functional modules, as follows:

1) High-Speed **3602 Communication Module** – equipped with 4 bi-directional 3606 Data Channels.
2) High-Speed **3603 Storage Module** – with 32,768 48-bit words, each with an additional 3 parity bits.
3) High-Speed **3604 Compute Module.**

Also included with the basic computer is the 3601 Console. The console contains an electric typewriter which, when used as an input device, has direct access to the accumulator. Used as an output device, its data is buffered through the Communication Module. Also included with the basic 3600 Computer is a 250 card per minute reader which has direct access to the accumulator. Figure 1 shows a diagram of the basic 3600 Computer.

3604 COMPUTE MODULE

Functioning as the heart of the 3600 Computer, the 3604 Compute Module performs all the computing and logical operations. In addition, it contains the control for *initiating* I/O operations. Having direct access to the core storage module(s), the 3604 operates in the parallel binary mode.

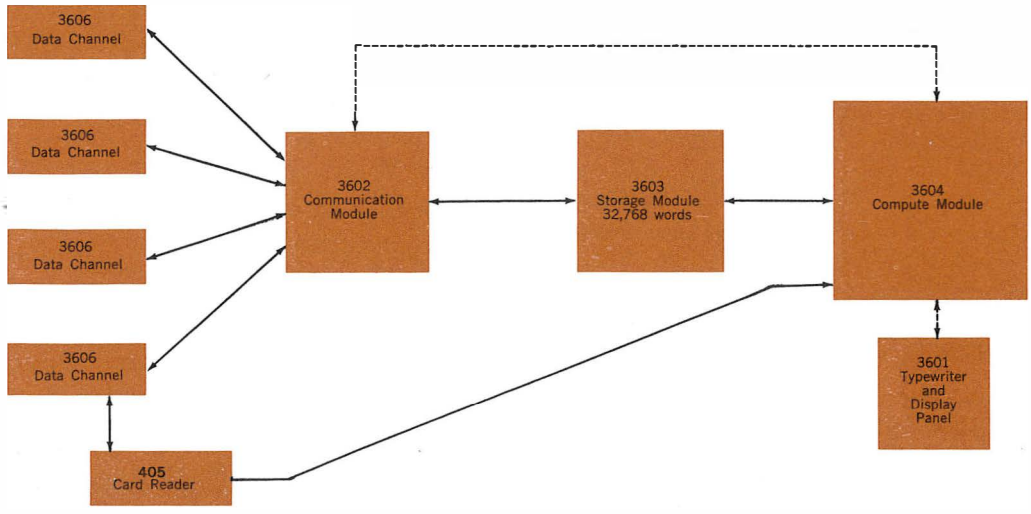


Fig. 1. Basic **Control Data** 3600 Computer.

Fixed point operations are performed modulus 2^{48}-1. Floating point operations are performed in either single or double precision. Single precision coefficient is 36 bits plus sign, double precision is 84 bits plus sign. A 10-bit plus sign exponent is used in both single and double precision operations.

The 3604 instruction repertoire consists of both half-word and full-word instructions. A sub-set of half-word instructions is identical to the **Control Data** 1604 Computer instruction repertoire, except for three I/O instructions in the 1604.

Several new categories of instructions have been included in the 3600 instruction repertoire, as follows:

- Commands which facilitate manipulating portions of a data word. For example, bytes of 48 bits or less may be transmitted to any portion of a register or storage word in a single operation. Provision is made for indexing through bytes in a word (horizontally) and through a list of such words (vertically) in the same operation.
- Double precision floating point commands include add, subtract, multiply, divide, fetch, and store. A 10-bit plus sign exponent is used with an 84-bit plus sign fraction.
- Two-address transmissive and repeated transmissive instructions are included with provision for any size address increment to be used in the repeated operations—independent of the number of words in the list.
- A special instruction for list processing, as well as several new indexing operations.
- A universal bit-sensing instruction which permits any bit in any register to be tested and branched upon. In addition, the bit sensed may then be complemented, set, cleared, or left unchanged.
- A powerful, extremely fast interrupt facility is provided, as well as instructions for processing interrupts.
- Indexing instructions which may, under program option, be performed in either one's or two's complement arithmetic.
- Six sense switches are included on the console and can be program sensed. These are in addition to three selective jump and three selective stop switches.
- A 48-bit sense-light register is included. Each position in the register may be set or cleared under program or manual control. Provision is made for sensing the status of each position and branching upon the condition of its complement.
- Two *bounds registers* of 18 bits each, used for memory lockout. Information is not written outside of the region of the core storage specified by the addresses contained within the *bounds registers*.

The 3604 Compute Module employs special circuitry to speed up the basic arithmetic processes. Thus, the basic cycle time of the adder network is 250 nanoseconds. The shift time is a constant 250 nanoseconds regardless of the number of places shifted. These times do not include storage references. Typical average execution times including storage reference are listed in the following table:

Instructions	Fixed Point	Single Precision Floating Point	Double Precision Floating Point
Multiply	7	6	27
Divide	15	13	27
Fetch/Store	2	2	4
Add/Subtract	2	4	6

Table 1. Typical Average Execution Times (in microseconds)

3603 STORAGE MODULE

The 3603 Storage Module provides high-speed, random access magnetic core storage of 32,768 48-bit words. A storage word may be two 24-bit instructions, a single 48-bit instruction, a 48-bit data word, or half of a 96-bit data word. Three parity bits are generated for each storage word; thus, a storage word is 51 bits in length.

The parity bits are generated each time a word is read from or written into storage. One of the three parity bits is assigned to each of the 15-bit addresses; the third parity bit is assigned to the remainder of the word.

Each 3603 contains two independent storage banks of 16,384 words. Within each such bank, storage addresses are consecutive, permitting the 3603 storage module to be treated as two independent storage units.

The storage cycle time of each 16,384 word sub-module is 1.5 microseconds, and is totally independent of other sub-modules.

3602 COMMUNICATION MODULE

Input-output operations are initiated by the compute module and controlled by the 3602 Communication Module. The basic 3602 contains a storage access control section, an arithmetic and control section, and four bi-directional data channels. Up to 8 bi-directional I/O data channels can be attached to this 3602. (From one to eight data channels may be attached to additional 3602's, at the user's option.)

Input-output operations may occur independently and asynchronously with operations in the compute module. Input or output data is transmitted to or from storage directly, and *does not pass through the compute module.*

The arithmetic and control portion of the 3602 supervises all I/O functions once operating conditions have been initiated. The compute module directs the selection of a specific external equipment and the channel in which I/O activity is to take place, as follows: A 48-bit control word is read from storage and entered into a 48-bit control register. The control word specifies a starting address, i.e., the storage address from which the first output word will be read . . . or where the first input word will be stored – along with a 15-bit word count. Once these initial operating conditions have been generated, the channel control supervises all I/O activity.

Each data channel is bi-directional, i.e., it may be used for both input and output communication. Each 48-bit data word is transmitted in 12-bit bytes and is assembled/disassembled in a 48-bit assembly/disassembly register. Assembly/disassembly time is less than one storage cycle, thus permitting the storage module to be used at its maximum rate and allowing full utilization of a parity bit for each 12-bit byte transmitted.

Peripheral equipment in the 3600 System operates on 12-bit data, as disassembled from the 48-bit data word. The use of 12 rather than 48 bits as the peripheral equipment common language results in reduced cabling and hardware while maintaining maximum data transfer rates. For special applications, other data channels may be attached to the 3602 Communication Module.

Upon completion of the assembly/disassembly of the 48-bit word, it is transmitted to the appropriate storage module via the access control section. The parity bits accompanying the output transmission are checked by the external equipment; parity bits accompanying input transmissions are checked by the 3602.

3600 COMPUTER EXPANSIBILITY

The basic 3600 Computer can be smoothly expanded to include up to eight 3603 Storage Modules, each with a capacity of 32,768 48-bit words, with each word having 3 additional parity bits. The fully expanded 3600 Computer is shown in Fig. 2.

If a 3600 employs more than one storage module, its compute module references each storage module in either one of two ways, or a combination thereof, as follows:

1) One type of instruction where the full 18-bit address is specified and/or
2) By means of two 3-bit bank address registers:
   a) an operand bank register
   b) a program address bank register

These two registers are *directly addressable* by the main computer program and can be changed at will.

All 24-bit instructions implicitly refer to these two registers; all other instructions explicitly contain an operand bank address together with one bit . . . indicating whether the implicit operand register address or the explicit instruction operand address is to be used in the instruction.

The stored program may thus be located in one storage module, while the operands, i.e., data, constants, etc., may be located in a different storage module – thus, significantly increasing the speed of the 3600 Computer.

Any of the four possible 3602 Communication Modules can *directly reference* any of the eight possible storage modules . . . once I/O operations have been initiated by the 3604 Compute Module.

For example, the 3604 Compute Module may use storage module #3 for operands and storage module #2 for stored programs. At the same time, communication module #1 may be transmitting data to storage module #5. Concurrently and asynchronously, communication module #2 may be transmitting data to storage module #4. And while communication module #3 is transmitting data to storage module #6, communication module #4 can be transmitting data to storage module #7.

Thus, six storage modules may be operating simultaneously and asynchronously at peak rates.

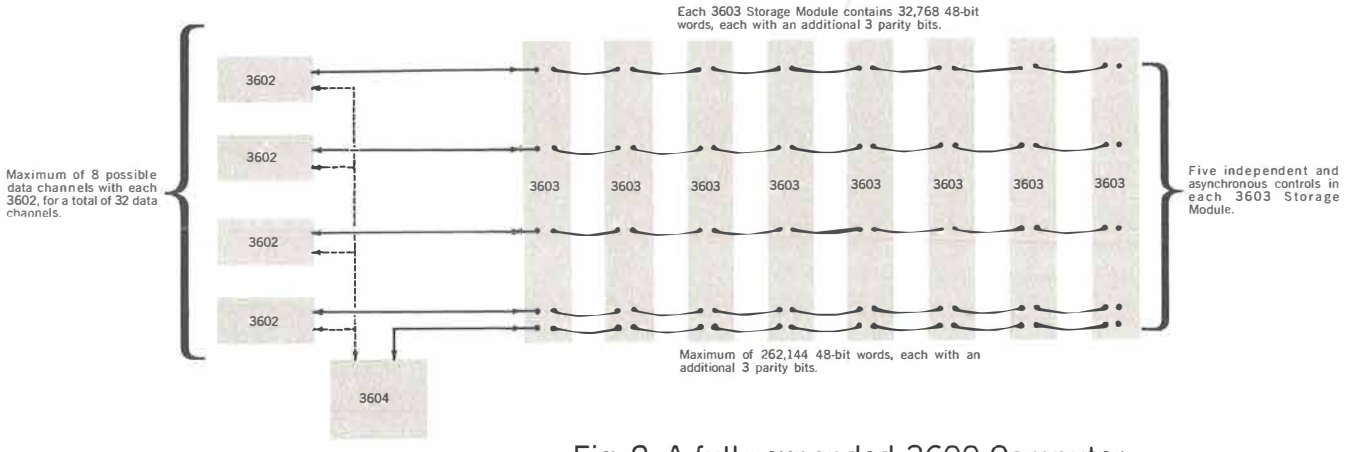


Fig. 2. A fully expanded 3600 Computer.

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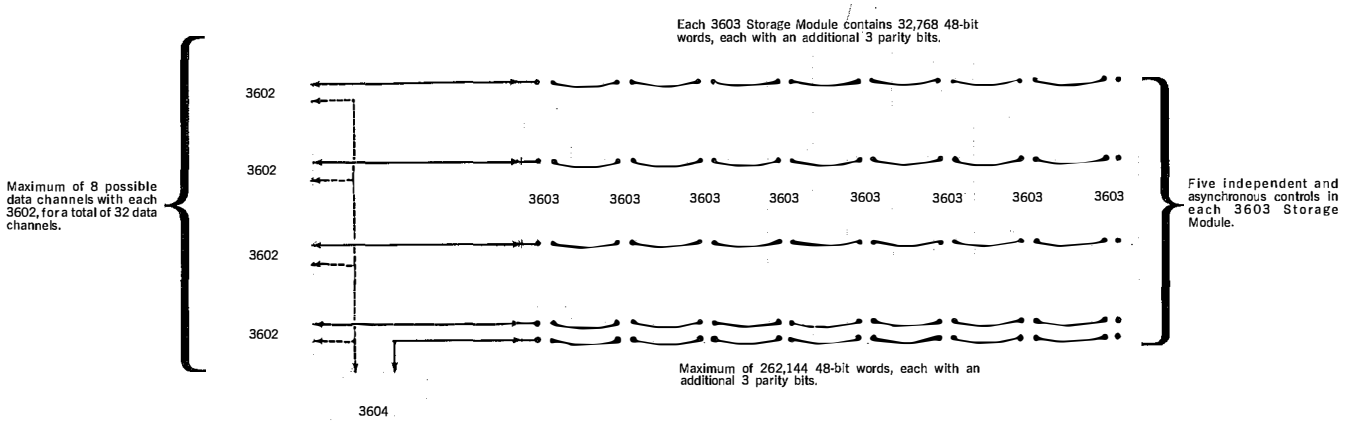

Fig. 2. A fully expanded 3600 Computer.

MULTIPLE 3600 COMPUTER SYSTEM

The 3600 is designed to permit multiple computer installations without need for special adaptors. All interconnecting of various modules between systems is via standard cables, and requires no special treatment. Two typical types of multiple computer installations are described to illustrate the flexibility of the 3600 System. Many other systems are possible.

In one mode, the compute module of each 3600 Computer can address eight storage modules. In a common system, the compute modules of each 3600 would address a fixed number of storage modules which the remaining compute modules could not address. In other words, the eight addressable storage modules are considered an integral part of each 3600 Computer in the common system.

However, each compute module in the common system can address a common pool of storage modules. The total number of storage modules in this common pool, and the number of modules connected to a given 3600 Computer, cannot exceed eight. Five such 3600 Computers can address this common pool of storage modules independently and asynchronously.

In the second operating mode, each 3602 Communication Module may contain up to eight 3606 bi-directional data channels. Each of these eight channels has provision for communication directly with identical channels in other 3600 Computers in the common system.

These 12-bit data channels exchange control and computer-identity information. They also permit one 3600 Computer to interrupt any other 3600 in the common system . . . under program option.

Should they occur, machine malfunctions, e.g., a parity error, are instantly transmitted via these 12-bit channels to any other 3600 Computer in the common system.

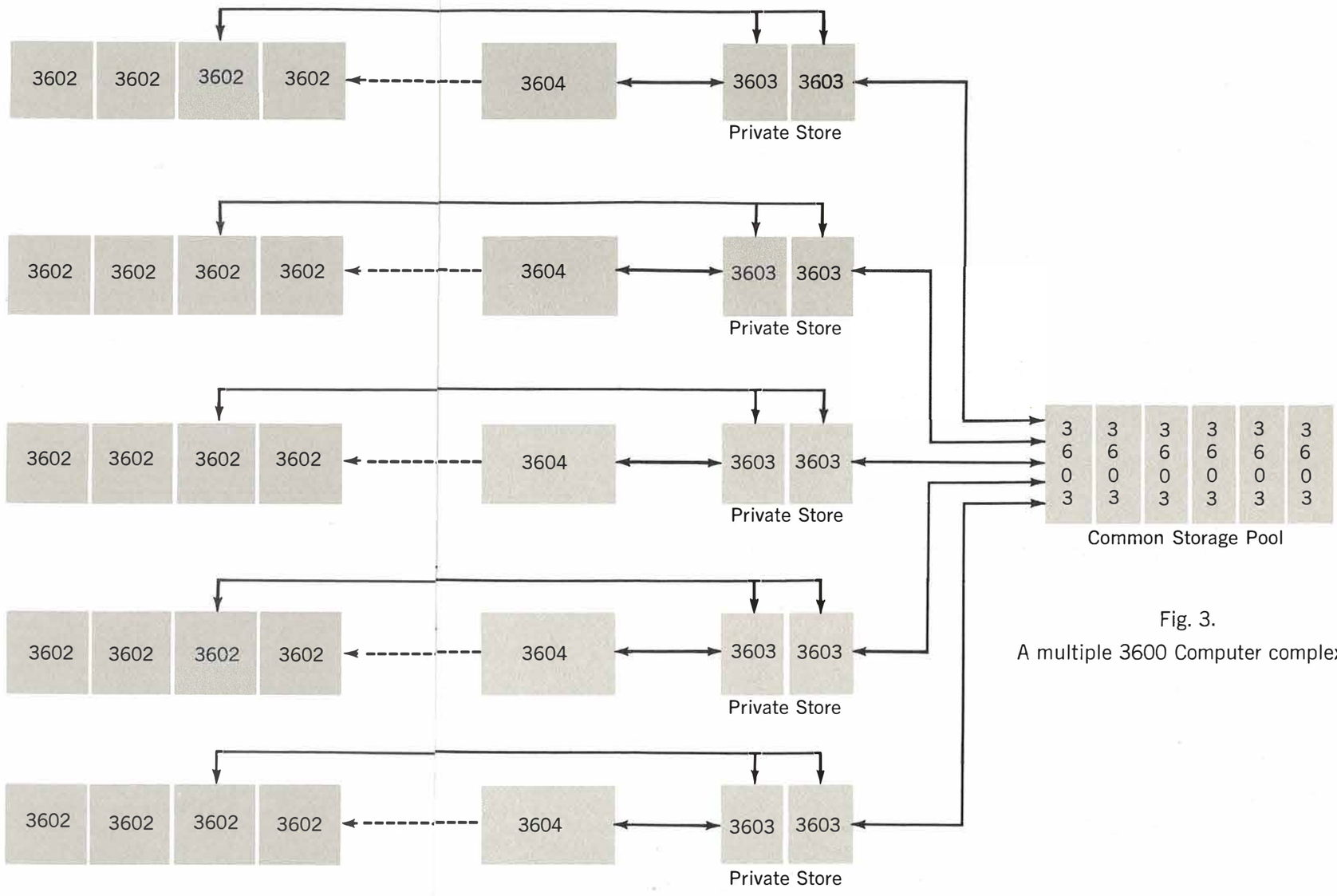

Fig. 3.
A multiple 3600 Computer complex.

3600 COMPUTER SOFTWARE

The 3600 Computer software system will be oriented around a Master Control System (MCS). The MCS will act as a common communication link among all programming systems and I/O devices, interrupt, and memory allocation functions. Thus, the MCS will allow programming systems to be independent of particular machine configurations . . . as well as of types and numbers of I/O media. In addition, the MCS will provide the following:

- A library common to all systems such as FORTRAN and COBOL which will operate within the MCS.
- An open-ended ability to incorporate new compilers and operating systems as they are developed.
- A linking loader that will permit joining together in one program several sub-programs that may have been separately and independently compiled or assembled.
- A system easy to modify and adapt when necessary to the needs peculiar to a given installation.

Some of the important programming systems operating under control of the MCS will be:

MONITOR SYSTEM: a complete operations supervisory system for automatic control of all jobs. It will allow stacking of jobs with arbitrary intermixing of different job types, such as assembly, compilation, and execution.

COMPASS: a comprehensive assembly system with versatile language features for representing the extensive instruction repertoire in a simple symbolic notation, employing advanced assembly techniques.

FORTRAN: an algebraic compiler with extensions to, and generalizations of, the basic Fortran language using advanced compiler techniques for producing optimum object programs.

COBOL: a complete compiling system for business-oriented applications.

1604 COMPATIBILITY PACKAGE: a software package which will execute interpretively all trapped I/O instructions of a 1604 program running in the 1604 compatibility mode.

3600 COMPUTER CIRCUITRY

The 3600 Computer circuits have been under development at Control Data for over two years. They are the result of extensive development efforts expended in producing the **Control Data** 3600 Computer. These circuits have received the benefits of many refinements made in evaluating the most reliable commercially available components.

The basic building block is a bi-level amplifier-inverter which operates at an equivalent phase rate of 16 megacycles. Several levels of logic can be performed in one phase time of 62.5 nanoseconds. In addition, various special high-speed circuits employing tunnel diodes are used (4 nanoseconds per stage).

Printed-circuit cards similar to those found in the 1604 Computer are used in the 3600. The dimensions have been changed slightly, and the component packing density has been increased. The voltage levels are -5.5 volts and -1.5 volts. All cards are pluggable and have eyelet test points for attaching oscilloscopes.

3600 PERIPHERAL EQUIPMENT

A variety of optional on/off-line peripheral items may be used with the 3600 Computer. These include 12-, 24-, and 48-bit bi-directional data channels; special function generators; magnetic tape handlers and tape synchronizers; medium- and high-speed card readers; card punches; low- and high-speed line printers; paper tape I/O equipment; keyboard entry devices and typewriters; and disc files.

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