

Computing at CERN

A review of the past, present and future of computing at CERN concentrating on the large central computers which bear the brunt of CERN's workload.

Inside the computer room where the CDC 6600 has served as CERN's main computer. To the left and in the background are magnetic tape units. In the foreground is the console where the operators are in communication with the computer's operating system. On the displays they can see which programs are running at that time and also the various stage which the programs going through the computer have reached.

D. Ball

The Past

Computing at CERN started in the Autumn of 1958 with the installation of a Ferranti Mercury, which was, for its time, a modern and powerful European-built computer. It was bought to provide data-handling facilities for CERN's physics programme. Its installation taught CERN that computers are a mixed blessing, requiring a staff of experts to nurse them along particularly during their first year or so of life, but, despite the problems, physicists quickly became addicted to computing and could not get enough.

The increase in workload from bubble chamber and electronics experiments at the proton synchrotron early in 1960, meant that the Mercury was saturated before its successor arrived. This was an IBM 709 which provided a four-fold increase in computing capacity. Since it was a well established machine, CERN was

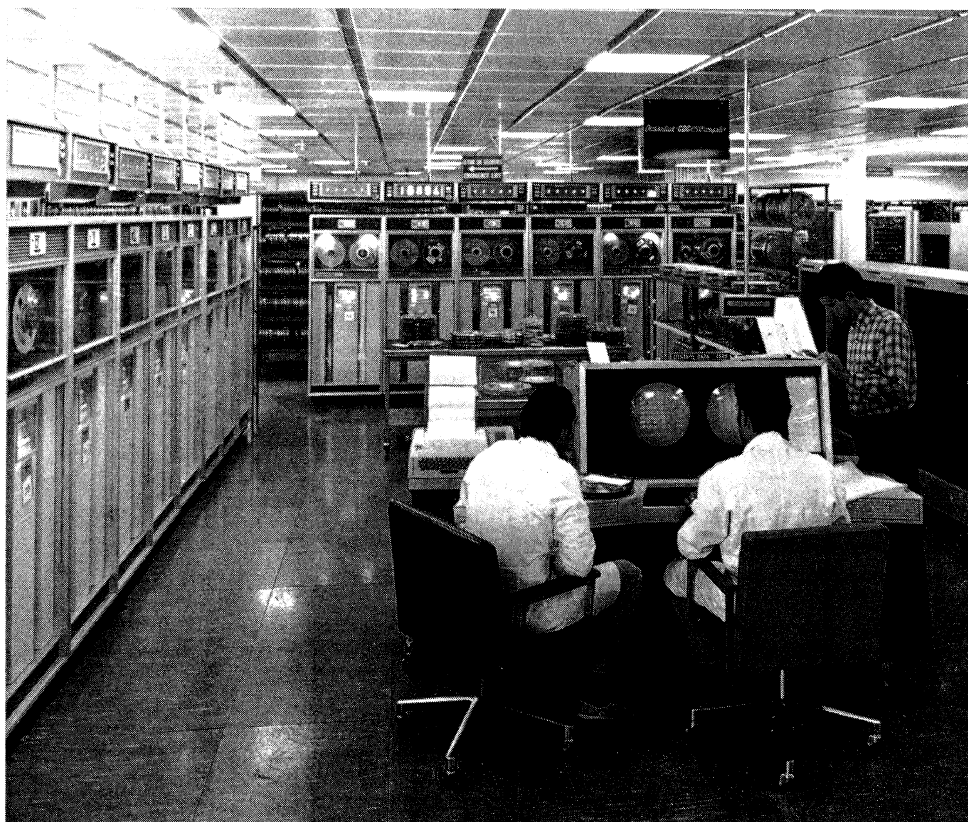
spared a painful running-in period. The FORTRAN era came with it. The problem of the mismatch of mechanical input/output speed to that of electronic computation soon became apparent and a small 'satellite' computer, an IBM 1401, was installed to relieve the 709 of some of the drudgery. In 1962 a flying spot digitizer to measure bubble chamber film was connected to the IBM 709 — the first use of computers on-line at CERN.

By mid-1963, the 709 was saturated and was replaced in September of that year by an IBM 7090 which gave another increase of four in computing capacity. This changeover was painless for the users as the new machine was completely compatible with the 709 and no programming changes were required. It also involved no change in the mode of operation, one program completed its computing cycle before another started.

The growth in demand for computing at CERN continued unabated, amounting to a doubling each year, and this situation, plus the increasing importance of computers in the work of the Laboratory, necessitated a jump in computing capacity preferably of the order of a factor of ten. The only computer which could give this increase was the Control Data Corporation 6600 and, in March 1964, CERN placed its order. The 6600 was delivered at the beginning of 1965. It was one of the first of the series and problems came with it. The effect on the Laboratory's computing was eased by using outside computing facilities but the development plans for computing services around the 6600 were delayed for at least two years.

This computer also brought the wonderland of multiprogramming as the next stage in the continuing battle to bridge the gap between computing and input/output speeds. In order to provide increased capacity and a more reliable service, the CDC 6400, a smaller compatible brother of the 6600 was installed in April 1967.

About the same time manufacturers were asked to send information on their future products and technical discussions were started. CERN estimated its future needs as a system which had a potential capacity by the years 1974-75 of ten times that then installed and the discussion revealed that several firms had plans to make machines larger than the CDC 6600. However the possibility of getting a new, large, well-proven machine by 1970 was very unlikely and CERN obviously wanted to avoid any repeat of its 6600 experience. A further conclusion from the studies was that the new system should be based on two compatible machines with an interval of two to three years between their purchase. Thus it was decided to go for an interim solution, either by extending the CDC 6000 system or



CERN 366.8.69

CERN's new central computer, a CDC 7600, was flown into Geneva airport mid-February and can be seen being unloaded from the plane and being wheeled across the tarmac.

by choosing a medium-sized machine from another manufacturer, the medium-sized machine to be compatible with a larger machine. The first solution was adopted and at the end of 1969 the CDC 6400 was upgraded by increasing the memory and adding a second processor, converting it into a 6500. Extra disk and drum capacity were also added.

In the summer of 1969, there was a further investigation to see what large computers would be available for delivery by the end of 1971. The most economic solution proved to be a CDC 7600 which has a computing capacity about five times that of the 6600. There is still no computer on the European market providing comparable capacity. With the slowing down of the expansion of Laboratory I since the construction of the big new accelerator was approved, it is estimated that CERN will need a second 7600 in 1976 rather than 1974 or 1975. (Laboratory II, incidentally, is a customer of Laboratory I for its large-scale computing). Overall, the demand for computing is continuing to grow but the rate of growth has at least slackened off from a doubling every year, which was the case through to the mid-60s, to a doubling about every two years.

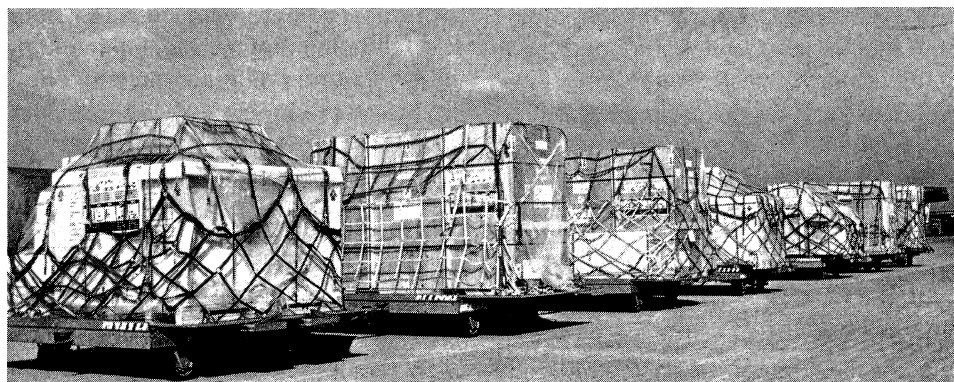
The Present

The present central computing service operates 24 hours per day, seven days per week including most holidays. It is still predominately 'batch-oriented' with the main programming languages being FORTRAN and assembly language. A very large program and subroutine library is available on disk in re-locatable form, and a tape library of some 35 000 labelled tape reels is maintained close to the two computers.

Batch input/output using card readers and line printers is via three



CERN 181.2.72



CERN 165.2.72

remote self-operated input/output stations (RIOS) as well as by card readers and line printers located at the central computers themselves. In addition, there is a car delivery service to a number of remote parts of CERN.

Semi-interactive facilities are available on the FOCUS system which is implemented on a CDC 3100 with channel-to-channel connections to the CDC 6500 and 6600. FOCUS was developed to provide economic facilities for quick sampling of experimental data (collected by small process computers) at the central computers. Thus the 3100 has direct data-links to the experimental halls. It has much wider application, however, since it allows about twenty users simultaneously to manipulate files at terminals and transfer job input files to either 6000 machine for processing (with priority if appropriate) and receive job output files back at their terminals. All termi-

nals are connected to the CDC 3100 via a Hewlett Packard 2116B computer.

An interactive display is attached to the 6600 via a Ferranti Argus 500 computer and is used for interactive work which requires the computing power of the 6600. For graphics work requiring less computing a CDC 3200 is available which has a large CDC interactive display attached. It is used particularly for the re-measurement of bubble chamber events which have been rejected by the off-line chain of programs.

Over the last two years or so an interesting change has taken place in the manner in which many users run their jobs. With the introduction of FOCUS on a wider scale, a number of users changed their working habits. Keeping their programs in the permanent storage system of FOCUS, changes were made directly to this version rather than to the card deck.

With direct access via the 3100, programmers could obtain a larger number of 'debug runs' than was possible with the operator input/output system. Also a number of new applications became practical — for example, maintaining equipment inventories which required frequent changes and periodic listings.

The addition of the remote input/output stations which took place in 1971 brought about a further major change. The RIOS eliminated the delay introduced by waiting for operator intervention and users can now obtain many more runs per day. Within a very short time a substantial proportion of the total number of jobs was being fed to the 6500 and 6600 via FOCUS and the RIOS and already fifty percent is input by the user himself. The number of short jobs has rapidly increased, at present nearly 9000 jobs are processed each week, needing 5000 tapes to be mounted.

The Future

On 15 February the new central computer, a CDC 7600, was shipped to the site. The future of large-scale computing at CERN for the next few years centres around this machine which is expected to be operational by the end of March. The arithmetic power of the computer is such that it can perform an addition in 110 ns, and a multiplication in 137.5 ns. As with the 6600, many instructions can be in process at any time. The effective rate of executing instructions is around 20 million per second. It is instructive, confronted by these figures which represent one of the most advanced computer systems now available, to remember that just thirteen years ago with the Mercury the 'add' time was 180 μ s and only one instruction could be in progress at any one time.

The 7600 has two ferrite core

memories, one of 65 K words of 60 bits plus 5 parity bits, and the other of 512 K words of 60 bits plus 4 parity bits. Programs are executed in the smaller memory, but can transfer information between the two cores at a rate in excess of 36 million words per second. Input and output operations are carried out via small peripheral computers with access to part of the small core memory.

The problem once again, however, is to feed the information between the processor and the outside world at a sufficient rate since, in general, the peripheral equipment is very similar in speed to that of the 6600 (in some cases it is the same equipment). The one exception is a very fast fixed disk (a 7638) with a large capacity and fast transfer rate. Thus CERN has decided that the *only* peripheral equipment attached directly to the 7600 shall be two of these disks. All other peripheral equipment will be attached initially to a 'front-end' CDC 6400 computer which is connected to the 7600 by a high-speed link. As a result all program input/output is between large core buffers and the 7638s. Thus all files must be created on the disk whether they be ultimately cards, printed output, magnetic tape input and output or permanent files residing on a multiple spindle disk drive.

Copying between the 7638 disk and the external media will be taken care of by the system and is called 'staging'. This is not new for card input/output and printed output (it is used on most large computers including the 6000 machines) but it is new (and unique) for complete magnetic tape reels or disk files. Only the very large capacity of the 7638 disk makes it possible to include magnetic tapes in the staging philosophy - one 7638 disk can hold about fifty complete tape reels. The advantage of staging everything is that input/output for active

jobs is done exclusively using a device with a very high instantaneous transfer rate (about fifty times that of the tape units). In fact a sequential scan of a large file on the 7638 is very fast, a complete reel requiring about ten seconds to read through.

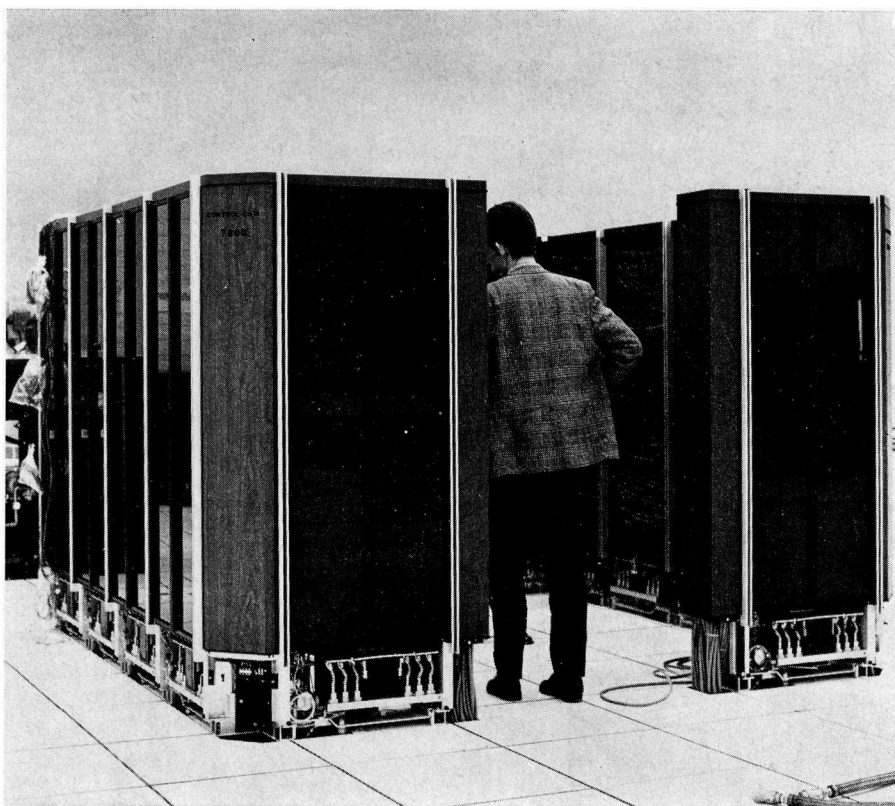
The peripheral equipment attached to the 'front end' 6400 reflects the way computing is expected to evolve at CERN (and elsewhere). The major items are :

High speed 9-track units for densities up to 1600 bpi illustrating the continuing trend towards higher densities (the present units have densities up to 800 bpi) ;

Multi-spindle disk drives to provide permanent file storage ;

Remote input/output stations based on Computer Technology Model 10 Satellite One computers consisting of processors with 8 K, 1.5 μ s core memory, card reader and line printer. Five of these RIOS will be installed initially and are scheduled to be operational around the middle of this year. Another five will probably be installed later in the year. It is interesting to note that, although once again CERN was obliged to buy its large computer from the United States, the best value for money for RIOS was provided by a European manufacturer. An important criterion in making the selection was the expandability of the stations since there is a clear need to attach other peripherals, including tape units, to them in the near future. This implies increasing the speed of the link between the station and 6400 ; *Card Reader, Card Punch, Line Printers* to provide the usual peripheral facilities. However, the volume of output generated will be so high that it is planned to attach a high speed alpha-numeric microfilm printer at the beginning of 1973 to handle a substantial part of it.

In comparing the advent of the 7600 with that of the 6600 it is impor-



CERN 200.2.72

tant to note that the serial number of the 7600 is 19, whereas that of the 6600 was 3. Thus there are already many 7600s in operation (all in the USA with the exception of one in the UK which is at ICL's factory for interfacing to an ICL 1904A as a front-end; others will be installed in Europe this year). The first 7600 has been operating for a customer for two years. Also, CDC have obviously used their experience with the 6000 series of machines in the design and manufacture of the 7600. Thus the memories now have parity bits and a lot of thought has gone into the diagnosis and repair of failures. The 7600 is fitted with a maintenance control unit in the form of a peripheral computer which monitors the 7600's operation and diagnoses malfunctions. To repair a fault normally consists of replacing the defective subassembly and, up to now, average repair time has been less than two hours.

The software of the 6600 (or rather lack of) was a major headache for CERN and for the 7600, while the position is very much healthier, it is more of an unknown than the hardware. CERN will be one of the first users of the 7600 software called SCOPE 2.0 (the software in the front-end is modified SCOPE 3.3 which is well established as the normal CDC 6000 operating system). It has been decided to use standard CDC software making only such changes as

can be carried over easily from one CDC version to another.

An extensive hardware and software acceptance test was carried out successfully in CDC's factory in Minneapolis running CERN programs. This is being repeated at CERN prior to having a thirty-day 'live' acceptance period during which users will run their normal work on the machine. All the evidence to date suggests that CERN's 7600 is one of the best.

The disadvantage, from the reliability point of view, of channelling all input/output via a front-end machine is obvious. To overcome this the CDC 6500 will be shutdown in the Autumn and modified in readiness for attaching to the 7600 as a second front-end. The modifications include adding ten more peripheral processors and twelve more channels to bring it into line with the front-end 6400. Peripheral equipment (including that at present on the 6500) will be allocated to one or other of the 6400 and 6500, but, if either fails, its equipment, including RIOS and terminals, can be switched to the other machine.

Interactive facilities will be provided using the subsystem INTERCOM on the front-end machines. CERN's requirements here are, primarily, on-line file editing and job submittal in a batch processing environment. INTERCOM will allow users to have access to files stored in the SCOPE permanent file system, modify files, create

new files, and submit jobs to the batch processing system of the 7600. Output files may be retrieved at the terminal for examination. INTERCOM does allow jobs to be run on the 6000 machine with a measure of interaction and this will be exploited for CERN's interactive work, for example the GAMMA system (see the articles on interactive computing). Interactive work will be able to use a large core memory of 500 K words which will be shared between the 6400 and 6500. In particular, it provides a very convenient backing store to which programs can be swapped.

While the permanent file space will be adequate for storage of program and small data sets, it falls far short of the capacity needed to substantially reduce the use of magnetic tapes. It is probable that by 1974 the computing centre will have around 70 000 magnetic tapes. As a first step to increase the capacity of on-line storage it is planned to replace the multi-spindle disk drives by larger capacity units which will become available at the end of this year. However, this will only 'buy time' and CERN is investigating the addition of a 10^{12} bit data bank about the end of 1973 (see the article on data storage). This data bank will be accessible by a number of computers and form part of a network of computers which is being studied.

Quantitative performance analysis of large systems such as the 7600 with the long term aim of performance prediction is an area of increasing importance since intuitive ideas are often wrong. CDC has developed a special hardware monitor for CERN which will be used to study the flow of work through the system.

As mentioned earlier the 7600 is installed in a new computer centre. The building consists of two parallel concrete wings, where there are offices and technical equipment, which



CERN 374.2.T2

Installation of the 7600 well advanced in the large hall of the new computer centre. Top left, the shape of the main-frame can be picked out. Then comes the 6400 computer, the large core memory which will be shared by the 6400 and 6500 (Extended Core Store) and, nearest to the camera, a number of controllers which connect peripheral equipment to the 6400. On the right and in the foreground are the operator displays.

enclose the computer hall proper and support its roof. This hall has an area of 1600 m² and its height between false floor and false ceiling is six metres. There is also a basement which is occupied partly by air-conditioning equipment and electrical generators and partly by computer supplies. In particular, the bulk of the tapes will be stored directly under the area where the tape units are located. A paternoster is installed for the physical transfer of the tapes.

The equipment in the hall is arranged by function, therefore there is one area for input, one for consoles, etc. Part of the hall is taken up by a 'Cœur Central' which houses all the user facilities. This area has two floors, the ground one will house a remote input/output station and general input/output facilities. Cards, printed output, etc. will be physically moved between the Cœur and the hall via conveyor belts. The first floor houses the Advisory Services, a programmer work area, a conference room and a visitors' gallery.

This splendid new building is now being progressively occupied by the staff of the Data Handling Division.

The smaller computers

So far we have concentrated on the glamorous super-computers which cater for the large-scale computing needs of the Laboratory. A recent survey identified 80 other computers sprinkled around the CERN site. They are from fourteen manufacturers; 59 of them belong to CERN and 21 have been brought in by visiting groups from research centres in the Member States. Many of the machines are quite small, such as the PDP-8, PDP-9, PDP-11, PDP-15, DP516, HP2116, IBM 1800 but they range as large as the CDC 3100, IBM 360/44, CII 10070.

Almost all of them (with the exception of an IBM 360/30 used in administrative data processing and a PDP-11 coming into use for library needs) are involved in the physics programme. Examples of their applications are — on-line acquisition and control in electronics experiments, on-line data acquisition and control in scanning and measuring system for bubble chamber film, interface and file-handling between a number of computers, control of accelerators and beam transport systems, etc.

There is a strong trend, noticeable

everywhere, towards 'distributed computing' — that is, having computers individually assigned to specific functions rather than trying to use one large central installation to cope with everything. Examples of this are the Omega and Split Field Magnet computer system (described later) centred on a CII 10070 and the ERASME computer system (also described later) centred on a PDP-10. In the electronics experiments field and the bubble chamber film measuring field, respectively, these are among the most advanced of their kind in the world.

Nevertheless, apart from the big dedicated computers there is growing need of data links between computers. Higher data taking rates and larger total volumes of data to be analysed are expected from the detection systems coming into use. This can only lead to even more extensive use of computers in real-time, requiring either increased computing capacity or more data links to a medium or large multi-programming computer. There are already four data-links into the central computers via the FOCUS system. A considerable number of the 80 computers will require links in the future to larger machines.

The following articles go into the various computer applications in more detail.