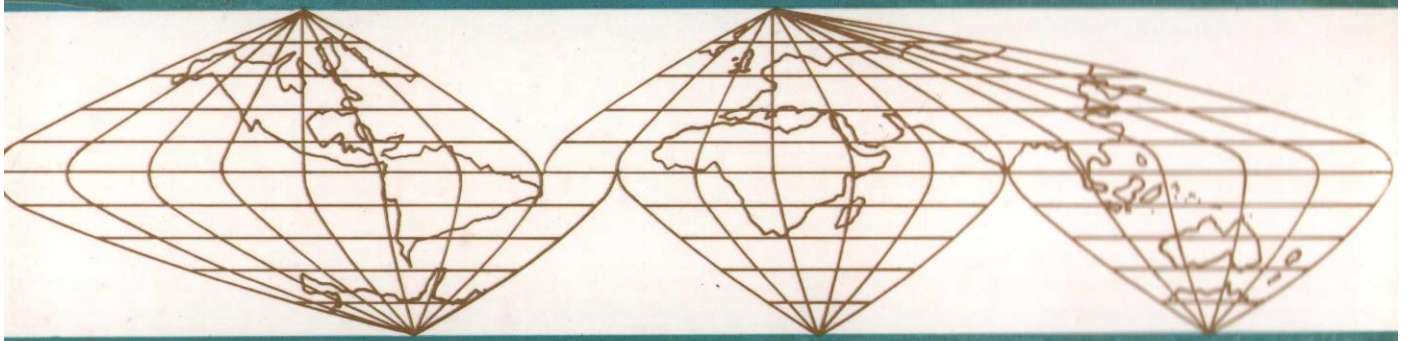


Ferranti Computing Systems *Atlas*



Ferranti Computing Systems *Atlas*



The Atlas Input Area at Manchester University

Ferranti Computing Systems *Atlas*

The Background of Atlas

The Ferranti Atlas computer is one of the two or three most powerful machines in the world today. It marks the culmination of a long and fruitful collaboration between Ferranti Ltd. and the Department of Electrical Engineering at Manchester University. This joint effort began with the construction of the Ferranti Mark 1 computer, which was the first stored program digital computer ever built for sale by a manufacturer. The collaboration has continued with the development of the well-known Ferranti Mercury computer, installed at Harwell, CERN, London University and sixteen other locations.

Ferranti Ltd. also have a number of design groups of their own located at West Gorton (Manchester), Wythenshawe, Bracknell and Toronto. These groups have produced a range of computers of which perhaps the best known are the Pegasus and Sirius general purpose computers, the Orion computing and data processing system and the Argus series of process control computers. The range also includes custom-built systems for such applications as air traffic control and seat reservation.

Design and manufacture are backed up by a powerful software organisation which produces a full range of compilers and programming schemes. In the case of Atlas for example, the software includes a FORTRAN compiler, a complete package of routines for large scale linear programming and other major facilities.

The Scale of Atlas

Atlas has a minimum main store of 114,688 48-bit words of which at least 16,384 words are in cores and the balance is in drums. These stores are integrated by special hardware so as to appear as a single level store to the user. What appears to the user as a continuous strip of storage is physically represented by a series of 512-word blocks distributed throughout the core and drum stores. The allocation of this storage is carried out entirely automatically.

Atlas has 128 index registers, double modification and a floating point accumulator. Overall speeds are of the order of 700,000 instructions per second. A unique feature of Atlas is the fixed store, which provides exceedingly rapid access to a set of permanent routines which are thus built into the machine. The allocation of storage mentioned above is carried out by routines in this fixed store which ensure continuous optimisation of store use. Similarly, fixed store routines control input and output operations and provide extensions to the basic function code of the machine.

The Operation of Atlas

The Atlas system operates on a thoroughgoing multi-programming basis. Programs written entirely independently share time on the central computer. This is possible because full hardware protection against mutual interference of programs is a direct consequence of the method of automatic storage allocation used.

The tasks to be carried out by Atlas are scheduled entirely automatically by a supervisor routine of advanced conception. Jobs to be run on the computer are first assembled on magnetic tape by the supervisor, they are then executed along with a few other appropriate companion jobs with which they share the central computer and the results are distributed via magnetic tape to appropriate output peripherals.

In general, around 200 jobs may be in the system at any one time, of which perhaps a dozen may be in the execution phase. The management of the whole work load so as to ensure optimum use of the central computer and its peripherals is carried out entirely automatically by the supervisor.

The Scope for Atlas

The Atlas system thus provides very large quantities of computing at an extremely low cost per operation, with access to extremely large areas of storage backed by very fast tape. These facilities are essential to all those users who need an economic means of achieving a major breakthrough in computing power in order to advance their work to the next stage. Such users include all the leading groups in the fields of crystallography, meteorology, supersonic aviation, nuclear engineering and space research. In addition to these well-established consumers of ever-growing quantities of computing there are innumerable other scientific and technical projects whose progress can be accelerated by cheap access to relatively small amounts of computer time. The Atlas computer with its automatic supervisory system enables the needs of all these users, both great and small, to be met. Atlas provides the ideal nucleus for a multiple user computing facility, providing better service at lower cost than is obtainable in any other way. That is why Harwell and London University have ordered Atlas. It is a choice to be considered carefully by every large user.

The Stores of Atlas

Atlas has a series of stores at different levels of access time. The fastest of these is the fixed store of 8,192 words which has an access time of $0.3 \mu\text{s}$. Once the contents of this store have been determined and set they cannot be changed by an operation of the machine but only by physically altering the hardware. The store itself is constructed from a woven wire mesh into which are inserted ferrite rods to represent ones and copper rods to represent zeros as shown in Figure 1. It contains certain routines – known as extracodes – for common mathematical functions such as polynomial evaluation and trigonometric functions. An extracode routine can be called in by the programmer as a single instruction and he need have no knowledge whatsoever of its interpretation within the fixed store. The extracodes take up about 2,000 of the available 8,192 words, the remainder being allocated to the supervisor program.

The fixed store has associated with it a subsidiary store of 1,024 words which it uses as working space. This store has a $2 \mu\text{s}$ cycle time and is locked out from all ordinary program commands. It is thus private to the fixed store routines.

After the fixed store the next in speed is the B-store. This contains 128 half-word (24-bit) index registers to which access can be made in $0.35 \mu\text{s}$. Associated with the B-store is the B-arithmetic unit used for operations on indices; this unit is quite distinct from the floating-point accumulator and floating-point arithmetic may take place at the same time as indexing arithmetic.

The main core store of Atlas has a cycle time of $2 \mu\text{s}$. This time is, however, effectively reduced by the provision of a number of distinct access systems to sections of the store. The core store of a basic machine is 16,384 words. The core store is backed up by drums containing 24,576 words per drum. A basic installation will normally have 4 drums. Both levels of storage may be increased up to a theoretical maximum of 1,048,576 locations of core and drum store combined. A drum cabinet contains 4 drums and additional drums will usually be added in multiples of 4. A drum co-ordinator organises transfers of information between core and drum stores and can be attached to a maximum of 16 drums. Further co-ordinators are required if more than 16 drums are attached. Words are written on the drums in multiples of 512 words, and transfers between drums and core store are by these blocks; 512 words is also the block length on the magnetic tape. A drum revolves at 5,000 r.p.m. giving a revolution time of 12 ms and a time to transfer one block of 2 ms plus any waiting time necessary.

Finally, there is a set of registers which are referred to collectively as the V-store. These consist mainly of information and control signals connected with magnetic tape, drums and other peripheral equipments. They are not located in the same area geographically but in different parts of the machine. The page-address registers which the 'one-level store' concept depends on, are part of the V-store. The organisation of the storage system as a whole is shown in Figure 2.

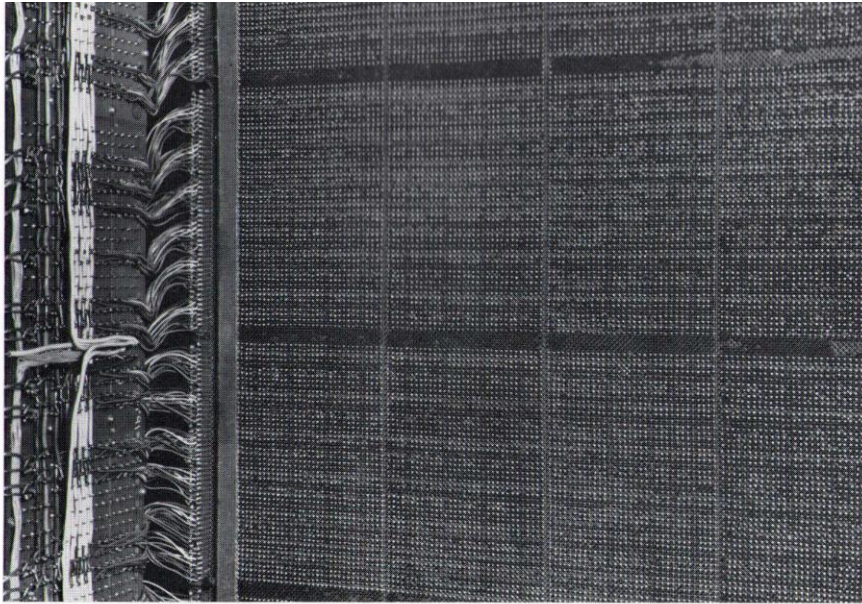
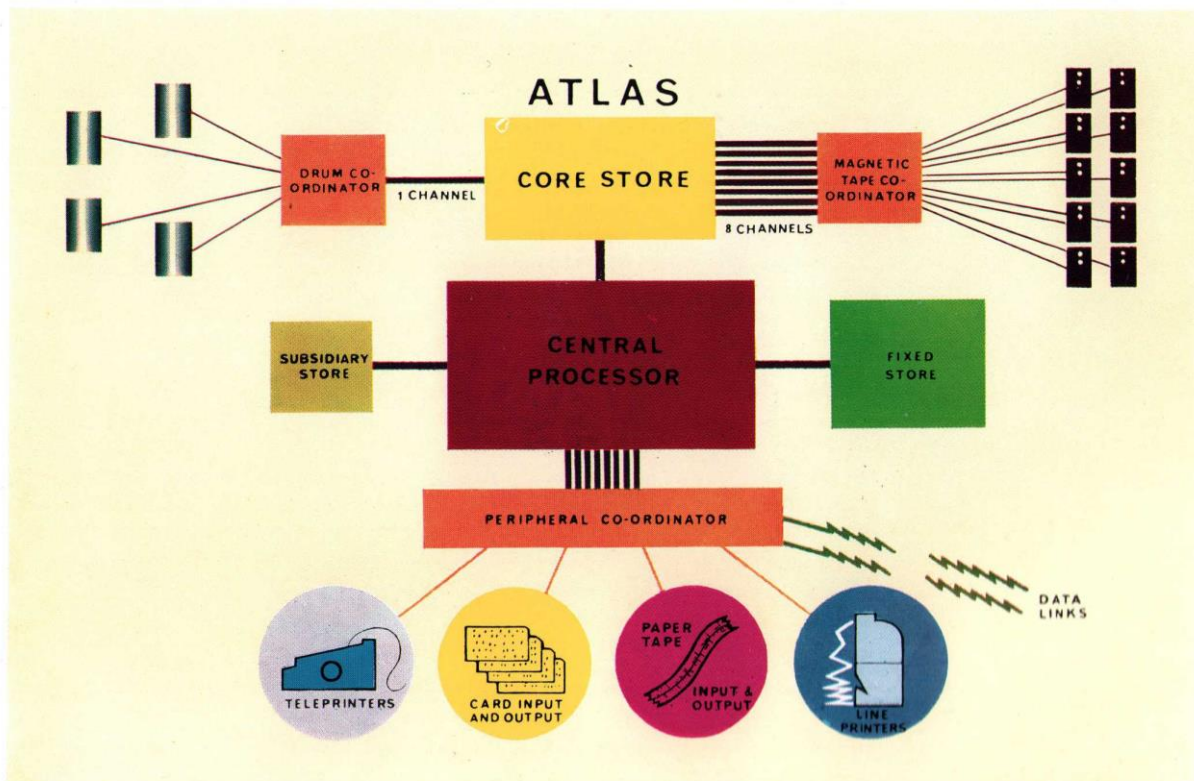


Figure 1
The Fixed Store, in which permanent routines are stored by inserting copper and ferrite rods into a woven wire mesh.

Figure 2 The organisation of the Atlas System.



The Peripheral System for Atlas

The speed of Atlas makes it possible to simplify the method of attaching peripheral devices. Transfers to and from all devices except Ampex magnetic tape and drums are handled by a single peripheral co-ordinator. Whereas in other large machines comparatively large sections of information are transferred by special control units, in Atlas transfers are carried out under the control of fixed store programs via small buffers in units of information of character size. For example, this unit will be one 5 or 7-hole character for paper tape equipment, one column of an 80-column card for a card reader and 16 6-bit characters for I.B.M. magnetic tape.

Peripheral Co-ordinators

The small amounts of electronics associated with each peripheral device are housed in a peripheral co-ordinator, two types A and B of which are offered. The maximum number of devices which can be attached to these co-ordinators are:

	Type A	Type B
TR5 reader	4	8
TR7 reader	1	4
Teletype 110 punch	4	8
Creed 3000 punch	1	4
Creed 75 teleprinter	3	4
Anelex printer	2	4
Card reader	2	4
Card punch	1	2
Graphical output	1	1
IBM Tape Channel	1	1
General Channel, 24-bits in/out	6	6
General Channel, 12-bits in/out	12	12
General Channel, 4-bits in/12-bits out	12	12

An instruction counter and clock are also included.

In the case of Ampex Tape and Drums, two special co-ordinators are provided, called the Tape Co-ordinator and the Drum Co-ordinator.

Standard Peripherals

Paper Tape

Input and output is normally via 7-channel paper tape but 5-hole tape may also be used. The readers which can be attached are the Ferranti TR5 and TR7 readers operating at maximum speeds of 300 and 1,000 ch/sec. respectively.

Output can be either by the Teletype 110 ch/sec. or by the Creed 3000 punch with a maximum speed of 300 ch/sec.

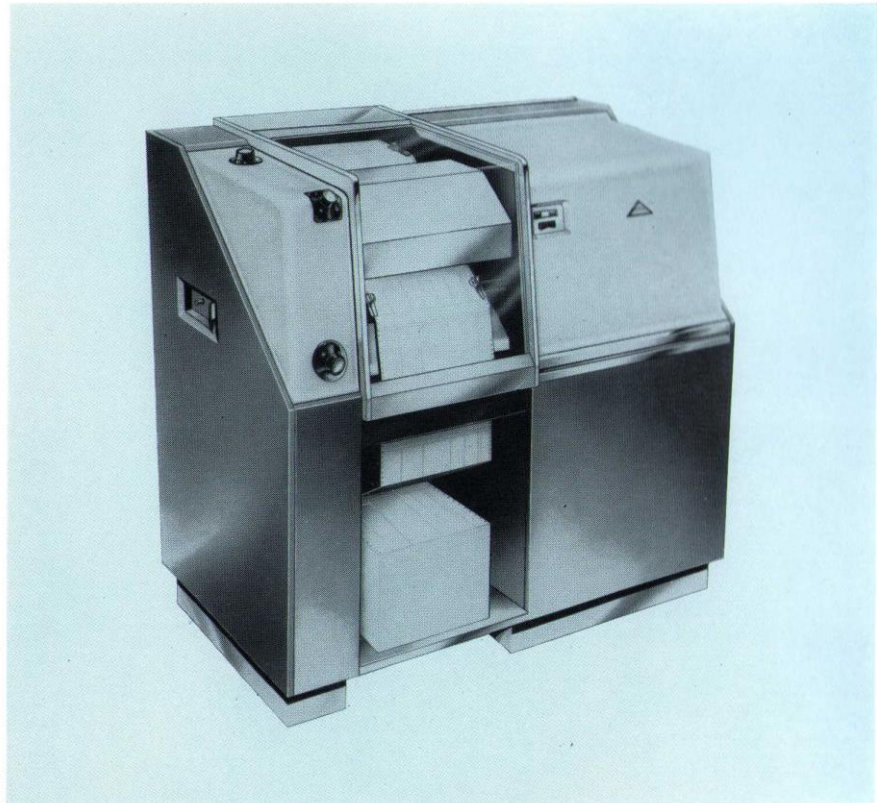
Card Input/Output

The standard card reader on Atlas is the I.C.T. 593, which has a maximum speed of 600 cards/minute.

The I.C.T. 582 punch operates at 100 cards/minute.

Both these devices operate on 80-column punched cards.

Figure 3
The Anelex 4/1000 Line Printer.



Line Printer

The Anelex 4/1000 printer has been adopted as standard on Atlas. It has a maximum printing speed of 1,000 lines/minute under the most favourable program conditions and a minimum speed of 815 lines/minute. There are 120 printing positions on a line. This printer is illustrated in Figure 3.

Optional Peripherals

I.B.M. Peripheral Magnetic Tape

I.B.M. $\frac{1}{2}$ in. magnetic tape can be attached to Atlas via the peripheral co-ordinator. Up to three 729 MK. IV decks can be attached but only one may be in operation at any one time. A 96-bit buffer is provided in the co-ordinator enabling the I.B.M. tape to run at its maximum speed of 62,500 ch/sec.

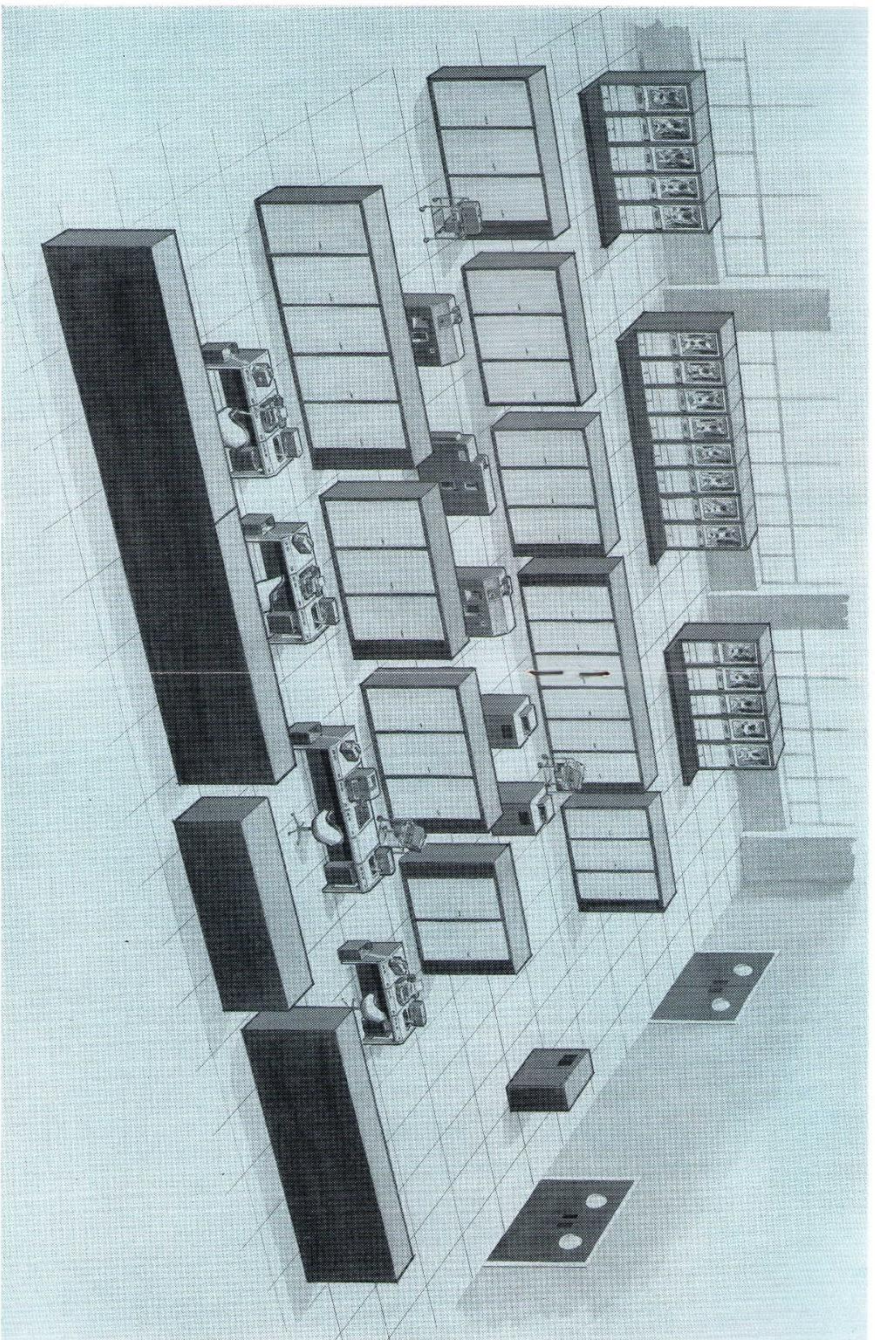
The format of the tape is standard I.B.M., i.e. variable length records with lateral and longitudinal parity.

Special Devices

A graphical output device consisting of a $4,096 \times 4,096$ array can be attached to each type of peripheral co-ordinator.

Other devices can be attached such as M.P.L. magnetic tape which is connected to Atlas through one paper tape input channel and one paper tape output channel. This tape is $\frac{1}{2}$ in. and has a packing density of 100 bits/in. It can be run at four different speeds the maximum being 10 in./sec.

The general channels on the peripheral co-ordinator can be used for other suitable devices.

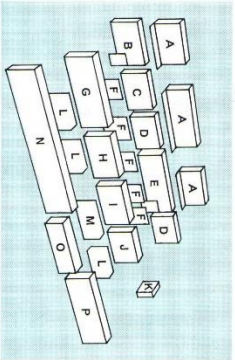


Typical

Atlas

Computer

Installation

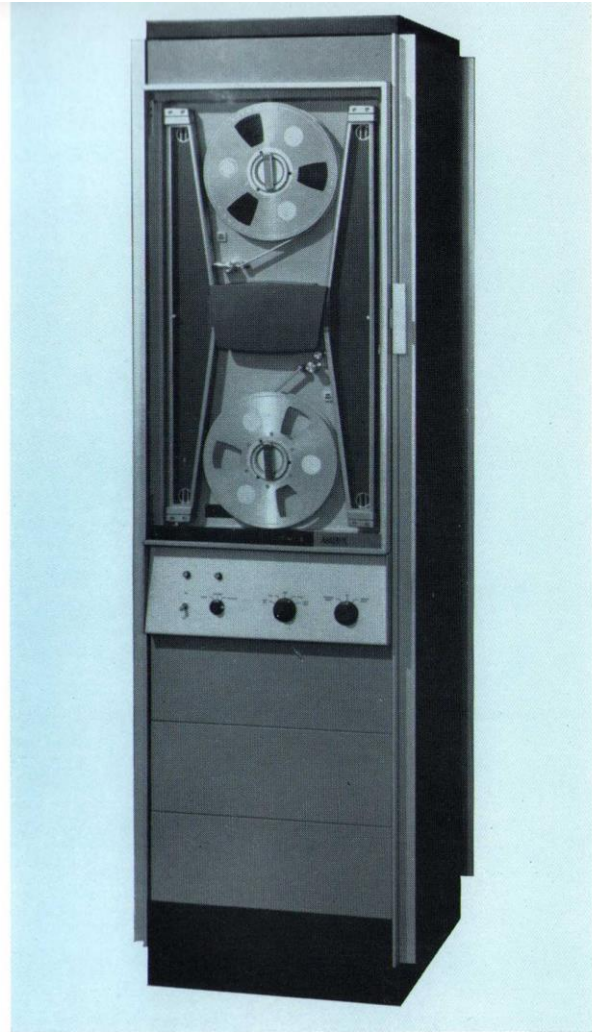


- | | | | |
|---|--|---|---|
| A | Magnetic Tape Units (Ampex/IBM) | I | Central Computer |
| B | Magnetic Tape Co-ordinator | J | Fixed Store |
| C | 4-Drum Unit | K | Core Store Power Supply |
| D | Core Store | L | Slave Console with Tape Reader, Flexowriter, Teletype Punch |
| E | Core Store Co-ordinator | M | Main Console with Tape Reader, Teletype Punch, Engineers Control and Teletype Punch |
| F | Card Reader, Card Punch | N | Power Supplies |
| G | Magnetic Tape Switching and Control Unit | O | Battery Box |
| H | Drum Co-ordinator | P | Distribution Panel |
| | Peripheral Co-ordinator | | |
| | Subsidiary Store | | |

The Atlas Ampex System

Figure 4

Ampex TM2 decks form the main tape system of Atlas. They provide a transfer rate equivalent to 120,000 decimal digits per second for numeric data.



The main magnetic tape mechanism on Atlas is the Ampex TM2 system as shown in Figure 4, operating with 1 in. tape. Each machine has 8 channels through which simultaneous tape transfers can take place, and an installation can have a maximum of 32 decks. A switching unit controls 8 decks on two channels thus enabling two of each group of 8 decks to be operating at one time. The tape can be read while it is travelling either forwards or backwards but writing can only take place in the forward direction.

The tape is divided into 512 48-bit word blocks enabling about 5,000 blocks, i.e. 20 million characters, to be held on one 3,600 ft. tape. There are 16 tracks across the tape of which 12 are for information. A 48-bit word is therefore represented by four 12-bit stripes across the tape. At the end of each block is recorded a 24-bit checksum and each block is preceded by a block marker and block address and is terminated by a trailing block marker and what is effectively a zero block address. The speed of the tape is 120 in./sec. which implies an instantaneous transfer rate of 90,000 ch/sec. The effective transfer rate, i.e. the rate allowing for the gap between each 512-word block, is 64,000 ch/sec. This also means that if purely numeric data are present on the tape the instantaneous transfer rate is equivalent to 120,000 decimal digits/second.

All tapes are pre-addressed by a special run on the machine thus making it possible to omit faulty blocks on a tape before it is used. All the tape transfers together with wind and rewind procedures are under the control of fixed store routines. These routines are designed to diagnose as far as is possible any errors occurring during operation. For example, when a block of information is being read from tape a checksum is formed and if this fails to agree with the checksum on the tape, the block is re-read. In all three attempts are made to read the block. If this is unsuccessful a further attempt is made to read the block and if all fail the tape is rewound and an attempt is made to read the suspect block but this time with reduced bias

level. The mechanism will be disengaged and the program suspended if this again fails. If it is successful, however, the tape is copied to a free tape and the operator is instructed to re-address the faulty tape. If the first block has not been read successfully it is most likely that the mechanism itself is faulty and the operator is instructed to remount the tape on another deck.

At all times during this and any other fault procedure, the engineers are informed of any errors.

Consoles

There are three types of console in an Atlas installation – main, slave and engineer's. A standard installation will have one main, two slave and one engineer's console but additional slave consoles can be attached if necessary.

On the main console there will be on-line a TR5 tape-reader, Teletype 110 tape punch and a Creed 75 teleprinter, and off-line a Flexowriter for tape-editing purposes. The teleprinter will normally be used by the supervisor for informing the operator of the state of the machine and giving him any instructions or monitoring information.

Slave consoles will be similar to main consoles but with no teleprinter.

The engineer's console has a TR5 tape-reader, Creed 75 teleprinter, the display lights which form B-line 120 and the engineer's switches and controls. It will normally be reserved for maintenance while the principal operator will use the main console and from there will be able to give instructions to the supervisor. Slave consoles are purely input/output stations.

There is also a Creed 75 teleprinter for giving information and instructions to the magnetic tape operators.

Atlas Words and Number Representation

The Atlas word length, excepting the B-store, is 48 bits, each 24-bit half-word having a parity bit associated with it. The word can be thought of for example as a 'single-address' machine instruction, 8 characters of 6 bits each or as a single floating point number, as shown in Figure 5.

In the Atlas representation of a floating point number 8 bits are used to represent the exponent y and 40 bits the mantissa and sign x . The exponent is an octal one and the number represented is therefore $x.8^y$. Twos complements are used for negative numbers, so that when normalised, $\frac{1}{8} \leq x < 1$ or $-1 \leq x < -\frac{1}{8}$ and $-128 \leq y < 128$. Floating point arithmetic makes use of a floating point accumulator, in which the mantissa is double length (sign and 78 bits).

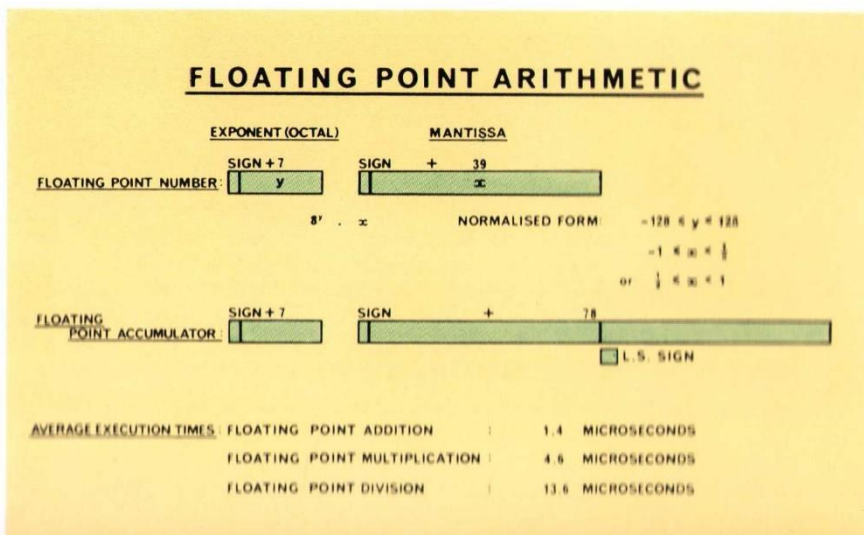


Figure 5

The Structure of Atlas words.

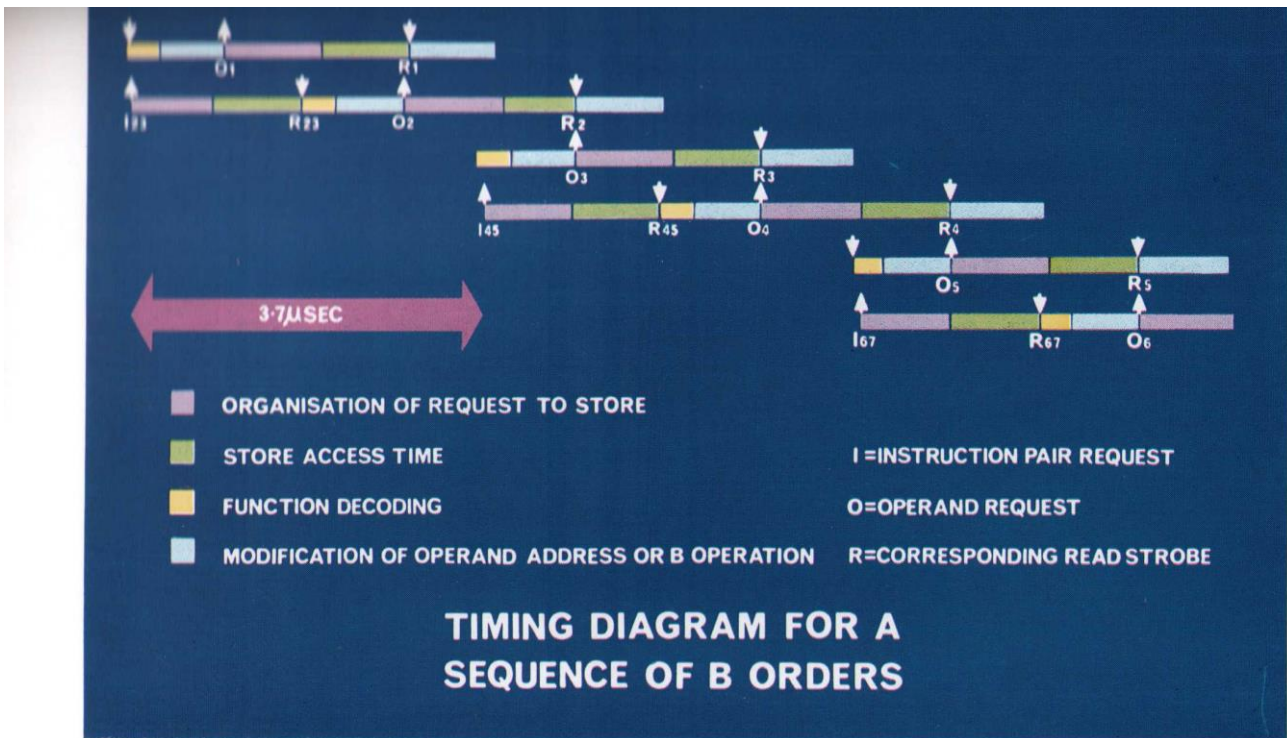


Figure 6 The overlapping of Atlas instructions-indexing operations.

Data Links, Remote Control Desks, Satellite Computers

There are many far-flung organisations in which satellite computers, data links or remote control desks would be necessary to utilise a large central computer adequately. Ferranti Ltd. are at present developing such equipment and will be pleased to put forward proposals for any such system.

High Speed Achieved through Instruction Overlapping

There are several distinct phases in the obeying of an Atlas instruction. These are generally as follows:

- find instruction in core store
- decode instruction
- find operand in core store
- obey instruction

The overlapping of instructions means that when an instruction is being obeyed another one may be being decoded while yet another is being fetched from the store, as illustrated for indexing operations in Figure 6.

It follows in a similar way that the addition time of two floating point numbers on Atlas depends on their context in the program since there is a great deal of 'overlapping' of instructions. The average time of addition and subtraction is $1.4 \mu s$ and of multiplication $4.7 \mu s$. Division time is $11-13 \mu s$. In addition, indexing operations may be carried out at the same time as floating point operations, as well as time-shared peripheral transfers.

Atlas Programming

A single machine instruction on Atlas is 48 bits long. It is divided up into four parts as shown in Figure 7.

Each instruction is of the single-address type and refers to two index registers B_n and B_m . F represents the function being obeyed and S is either a store address or in some cases a number. Of these 24 bits, the last three denote a particular 6-bit character within an address. The first bit is 0 if referring to a main store address (see diagram) or 1 if referring to a private store address. Normally a 1 in this position will be a program error and will cause entry to the supervisor. The only exception to this rule is if the first three bits indicate a fixed store address (i.e. if they are 100).

The function number is usually written as a binary digit followed by three octal digits (ranging from 0000 to 1777). If the binary digit is 0 then a machine instruction is indicated; if 1 then an extracode entry is made, i.e. a built-in routine in the fixed store is entered although to the programmer it appears to be a single instruction. If the first four bits of an instruction (i.e. the binary number and the first octal number) are 0101 or 0111 and the instruction is being obeyed in an extracode routine then they cause return to the object program at its next instruction.

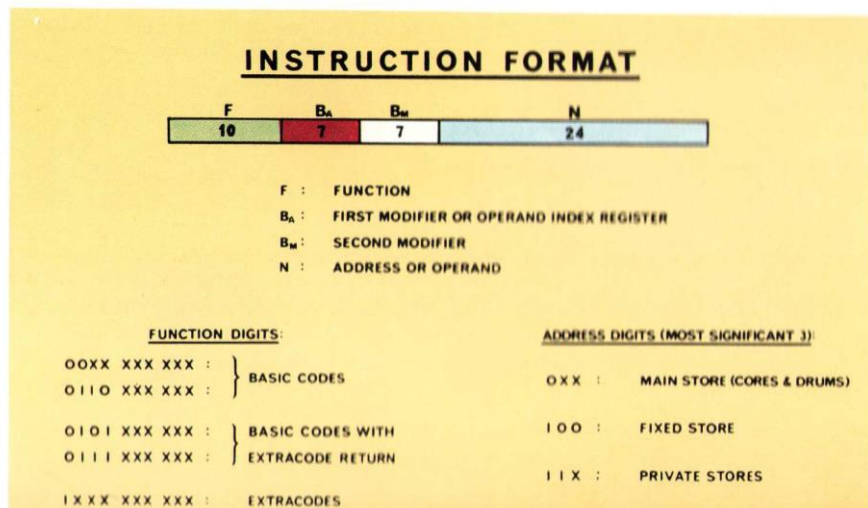
In an accumulator instruction, i.e. one which refers to the floating-point accumulator, the instruction is normally doubly modified, i.e. the contents of both the B_n and B_m index registers are added to the address (denoted by S) before the instruction is obeyed. For an index instruction, i.e. a B-type instruction, the contents of B_m are added to S before obeying and B_n is the index register on which the operation is being performed. Typical machine instructions are the following:

- 0122, 36, 0, 10 – this instruction subtracts the number 10 from B_{36} and leaves the result in B_{36} .
- 0356, 0, 0, 5000 – place a copy of the contents of the floating point accumulator into store location 5000.
- 1670, 0, 0, 1000 – put the sine of the floating point number in location 1000 in the floating point accumulator (extracode function).

In order to test the size of an index without altering it, a special register is provided which can be used to record the sign and zero-equivalence of either s-b, b-s, n-b, b-n. This register is the B-test register B_t and four commands are available to test its contents b_t , to see if it represents the states designated =0, $\neq 0$, > 0 , < 0 . Typical of the instructions are:

- 0172, 56, 0, 7 $b_t = b_{56} - 7$
- 0224, 127, 0, 1000 if $b_t = 0$, i.e. if $b_{56} = 7$, place the integer 1000 in the main control register (B_{127}).

Figure 7
The Atlas instruction format.



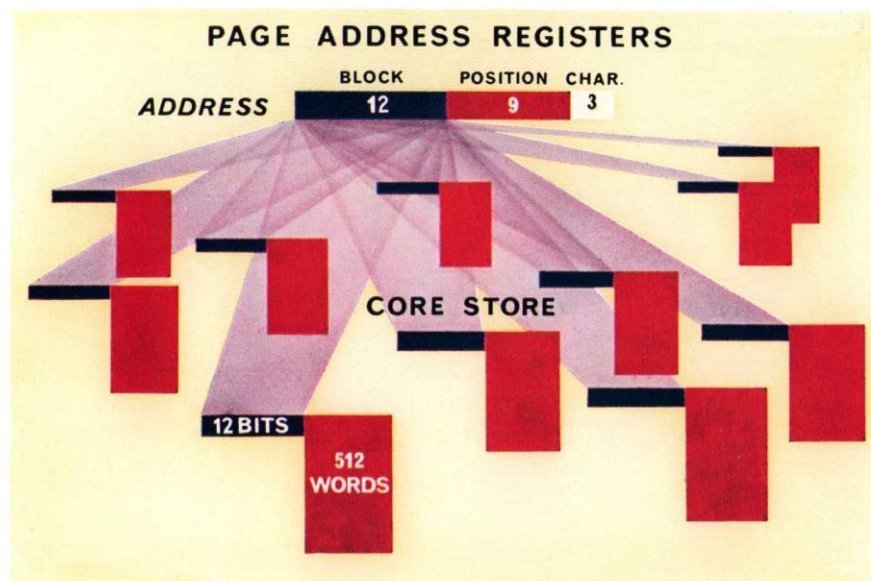


Figure 8 Operation of the One-level Store. When a particular store access is required, the page address registers are scanned extremely rapidly in parallel to locate the block required in the core store or to initiate a drum transfer.

One-level Store Concept

Although the main-store of the machine is a combination of both drum and core stores, to the programmer it may be regarded as a 'one-level' store, i.e. the core and drum stores have been unified and any location specified by the programmer can be in either. This unification is achieved by a set of registers in the V-store known as the page-address registers. These registers contain a list of all the blocks currently in the core store. When a particular store access is required, the page address registers are scanned extremely rapidly in parallel by special hardware as illustrated in Figure 8. If one of these registers contains the number of the block in which the required word lies, recognition occurs and the corresponding 'page' in the store is used for the command. Thus, so long as the required commands and their data are in the core store, access can be made at the full speed of the core store. If ultimately a word is called for which is not in the core store, then none of the page address registers signals agreement. When this happens the program is automatically interrupted and control is transferred to a special routine in the fixed store, called the drum transfer routine.

Each page address register is 12 bits in length and the most significant bit is set only if the block is 'locked out' because the particular program to which it belongs has been interrupted (see section on the supervisor). It is thus possible for programmers to use the same store address in different programs and be certain that they are completely independent.

To determine which block inside the core store is transferred to drum when a drum transfer is required a special routine is included in the supervisor known as the drum learning program. This seeks to arrange the programs inside the one-level store so as to minimise the drum transfers that take place when programs are obeyed. It will be noted that two successive blocks of program or data need not be in consecutive pages in the core store – the core store is in fact a set of pages the contents of which have been re-arranged into the most convenient order. The programmer, of course, need not be aware of this.

The Supervisor

From the outset Atlas was designed as a multiprogramming machine. This is fundamental to the operation of the machine and is achieved both by special hardware and by built-in program. This program is known as the supervisor and controls all the activities of the Atlas system including scheduling of programs and operation of all peripheral transfers.

In the past most computers have been only able to obey a single program at a time and this has meant that the operation time of programs has often been dominated by the speed of input and output. The first time-sharing machines, therefore, concentrated initially on autonomous operation of peripheral equipment. Even this is not sufficient with a machine of the size and speed of Atlas and it soon became clear that something of more advanced concept would be required. This was essential because many jobs on Atlas would run for only a few seconds and operators would be hard pressed to keep the machine fully occupied. Hence supervisor-controlled multiprogramming is provided on Atlas.

The supervisor may be entered from an object program for one of the following reasons:

- 1 A peripheral equipment signals that it needs attention.
- 2 An object program may enter an extracode which in turn enters the supervisor. This will usually be for a peripheral transfer.
- 3 Monitor action for any reason such as exponent overflow or division by zero.
- 4 More than $\frac{1}{10}$ sec. has passed since it was last entered; or 2,048 instructions have been obeyed.
- 5 Failure of any part of the Atlas system, e.g. parity.

Program and data are divided into what are known as documents which can be put into the machine in any order. Each document may be a piece of program, an item of data or a job description, and must enter the system on a single input channel, although different documents can enter the machine at different times and on different inputs. The purpose of the job description is to give to the machine a list of all the documents required for that particular job and also, optionally, such data as estimated computer time and storage space. A typical job description would be as follows:

```
JOB
  AUTOPROCESS 3
  STORE 2
  COMPUTING 10.0 SECONDS
  INPUT
    1 EXPERIMENT A
    2 EXPERIMENT B
  OUTPUT
    1 TELETYPE 1 BLOCK
  COMPILER MERCURY AUTOCODE
then the program itself terminated by
***Z
```

This tells the machine that it is to obey a program named AUTOPROCESS 3 which is written in Mercury Autocode. The compiled program will require at most 2 blocks in the main store and should run for no more than 10 seconds. There are two data tapes, named EXPERIMENT A and EXPERIMENT B, and output should be at most one block and it is required on a Teletype 110 ch/sec. paper tape punch. If the estimates for store used, computing time and amount of output are exceeded the program is interrupted and the operator informed. The ***Z signifies the end of the document to the supervisor.

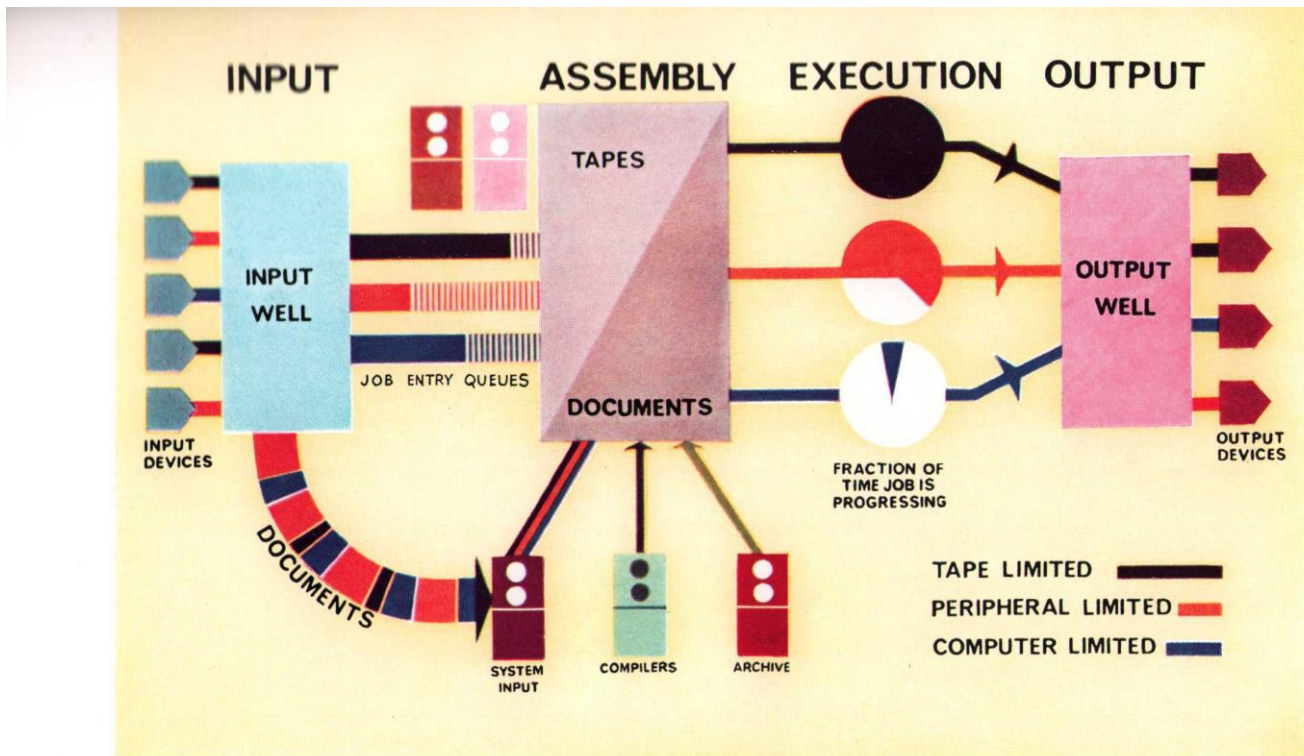


Figure 9 The Atlas supervisor controls the flow of jobs from input through assembly and execution to output, so as to optimise system utilisation continuously.

The operation of the supervisor is illustrated in Figure 9. An 'input well' is reserved for all documents and consists of part of the main store together with a magnetic tape deck – the 'system input tape'. When a job is complete, i.e. all the necessary documents have been assembled in the input well, the job is entered on one of three queues of programs waiting to be obeyed. These queues are for programs whose speed of execution is limited by the speed of magnetic tape, 'large computing' jobs with a great deal of calculation, and small jobs.

One of the routines in the supervisor is the scheduler routine whose task it is to place jobs on the 'execution list' – i.e. the list of those jobs actually being obeyed. Jobs will be selected which keep the machine and its peripherals as fully occupied as possible. When a job is completed it will be replaced by one from the appropriate queue. The actual order in which programs are put into the machine does not, therefore, determine the order in which they are obeyed, although this may be influenced by actions on the part of one of the operators.

Similar to the 'input well' is the 'output well' into which all output is fed by the computer. This consists of main store together with a system output tape. This well is emptied at rates appropriate to the particular output devices.

The size of these input and output wells varies depending on the mixture of programs being executed, and considerably helps to 'smooth out' input and output to the machine.

Conclusion

Atlas provides an extremely powerful computing system able to take in every sort of job as it arises through whatever appropriate peripherals are free and to output the results in a similarly flexible manner. The work is automatically scheduled to make the best use of the system at all times. Such a system provides the ideal means of meeting the needs of the largest organisations, and of providing the most widespread computing service coverage in the most economical way.

Ferranti Ltd *Computer Department*

Enquiries to:

London Computer Centre
68 Newman Street, London W1
Telephone MUSEum 5040

Canada

Ferranti-Packard Electric Limited
Industry Street
Toronto 15, Ontario
Telephone 762-3661

USA

Ferranti Electric Inc.
Industrial Park No.1
Plainview, L.I., New York
Telephone 516 WElls 8-7500

Australia

Ferranti Ltd.
34 Queen's Road
Melbourne SC2, Victoria
Telephone 26 3243

List DC.46
Printed in England by
Lund Humphries, Bradford
December, 1962
© Ferranti Ltd 1962