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A COMPARISON
EL X8 AND CDC 3200 FOR ON-LINE USE

by

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Chapter 1. PREFACE.

On instigation of Dr. R. van Lieshout and Prof. Dr. A.H. Wapstra I have written a report in which according to the commission I have tried to compare the two computers EL X8 and CDC 3200 with a view to their suitability to meet I.K.O.'s need for the application of an on-line computer.
I am aware of the fact that due to the short time interval which was given to finish the machine studies, this report will suffer from several limitations.
As a last remark this study, to my opinion incomplete because only two machines are considered, does not justify a final choice.

Chapter 2. LIST OF DEFINITIONS.

1. Hardware : the mechanical, magnetic, electrical and electronic devices from which a computer is constructed.

2. On-line : in direct electronical connection, via transmission lines and/or input/output channels with the central part of the machine.

3. Real time : working made of a computer in which the speed is sufficient to give an answer or to execute a task in the actual time and on the actual moment required by the experiment.

4. Software : all hand written machine programs consisting of sequences of instructions.

Chapter 3. ARGUMENTS FOR ON-LINE USE OF A GENERAL PURPOSE COMPUTER

Already during the Grossinger conference in 1962 on the utilisation of multiparameter analysers in nuclear physics it was stated that a rapid increase in complexity of the data reduction apparatus used in this field is observed.

There are two main arguments that can justify the use of a general purpose computer (g.p.c.) on-line with experimental set ups:

1. physical argument:

   From a physical point of view it is justified to use a g.p.c. on-line in all those cases where in:

   a. for the sake of following the experiment, experimental control and steering, the immediate interpretation of intermediate experimental results requires complicated computations and data processing.

   b. large quantities of information have to be stored with a high speed and in such a manner that later economically off-line data reduction by a computer can be done.

2. financial argument:

   If the amount of money that must be invested in traditional analysers required for a certain range of experiments rises to such an extent that it is comparable with the cost of a g.p.c., then it is justified to apply a g.p.c. because of the much greater flexibility.

   For a greater flexibility, means a more economical use of the invested capital: the more flexible the information processing system is, the greater the variety of experiments which can be done with it.

Chapter 4. A SURVEY OF MINIMUM REQUIREMENTS

1. Minimum requirements of the computer as a whole.

Minimum requirements have been specified in order to be able to find out which computer could meet I.K.O.'s needs for on-line information processing and on-line computations as satisfactorily as possible. Below these requirements are listed while in a later section some specifications and motivations are given.

1.1. The computer must be a stored programme, general purpose, digital computer of modern design.

1.2. Its solid state components must be carefully packaged for resistance to electrical and magnetical disturbances.

1.3. It must be capable of operating 24 hours a day, 7 days a week, requiring only a minimum of maintenance. (required maintenance time will be less than 2 hours a day as an average).

1.4. The computer hardware and software must have special provisions for multiprogramming.

1.5. Furthermore the computer should be capable of:
performing real time operations;
rapid programme testing and diagnostics;
machine failure diagnostics with extensive indication on the operator console.

2. Minimum hardware requirements.

2.1. Central processor unit (c.p.u.)

a. it must work binary.

b. single word instructions have to operate on words with a length of approximately 25 bits (the required accuracy for on-line correction computations is of the order of 10^{-7}).

c. Fast hardware fixed point arithmetic must be available, fixed point multiplication time should be of the order of 30-50 microsec.

d. hardware for double precision instructions is necessary.

e. floating point hardware is absolutely required.

f. furthermore the instruction repertoire should include left and right, open and round shifts, logical instructions, jump instructions including subroutine jumps, jumps combined with automatic index register incrementation, condition setting and testing for all instructions, instructions for automatic array transfer in memory, from memory and to memory, address modification for all instructions.

2.2. Input/output channels and control (for motivations see chapter 5,1).

a. the i/o channels must have the possibility to be connected with asynchronous laboratory equipment.

b. the i/o channels have to be buffered.

c. as many as possible i/o channels should be available, all having direct access to mainstore, bypassing as much as possibly the c.p.u., such because of the great need for many simultaneous information flows between the computer and the experimental set up.

d. the i/o channels or the i/o control unit must be capable of sending an "end of record signal" to an external information source or to an external information acceptor.

e. the i/o control unit must provide external interrupt setting:
if external demands for interrupt of the c.p.u. arrive,
if an end of record signal is produced.

f. internal interrupt setting have to be executed:
if overflow is detected,
if case of different machine failures,
at the end of an array transfer.

2.3. Priority distribution by the c.p.u. (see rapport by v. Oers, Tjin A Djie and Jonkers).

It is extremely important that the computer can honor interrupts in a sequence according to a programme dependent priority distribution. It should be stated clearly that a fixed priority sequence is not acceptable because of the on-line application of the computer.

2.4. Multiprogramming.

Hardware programme relocation and multilevel indirect addressing

have to be available.
Because of the need for time-sharing and flexible switsching from one programme to another, memory protection, input-output device protection and register saving provisions are required.

2.5. Memory capacity.(for motivation see chapter 5,2)
In order to be able to use the computer on-line with the experiments planned in the I.K.O. laboratory a memory capacity of 16000 words is required.
It should be stated clearly here that it is better to save money by cutting off peripheral equipment from a certain configuration than by using only a 8 k memory capacity.

2.6. Memory extensions (for motivation see chapter 5.3)
At least 3 magnetic tape units with a speed in the order of 90-120 kch/sec are required.

2.7. Slow input/output equipment.
a. the console of the computer has to include a i/o typewriter.
b. further the configuration has to include a 5, 6 or 7 channel paper tape reader with a reading speed between 500-1000 ch/sec and a paper tape puncher (5,6 or 7 holes) with a punch speed of approximately 150 ch/sec.
If enough money is available then a line printer would be an extra-ordinary important tool for the institute.

2.8. The console.
The console has to provide display of all machine registers and failure testing results such as parity fault, overflow, etc.

3. Minimum software requirements.

3.1. Compiler.
An ALGOL 60 compiler and if available a FORTRAN compiler should be delivered with a set of numerical subroutines, defined in machinecode as well as in ALGOL or FORTRAN.

3.2. Monitor.

The software system delivered must also include a monitor programme which coordinates and supervises time sharing and memory sharing. The monitor must be capable of controling many simultaneously operating programmes which may be written in different languages. The monitor shall also include flexible input/output routines.

3.3. Documentation.

Of all delivered programmes, compilers and subroutines extensive documentation should be provided by the manufacturer. This requirement is very important indeed.

4. Further requirements.

4.1. Manufacturer settlement.

Because of the fact that for the on-line use of the computer new electronical interphases have to be developed by the manufacturer or in our laboratory it is highly desirable that there will exist a close coöperation between the manufacturer and our laboratory. Therefore the manufacturer should at least have a settlement in Europe.

4.2. Service.

Service and maintenance should be done by a permanent, on site engineer of the manufacturing company.

4.3. Spare parts.

Spare parts should not have to come from stores situated far away.

4.4. Computer documentation.

A complete set of circuit schematics, logic diagrams and other engineering information for servicing and modifying the equipment must be delivered with the computer.

Chapter 5. SOME MOTIVATIONS.

1. Input/output channels. (chapter 4, paraf. 2, 2.2.)

The i/o channels have to be buffered beoause asynchronous laboratory equipment has to be connected with these channels.
When the computer operates on-line with an experiment then, according to specifications formulated by MacLeod (CERN), several different types of work can be defined.
The computer has to perform the following jobs:

a. D.A. = data acquisition : the collection and storage of data produced by the experiment. Thisjob has to be done on a strict real time basis.
b. D.D. = data display: a part of the whole collected information has to be displayed for following and controling the experiment by the experimentator. In many cases it will be necessary to apply numerical corrections and other data reduction actions on the data before display.
c. C.C. = checking and control.
d. E.S. = experimental steering; the computer changes certain experimental parameters according to programme decisions.
e. S.C. = sample computation: computations that have to be applied on limited quanta of experimental data for the sake of compressing information before storage and for condensation of display information patterns.

All these jobs have to be done more or less simultaneously. That means that the corresponding programmes have to be executed by the computer on a time sharing and memory sharing basis.
In order to obtain a maximum of efficiency the computer configuration should include as many independent information i/o channels as possible.
For, the more channels there are (with direct memory access bypassing the c.p.u.), the more simultaneous automatic information transports can take place without disturbing the c.p.u.

2. Memory capacity. (chapter 4, paraf. 2, 2.5)
Below we shall quote a short report written by prof. E.W. Dijkstra.

Therein the minimum memory capacity requirements are given in case of the on-line use of the ElX8.

"In order to maintain a maximum data flow in a asynchronous application we consider the information flow in a period of 25 millisec. In case of 5 information transports an interrupt will be set every 5 millisec. Thus honoring one interrupt the computer needs approximately 0.5 millisec. for switching over from one transport to another. This implies a time consumption of 10 %.

In 25 millisec. a cyclotron experiment can produce approximately 500 words corresponding to 500 samples or less.

For memory buffer areas we need:

1 k buffer area for the cyclotron experiment (2 x 0.5 k for 2 bufferareas used alternately).

1 k buffer area for information transfer to the magnetic tape units.

0.5 k for the prepared display pattern when a pattern is chosen of 64 x 64 points. For display of a pattern of 128 x 128 points a memory capacity of 2 k is needed.

0.25 k as bufferspace for the slow communication equipment as tapereader, tape puncher, typewriter.

2.75 k or 4.75 k in total if a 128 x 128 point display is used.

Programme space:

0.5 k for tape handling programme including actions like read-write instructions for the tape unit, control of return signals, detection of end of tape signals and the announcements of it to the operator, tests for exceeding the block boumdaries and automatisation of repair actions as rewrite- reread in case of failure detection.

0.5 k for the console communication programme including translation and transfer of manually inserted information and analysis, and display of information given by the computer to the operator.

0.5 k for the coordinating programme which has to perform time sharing and memory sharing control, the change of priority

distribution as a function of internal and external criteria, and the honoring of signals produced by one or more real time clocks, etc.
This estimation is chosen very tight, especially when more is asked of the coordinator for instance in case of dynamical random supply and removal of programmes. This is very likely with for example programmes as data display, calculation programmes, different experimental steering routines, etc.

0.5 k for checking and control. For this job a set of non-systematical actions and reactions have to be performed by the computer. The more refinement is asked from the computer, the larger the required programme space will be.

1 k at least, for kicksorter programme including storage according to the partition method and corrections.

0.5 k for servicing the beta spectrometer.

0.5 k for working space of the coordinator, including the memory locations primarily assigned to the communication equipment containing: information concerning the state of the equipment and start and stop instructions for transfer.

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4 k

4 k for registering and kicksorting of coincidence spectra in a 64 x 64 points resolution.

10.75 k Total of buffer areas, programme areas and coincidence spectra areas"

If two or more pictures have to be displayed each approximately having a point density of 64 x 64, or if one such 64 x 64 raster has to be displayed combined with several single spectra, then the required memory capacity rises up to 12 - 14 k.
In these estimates no memory space was reserved for numerical data reduction programmes such as defined in l. e S.C.
All these considerations show clearly that a memory capacity of 8 k will never satisfy the needs which will rise when the computer will be applied on-line with the experiments planned in I.K.O.

3. Memory extension. (chapter 4, parf. 2, 2.6.)

In order to be able to store large quanta of experimental information, the memory capacity of the computer configuration has to be extended with at least 3 magnetic tape units.
It must be possible to operate 2 units simultaneously. Especially for sorting purposes it is very important to be able to write information on one unit while simultaneously new information can be transported from the other unit to the computer memory and vice versa. Also for D.A. it is very important to use two units in simultaneous operation for the sake of time saving.
Because of the fact that in general it is experienced that magnetic tape units are rather unreliable, a third unit is very desirable to be available in case of repair of the others.
The reading and writing speed should be approximately 90-120 kch/sec. because of the data flows expected by the experimentalists.

Chapter 6. COMPARING TABLE OF EL X8 AND CDC 3200.

	EL X8	CDC 3200
DATA STRUCTURE		
Word length in bits	27 + 1 parity	24 + 4 parity
Floating point radix	binary	binary
Floating point exponent size	sign + 11	11
Floating point mantissa size	2 sign + 40	sign + 36

	El X8	CDC 3200
CENTRAL PROCESSOR UNIT		
Arithmatic radix	binary	binary
Operand length in words per instruction	1 or 2	1 or 2
Instruction length in words	1	1
Addresses per instruction	1	1
Bits per address	15	15
Bits per function	12	9
Execution times in µsec.		
of: basic fixed add	2.5	2.5 - 2.9
basic multiply	30	8.75 - 12.6
basic divide	40	12
floating add	7.5 - 11.5	12
floating multiply	27 - 54	29
floating divide	67	29
Provisions for extended precision	yes	yes
Number of fully independent accumulators	3	2
Number of index registers	3	3, not equally usable
Multiple level indirect addressing	yes	yes
Separate float. point register	yes	yes, optional
Condition register	yes	no
Overflow register	yes	yes, not independent
Interrupt system with programmable priority distribution	yes	yes
Direct input access to index registers	yes	no

	EL X8	CDC 3200
MEMORY		
Type of memory	core	core
Access time	2.5 μsec.	1.25 μsec
Parity check	1 parity bit	4 parity bits
Minimum capacity, directly addressable	16 k	8 k
Maximum capacity, directly addressable	262 k	32 k
Automatic array transport from and to memory, bypassing the c.p.u.	yes	yes

MAGNETIC TAPE UNITS		type 604	type 607
Information density in symbols per inch	200, 556, 800 symb/i.	200, 556, 800	200, 556,800
Tape speed	$112^{1}/_{2}$ or 150 inch/sec	75 inch/sec.	150 inch/sec
Tape length	2400 feet	2400 feet	2400 feet
Tape width6	1/2 inch	1/2 inch	1/2 inch
Gap length	3/4 inch	?	?
Maximal block length	4 k words	?	?
Number of record tracks	6 inform.+ 1 parity	6 inform. + 1 parity	6 inform. + 1 parity
Longitudinal parity check after parts of blocks	yes	?	?

	EL X8	CDC 3200
PUNCHED PAPER TAPE READER		
Reading speed	1000 ch/sec	350 ch/sec.
Type of reader	photoelectric	?
PAPER TAPE PUNCHER		
Punching speed	150 ch/sec.	110 ch/sec

Chapter 7. MACHINE COMPARISON AND CRITICAL DISCUSSION.

7.1. Machine speed.

It can be stated in general that it is not justified to base a machine speed comparison on a consideration of the execution times of a few instructions.

Even the scientific mix indices do not give reliable speed ratio figures.

This general statement is underlined again when one compares the EL X8 and CDC 3200 execution times.

As is shown in chapter 6 the average instruction execution times are considerably shorter for CDC 3200.

However a more detailed study of the instructions repertoires of both machines has shown that in general the CDC 3200 needs 3-6 x as many instructions as the EL X8 to perform the same task. Thus, although the single CDC 3200 instructions are on the average 2-3 x as fast as the EL X8 instructions, the CDC 3200 is in fact about $1^{1}/_{2}$-3 x slower than the EL X8 in executing the same task. Moreover an other important shortcoming of the CDC 3200 in this respect concerns the memory capacity. When this capacity is limited it is a severe disadvantage that the CDC 3200 needs 3-6 x more programme space in memory. The memory capacity requires for on-line operation with the CDC 3200 can therefore be derived from chapter 5.2 and turns out to be, at a conservative estimate, 16.25 k.

7.2. Instruction repertoires.

The fact that the EL X8 has 12 function bits and the CDC 3200 only 9, indicates already that the instruction repertoire of the CDC 3200 must suffer from more restrictions.

In the first place this leads to the above mentioned very unpleasant effects.

An other consequence of these restrictions of the CDC 3200 is, that a number of programming methods can not be used. For example: indirect addressing and address modification are not applicable in case of the following instructions:

halt, selective jump, return jump, index jump incremental and decremental, load A character, load Q character, load index, store A character, store Q character, etc.

Therefore indirect addressing is impossible in programmes for data reduction and information transfer (in our case 70 % of all programmes).
Thus multiprogramming on a memory - and time-sharing basis is almost impossible, especially if programme locations have to be changed dynamically.
In contrast with the EL X8 the 3 B-registers of the CDC 3200 can not all be used equally.
There are several instructions that can only cooperate with one fixed B-register. This is a great disadvantage in formulating general saving rules for programme to programme switching or subroutine jumps.
With respect to the memory-register communication the floating point register E_u - E_l of the CDC 3200 can not be handled in the same way as its accumulators, the EL X8 floating point register can be used in the same way as the other accumulators.
Almost all instructions of the EL X8 can influence a condition register and can be carried out conditionally.
The CDC 3200 instruction repertoire includes only conditional jumps, increasing therefore the complexity of programmes considerably.

7.3. Input/output channels.

An advantage of the CDC 3200 is that there are more i/o channels available which have direct access to the memory (bypassing the c.p.u.). The CDC 3200 has one channel per 8 k memory capacity, with the EL X8 has one per 16 k.

7.4. Software.

Considering compilers it should be remarked that Electrologica has more experience in constructing ALGOL compilers than CDC has.
The quality of the ALGOL compiler that will be delivered by CDC in about one year is not yet known.
The quality of the FORTRAN compiler for the CDC 3200 could not yet be determined because not enough information was available.
The same holds for the monitor programmes.
The names and experience of the team leaders of the software

development groups who work for Electrologica do justify good expectations for this field.

7.5. Manufacturer settlement, cooperation with I.K.O.

Because of the fact that the Electrologica factories and laboratories are situated in Rijswijk and Amsterdam, and the CDC laboratories in America, it will be much more easy and cheaper to cooperate with Electrologica for the development of interphase hardware.
Also for the development of new software there are 3 groups in the Netherlands, situated in Amsterdam, Eindhoven and Utrecht, which can cooperate closely with I.K.O.
Also from the point of view of servicing and supply of spare parts the situation of Electrologica is advantageous compared with that of CDC.

7.6. Prices, a warning.

Both CDC and Electrologica have formulated and done some offers. When the prices of these offers have to be compared, one should never forget that CDC has not mentioned transport and insurance costs nor import duties.
These costs may rise to approximately 15 % of the total purchase price.