Version 31, December 2016 **E2X3**

Instruction sets and instruction times for the Elliott 400 Series computers.

Elliott 401.
The format of the 32-bit instruction is as follows:

10	3	3	3	3	10
A2	**S**	**F**	**D**	**C**	**A1**
Address of next instruction	Acc source	Op. code	Acc dest.	Control (K)	Operand address (also called *timing)*

The main user-accessible registers are:

R1 = accumulator;
R2 = accumulator extension;
R3 = Multiplier register, M;
R4 = general register X;
R5 = general register Y.

The 10-bit addresses A1 and A2 refer to locations on the 401's disc store. A 10-bit address is formed as three track-digits followed by seven location-digits. The {S, F, D, C} bits give about 28 useful operations, via the following combinations:

	S	**F**	**D**	**C**
000	Nowhere	ADD	Nowhere	Normal
001	All ones	MPY	Round off	Test acc negative
010	Input	Left shift n	Output	Test acc zero
011	R3	Shift right n	R3	Use R3 to modify
100	R4	LOAD	R4	Use R4 to modify
101	R5	NEQ	R5	Use R5 to modify
110	Memory	SUB	Memory	Double length
111	Handkeys	AND	Track 7 switch	Optional stop

Some combinations are forbidden, for example {6, -, 6, -} which attempts to specify memory as both the source and destination. Further explanation of some of the Elliott 401 instructions is now given.

- The *NEQ* instruction is the logical *Not Equivalence* operation, also called *Exclusive OR.*

- The Handkeys signify a 32-bit value set up manually via switches.

- When shifting the accumulator up or down arithmetically by n places, the value of n is given by the difference (A2 – A1).

- During multiplication, the contents of R2 are multiplied by the contents of R3, leaving the product (62 digits plus a sign digit) in R1 (more significant half) and R2 (less significant

half). If only the most significant half of a product is required, round off may be used. The product, rounded to 31 binary places, is then placed in R1.

- When using the *Double Length* indicator, R1 and R2 together form a two-word accumulator.

- When using the *Optional Stop* indicator, the computer will halt before obeying the instruction and wait until the operator presses the single-shot key on the control console. The machine can be set to ignore *Optional Stop* instructions by depressing a switch on the console.

Selecting the *Input* combination of the S-bits in an Elliott 401 instruction causes a row to be read from the 5-track Tape Reader and the tape to be advanced by one row. The integer represented by the 5-bit combination is placed in the least significant end of the accumulator. When the O*utput* combination of the D-bits is selected, either a paper tape punch or a typewriter (teleprinter) is activated, the choice being determined by the setting of a manual switch on the equipment. In either case, the least-significant five bits of the accumulator are either punched on 5-track paper tape or printed as an alpha-numeric character on a page.

Further instruction set details are given in:
http://www.ourcomputerheritage.org/ccs-e2xtra4.pdf
where a reproduction of an original 401 programming manual will be found.

Elliott 402.
The Elliott 402's 32-bit instruction had a similar format to that of the 401 given above. As before, the format included ten bits of operand-address and ten bits for specifying the address of the next instruction. However, with the 402 the first 16 addresses 1 to 15 were mapped onto 15 fast registers called the *Immediate Access Store* and the handkeys were mapped onto address 0. This eliminated the need to refer explicitly to the 401's named registers R4 (X) and R5 (Y) and thus allowed the S-field and the D-field to be reduced in size. The remaining 12 bits of the 402's instruction were re-allocated into five fields, of which the B-field allowed seven of the 15 fast registers (IAS) to be used for address-modification (B = 0 indicating 'no modification'). The layout was as follows.

10	3	3	2	2	10	3
A2	**S**	**F**	**D**	**C**	**A1**	**B**
Next-instruction address	Acc source	Op. code	Acc dest	Control	Operand address	modifier

Actually, the fields were physically arranged in a slightly different order as follows, assuming the least-significant end of the word is at the right-hand side:

<**A2**> <**S**> <**F**> <**D**> <**A1**> <**C**> <**B**>

The new repertoire of ALU operations was defined for the Elliott 402 as follows (*see next page)*:

	S	F	D	C
000	Zero	ADD	Nowhere	Normal
001	M register	MPY or DIV	M register	Test negative or Divide
010	Memory	Left shift n	Memory	Count
011	Input	Shift right n	Output	Track 7 switch
100	-	LOAD	-	-
101	-	AND	-	-
110	-	SUB	-	-
111	-	Negate	-	-

Further instruction set details are given in:
http://www.ourcomputerheritage.org/ccs-e2xtra4.pdf
where a reproduction of an original 402 programming manual will be found.

Elliott 403.
The Elliott 403 had three visible index registers (B-lines), pre-selected by program from four sets held in the 12 fastest storage locations (single-word nickel delay lines) of the 512-word *Immediate-Access* store. For B1 and B2, digits 20 – 32 are added to the current instruction, thus modifying the Function (op code) and operand-address fields. If B3 is specified, the address of the next instruction (not to be confused with the next word) is added to the current order's address digits.

The 403's 17-bit instruction was laid out as follows:

5	9	2	1
F	**A**	**B**	**C**
Op code	Operand-address	Modifier register	Code

When C = 0, the instruction refers to arithmetic operations. When C = 1 *input/output transfer* instructions are specified, as described later.

When C = 0 there are 32 ALU instructions as specified by the F bits, most of them acting variously on the double-length and single-length accumulators. The accumulator-based repertoire includes:

Add; Subtract; Clear; Clear and Add; Clear & Subtract; Store;
Swap – (ie, swap the contents of the accumulator with the contents of a store address);
AND; Logical shift left; Logical shift right; Multiply; Divide; Normalize.

Unlike the other computers in the Elliott 400 series, the 403 has three instructions relevant to multiplication, whose action is as follows:

SET MULTIPLIER REGISTER. This loads the multiplier register R with the contents of a specified memory location. This is the only means by which a programmer can refer to the multiplier register.

MULTIPLY and ADD. The contents of a specified memory location is multiplied by the number in the multiplier register R and the 66-digit double-length product is added to the accumulator.

MULTIPLY and SUBTRACT. As above, except that the product is subtracted from the accumulator.

Additionally with C = 0, the Elliott 403 has six *test and jump* instructions involving tests on the contents of the accumulator and two *test, jump and count* instructions involving the contents of modifier registers (B-lines). There are two instructions for loading a value from memory into a selected B-line. Each B-line was 17 bits (defined as the *even* half of a word).

Finally with C = 0, the Elliott 403 has a special *Use Logic* instruction. To quote the original programming manual reproduced at http://www.ourcomputerheritage.org/ccs-e2xtra4.pdf
"One special order is reserved in the 0-code orders to determine the mode of operation of the machine. Allowance has been made for up to 8 different modes of operation, each one of which may be sub-classified in 64 ways. Only one mode has been attached to [ie implemented in] the machine to date, namely, the 'use B-lines' mode". This instruction configures various B-line options, namely:

a) specifies the group of three B-lines, from the four available groups, which will be switched to high speed store addresses 1,2,3 respectively;
b) specifies the B-line to which various *test-and-jump* instructions apply;
c) specifies the two B-lines which may be added together before being used as modifiers.

When C = 1, the machine obeys one of 32 Input/Output instructions as specified by the five F bits. The repertoire includes:

four instructions for handling slow, 5-bit, input/output;
16 instructions for handling magnetic tape input/output;
two instructions for transferring 64-word blocks of data to/from the disc.

The reason why there were as many as 16 magnetic tape instructions is that, originally, the Elliott 403 had a single magnetic tape control channel. A second, independent, channel was then introduced. It was decided to dedicate new instructions to the second channel so as to preserve the integrity of pre-existing program code.

Further instruction set details are given in:
http://www.ourcomputerheritage.org/ccs-e2xtra4.pdf
where a reproduction of an original 403 programming manual will be found.

Elliott 405.

The 16-bit instructions for the Elliott 405 are packed two to a word. The machine obeys first the one in the most significant half (i.e. the one which occupies digit positions 17 to 32), and secondly the other which occupies positions 1 to 16. The Elliott 405 instructions were divided into two groups, distinguished by the setting of the least-significant bit, denoted as C. When C = 0 the format was:

4	9	2	1
F	**A**	**B**	**C**
Op code	Operand address	Modifier register	0

The Elliott 405 had 16 computational instructions, denoted as *0-codes*, for which C = 0. Briefly, these acted as follows:

(a). Operations between the contents of the accumulator and the contents of a memory address:

Add, Subtract, Reverse subtract, Multiply, Divide, AND, Swap (ie exchange), Load. Note that both single- and double-length multiplication are available. For double-length, the remaining 31 digits of the full product are left in *Immediate Access Store* location 3. The type of multiplication is set by a *1-Code* instruction – see below. Once double length working has been set, all subsequent multiplications will be double length until another order resets to single length working. Multiplication instructions take 33 word times. The Elliott manuals contained a special warning for the Divide instruction, as follows: "the logical process involved requires that the divisor be or be made greater in absolute magnitude than the dividend before division takes place. The result may be in error by up to 2^{-31} so that if the actual divisor is a factor of the dividend, the result may be slightly different from the true result. This order takes 33 word times".

(b) Operations on the accumulator involving a constant (literal): Logical left shift n times ($1 \leq n \leq 16$); Logical right Shift n times ($1 \geq n \leq 16$); Multiply by n (where n = 0, 2,4,8,10,12). This last instruction is designed to speed number-conversion in decimal or sterling calculations.

(c) Control transfer instructions: unconditional absolute jump; absolute jump if Accumulator is negative; absolute jump if the contents of address (1) is zero and add 2^{-12} to address (1) in any case.

(d) Move instructions: these permit any block of 16 words to be moved to any other block-position in primary memory, the size/position being chosen so as to correspond to one of the 16-word nickel delay lines making up the memory. One *Move* instruction covered the address-range 0 – 255, another *Move* instruction covering the range 256 – 511. There was an oddity if the lowest block ('line 0') was specified. Locations 0 – 3 of block 0 are not part of the *Quick Access Store*, since addresses 0 – 3 designate the number generator (0) and *Immediate Access Store* locations 1 – 3. These four addresses are known as 'ghost locations'. (If the contents of any other block are transferred to block 0, the first four words pass into these ghost locations and remain there unaltered until the whole block is again transferred elsewhere. The only arithmetic functions in which the contents of the ghost locations can take part immediately are Multiplication and Division).

When C = 1, the so-called *1-Code* instructions mostly concerned input/output transfers and backing-store activity. An exception is a group of three *1-Code* instructions that are strictly part of normal computational activity. These three are placed in a group known as *Overall Machine Control* in the Elliott 405 literature, for which the S-bits (see below) are set to the value 7. The three instructions are:

Set single length multiplication.
Set double length multiplication.
Set link. This stored the contents of the Program Counter (called the *Sequence Control Register*) in memory location 1.

The general 16-bit format for *1-Code* instructions for the Elliott 405 is as follows:

9	3	3	1
N/T	**F**	**S**	**C**
Number/mechanism	Function	Unit	1

The S-bits are assigned as follows:

S = 0: a group of instructions for handling input from paper tape and punched cards.
S = 1: a group of instructions for character-based output to paper tape, typewriter or magnetic film.
S = 2: a group of instructions for block transfers (64 words) to/from disc or drum.
3 ≤ S ≤ 3: a group of instructions for block transfers to/from magnetic film.
S = 7: the three *overall machine control* instructions described above.

As might be deduced, only some of the possible combinations of the N/T, F and S bits are assigned, thus allowing for future expansion if new devices were to be introduced for the Elliott 405. Further details are given in http://www.ourcomputerheritage.org/ccs-e2xtra4.pdf where a reproduction of an original 405 programming manual will be found.

Instruction times for the 400 series.

The times are dependent upon a number of factors and particularly upon the physical location and relative addresses of instructions if a sequence of, say, ADD orders are being executed. For example, there was much more opportunity for producing fast inner loops of time-critical instructions in the Elliott 403 computer than in the 402.

The following times in milliseconds are indicative.

		401	*402*	*403*	*405*
Fixed-point ADD:	minimum	0.204	0.204	0.204	0.306
	maximum	13.204	13.204	*(see below)*	10.71
Fixed-point MULTIPLY:	minimum	7	3.3	3.3	3.3
	maximum	23	16.3	*(see below)*	?

Reference [15] gives the following instruction times for the Elliott 403:

Addition, logical operations, etc.:	0.102 to 0.408 milliseconds.
Multiplication:	1.738 milliseconds.
Division:	3.468 milliseconds.
Square Root (Programmed):	7 to 15 milliseconds.