

USERS' GUIDE FOR ee9: AN ENGLISH ELECTRIC KDF9 EMULATOR

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0: INTRODUCTION

This document is a guide for users of **ee9**, a program emulating the EE KDF9 computer. Readers not yet familiar with the KDF9 should consult the companion document, *The English Electric KDF9*; you will be referred to the 'Manual' for further details; this is the *KDF9 Programming Manual*, the nearest thing we have to a definitive reference work. **ee9** is intended to be portable to any system with a basic POSIX API. It is written in Ada 2012 using GNAT, the GNU Ada compiler and is available for a range of computer architectures and operating systems. For the characteristics of this version, see §6.

1: USING ee9 CONVENIENTLY

ee9 can be invoked directly, but it is very much easier to use the shell command files described in this section. The default setup runs them in the directory **Testing**, so **Testing** should be in your search path to make them visible to the shell. That is what the following descriptions assume. However, they can be used elsewhere so long as you establish a compatible execution environment: see Appendix 1 and §3.1, *inter alia*.

ee9 uses the Latin-1 character set and requires the terminal window background to be set to a colour other than black or red; white gives the best approximation to the appearance of KDF9's console Flexowriter printout.

Using these commands on Microsoft Windows requires a **bash**-compatible shell, although you might run **ee9** itself without one. See the 'm' visibility option (§5) to suppress SGR codes in a Windows command line that lacks ANSI terminal support.

A list of **ee9** error messages and explanations is given in Appendix 8.

```
nine prog [data| - ] [mode| - ] [miscellany| - ] [tt [tt ]]
```

nine runs the KDF9 machine code program *prog*. The executable is taken from **Binary/prog**; the data for paper tape reader 1 (TR1), if specified, is taken from **Data/data.txt**. A parameter may be given as '-' if it is not needed but a later parameter must be specified. For a first go, all the optional parameters can be omitted, as they default wisely.

The allowable execution *mode* characters (see §2.1) are:

- **f**: for fast mode, the default (if **f** is explicitly specified, the real CPU time for the run is displayed on termination)
- **p**: for pause mode
- **t**: for trace mode
- **x**: for external trace mode

The allowable characters in the optional *miscellany* parameter are described in §5.2.

The parameters *tt* specify the character codes to be used by either one or two paper tape punches (the first *tt*), or paper tape readers (the second *tt*). *tt* is either one or two characters, each being either k/K or l/L, specifying KDF9 paper tape code or Latin-1 code respectively. If *tt* is one character, it refers to unit 0 of the type (i.e. TP0 or TR0). If *tt* is two characters, the first refers to unit 0 and the second to unit 1 of the type. The default code is Latin-1. See also §3.4 and Appendix 2.

```
tsdnine prog [data| - ] [mode| - ] [miscellany| - ] [tt [tt ]]
```

tsdnine runs the named program with any data supplied as TR1, under the control of Time Sharing Director (the original KDF9 operating system from English Electric). The parameters are as described for **nine**. See Appendix 9 for a primer on console operating with the Time Sharing Director. (Before booting the Director, **tsdnine** runs the **RLT** program to ensure that the magnetic tape files have valid labels; see Appendix 11.)

Binary programs for execution by **nine** or **tsdnine** can be created by compiling Usercode or Kidsgrove Algol sources.

```
ucc prog
```

ucc compiles a Usercode source program using the **kal3** assembler. The source code is taken from **Assembly/prog.k3** and the object program is placed in **Binary/prog**; a compilation listing is stored in **Assembly/prog-listing.txt**.

kalgol prog

kalgol has one parameter, the name of an Algol source program held in Kidsgrove/*prog.a60*. The *mode* and *miscellany* parameters for the *compiler* may be given in the environment variables KIDSMODE and KIDSMISC. By default KIDSMISC=w to suppress the compiler's voluminous Flexowriter output. The Usercode object program is left in Assembly and the executable binary in Binary. See Appendix 12 for more help with Algol.

kids prog [data | -] [mode | -] [miscellany | -] [tt [tt]]

kids both compiles and runs a Kidsgrove Algol program (using **kalgol** and **nine**). It is not necessary to recompile a Kidsgrove Algol program each time you run it, although it normally takes only a fraction of a second to do so. The executable object program left in the Binary directory can be run using the **nine** command in the usual way. To compile a Kidsgrove Algol program without running it, use the **kalgol** command.

nine_test prog [data | -] [mode | -] [miscellany | -] [tt [tt]] }

nine_test operates like **nine**, except that the program in Binary/*prog* is executed in **test program** mode.

crnine prog [data | -] [mode | -] [miscellany | -]

crnine operates analogously to the **nine** command, except that the data, if specified, is made available via the punched card reader file, CR0.

whet prog [mode | -] [miscellany | -]

whet runs the Whetstone Algol system on the Algol program and its stream 20 data, given consecutively in the single file Whetstone/*prog.a60*. They are read respectively by the Translator (compiler) and the Controller (interpreter). See Appendix 12 for more help with Algol.

stone [1964 | thecrows]

stone runs the Whetstone Benchmark program using **whet**. If 1964 or thecrows is given it runs in authentic timing mode; in other words, as slowly as Whetstone Algol did in 1964 on a real KDF9, taking about 7 minutes of real time.

sttl prog [store [time]]

sttl uses the **sed** stream editor to amend the ST (store size) and TL (time limit) fields of the Usercode object program generated by **kalgol**. If the *time* parameter is omitted, a value of 3000 seconds is used. If the *store* parameter is omitted, a value of 7680 words is used.

strop prog

strop uses the **sed** stream editor to do most of the work of converting an Algol program in Whetstone format to Kidsgrove format. It takes the name of a program file in the Whetstone directory and writes the converted program to a file of the same name in the Kidsgrove directory. The latter may need a little tidying-up before it passes compilation by **kalgol**.

ports prog

ports (**strop** backwards) uses the **sed** stream editor to reverse the transformations made by **strop**. It takes the name of a program file in the Kidsgrove directory and writes the converted program to a file of the same name in the Whetstone directory. You may find that a more convenient way of typing in a new Whetstone program, because using the Flexowriter-style underlining for reserved words is both tedious and error-prone.

2: EMULATION MODES

2.1: DIAGNOSTIC MODES

A KDF9 program is run, at option, in one of four **diagnostic modes**. These are:

- **fast** mode; in which **ee9** runs the program at maximum speed, with no execution tracing or interactive diagnostic facilities available
- **pause** mode, in which **ee9** single-shots the program, pausing to interact with the user after each instruction
- **trace** mode, in which **ee9** runs the program at speed with extensive retrospective tracing enabled
- **external** trace mode, in which **ee9** writes a summary of every traced instruction to an external file

More precisely, things work as follows.

In fast mode **ee9** interacts with the user only by providing informative messages, either because the KDF9 program has terminated, or to log significant events during the run (such as the allocation of an I/O device). All tracing overhead is avoided in fast mode.

In pause mode **ee9** uses console-window text I/O to interact with the user. After each instruction is executed a short summary of the machine state is displayed and a prompt asks the user how to continue. The user replies with an optional single letter (which may be given in upper case or lower case) followed by RETURN, selecting one of the following:

- **f**: execution proceeds in **fast** mode
- **p**: execution proceeds in **pause** mode
- **t**: execution proceeds in **trace** mode
- (nothing): execution proceeds in the current mode.

All retrospective tracing types described in §4 are available in pause mode, trace mode, and external trace mode; but the manner of execution depends on whether the current instruction execution lies within a set range of addresses, and within set instruction-count bounds. If so, instructions are added to their appropriate traces; and breakpoints and watchpoints are monitored. If not, execution proceeds as in fast mode (but at about a third of the speed).

2.2: RUN STATES

The run state specifies how the emulated KDF9 is to run the program:

- In **boot** mode the KDF9 reads a 9-word bootstrap routine from TR0, then jumps to word 0, in **Director** state.
- In **problem program** mode **ee9** reads into core, from TR0, a binary program prepared by a compiler. Its execution starts at word 0, in **program** state. **ee9** itself implements any OUTs (system calls) requested by the program, so that it is not necessary to have a Director running.
- In **test program** mode **ee9** reads a binary program into core from TR0, just as in problem program mode. Its execution starts at word 0, but in **Director** state. The emulator implements any OUTs requested by the program.

2.3: BREAKPOINTS, FETCHPOINTS, STOREPOINTS, AND WATCHPOINTS

Certain addresses in core can be marked as breakpoints or as watchpoints, to force diagnostic interaction with the user. A **breakpoint** is set on an instruction word, and causes interaction after an instruction beginning in that word has been executed. A **fetchpoint** is set on a data word, and causes interaction after data has been fetched from that word. A **storepoint** is set on a data word, and causes interaction after data has been stored into that word. A **watchpoint** combines a fetchpoint and a storepoint on the same word.

2.4: AUTHENTIC TIMING MODE

At option, **ee9** can be made to insert timed pauses into its execution so that the elapsed time of a program run by **ee9** approximates the elapsed time of a run on the real KDF9 hardware. This may be instructive for younger users, who have never seen characters being output by a computer, one at a time, and with noticeable delays! This mode can be set using the authenticity setting, see under ‘A’ in §5.1, or by means of the command-line miscellany parameter **t**; see §5.2.

3: INPUTS AND OUTPUTS

3.1: EMULATED KDF9 I/O DEVICES

At the start of a run **ee9** looks in the current directory for files to represent the KDF9 peripherals. There is a fixed assignment for the console Flexowriter, which is associated with the user’s interactive terminal window. Other devices are associated with files having names derived from the device type. Magnetic tape deck *d*, for example, is always associated with the file named MT*d*. The full list of these associations is as follows:

- a card punch is CP*d*
- a card reader is CR*d*
- a drum store is DR*d*
- a fixed disc store is FD*d*
- a graph plotter is GP*d*
- a line printer is LP*d*
- a KDF9 type 1081 magnetic tape deck is MT*d*
- a Standard Interface device is SI*d*
- an IBM-compatible seven-track tape deck is ST*d*
- a paper tape punch is TP*d*
- a paper tape reader is TR*d*

Every device file actually used in a run must exist, and be appropriately accessible, when **ee9** is invoked. A magnetic tape file, if not completely empty, must have a valid label block. (See **RLT** in Appendix 11.) The assignment of devices to buffers (KDF9 DMA channels) is set by default, but can be changed by the user (see the K option in §5.1).

3.2: THE FLEXOWRITER CONSOLE TYPEWRITER

The terminal window is the means by which users, in their rôle as KDF9 operators, can mimic Flexowriter I/O. The Flexowriter is used to type-in responses to prompts output by problem programs or by Director. Repeatedly typing these responses quickly becomes tedious. If a file named FW0 exists, it is used as a source of “canned” responses. They are defined, with their identifying prompts, in FW0; and are picked up automatically by **ee9**. If a prompt spreads over more than one line, a KDF9 Line Shift can be represented in FW0 by a ‘®’, and a KDF9 Page Change by a ‘©’.

When a prompt is issued, **ee9** scans FW0, down from the last match found. If it finds a new match, it injects the given response into the Flexowriter input stream; but if it reaches the end of the file without finding a match, it returns control of the Flexowriter to the user’s terminal window, so that a manual response can be given. If a prompt matches a line in FW0 that specifies a null response string (c.f. the second ‘OUT;’ in the following example) then **ee9** terminates the run.

For example, the Whetstone Algol compiler prompts ‘OUT;’ to which a typical reply is ‘N. |’. If the Algol program compiles, it runs and prompts ‘STREAM;’ to which a typical reply is ‘30. |’; but if the compilation fails the compiler loops back to its ‘OUT;’ prompt, where the user will normally want to terminate the run so that the Algol source code can be amended. The following data in FW0 will achieve this without user intervention:

```
OUT;N. |
STREAM;30. |
OUT;
```

For a second example, as the Time Sharing Director bootstraps it issues a series of requests for basic configuration parameters. The following data in FW0 supplies suitable responses without user intervention:

```
CORE MODULES;8. |
OUT 8 REEL NO;9. |
LEVELS;N. |
DATE D/M/Y;4/5/67. |
TIME ON 24-HOUR CLOCK@HOURS/MINS;1/23. |
```

This facility had a real equivalent: the Flexowriter incorporated an ‘edge-punched card’ reader. It read data (in paper tape code) from the edge of a non-standard punched card. Cards prepared with replies to prompts could be inserted into the reader and read at the maximum rate, thus speeding input and avoiding any delay due to typing errors by the operator.

Note that ee9 requires every Flexowriter input string to be terminated by a RETURN, even when a read-to-End Message instruction is being obeyed. In reality, KDF9 would end the transfer immediately at the End Message, or when the required number of characters had been read; but data is not transferred to **ee9**’s input buffer until a RETURN is typed. A merely terminating RETURN is discarded from the input by **ee9**, and is not passed to the KDF9 program.

In response to CTRL-C, **ee9** outputs a prompt of its own that lets the diagnostic mode be changed. Replying with a RETURN (only) causes a FLEX interrupt; when running Director in boot mode, this evokes a ‘**TINT**’ prompt.

Output to the Flexowriter was typed in red; input from the computer operators in black. This is simulated in **ee9** by using ANSI-standard SGR escape sequences to vary the displayed font style. Some Windows terminal utilities do not implement SGR escape sequences, so Flexowriter output styling can be disabled with a miscellany parameter or a settings file option.

3.3: READING MORE THAN ONE ROLL OF PAPER TAPE OR DECK OF CARDS

A means is provided to simulate the way in which KDF9’s computer operators could satisfy a program’s demand for data with several physically-separate rolls of paper tape or decks of cards, loaded into a reader in succession. If a program attempts to read from a tape reader, and the end of the associated file has been reached, **ee9** allows the user to specify a successor file to which the tape reader is re-attached. A prompt requesting more data is displayed. If the user responds ‘=’ then the tape reader is connected to the user’s terminal so that the data may be typed then and there. If the user responds ‘/’ then the pathname of a file supplying the next “roll of tape” may be specified: **ee9** asks for the name *n*; if it is not readable the tape reader is left in the ‘abnormal’ condition and any further attempt to read from it provokes a parity error. If the user responds ‘@’ then the name of a file within the directory specified by the KDF9_DATA environment variable may be specified: See Appendix 1. See also the **N** option in §5, about disabling this feature in non-interactive mode. The foregoing also applies, *mutatis mutandis*, to the punched card reader, CR0.

Examples (user’s responses in **green**):

1.
ee9: Type @ or / to name a file, = to type in the data, or ENTER key for EOF: =
ee9: Type the data for TR1:
3|
2.
ee9: Type @ or / to name a file, = to type in the data, or ENTER key for EOF: /
ee9: Give the pathname of the file: **../next.txt**
The KDF9 operator must have made a mistake: ../next.txt cannot be read.
3.
ee9: Type @ or / to name a file, = to type in the data, or ENTER key for EOF: /
ee9: Give the pathname of the file: **Data/next.txt**
4.
ee9: Type @ or / to name a file, = to type in the data, or ENTER key for EOF: @
ee9: Give the name of a file in Data/: **next.txt**

3.4: REPRESENTING THE KDF9 CHARACTER SETS

The KDF9 had its own, somewhat idiosyncratic, character sets. They are tabulated in Appendix 2a. For the convenience of the user, external data read and written by the paper tape readers and punches may be represented in either KDF9 paper tape code, or in the ISO Latin-1 character set with automatic conversion between Latin-1 and KDF9 codes. Several characters in the KDF9 paper tape set are absent from Latin-1, so a simple transliteration is used to represent them externally.

For the Flexowriter, and for Latin-1 I/O with tape punches and tape readers, Case Normal and Case Shift characters are generated on input, and interpreted on output. This means that when you are typing an input text, it is not necessary to type Case Normal and Case Shift characters, although there usually is no harm in doing so. When such a text is being read as the input stream for a two-shift device, an appropriate case-character is generated automatically by the emulator, if the Latin-1 character being read is not available in the input device’s current shift state. Two-shift output works in the complementary manner. Two-shift devices always start out in the Case Normal condition.

For example, the external Latin-1 string ‘Bill Findlay’ may be read into the KDF9 core store as the characters ‘BBILL ñFBINDLAY’, with ß denoting the Case Shift character and ñ denoting the Case Normal character. A KDF9 program that writes the characters ‘BBILL ñFBINDLAY’ to a two-shift device in Latin-1 mode will generate the Latin-1 string ‘Bill Findlay’ as its external representation.

Text-file input to **ee9** may use any of CR, LF, or a CRLF pair as the line terminator: **ee9** treats all three the same. Text-file output from **ee9** writes the line terminator most appropriate for the host’s operating system.

Non-graphic KDF9 characters also have Latin-1 external representations, to enable 1-to-1 inter-conversion between the internal and external data formats. Apart from the format effectors (Horizontal Tab, New Line, Form Feed), users should never need to type these characters, as they could not be typed on a Flexowriter.

In KDF9 mode, characters are transmitted verbatim using the KDF9 paper tape format, in which devices use an 8-bit byte externally, supplementing the 6 internal data bits with two ‘parity’ bits (see also the Manual, §17.4 and Appendix 2b).

KDF9 object programs are never given in Latin-1, but always natively, in the KDF9 paper tape code.

Characters displayed in tracing output are shown using their Case Normal Latin-1 transliterations, except as follows:

- the KDF9 Horizontal Tab character is depicted as **␣**
- the KDF9 Line Shift or LS character (Carriage **R**eturn) is depicted as **®**
- the KDF9 Page Change or PC character (Form Feed) is depicted as **©**
- the KDF9 Filler character is depicted as **∅**

These depictions are also used by the card reader and card punch. Card images of less than 80 characters are padded with blanks to fill all 80 columns; any input line longer than a card is truncated to 80 characters. In ‘direct’ mode, card images may have up to 160 characters, notionally two per card column. The card punch writes files that are valid as input to the card reader and can be read to exactly reproduce the original data in core.

The representation of magnetic tapes is described in detail in Appendix 10.

Drums and disc drives are represented as plain POSIX files using the Latin-1 Case Normal transliteration. Sector boundaries are not explicitly represented: they are implicit in the data address within the POSIX file, occurring every 320 bytes for disc drives and every 1024 bytes for drums.

3.5: GRAPH PLOTTING

ee9 includes an emulation of the model 564 Calcomp graph plotter, as described in Appendix 6, §5, p.302 of the Manual (but see what I say about this in §6: Caveats, and in Appendix 3). There was provision on the KDF9 to switch a buffer manually between a tape punch and a graph plotter; in **ee9** this is done with **g** in the *miscellany* parameter, with a settings file option **G**, or with a settings file option **K**. When one or more of these is given, GP0 replaces TP1 on the shared buffer. In non-boot modes the buffer automatically switches when the running program requests the allocation of a graph plotter, even when none of these options specified.

The KDF9 graph plotter takes commands that move the plotting position in steps of 0.005 inches; see Appendix 3 for the command codes. Steps are accumulated into vectors by **ee9**, and PostScript vector drawing commands are output to GP0, creating an Encapsulated PostScript (EPS) file. It is possible to fit the plotter with ‘pens’ having a variety of ink colour and ball-point tip size. See under **G** in §5.

4: LOGGING AND TRACING

Messages that record the progress of the emulation, and details of any errors that were detected, are written to the interactive console window, along with interactive diagnostics and output produced for the KDF9 Flexowriter. A selection of these messages is also written to the file `KDF9_log.txt`. On completion of a run, the final machine state, any requested core store areas, and any retrospective traces may be written to the log file and to the console window.

It is possible to request the output of certain areas of the KDF9’s core store, in a variety of suitable formats. These printouts can be taken either before the start of execution; or on termination; or at both times, to allow comparisons.

In the **interrupt** trace, which is produced only in boot mode, interrupt requests are listed with the privilege state and priority of the interrupting device; the elapsed time of occurrence (in μ s); and the value of ICR, the Instruction Count Register, which is a count of the number of instructions executed so far. The interrupt trace also logs EXITD, return from interrupt, instructions.

The tracing of executed instructions is subject to instruction-count and address-range bounds. Instruction executions within those bounds are traced; those that fall outside the bounds are not.

In the peripheral I/O trace, the events shown are transfer initiations and terminations, busy-buffer and store-access lockouts, and I/O status test operations. Each is listed with the device name, Q-store parameter, privilege state (P for problem program state and D for Director state) and priority of the transfer; the elapsed time of occurrence of the event; and the current instruction count.

The C part of the parameter used in a disc seek operation is logged in the format `DdPppSss`, where *d*, *pp* and *ss* are, respectively, the drive number, platter number and *seek area* number being addressed. In a disc data transfer *d* and *pp* are irrelevant and *ss* is the starting *sector* number for the transfer.

The C part of the parameter used in a drum transfer is logged in the format `SECTsssDd` where *d* and *sss* are the drive number and the starting sector number.

Transfer operations appear twice, once for the initiation (S) and once for the termination (E). Lockouts appear once, when they happen. A test operation gives the result of the test as a Boolean.

In the retrospective trace, instructions are listed in order, starting with the most recently executed. The trace includes the instruction itself, and its most relevant operand; ‘ND’ and ‘SD’, the Nest and SJNS Depths; ‘V’ and/or ‘T’ showing whether overflow and/or the test register is set; the CPU time of occurrence of the event; and the value the current instruction count. In the case of a store order, the traced operand is the value written to store. In the case of a fetch order, it is the value fetched. For a Q-store order, it is the content of the relevant Q register. For a conditional jump it is the determining value. For subroutine jump or exit, it is the relevant value in the SJNS. For a 1-syllable or 2-syllable ALU order, it is the value left in the top of the nest. And so on.

External trace mode is like retrospective mode, with additional output to the file `trace.txt`. This output has one line for each traced instruction. It contains: the instruction’s address; the value of ICR; the CPU time; the nest depth; the SJNS depth; ‘V’ and/or ‘T’ if overflow and/or the test register is set; the value in N1, if the nest is non-empty; and the disassembled instruction.

When tracing, and if requested, **ee9** will tally the number of traced executions of each type of KDF9 instruction. On termination of a run a histogram of dynamic instruction-type frequencies may be logged. A similar plot may be produced showing the frequency with which each instruction-containing word is executed.

At option, all tracing modes can compute a digital signature of the execution: a 48-bit cumulative hash, displayed in octal, of the contents of all the relevant KDF9 registers (nest, SJNS and Q stores) at the end of each traced instruction. Known values for this hash can be used to verify the proper operation of an implementation of **ee9**. (When the signature is enabled, the starting time-of-day is forced to midnight, to ensure a repeatable hash value.)

For examples of the output that can be obtained using these facilities, see Appendices 7A-7G.

5: THE MODE SETTINGS FILES AND THE MISCELLANY PARAMETER

The emulator has default settings for all of its options, but they may be over-ridden by settings specified in files that the emulator attempts to read as part of its initialization, and/or by specifying a miscellany parameter on the command line.

5.1: SETTINGS FILES

The file `settings_1.txt` applies to a first or sole program to be run, and `settings_2.txt` applies to a second program overlaid by it (e.g. the Whetstone Controller, overlaid after a successful compilation by the Translator). A setting specified by the command line over-rides a similar option specified in the `settings_1.txt` file.

The settings files contain a line for each option to be set, beginning with a letter that specifies the option concerned. This may be followed by one or two parameters. Numbers may be given in octal—preceded by a hash sign ('#')—or in decimal; and this convention is also used systematically in output messages from the emulator. The options are presented here in upper case, but lower/mixed case is also accepted. The available options are as follows:

A MODERN_TIMES_MODE | AUTHENTIC_TIME_MODE

The **A** flag sets aspects of the AUTHENTICITY of execution. It takes one symbolic parameter. It is possible to set authentic elapsed timing (see §2.4), with the AUTHENTIC_TIME_MODE parameter; in MODERN_TIMES_MODE emulation proceeds at the full speed of the host computer.

B start [end]

This flag has either one or two parameters, which are instruction-word addresses. It sets a BREAKPOINT on every instruction word in the given range of addresses.

C l h

This flag is used to set two COUNT values, say *l* and *h*, that determine when tracing is done. No breakpoint or watchpoint fires, and no instruction is traced, unless $l \leq i \leq h$ is satisfied; where *i* is the current value of ICR. With suitable *l* and *h* values, tracing can be confined to a set time during execution (for example, the last few instruction executions before a program fails). The values *l* and *h* are given as unsigned decimal integers.

D FAST_MODE | TRACE_MODE | PAUSE_MODE | EXTERNAL_MODE

This flag sets the DIAGNOSTIC mode, specifying the type of tracing and the kind of logging that may be generated.

Fi start end and Ii start end

These flags have two parameters, which are word addresses. They request that the contents of that range of addresses be output in a specified interpretation, INITIALLY, or FINALLY (i.e. after the end of the run).

For both *Ii* and *Fi*, the interpretation is given by the string of letters *i*, each letter of which must be one of: **A**, for strings in ASCII/LATIN-1 code; **C**, for strings in card code; **L**, for strings in LINEPRINTER code; **N**, for strings in paper tape code, with case NORMAL shown; **S**, for strings in paper tape code, with case SHIFT shown; **T**, for strings in paper TAPE code, with shift characters actioned; **O**, for syllabic OCTAL/ ORDERS; **U**, for orders in pseudo-USERCODE format; and **W**, for data WORDS in octal, syllabic octal, line printer characters, Q store format, and signed decimal.

When **U** is specified, **D** can also be given to display machine code addresses in DECIMAL instead of octal. For an example of pseudo-Usercode format, see Appendix 6.

The PIC, PID, POC and POD instructions for cards and paper tape permit the processing of data in arbitrary character codes. The **A** format for core-store printing is provided to facilitate the debugging of modern KDF9 programs that process data in ASCII/Latin-1, the native character set of **ee9**.

G [colour [tip size]]

This flag allows one or two optional symbolic parameters. The first, if given, sets the GRAPH PLOTTING pen colour from the list: BLACK (the default), BLUE, BROWN, CYAN, DARK_BLUE, DARK_CYAN, DARK_GREEN, DARK_GREY, DARK_MAGENTA, DARK_RED, GREEN, GREY, MAGENTA, RED, WHITE, YELLOW. If a colour is given, a second parameter may be given to set the pen tip size from the list: EXTRA_EXTRA_FINE (the default, 1 plotter step wide), EXTRA_FINE (2 steps wide), FINE (4 steps), MEDIUM (6), MEDIUM_BROAD (8), BROAD (10), EXTRA_BROAD (12).

In any case, the shared buffer is switched from TP1 to GP0.

Hh cutoff%

In tracing mode, **ee9** collects statistics on the execution of the KDF9 program. These may be displayed at the end of a run in the form of histograms. Two plots are available. If *h* contains P or p, an execution-frequency profile is output. If *h* contains T or t, then an instruction type frequency histogram is output. Both may be requested. *cutoff* is a number in the range 0.0 to 100.0, taken to be a percentage; the % is required to follow the number immediately. Histogram bins that account for less than that fraction of all executed instructions are suppressed. Nothing is output if the option is suppressed by the miscellany parameter.

K { buffer device }

This flag sets the KDF9 configuration by specifying the device types connected to the buffers. The parameters consist of one or more pairs of items, the first a buffer number (in the range 0 to #17) and the second a two-letter code, being the letters of the device name (e.g. DR or SI). GP may be specified; that automatically switches the TP1 buffer to GP0 in the program modes, but a g option in the miscellany parameter or in `settings_1.txt` (or both) is still needed in boot mode, because a Director has no access to **ee9**'s internal state.

The default setting in the absence of a **K** flag is given by the line:

```
K 0 FW 1 TR 2 TR 3 TP 4 TP 5 LP 6 CR 7 CP 8 MT 9 MT 10 MT 11 MT 12 MT 13 MT 14 FD 15 ST
```

At most 1 FD unit, 1 DR unit, 2 TP, TR, CP, CR, LP, SI, or ST units, and at most 8 tape decks of all kinds, can be configured. To leave a buffer without an attached device, specify the code NA; any attempt to use that buffer will be detected and fail. Every configuration must have FW on buffer 0 and TR on buffer 1. If a buffer is not listed it keeps its default device. The commands described in §1 may not work properly with some non-default configurations.

The **K** flag is actioned only at the start of a run; any **K** options in the `settings_2.txt` file are ineffective.

L [*t*]

This flag is used to set a value, say *t*, that specifies an execution time **LIMIT**. This determines how long the KDF9 program is allowed to execute before being terminated. The limit is specified in instruction executions rather than seconds, so the program is terminated if $ICR > t$ at the end of any instruction execution. The value *t* is given as an unsigned decimal integer. If the **L** flag is given without a parameter, or on the command line, the time limit is taken to be the default time limit for non-interactive mode (see §6).

N [*t*]

The **N** flag has one optional parameter, with the same meaning at the *t* parameter of the **L** flag. It makes **ee9** run in **NON-INTERACTIVE** mode, suitable for invocation from a command script. In this mode it is not possible to supply responses to prompts, whether from the KDF9 program or from **ee9** itself; so if an interactive input is requested in non-interactive mode, **ee9** terminates with a suitable diagnostic message. If the **N** flag is given without a parameter, or on the command line, the time limit is taken to be the default time limit for non-interactive mode (see §6).

O

The **O** flag outputs the current state of the diagnostics just before OUT1 is actioned; or just after, if the **Q** flag is also given.

P *address value*

This flag is used to **POKE** the *value* (given in octal or decimal) into the *address*. The *address* takes the form of an octal or decimal number, immediately followed by one of the letters **W**, **U**, **L**, **S** or **C**. If **W** is specified, the *value* overwrites the whole word at the *address*. If **U** or **L** is given, the *value* overwrites the specified halfword. If **S** or **C** is given, it must be followed by the position within the word of the syllable or character, respectively, to be overwritten. If a part-word is specified, the *value* must be within its storable range.

Q

The **Q** flag outputs any specified pre-run dumps and then quits. It is useful for getting a dis-assembly of a program without running it.

R *a b*

This flag is used to set two addresses, say *a* and *b*, that delimit the **RANGE** of instructions where tracing is done. No breakpoint or watchpoint fires, and no instruction is traced, unless $a \leq i \leq b$ is satisfied; where *i* is the address of the word containing the instruction to be executed. With suitable *a* and *b* values, instruction tracing can be confined to the sequence of instructions that you are currently debugging.

S *start [end]*

This flag has either one or two parameters, which are data-word addresses. It sets a **STOREPOINT** on every word in the given range of addresses.

T **BOOT_MODE** | **PROGRAM_MODE** | **TEST_PROGRAM_MODE**

This flag is used to set the **TEST** mode, specifying the kind of run.

V **ADEFHIMPRSTWZ**

The **V** flag is used to set the **VISIBILITY** of diagnostic output. It is immediately followed by a selection of the letters: **A** to suppress Director **API** messages, **E** to suppress confirmatory or warning messages, but not error messages, from **ee9**, **F** to suppress the **FINAL STATE** of the KDF9 at the end of a run, **H** for the **HISTOGRAMS**, **I** for the **INTERRUPT** trace, **P** for the **PERIPHERAL I/O** trace, **R** for the **RETRO** trace, **S** for the digital **SIGNATURE**, **W** for console Flexowriter output, and **Z** to combine the effects of all the output-suppression options.

A trace is output if it is provided by the requested diagnostic mode, **and** its output is not suppressed.

The default is that all traces provided by the diagnostic mode are to be output, i.e. **not** suppressed.

The option **D** can be given with the **V** flag, to **enable** the output of any optional **DEBUGGING** output.

The option **M** can be given with the **V** flag, to **disable** the use of ANSI SGR escape codes for **Microsoft Windows**.

The option **T** can be given with the **V** flag, to **enable** execution with authentic **TIMING** (see §2.4).

W *start [end]*

This flag has either one or two parameters, which are data-word addresses. It sets a **WATCHPOINT** (i.e., a **FETCHPOINT** **and** a **STOREPOINT**) on every word in the given range of addresses. Note that it is not possible to set a **FETCHPOINT** only.

X

The **X** flag over-rides other diagnostic options and runs the program in external tracing mode with only signature generation enabled.

/ | -

A line beginning with / or with - is taken to be comment and ignored.

5.2: THE MISCELLANY PARAMETER

The options permitted with the miscellany parameter on the command line are as follows:

adefghimnopqrstwxz0123456789-

The miscellany parameter is scanned and put into effect from left to right. The letters **gnopx** correspond to the option flags of the same name, with the defaults stated in §5.1 for their parameters. The letters **adefhimprstwz** correspond to the visibility options given with the **V** flag, as defined in §5.1. A digit *d* requests an execution time limit of $(d+1) \times 10_000_000$ instructions. A hyphen is ignored.

6: IMPLEMENTATION CHARACTERISTICS AND CAVEATS

CHARACTERISTICS

The defaults for the settable options in the present implementation of **ee9** are as follows:

- the default run mode is `PROGRAM_MODE`
- the default diagnostic mode is `FAST_MODE`
- the default diagnostic visibility generates all traces, the digital signature, and the histogram
- the default is to run interactively; that is, with non-interactive mode disabled
- the default elapsed time mode is `MODERN_TIMES_MODE`
- the default time limit allows for effectively unlimited execution
- the default time limit in non-interactive mode is 100 million instruction executions
- the default count bounds, *l* and *h*, are 0 and the time limit, respectively
- the default range bounds, *a* and *b*, are #0 and #7777, respectively
- no breakpoint, watchpoint, storepoint, or core dump is pre-set
- the default optional devices are FD0 (not DR0) and ST0 (not SI0)
- the shared buffer is switched by default to TP1, not GP0
- the default graph plotter pen colour is `BLACK`
- the default graph plotter pen tip is `EXTRA_EXTRA_FINE` (1 plotter step wide)

CAVEATS

- Do not be discouraged by the length of this list; **ee9** successfully runs all distributed KDF9 programs, whether surviving, resurrected or newly-written.
- OUTs other than OUT 0 through OUT 10 and OUT 17 are not yet implemented.
- There are some bogus OUTs, with numbers distinct from those of any historically valid OUT, that are implemented by **ee9** in program mode for various reasons of convenience. They may be withdrawn in future releases.
- KDF9's nest-depth checking caused a NOUV interrupt after the maximum or minimum depth had been transgressed. Presently, **ee9** checks for all of these violations before the offending instruction is executed. This makes little difference in practice. KDF9 had 'imprecise' interrupts, which made recovery from a NOUV error impossible: Director could do no more than terminate (or perhaps restart) the offending program. The behaviour of **ee9** makes debugging a bit easier.
- There is some doubt as to the semantics of the various division instructions, particularly with respect to rounding, and their results on overflow and on division by zero (other than setting the overflow bit).
- There is some doubt as to the semantics of the FLOAT and FLOATD instructions when the scale factor operand in N1 is outside the range $-128 \leq N1 \leq +127$ specified by the Manual. EE issued a library subroutine, L77, to deal with such cases, so it seems that the behaviour of the hardware with out of range operands was not entirely satisfactory. **ee9** takes a safety first approach and uses the least significant 8 bits of N1 as the effective scale factor, ignoring the rest of N1. This is compatible with the programming of the `sqr` function in the Kidsgrove Algol system.
- The FRB and TOB orders deliver results that differ from the KDF9 hardware in unusual cases involving radix values greater than 31, which are stated to be illegal in the Manual, and to malfunction in the hardware documentation.
- The all-zero syllable is documented as an invalid order, but evidence has come to light that the hardware actually treated it as a "no-op", like DUMMY, so **ee9** now does the same, identifying it in traces as DUMMY0.
- The Standard Interface (SI) device type is present only in an interim implementation, pending more information about it.
- The POE and POF orders, for TP and SI, produce NULs in lieu of paper tape runoff; this is suppressed in Latin-1 mode.
- It is assumed that the POF order for TP and SI is the same as the POE order, but that the count is multiplied by 8.
- The POK and POL orders are fully implemented for the CP and FD devices.
- The PMK and PML orders are fully implemented for 7-track Ampex tape decks.
- There is considerable doubt as to the effects of the PMG, PMK, PML, POK, and POL orders for all other devices.
- The CT order lets an ongoing transfer terminate normally, as if it were MANUAL; the hardware forced an immediate end.
- PIC and PID transfers for FW, TR, TP and SI0 devices copy each input byte *verbatim* to the least significant 8 bits of a word; POC and POD for those devices copy the least significant 8 bits of each word *verbatim* to a byte of output.
- PID and POD transfers for FW, TR, TP and SI0 devices terminate after a word that has the 8-bit paper tape code for an End Message, decimal 125, #175, in its least significant 8 bits.
- The POC and POD orders switch FW from writing to reading after a word that has the 8-bit paper tape code for a semicolon, decimal 60, #74, in its least significant 8 bits.
- **ee9** cannot properly implement the semantics of 5-hole paper tape. See Appendix 2c for more details.
- It is assumed that the graph plotter pen tip sizes and colours are the same as those of pens presently on sale.
- It is assumed that the plotter command codes listed in Appendix 5, §3, p.304 of the Manual are wrong, as there is an error whereby 11 plotting codes are claimed but only 9 are given. The codes used by **ee9** are given in Appendix 3 of this *Guide*. These have been confirmed by evidence from other computers of the era that had the same type of plotter.

- It is assumed that the POB and POD orders for the graph plotter have the same effect as POA and POC, respectively. The Manual says that the plotter responds to End Message with a ‘peculiar’ pen movement, but does not end the transfer, and that invalid codes have ‘unpredictable’ effects. **ee9** in these cases implements an arbitrary, but safe and potentially useful, operation: it moves the plotting position to the origin of the plotter co-ordinate system.
- An attempt to plot outside the bounds implied by the size of the roll of plotter paper causes an unrecoverable failure.
- It is assumed that the fixed-head area of the disk is platter 16, seek area 0.
- It is assumed that the drum has 20 tracks of 16 sectors, pairs of tracks being interleaved into 10 ‘bands’. This is based on the specification of the drum of the Philco 2000 computer, which is the only device of the era with the same distinctive combination of attributes: similar small capacity and exactly the same exceptionally high transfer rate.
- Many other hypotheses have been made in emulating discs and drums; it remains to be seen whether they are justified.
- I/O lockouts in **ee9** remain in force for the whole duration of a transfer and are cleared *in toto* at the end; KDF9 cleared the lockout of each 32-word group as soon as the transfer crossed the boundary into the next group.
- The emulation of OUT 8 by **ee9** has some differences from the authentic behaviour of TSD; see Appendix 5.
- There remain some issues related to the execution of problem programs under TSD control.
 - (a) The CPU time reported by TSD may differ by about 1% from that reported by running directly under **ee9**.
 - (b) TSD reports ludicrous execution times for some programs that terminate very quickly.
 - (c) The coordination of a FW0 transfer initiated directly by a problem program, with TSD’s typing-out of its own messages, is not entirely satisfactory. Note that programmers were strongly discouraged from direct output to FW0.
- Failures due to programming error can occur during a run. Some are required by the KDF9 architecture to cause a LIV interrupt in problem program state, and **ee9** implements that. LIV interrupts were inhibited by KDF9 in Director state, but **ee9** does not allow this, as it might make continued emulation fail unpredictably. Other failures were not detected by the KDF9 hardware, but are apparent to **ee9**. All such erroneous conditions lead to a controlled end of the run, with diagnostics according to the user’s options. See Appendix 8 for a list of the various kinds of error message.

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I am grateful to the group of supporters, all enthusiastic former KDF9 engineers, programmers, or satisfied users, for their encouragement during this project; and for their superb work in recreating a software ecosystem for **ee9**. I thank in particular David Hawley and Brian Randell, for their crucial caches of EE documents; David Holdsworth for his Usercode compilers and hardware insight; David Holdsworth, David Huxtable, Brian Wichmann, Graham Toal, and Roderick McLeod for resurrecting the Whetstone and Kidsgrove Algol systems, so that **ee9** has something really substantial to run; and David Holdsworth, Mike Hore, and Bill Gallagher for compiling and testing **ee9** ports. Others, whose names I have inexcusably forgotten, know who they are: to them also, my thanks. The plotter command file `GPT_data.txt` I code-converted to KDF9 plotting code from an ICL 1900 Series plotter test file made available by Bill Gallagher.

REFERENCES AND FURTHER READING

Included with distributions of **ee9**:

- *The English Electric KDF9, The Hardware of the KDF9, The Software of the KDF9, The KDF9 and Benchmarking, Buying a KDF9 in 1964 and The KDF9: a Bibliography*
- *ee9 Users’ Guide, ee9 Implementation Overview and ee9 Release History*
- *Kidsgrove Code Procedures, Kidsgrove Compilation Errors, Kidsgrove Compilation Limits, Kidsgrove Compiler Options, Kidsgrove IO Libraries, Kidsgrove Optional Output and Kidsgrove Runtime Errors*
- *README*
- *Whetstone Compilation Errors, Whetstone Controller-listing, Whetstone Runtime Errors and Whetstone Translator-listing*

Available at: www.findlayw.plus.com/KDF9:

- *KDF9 Programming Manual*, Publication 1002 mm ® 1001263; International Computers Ltd.; ‘the Manual’
- *KDF9 ALGOL programming*, Publication 1003 mm ® 1000565; English Electric–Leo Computers Ltd.

SEE ALSO

www.findlayw.plus.com/KDF9/#Emulator

which is updated occasionally with **ee9** news.

APPENDIX 1: ee9 COMMAND FUNDAMENTALS

The emulator is invoked from the command line, thus:

```
ee9 { -ss | -dd | -m[m] | -TPtt | -TRtt } +program_file_name
```

where the parameters introduced by ‘-’ are optional and can be given in any number or order; *m* is a short string that specifies a miscellany of options; *d* specifies a diagnostic execution mode; *s* is the initial CPU state for the KDF9 run; and *tt* specifies paper tape device character codes. Note that *program_file_name* is a path name; unlike the *prog* parameter of the **nine** shell command it is not by default made relative to **Testing/Binary**.

The allowable state flag characters *s* are:

- **b**: for **booting** into Director state, which is how operating systems such as the TSD are loaded and run
- **p**: for **problem** program state, the default, allowing user programs to be run without a Director
- **t**: for **test** program state, allowing programs to be run with OUTs serviced as in problem program state, but with the CPU actually in Director state; though inauthentic, this is useful for running ‘hardware test’ programs.

The allowable diagnostic flag characters *d* are:

- **f**: for **fast** mode, the default
- **p**: for **pause** mode
- **t**: for **trace** mode
- **x**: for **external** trace mode

The allowable characters in the string *m* (miscellany parameters) are described in §5.2.

The parameters *tt* specify the character code to be used by either one or two paper tape punches (with **-TP**), or paper tape readers (with **-TR**). *tt* is either one or two characters, each being either **k/K** or **l/L**, specifying KDF9 paper tape code or Latin-1 code respectively. If *tt* is one character, it refers to unit 0 of the type (i.e. **TP0** or **TR0**). If *tt* is two characters, the first refers to unit 0 and the second to unit 1 of the type. See also §3.4 and Appendix 2.

The current working directory in which **ee9** is invoked must contain files to represent the KDF9’s I/O devices. See §3.

Invoking **ee9** is not trivial—particularly when running the TSD or the Algol systems, which require a significant amount of preparation—so there are shell commands to do the donkey work for you. These are described in §1.

Example

```
cp Whetstone/GPS.a60 TR1; ee9 -sp -df -mn +Binary/KMW0201-UPU    # run Whetstone Algol
whet GPS                                                         # do it the easy way
```

The **ee9** distribution contains a hierarchy of directories to locate its files systematically and conveniently for the casual user. **Adjuncts**, **Testing**, and the **Assembly**, **Binary**, **Data**, **Kidsgrove** and **Whetstone** directories within **Testing** contain materials for KDF9 programs to work with. The **Adjuncts** directory contains non-**ee9** components required to build and run the Kidsgrove Algol compiler. However, these locations are defaults only, and others can be substituted if that better meets the user’s needs. To specify alternative places shell environment variables maybe used, as follows.

| | |
|---------------------------|---------------------|
| ADJUNCTS | ../Adjuncts |
| DIRECTOR | Binary/KKT40E007UPU |
| KDF9_USERCODE | Assembly |
| KDF9_BINARY | Binary |
| KDF9_DATA | Data |
| KIDSGROVE | Kidsgrove |
| WHETSTONE | Whetstone |
| environment variable name | default path |

If a KDF9 program overlays itself by means of OUT 1 (see Appendix 4), the executable is taken from the directory specified by **KDF9_BINARY**. If a program interactively requests additional data and the user gives the ‘@’ response (see §3.3), the file is looked for in the directory specified by **KDF9_DATA**. The default path in each case is used if the environment variable is unset (either undefined or containing the empty string).

The **DIRECTOR** variable selects the version of TSD used by **tsdnine**.

The defaults for unset variables conform to the distributed structure when the current working directory is **Testing**, where executable binaries and shell files are normally held. Another directory can be used in place of **Testing**, but for full functionality it must contain all the same non-directory files as **Testing** and should be ahead of it in the user’s search path.

Example

```
export KDF9_USERCODE=../..../usercode
export KDF9_BINARY=../..../bin
kids ZELLER
```

Running the KDF9 problem program ../..../bin/KAB00DH--USU in fast mode.

The Usercode is in ../..../usercode/ZELLER.k3 and the KDF9 executable is in ../..../bin/ZELLER

Running the KDF9 problem program ../..../bin/ZELLER in fast mode.

APPENDIX 2A: KDF9 INTERNAL CHARACTER CODES AND THEIR TRANSCRIPTIONS

| | | | | | | | | |
|---------------|----|-------|-------|-------|-------|-------|----------|----------|
| Line printer | SP | | LF | FF | | | % | ' |
| Punched Cards | SP | ISO:" | ISO:® | ISO:© | ISO:¬ | ISO:# | % | ' |
| Normal Case | SP | ISO:" | LF | FF | HT | ISO:# | CS ISO:β | CN ISO:ñ |
| Shift Case | SP | ISO:" | LF | FF | HT | ISO:# | CS ISO:β | CN ISO:ñ |
| Octal code | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 |

| | | | | | | | | |
|---------------|-------|-------|-------|-------|-------|--------|-------|----|
| Line printer | : | = | (|) | £ | * | , | / |
| Punched Cards | : | = | (|) | £ | * | , | / |
| Normal Case | ISO:& | ISO:? | ISO:! | ISO:% | ISO:' | ISO:\$ | ISO:~ | / |
| Shift Case | ISO:& | ISO:? | ISO:! | ISO:% | ISO:' | ISO:\$ | ISO:~ | : |
| Octal code | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |

| | | | | | | | | |
|---------------|----------|----|----|----|----|----|----|----|
| Line printer | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Punched Cards | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Normal Case | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Shift Case | ↑ ISO: ^ | [|] | < | > | = | × | ÷ |
| Octal code | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |

| | | | | | | | | |
|---------------|----|----|----------|---------------------|----|---------|----|----|
| Line printer | 8 | 9 | | ₁₀ ISO:Ⓞ | ; | + | - | . |
| Punched Cards | 8 | 9 | _ ISO: _ | ₁₀ ISO:Ⓞ | ; | + | - | . |
| Normal Case | 8 | 9 | _ ISO: _ | ₁₀ ISO:Ⓞ | ; | + | - | . |
| Shift Case | (|) | _ ISO: _ | £ | ; | ≠ ISO:± | * | , |
| Octal code | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 |

| | | | | | | | | |
|---------------|-------|----|----|----|----|----|----|----|
| Line printer | | A | B | C | D | E | F | G |
| Punched Cards | ISO:@ | A | B | C | D | E | F | G |
| Normal Case | ISO:@ | A | B | C | D | E | F | G |
| Shift Case | ISO:@ | a | b | c | d | e | f | g |
| Octal code | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 |

| | | | | | | | | |
|---------------|----|----|----|----|----|----|----|----|
| Line printer | H | I | J | K | L | M | N | O |
| Punched Cards | H | I | J | K | L | M | N | O |
| Normal Case | H | I | J | K | L | M | N | O |
| Shift Case | h | i | j | k | l | m | n | o |
| Octal code | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 |

| | | | | | | | | |
|---------------|----|----|----|----|----|----|----|----|
| Line printer | P | Q | R | S | T | U | V | W |
| Punched Cards | P | Q | R | S | T | U | V | W |
| Normal Case | P | Q | R | S | T | U | V | W |
| Shift Case | p | q | r | s | t | u | v | w |
| Octal code | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 |

| | | | | | | | | |
|---------------|----|----|----|-------|-------|--------|-------|-----------|
| Line printer | X | Y | Z | | | | | |
| Punched Cards | X | Y | Z | ISO:{ | ISO:} | → ISO: | ISO:\ | Ø |
| Normal Case | X | Y | Z | ISO:{ | ISO:} | → ISO: | ISO:\ | see notes |
| Shift Case | x | y | z | ISO:{ | ISO:} | → ISO: | ISO:\ | see notes |
| Octal code | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 |

NOTES

The transcription provides a Latin-1 representation for every KDF9 internal character code:

- Code 77 is represented by Ø on punched card devices and fast storage devices invariably, on two-shift devices for 'character mode' transfers only, and is otherwise suppressed on both input and output.
- An empty cell indicates a code that is completely suppressed by the line printer.
- SP is a blank space.
- LF is Line Feed, Line Shift (LS) in KDF9 terminology; it prints as ® in NEST displays, *etc.*
- FF is Form Feed, Page Change (PC) in KDF9 terminology; it prints as © in NEST displays, *etc.*
- HT is Horizontal Tab; it prints as ¬ in NEST displays, *etc.*
- CS is Case Shift.
- CN is Case Normal.
- 'y ISO:x' indicates that x is the ISO Latin-1 transcription of the non-Latin-1 KDF9 character y.
- 'ISO:x' indicates that x is the ISO Latin-1 external representation of a non-legible KDF9 character.
- Fast storage devices (e.g. magnetic tapes) always use the Normal Case representation.
- Except for 'character mode' output, β and ñ are acted upon by the Flexowriter, not transferred literally, so that output is presented in the correct case.

APPENDIX 2B: KDF9 PAPER TAPE CODES (WITH PARITY CHANNELS) AND THEIR TRANSCRIPTIONS

| | | | | | | | | |
|---------------|-----|-------|-------|-------|-------|-------|----------|----------|
| Line printer | SP | | LF | FF | | % | ' | |
| Punched Cards | SP | ISO:" | ISO:® | ISO:© | ISO:¬ | ISO:# | % | ' |
| Normal Case | SP | ISO:" | LF | FF | HT | ISO:# | CS ISO:ß | CN ISO:ñ |
| Shift Case | SP | ISO:" | LF | FF | HT | ISO:# | CS ISO:ß | CN ISO:ñ |
| Paper tape | 220 | 021 | 022 | 003 | 024 | 005 | 006 | 027 |

| | | | | | | | | |
|---------------|-------|-------|-------|-------|-------|--------|-------|-----|
| Line printer | : | = | (|) | £ | * | , | / |
| Punched Cards | : | = | (|) | £ | * | , | / |
| Normal Case | ISO:& | ISO:? | ISO:! | ISO:% | ISO:' | ISO:\$ | ISO:~ | / |
| Shift Case | ISO:& | ISO:? | ISO:! | ISO:% | ISO:' | ISO:\$ | ISO:~ | : |
| Paper tape | 030 | 011 | 012 | 033 | 014 | 035 | 036 | 017 |

| | | | | | | | | |
|---------------|----------|-----|-----|-----|-----|-----|-----|-----|
| Line printer | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Punched Cards | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Normal Case | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Shift Case | ↑ ISO: ^ | | | < | > | = | × | ÷ |
| Paper tape | 060 | 041 | 042 | 063 | 044 | 065 | 066 | 047 |

| | | | | | | | | |
|---------------|-----|-----|----------|---------------------|-----|---------|-----|-----|
| Line printer | 8 | 9 | | ₁₀ ISO:ø | ; | + | - | . |
| Punched Cards | 8 | 9 | _ ISO: _ | ₁₀ ISO:ø | ; | + | - | . |
| Normal Case | 8 | 9 | _ ISO: _ | ₁₀ ISO:ø | ; | + | - | . |
| Shift Case | (|) | _ ISO: _ | £ | ; | ≠ ISO:± | * | , |
| Paper tape | 050 | 071 | 072 | 053 | 074 | 055 | 056 | 077 |

| | | | | | | | | |
|---------------|-------|-----|-----|-----|-----|-----|-----|-----|
| Line printer | | A | B | C | D | E | F | G |
| Punched Cards | ISO:@ | A | B | C | D | E | F | G |
| Normal Case | ISO:@ | A | B | C | D | E | F | G |
| Shift Case | ISO:@ | a | b | c | d | e | f | g |
| Paper tape | 120 | 101 | 102 | 123 | 104 | 125 | 126 | 107 |

| | | | | | | | | |
|---------------|-----|-----|-----|-----|-----|-----|-----|-----|
| Line printer | H | I | J | K | L | M | N | O |
| Punched Cards | H | I | J | K | L | M | N | O |
| Normal Case | H | I | J | K | L | M | N | O |
| Shift Case | h | i | j | k | l | m | n | o |
| Paper tape | 110 | 131 | 132 | 113 | 134 | 115 | 116 | 137 |

| | | | | | | | | |
|---------------|-----|-----|-----|-----|-----|-----|-----|-----|
| Line printer | P | Q | R | S | T | U | V | W |
| Punched Cards | P | Q | R | S | T | U | V | W |
| Normal Case | P | Q | R | S | T | U | V | W |
| Shift Case | p | q | r | s | t | u | v | w |
| Paper tape | 140 | 161 | 162 | 143 | 164 | 145 | 146 | 167 |

| | | | | | | | | |
|---------------|-----|-----|-----|-------|-------|--------|-------|----------|
| Line printer | X | Y | Z | | | | | |
| Punched Cards | X | Y | Z | ISO:{ | ISO:} | → ISO: | ISO:\ | Ø |
| Normal Case | X | Y | Z | ISO:{ | ISO:} | → ISO: | ISO:\ | see note |
| Shift Case | x | y | z | ISO:{ | ISO:} | → ISO: | ISO:\ | see note |
| Paper tape | 170 | 151 | 152 | 173 | 154 | 175 | 176 | 157 |

NOTE

- Internal code 77 is represented by Ø on punched card devices and fast storage devices invariably, on two-shift devices for 'character' mode transfers only, and is otherwise suppressed on both input and output.
- 'Character' mode transfers on two-shift devices use the full 8-bit paper tape code and transfers to End Message terminate after the 8-bit internal code #175, which is the Latin-1 code for '}', not '|'.

APPENDIX 2C: KDF9 5-HOLE (FERRANTI) PAPER TAPE CODES

| | | | | | | | | |
|---------------|-----------|----|----|----|----|----|----|----|
| Normal Case | ISO: @ | A | B | C | D | E | F | G |
| KDF9 code | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 |
| Letters Case | <i>fs</i> | A | B | C | D | E | F | G |
| Figures Case | <i>fs</i> | 1 | 2 | * | 4 | (|) | 7 |
| Ferranti code | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 |

| | | | | | | | | |
|---------------|----|----|----|----|----|-----------|-----------|----|
| Normal Case | H | I | J | K | L | M | N | O |
| KDF9 code | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 |
| Letters Case | H | I | J | K | L | M | N | O |
| Figures Case | 8 | ≠ | = | - | ν | <i>lf</i> | <i>sp</i> | , |
| Ferranti code | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |

| | | | | | | | | |
|---------------|----|----|----|----|----|----|----|----|
| Normal Case | P | Q | R | S | T | U | V | W |
| KDF9 code | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 |
| Letters Case | P | Q | R | S | T | U | V | W |
| Figures Case | 0 | > | ≥ | 3 | → | 5 | 6 | / |
| Ferranti code | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |

| | | | | | | | | |
|---------------|----|----|----|-----------|--------|----------|-----------|-----------|
| Normal Case | X | Y | Z | ISO: { | ISO: } | → ISO: | ISO: \ | see notes |
| KDF9 code | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 |
| Letters Case | X | Y | Z | <i>ls</i> | . | ? | £ | <i>er</i> |
| Figures Case | x | 9 | + | <i>ls</i> | . | <i>n</i> | <i>cr</i> | <i>er</i> |
| Ferranti code | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 |

NOTES

The handling of 5-hole paper tape—in the teleprinter code of the Ferranti Pegasus, Sirius and Orion computers—is rather non-obvious. When a 5-hole tape was read by KDF9 the most significant bit of each input character was set to 1 by the hardware, adding #40 to the physical Ferranti code. On output to a 5-hole tape punch the hardware discarded that bit. This provided a 1-to-1 mapping and had the advantage that upper case letters got the same codes from 5-hole and 8-hole input tapes, namely the KDF9 native codes for those letters. **ee9** cannot implement this behaviour for direct transfers, because it does not always know whether a paper tape device is in 5-hole mode or 8-hole mode (for example, the type of the device attached to a buffer can be changed dynamically by the operators) and it has no way to find out. Consistency demands that transfers that are notionally from 5-hole tape readers and to 5-hole tape punches work in exactly the same way as for 8-hole devices in **ee9**.

Things are different when a program running under Director control writes to a 5-hole punch via OUT 8 streams 50-57. Most KDF9 characters with codes in the ranges #00-#37, and the letters A-Z, are output verbatim. Others are given special treatment. Director converts them in an attempt to preserve the appearance of a teleprinter transcription, inserting shift characters where necessary. Director also converts KDF9's Line Shift character into a *fs cr lf* sequence. Clearly, this has the potential for muddle if the KDF9 data includes characters that are absent from the Ferranti teleprinter set.

The **mtp** and **a2b** utilities (see Appendices 10 and 11) have facilities for converting from Ferranti code to Latin-1. They assume that the Ferranti codes are those generated by OUT 8:

- Ferranti code 00, denoted *fs*, is the Figures Shift character. It switches printing to the Figures Case character set.
- Ferranti code 33, denoted *ls*, is the Letters Shift character. It switches printing to the Letters Case character set.
- Ferranti code 14 is the ν character in Figures Case, but L in Letters Case. The ν was treated by English Electric software as if it were the KDF9 10 character. It is printed as 'ν' by **mtp** and **a2b**.
- Ferranti code 15, denoted *lf*, is the Line Feed character in Figures Case but M in Letters Case.
- Ferranti code 16, denoted *sp*, is the blank space character in Figures Case but N in Letters Case.
- Ferranti code 22 is the ≥ character in Figures Case, but R in Letters Case. It is printed as ']' by **mtp** and **a2b**.
- Ferranti code 24 is a right-arrow character in Figures Case, but T in Letters Case. It looks like, but is not, a KDF9 End Message. It is printed as '»' by **mtp** and **a2b**.
- Ferranti code 35 is the *n* character in Figures Case, but ? in Letters Case. This Ferranti code works like End Message for 5-track data, since it generated the KDF9 End Message internal code (#75) when read by the hardware. In Figures Case it was treated by English Electric software as if it were an underlined End Message. It is printed as 'n' by **mtp** and **a2b**.
- The KDF9 Line Shift character has the same CR/LF effect as the ASCII Newline, but in Ferranti code there are separate CR and LF characters, available only in Figures Case.
- Ferranti code 36, denoted *cr* above, is the Carriage Return character in Figures Case but £ in Letters Case.
- Ferranti code 37 was used to erase paper tape characters by punching holes in all five positions of the tape frame. It is suppressed on output by **mtp** and **a2b**, as #77 is for devices working with KDF9 codes.

APPENDIX 3: KDF9 GRAPH PLOTTER CODES

| Action | Decimal | Octal | Binary |
|-------------------------------|---------|-------|--------|
| None | 0 | #0 | 000000 |
| Step paper back | 1 | #1 | 000001 |
| Step paper forward | 2 | #2 | 000010 |
| Step pen right | 4 | #4 | 000100 |
| Step pen right, paper back | 5 | #5 | 000101 |
| Step pen right, paper forward | 6 | #6 | 000110 |
| Step pen left | 8 | #10 | 001000 |
| Step pen left, paper back | 9 | #11 | 001001 |
| Step pen left, paper forward | 10 | #12 | 001010 |
| Lower pen | 16 | #20 | 010000 |
| Raise pen | 32 | #40 | 100000 |

NOTES

- All other 6-bit character codes represent invalid plotter commands.
- The plotter command list in Appendix 6, §5, p.302 of the Manual has an obvious error whereby 11 plotting codes are claimed but only 9 are given, the last of them being inconsistent with the others. The present list provides the two missing codes and corrects the incorrect code for a step right and backwards. The codes listed here have been confirmed by the evidence of other computers of the era that used the same plotter; the bit positions and their interpretations correspond directly to the control bits in the Calcomp plotter's hardware interface.

APPENDIX 4: TIME SHARING DIRECTOR OUTS (SYSTEM CALLS)

Director, the English Electric operating system, provides an API that is accessed by the OUT instruction with parameters in the NEST. In particular, N1 must contain the identifying number of the system service being requested. See Table A.4.1.

TABLE A4.1: DIRECTOR OUT PARAMETERS

| N1 | N2 | N3 | Action |
|----------|-----------------------|-----------|---|
| 0† | | | Terminate this run normally. |
| 1† | Program ... | ... name | Terminate this run and overlay the program whose name is in N2-3. |
| 2† | Time limit in seconds | | Restart this self-overwritten program. Allow it the new time limit given in N2. |
| 3† | | | Return the CPU time used in N1. The result is given as seconds to 23 integral places. |
| 4‡ | Tape label | | Allocate the tape deck with the reel having the 1-word label in N2. Return its buffer number in N1. |
| 5‡ | Device type code | | Allocate an I/O device of the type given in N2; see Table A4.2. Return its buffer number in N1. |
| 6‡ | Buffer number | | Deallocate the I/O device with buffer number in N1. If it is a tape deck, unload any mounted tape reel. |
| 7‡ | Buffer number | | Deallocate an allocated tape deck with buffer number in N1. Do not unload any mounted tape reel. |
| 8, #10‡ | Control word | | Spool output. See Appendix 5. |
| 9, #11‡ | | | Return the time of day in N1. The result is given as seconds since midnight to 23 integral places. |
| 10, #12‡ | Tape ... | ... label | Allocate the tape deck with the reel having the 2-word label in N2-3. Return its buffer number in N1 and the 'Tape Serial Number' (TSN), as read from the label block, in N2. |
| 17, #21‡ | | | Return the CPU Time in N1 and the Notional Elapsed Time in N2. The results are given as seconds to 23 integral places. |

NOTES

† See the Manual, §26.2. 1.

- Obeying OUT with an empty NEST has the same effect as OUT 0.
- OUT 1 overlays the current program with a program read from external media. It is used by compile-and-go compilers. The program name for OUT 1 consists of 12 Normal Case characters, e.g. "KMW0301--UPU".
- OUT 2 starts the execution of a new program that has already been set up in core. It is used by in-core compilers.

‡ See the Manual, §17.3.

- The tape label for OUT 4 consists of 8 Case Normal characters. e.g. "PRINTEND"
- The tape label for OUT 10 consists of a plus sign followed by 15 Case Normal characters. e.g. "+KOUTPUT/0023004".

TABLE A4.2: DEVICE TYPE CODES

| Type | FW | TP | TR | LP | CR | TP § | CP | GP | SI | PDP-8 * | MT † |
|---------|-----|-----|-----|-----|-----|------|-----|-----|-----|---------|------|
| Decimal | 0 | 1 | 2 | 3 | 4 | 5 | 7 | 16 | 17 | 53 | 55 |
| Octal | #00 | #01 | #02 | #03 | #04 | #05 | #07 | #20 | #21 | #65 | #67 |

NOTES

- Add 8 (#10) to codes 1-7 to reclaim a previously-relinquished device.

§ Type 5 is for a 5-channel tape punch, using Ferranti paper tape code

* The PDP-8 front end for Eldon 2 and COTAN was attached to a magnetic tape buffer

† A magnetic tape deck given type #67 is treated as having an unlabelled tape, which is not to be read

APPENDIX 5: OUT 8

Director implements an output spooling system for paper tape punches and line printers. It also administers access to the console Flexowriter. Up to 32 virtual output streams are provided to each running problem program; see Table A5.1.

Stream output is written first to a designated magnetic tape. When that becomes full, or at the behest of the computer operator, it is rewound and the accumulated data for each stream is transferred from the tape to its associated device. A second magnetic tape may be designated to take output while this is happening, and the two tapes may switch rôles as often as necessary to transfer all the outputs to their intended destinations.

OUT 8 takes a parameter word in N2 that controls the spooling action. It is in Q store format. If the C-, I-, and M-parts are equal, and contain a stream number, that stream is closed. Otherwise the I-part is taken to be the starting address, a , of an output area and the M-part as its ending address, b .

If $b = a + 1$ and the area is laid out as follows:

- word $a+0$: *stream number*
- word $a+1$: control word in Q store format: 4095 / -1 / n

then a device-dependent ‘gap’ is written to the stream; for a tape punch stream this takes the form of runout (unpunched) tape, of length n characters, for $n / 10$ inches; applied to a line printer stream it produces a Page Change character.

Otherwise, and more usually, the words in address range a to b inclusive are written to the OUT 8 tape by a transfer-to-End-Message operation, the word at a having been overwritten by ‘red tape’ identifying the stream.

TABLE A5.1: OUT 8 STREAMS IMPLEMENTED BY DIRECTOR

| stream number | Output Device |
|---------------|---|
| #00 | Flexowriter |
| #10 .. 17 | An 8-hole paper tape punch selected by the operator |
| #20 .. 27 | Not used |
| #30 .. 37 | The line printer |
| #40 .. 47 | Not used |
| #50 .. 57 | A 5-hole paper tape punch selected by the operator |
| #60 .. 67 | Not used |
| #70 .. 77 | The line printer or a paper tape punch, at the operator’s discretion |

Special provision is made for prompted responses from the Flexowriter console, which are implemented immediately, not deferred. In this case the parameter word in N2 must have a C-part of #100000. The output area must be laid out with a prompt (ending with a ‘;’ character) and be followed by an input area for the response. Various restrictions are imposed to preserve a tidy layout of the console’s typed log. In particular, word a is overwritten by Director with suitable format effectors.

In its problem program and test program modes, **ee9** emulates OUT 8 not by spooling, but by directly transferring the output to the intended destination device. Note that outputs to multiple streams intended for the same device are therefore interleaved by **ee9**, but are not interleaved by Director. In doing so **ee9** is somewhat more specific than Director in its provision of output streams, as indicated in Table A5.2. Streams 11, 13, 15 and 17 are directed to TP1 instead of TP0, as a small mitigation of the interleaving issue.

The 5-hole mode is not implemented by **ee9**; all paper tape output is in 8-hole mode.

Director requires a line of output to be written in a single OUT 8 call, the line ending in a Line Shift, Page Change or End Message character. **ee9** allows a line to be built up incrementally, in a series of calls to the emulated OUT 8. This behaviour was necessary to support an earlier version of the reconstructed I/O library in the Kidsgrove Algol run time environment.

So far these differences between **ee9** and Director have not been problematic.

TABLE A5.2: OUT 8 STREAMS IMPLEMENTED BY ee9

| stream number | Output Device |
|-----------------|---------------|
| #00 | Flexowriter |
| #10, 12, 14, 16 | TP0 |
| #11, 13, 15, 17 | TP1 |
| #30 .. 37 | LP0 |
| #50 .. 57 | TP1 |
| #70 .. 77 | LP0 |
| others | Invalid |

The KDF9 Algol I/O procedures work on notional I/O streams, identified by decimal numbers that are made to look like OUT 8 octal stream numbers. For example, output to Algol stream 30 goes to OUT 8 stream #30. Algol input uses the 20 range of stream numbers which OUT 8 does not use.

APPENDIX 6: DISASSEMBLED MACHINE CODE

The U format core printing routine analyses the program's control flow, and uses simple heuristics, to determine whether a given word represents data or instructions. These do a good job, but cannot always be correct. Words thought to be data are output in a variety of formats. Instructions are shown with octal or decimal operand addresses, at option. If the operand of a SET instruction is greater than 7, its octal representation is complemented by its decimal representation as a comment; and *vice versa*.

An instruction that is the target of a jump starts a new line labelled by its address. An address is also given for the instruction sequentially following a subroutine jump (JS...), as that is the link value stored in the SJNS, and may be useful for following the course of execution.

Here is an example for which the heuristics work well. Lines of the form *Vn=value*; are local static data declarations; and the executable code begins with 'V14; =V13;':

```
P51V15;
    V0=F0.019042127887;
    V1=F0.019042129240;
    V2=F0.038082414120;
    V3=F0.076666493927;
    V4=F0.121226383896;
    V5=F0.725940450930;
    V11=Q6/1/0;
    V12=Q4/1/0;
    V14=F1.0;
    V15=F0.5;
    V14; =V13;
    DUP; DUP; ×F; V14; +F; JSP40; =V6;
    V12; =Q13;
2;    V13; V6M13; +F; V15; ×F; =V13;
    V13; V6M13Q; ×F; JSP40; =V6M13; J2C13NZ;
    V11; =Q13;
    V0M13Q; ZERO; REV; FIX; FLOATD;
1;    V0M13; V5M13Q; ×+F; J1C13NZ;
    ROUND; ÷F; EXIT1;
```

And here is its **UD**-format output:

Core store interpreted as instructions.

```
1393/0: #1742337743622052 = 68337217250346 = 1.90421278869E-2
1394/0: #1742337743651250 = 68337217262248 = 1.90421292400E-2
1395/0: #1744677611614626 = 68504697379222 = 3.80824141200E-2
...
1409/0:
    E1407; =E1406;
    DUP; DUP; ×F; E1407; +F;
    JSE1263/0;
1411/4:
    =E1399;
    E1405; =Q13;
1413/0:
    E1406; E1399M13; +F; E1408; ×F; =E1406;
    E1406; E1399M13Q; ×F;
    JSE1263/0;
1417/0:
    =E1399M13;
    JE1413/0C13NZ;
    E1404; =Q13; E1393M13Q; ZERO; REV; FIX; FLOATD;
1420/0:
    E1393M13; E1398M13Q; ×+F;
    JE1420/0C13NZ;
    ROUND; DIVF;
    EXIT 1;
```

APPENDIX 7: TRACING

These examples give an indication of the types of diagnostic output that can be obtained.

APPENDIX 7A: THE RETROSPECTIVE TRACE

Under ND is given the NEST depth and under SD the depth of the SJNS. Under VTD are the states of the overflow and test registers and whether running in Director mode. For example:

Retrospective trace of all instructions.

| | | | ND | SD | VTD | CPU TIME | ICR |
|---------------|--------------------|-----------------------------|----|----|-----|------------|-----------|
| Ended #23/4: | OUT | 0 | 3 | 0 | V | 1674616069 | 306451954 |
| After #23/3: | ZERO | #0000000000000000 | 4 | 0 | V | 1674616056 | 306451953 |
| After #23/0: | OUT | 4 | 3 | 0 | V | 1674616054 | 306451952 |
| After #22/3: | SET6 | #0000000000000006 | 5 | 0 | V | 1674616041 | 306451951 |
| After #22/1: | C13 | #0000000000000004 | 4 | 0 | V | 1674616029 | 306451950 |
| After #21/5: | POEQ13 | Q #000004/ #000000/ #000454 | 3 | 0 | V | 1674616024 | 306451949 |
| After #136/5: | EXIT2;(1) | #20/5 | 3 | 0 | V | 1674616005 | 306451948 |
| After #136/2: | JE#137/2NE | #0000000000000035 | 3 | 1 | V | 1674615986 | 306451947 |
| After #135/5: | SET29 | #0000000000000035 | 4 | 1 | V | 1674615981 | 306451946 |
| After #135/2: | JE#133/5LTZ | #0000000000000035 | 3 | 1 | V | 1674615977 | 306451945 |
| After #135/1: | DUP | #0000000000000035 | 4 | 1 | V | 1674615973 | 306451944 |
| After #135/0: | - | #0000000000000035 | 3 | 1 | V | 1674615971 | 306451943 |
| After #134/3: | SET32 | #0000000000000040 | 4 | 1 | V | 1674615970 | 306451942 |
| After #134/1: | SHLD+6 | #0000000000000075 | 3 | 1 | V | 1674615959 | 306451941 |
| After #134/0: | ZERO | #0000000000000000 | 3 | 1 | V | 1674615956 | 306451940 |
| After #133/5: | ERASE | #7500000000000000 | 2 | 1 | V | 1674615954 | 306451939 |
| After #133/4: | DUP | #7500000000000000 | 3 | 1 | V | 1674615953 | 306451938 |
| After #133/1: | E25472M7Q;(#61600) | #7500000000000000 | 2 | 1 | V | 1674615951 | 306451937 |
| After #132/5: | POBQ14 | Q #000004/ #061600/ #061775 | 1 | 1 | V | 1674615944 | 306451935 |
| After #132/3: | PIBQ15 | Q #000002/ #061600/ #061775 | 1 | 1 | V | 1674615912 | 306451933 |
| After #132/1: | IM15 TO Q14 | Q #000004/ #061600/ #061775 | 1 | 1 | V | 1674615880 | 306451931 |
| After #131/5: | =M15 | Q #000002/ #061600/ #061775 | 1 | 1 | V | 1674615876 | 306451930 |
| After #131/4: | + | #0000000000061775 | 2 | 1 | V | 1674615866 | 306451929 |
| After #131/2: | I15 | #0000000000061600 | 3 | 1 | V | 1674615865 | 306451928 |
| After #130/5: | SET125 | #0000000000000175 | 2 | 1 | V | 1674615859 | 306451927 |
| After #130/3: | =RM7 | Q #000000/ #000001/ #000000 | 1 | 1 | V | 1674615855 | 306451926 |
| After #130/2: | ZERO | #0000000000000000 | 2 | 1 | V | 1674615852 | 306451925 |
| After #130/0: | =RM6 | Q #000000/ #000001/ #057165 | 1 | 1 | V | 1674615850 | 306451924 |
| After #20/5: | JSE#130/0 | #20/5 | 2 | 1 | V | 1674615847 | 306451923 |
| After #20/2: | SET24181 | #0000000000057165 | 2 | 0 | V | 1674615836 | 306451922 |
| After #52/3: | JE#20/2EQZ | #0000000000000000 | 1 | 0 | V | 1674615832 | 306451921 |
| After #52/1: | SHL+24 | #0000000000000000 | 2 | 0 | V | 1674615821 | 306451920 |
| After #51/4: | E0;(#0) | #4013001200000000 | 2 | 0 | V | 1674615817 | 306451919 |
| After #51/3: | ERASE | #0000000000000004 | 1 | 0 | V | 1674615803 | 306451918 |
| After #51/2: | ERASE | #0000000000000000 | 2 | 0 | V | 1674615802 | 306451917 |
| After #51/0: | =RM2 | Q #000000/ #000001/ #000000 | 3 | 0 | V | 1674615801 | 306451916 |
| After #50/5: | DUP | #0000000000000000 | 4 | 0 | V | 1674615798 | 306451915 |
| After #50/4: | DUP | #0000000000000000 | 3 | 0 | V | 1674615796 | 306451914 |
| After #50/3: | ZERO | #0000000000000000 | 2 | 0 | V | 1674615794 | 306451913 |
| After #160/1: | EXIT1;(0) | #50/0 | 1 | 0 | V | 1674615792 | 306451912 |
| After #157/5: | POAQ14 | Q #000004/ #061600/ #061600 | 1 | 1 | V | 1674615779 | 306451911 |
| (etc) | | | | | | | |

After earlier instructions, whose tracing is now lost.

APPENDIX 7B: THE EXTERNAL TRACE OF ALL INSTRUCTION TYPES

| LOCATION | ICR | CPU TIME | ND | SD | VT | [N1] | INSTRUCTION |
|----------|---------|----------|----|----|----|--------------------|-------------|
| #00000/0 | 1 | 8 | 0 | 0 | | | J#00012/0 |
| #00012/0 | 2 | 12 | 1 | 0 | | #0000000000000002 | SETB2 |
| #00012/3 | 3 | 19 | 2 | 0 | | #0000000000000005 | SETB5 |
| #00013/0 | 4 | 32 | 1 | 0 | | #0000000000000002 | OUT |
| #00013/3 | 5 | 35 | 0 | 0 | | | =C15 |
| ... | | | | | | | |
| #00236/2 | 3439084 | 19706693 | 1 | 2 | V | #0000000000000004 | JS#00063/2 |
| #00063/2 | 3439085 | 19706697 | 2 | 2 | V | #00000000000001243 | M2 |
| #00063/4 | 3439086 | 19706699 | 3 | 2 | V | #00000000000001243 | DUP |
| #00063/5 | 3439087 | 19706703 | 2 | 2 | V | #00000000000002506 | + |
| #00064/0 | 3439088 | 19706705 | 1 | 2 | V | #0000000000000004 | =M3 |
| #00064/2 | 3439089 | 19706709 | 2 | 2 | V | #0000000000000001 | M1 |
| #00064/4 | 3439090 | 19706715 | 1 | 3 | V | #0000000000000004 | =LINK |
| #00065/0 | 3439091 | 19706721 | 2 | 3 | V | #0000000000000000 | E#253M3 |
| (etc) | | | | | | | |

APPENDIX 7C: THE SINGLE-STEP TRACE

In pause mode **ee9** executes instructions one-by-one, interacting with the user at each step and presenting the values in the registers relevant to the instruction just obeyed. Here it is, stepping through P40:

At #01313/4 (715/4); ICR = 182908; EL = 9111955; the instruction was
 #200:324:357, i.e. JSE#02357/0
 JB: #01313/4; SJNS depth: 2
 NEST:

N1:
 #1766314631463146 = 69709037200998 = 1.999999999998E-1 = 0.4953124999999997
 = Q #037546/ #063146/ #063146 = Q 16230/ 26214/ 26214
 = #077 #146 #146 #146 #146 #146 = "/V9F9F9F"

Breakpoint: at #02357/0 (d:debug | f:ast | t:race | p:pause or q:uit)? p

At #02357/0 (1263/0); ICR = 182909; EL = 9111957; the instruction was
 #042, i.e. DUP
 NEST:

N1:
 #1766314631463146 = 69709037200998 = 1.999999999998E-1 = 0.4953124999999997
 = Q #037546/ #063146/ #063146 = Q 16230/ 26214/ 26214
 = #077 #146 #146 #146 #146 #146 = "/V9F9F9F"

N2:
 #1766314631463146 = 69709037200998 = 1.999999999998E-1 = 0.4953124999999997
 = Q #037546/ #063146/ #063146 = Q 16230/ 26214/ 26214
 = #077 #146 #146 #146 #146 #146 = "/V9F9F9F"

Breakpoint: at #02357/1 (d:debug | f:ast | t:race | p:pause or q:uit)?

At #02357/1 (1263/1); ICR = 182910; EL = 9111961; the instruction was
 #203:104:366, i.e. JE#02366/3LEZ
 NEST:

N1:
 #1766314631463146 = 69709037200998 = 1.999999999998E-1 = 0.4953124999999997
 = Q #037546/ #063146/ #063146 = Q 16230/ 26214/ 26214
 = #077 #146 #146 #146 #146 #146 = "/V9F9F9F"

Breakpoint: at #02357/4 (d:debug | f:ast | t:race | p:pause or q:uit)?

At #02357/4 (1263/4); ICR = 182911; EL = 9111967; the instruction was
 #045, i.e. FIX
 NEST:

N1:
 #7777777777777776 = -2 = -6.189700196427E+26 = -0.0000000000000014
 = Q #177777/ #177777/ #177776 = Q -1/ -1/ -2
 = #377 #377 #377 #377 #377 #376 = "00000000\"

N2:
 #3146314631463000 = 112589990684160 = 6.044629096666E+22 = 0.7999999999999272
 = Q #063146/ #063146/ #063000 = Q 26214/ 26214/ 26112
 = #146 #146 #146 #146 #146 #000 = "9F9F9F8 "

Breakpoint: at #02357/5 (f:ast | t:race | p:pause or q:uit)? q

APPENDIX 7D: THE PERIPHERAL I/O EVENT TRACE

Under CPL is given the TSD context (P, Q, R or S) if the transfer was initiated by a program, or D if initiated by Director; and the current priority level. Under the heading T the value of the T register is shown as Y (for 1) or N (for 0) in the case of an order, such as BUSY, that tests device status. S and E in the next column show the start and end of a transfer.

Retrospective trace of peripheral I/O events.

| | | | | CPL | T | EL. TIME | ICR |
|----------------|----------|--------------------|----------|---------|-------|------------|-----------|
| After #4310/3: | CLOQ7 | Q #072500/ | #004640/ | #077337 | D 0 N | 2052470495 | 366874014 |
| After #2520/4: | TWQ7 | FWO Q #000000/ | #000472/ | #000472 | D 0 E | 2052465840 | 366871442 |
| After #2472/0: | BUSYQ0 | FWO Q #000000/ | #000000/ | #000000 | D 0 Y | 2051676802 | 366873352 |
| After #1062/4: | CTQ6 | TR1 Q #000002/ | #177777/ | #000002 | D 0 N | 2051672349 | 366872593 |
| After #2520/4: | TWQ7 | FWO Q #000000/ | #000472/ | #000472 | D 0 S | 2051665840 | 366871441 |
| After #2472/0: | BUSYQ0 | FWO Q #000000/ | #000000/ | #000000 | D 0 N | 2051665650 | 366871408 |
| After #21/5: | PGAPQ13 | TP0 Q #000004/ | #000000/ | #000454 | P 0 E | 2051660310 | 366870057 |
| After #1534/4: | MANUALQ6 | TP0 Q #000004/ | #000001/ | #000004 | D 0 Y | 2051660310 | 366870512 |
| After #1255/2: | PARQ7 | TP0 Q #000004/ | #000000/ | #000000 | D 0 N | 2051660106 | 366870474 |
| After #1255/2: | PARQ7 | TP0 buffer lockout | | | P 0 | 2051660106 | 366870473 |
| After #623/5: | BUSYQ7 | TP0 Q #000004/ | #000000/ | #000000 | D 0 Y | 2051654372 | 366870467 |
| After #21/5: | PGAPQ13 | TP0 Q #000004/ | #000000/ | #000454 | P 0 S | 2051652220 | 366870056 |
| After #132/5: | PWEQ14 | TP0 Q #000004/ | #066440/ | #066635 | P 0 E | 2051660025 | 366869806 |
| After #132/3: | PREQ15 | TR1 Q #000002/ | #066440/ | #066635 | P 0 E | 2051651903 | 366869805 |
| After #132/5: | PWEQ14 | TP0 Q #000004/ | #066440/ | #066635 | P 0 S | 2051650935 | 366869805 |
| After #157/5: | PWQ14 | TP0 Q #000004/ | #066440/ | #066440 | P 0 E | 2051723445 | 366869784 |
| After #132/3: | PREQ15 | TR1 Q #000002/ | #066440/ | #066635 | P 0 S | 2051650903 | 366869804 |
| After #157/5: | PWQ14 | TP0 Q #000004/ | #066440/ | #066440 | P 0 S | 2051650725 | 366869783 |
| ... | | | | | | | |
| After #132/3: | PREQ15 | TR1 Q #000002/ | #066440/ | #066635 | P 0 E | 373054471 | 59581364 |
| After #132/5: | PWEQ14 | TP0 Q #000004/ | #066440/ | #066635 | P 0 E | 373010462 | 59578367 |
| After #132/3: | PREQ15 | TR1 Q #000002/ | #066440/ | #066635 | P 0 S | 372953471 | 59581363 |
| After #132/3: | PREQ15 | TR1 Q #000002/ | #066440/ | #066635 | P 0 E | 372945668 | 59578366 |
| After #132/5: | PWEQ14 | TP0 Q #000004/ | #066440/ | #066635 | P 0 S | 372937742 | 59578366 |
| After #132/5: | PWEQ14 | TP0 Q #000004/ | #066440/ | #066635 | P 0 E | 373001334 | 59576600 |
| After #132/3: | PREQ15 | TR1 Q #000002/ | #066440/ | #066635 | P 0 S | 372937668 | 59578365 |
| After #132/3: | PREQ15 | TR1 Q #000002/ | #066440/ | #066635 | P 0 E | 372936540 | 59576599 |
| After #132/5: | PWEQ14 | TP0 Q #000004/ | #066440/ | #066635 | P 0 S | 372928614 | 59576599 |
| After #20/0: | PGAPQ13 | TP0 Q #000004/ | #000000/ | #000454 | P 0 E | 375655473 | 59576588 |
| After #132/3: | PREQ15 | TR1 Q #000002/ | #066440/ | #066635 | P 0 S | 372928540 | 59576598 |
| After #20/0: | PGAPQ13 | TP0 Q #000004/ | #000000/ | #000454 | P 0 S | 372928473 | 59576587 |

(etc)

After earlier interrupts, whose tracing is now lost.

Total time waiting for unoverlapped I/O to finish = 6635ms.

APPENDIX 7E: THE INTERRUPT TRACE

Under CPL is the context (P, Q, R or S) and priority level of the interrupted program. In addition, the trace shows control returning from Director to a problem program by means of the EXITD instruction, with the BA, NOL, and instruction address values for the resumed program.

Retrospective trace of interrupt requests.

| | | | | CPL | EL. TIME | ICR |
|----------------|-------|-------------------------------|---------|-----|-----------|----------|
| Ended #575/4: | EDT | MT0 Q 8/#004335/ | #004336 | P 0 | 435959729 | 69288606 |
| After #76/4: | EDT | FWO Q 0/#005246/ | #005250 | P 0 | 435943366 | 69285714 |
| After #416/3: | OUT | 0 | | P 0 | 433847319 | 69079602 |
| After #116/3: | EXITD | BA #004640 NOL 8191 @ #416/2 | | P 0 | 433847299 | 69079600 |
| After #415/5: | OUT | 8 | | P 0 | 433827181 | 69076031 |
| ... | | | | | | |
| After #116/3: | EXITD | BA #004640 NOL 8191 @ #4430/0 | | P 0 | 429984577 | 68459560 |
| After #4427/3: | CLOCK | 1048580 KDF9 us | | P 0 | 429982227 | 68459073 |
| After #116/3: | EXITD | BA #004640 NOL 8191 @ #4430/0 | | P 0 | 428934534 | 68285222 |
| After #4427/3: | CLOCK | 1048584 KDF9 us | | P 0 | 428925791 | 68283615 |
| After #116/3: | EXITD | BA #004640 NOL 8191 @ #3153/4 | | P 0 | 427877727 | 68109705 |
| After #60/5: | EDT | MT0 Q 8/#011657/ | #011702 | P 0 | 427877343 | 68109622 |
| After #3153/4: | LOV | at #011656 (E2574) | | P 0 | 427877149 | 68109587 |
| After #116/3: | EXITD | BA #004640 NOL 8191 @ #2056/4 | | P 0 | 427877113 | 68109584 |
| After #2056/1: | OUT | 8 | | P 0 | 427858473 | 68106231 |
| ... | | | | | | |
| After #116/3: | EXITD | BA #004640 NOL 8191 @ #3270/0 | | P 0 | 412965422 | 65759551 |
| After #3267/3: | EDT | FWO Q 0/#000472/ | #000472 | P 0 | 412956544 | 65757930 |
| After #116/3: | EXITD | BA #004640 NOL 8191 @ #3153/4 | | P 0 | 412161464 | 65636232 |
| After #60/5: | EDT | MT0 Q 8/#011657/ | #011702 | P 0 | 412161080 | 65636149 |
| After #3153/4: | LOV | at #011656 (E2574) | | P 0 | 412160886 | 65636114 |
| After #116/3: | EXITD | BA #004640 NOL 8191 @ #2056/4 | | P 0 | 412160850 | 65636111 |
| After #2472/0: | EDT | FWO Q 0/#000472/ | #000472 | P 0 | 412148327 | 65633868 |
| After #2056/1: | OUT | 8 | | P 0 | 411606886 | 65632757 |
| ... | | | | | | |
| After #116/3: | EXITD | BA #004640 NOL 8191 @ #2056/4 | | P 0 | 411352623 | 65591525 |
| After #715/0: | EDT | MT0 Q 8/#004335/ | #004336 | P 0 | 411340926 | 65589427 |
| After #2472/0: | EDT | FWO Q 0/#000472/ | #000472 | P 0 | 411340010 | 65589283 |
| After #712/5: | EDT | MT0 Q 8/#004335/ | #004336 | P 0 | 410541042 | 65587978 |
| After #1027/5: | LOV | in #066440/#066635 for TR1 | | P 0 | 410532559 | 65586511 |
| After #2472/0: | EDT | FWO Q 0/#000472/ | #000472 | P 0 | 410531063 | 65586264 |
| After #457/4: | EDT | MT0 Q 8/#004335/ | #004336 | P 0 | 410035534 | 65585510 |
| After #713/5: | LOV | MT2 is busy | | P 0 | 410026286 | 65583901 |
| After #2472/0: | EDT | FWO Q 0/#000472/ | #000472 | P 0 | 410021744 | 65583150 |
| After #1045/3: | EDT | MT0 Q 8/#003021/ | #003023 | P 0 | 409224283 | 65581808 |
| After #2472/0: | EDT | FWO Q 0/#000472/ | #000472 | P 0 | 409212381 | 65579669 |
| After #2056/1: | OUT | 8 | | P 0 | 409007105 | 65578559 |
| After #116/3: | EXITD | BA #004640 NOL 8191 @ #3157/0 | | P 0 | 408914735 | 65562404 |
| After #2472/0: | EDT | FWO Q 0/#000472/ | #000472 | P 0 | 408905390 | 65560684 |
| After #3156/3: | OUT | 17 | | P 0 | 408408682 | 65559504 |
| After #116/3: | EXITD | BA #004640 NOL 8191 @ #0/0 | | P 0 | 408407665 | 65559338 |
| After #2565/0: | EDT | TR1 Q 2/#004650/ | #011447 | P 0 | 408332663 | 65546631 |

(etc)

After earlier interrupts, whose tracing is now lost.

APPENDIX 7F: THE INSTRUCTION-TYPE AND INSTRUCTION-LOCUS FREQUENCY HISTOGRAMS

Either, both or neither of these plots may be obtained, at option. The examples show two different programs.

Histogram of the opcodes of 3438705 executed instructions with frequency >= 0.20%

| | | | |
|---------------------|--------|--------|---|
| 004: ×F | 54250 | 1.58% | : |
| 012: PERM | 68668 | 2.00% | : |
| 024: FLOAT | 10291 | 0.30% | : |
| 027: NEG | 54524 | 1.59% | : |
| 033: NOT | 14503 | 0.42% | : |
| 034: ×D | 37146 | 1.08% | : |
| 036: − | 66571 | 1.94% | : |
| 037: SIGN | 33410 | 0.97% | : |
| 041: ZERO | 41389 | 1.20% | : |
| 042: DUP | 136649 | 3.97% | : |
| 043: DUPD | 33299 | 0.97% | : |
| 045: FIX | 14447 | 0.42% | : |
| 050: CONT | 37951 | 1.10% | : |
| 051: REVD | 48162 | 1.40% | : |
| 052: ERASE | 52997 | 1.54% | : |
| 056: + | 141379 | 4.11% | : |
| 060: / | 17040 | 0.50% | : |
| 062: /F | 12042 | 0.35% | : |
| 065: REV | 119555 | 3.48% | : |
| 066: CAB | 17098 | 0.50% | : |
| 074: +F | 45208 | 1.31% | : |
| 075: −F | 49204 | 1.43% | : |
| 102: MkMqQ | 20663 | 0.60% | : |
| 140: M+Iq | 43817 | 1.27% | : |
| 141: M−Iq | 69939 | 2.03% | : |
| 151: MqTOQk | 15744 | 0.46% | : |
| 161: SHA | 51219 | 1.49% | : |
| 164: SHL | 15755 | 0.46% | : |
| 166: SHLD | 7628 | 0.22% | : |
| 170: =[R]{Q C I M}q | 250329 | 7.28% | : |
| 171: {Q C I M}q | 188054 | 5.47% | : |
| 172: =+{Q C I M}q | 23666 | 0.69% | : |
| 173: LINK | 40057 | 1.16% | : |
| 174: =LINK | 64503 | 1.88% | : |
| 206: JrNEZ | 9476 | 0.28% | : |
| 213: Jr | 62570 | 1.82% | : |
| 215: JSr | 74752 | 2.17% | : |
| 217: EXIT | 99197 | 2.88% | : |
| 221: JrEQ | 7125 | 0.21% | : |
| 222: JrLTZ | 12845 | 0.37% | : |
| 224: JrGTZ | 12795 | 0.37% | : |
| 226: JrEQZ | 44682 | 1.30% | : |
| 260: JrCqNZ | 32457 | 0.94% | : |
| 300: EeMq | 587012 | 17.07% | : |
| 301: =EeMq | 214536 | 6.24% | : |
| 303: =EeMqQ | 112303 | 3.27% | : |
| 304: SET | 201893 | 5.87% | : |

Executions accounted for in the profile: 76.5%

Histogram of the loci of 306451954 executed instructions with frequency $\geq 0.50\%$

| | | | |
|-------|----------|------|---|
| #63: | 21524493 | 7.0% | : |
| #64: | 21524493 | 7.0% | : |
| #65: | 14349662 | 4.6% | : |
| #66: | 7174831 | 2.3% | : |
| #70: | 2544372 | 0.8% | : |
| #71: | 1980726 | 0.6% | : |
| #72: | 2592966 | 0.8% | : |
| #73: | 3791307 | 1.2% | : |
| #74: | 2939526 | 0.9% | : |
| #75: | 28793967 | 9.4% | : |
| #76: | 7174831 | 2.3% | : |
| #77: | 11635855 | 3.8% | : |
| #100: | 12165488 | 3.9% | : |
| #101: | 12165488 | 3.9% | : |
| #102: | 3041372 | 0.9% | : |
| #110: | 3274426 | 1.0% | : |
| #111: | 2971022 | 0.9% | : |
| #112: | 4667583 | 1.5% | : |
| #113: | 3073182 | 1.0% | : |
| #114: | 6069284 | 1.9% | : |
| #115: | 6069284 | 1.9% | : |
| #124: | 1630169 | 0.5% | : |
| #125: | 2220330 | 0.7% | : |
| #126: | 2331633 | 0.7% | : |
| #127: | 1554422 | 0.5% | : |
| #167: | 2697092 | 0.8% | : |
| #171: | 1992671 | 0.6% | : |
| #172: | 1977597 | 0.6% | : |
| #173: | 1977597 | 0.6% | : |
| #174: | 2022819 | 0.6% | : |
| #204: | 2697092 | 0.8% | : |
| #206: | 2692318 | 0.8% | : |
| #207: | 6742730 | 2.2% | : |
| #210: | 9439822 | 3.0% | : |
| #211: | 13485460 | 4.4% | : |
| #212: | 6573495 | 2.1% | : |
| #213: | 4552883 | 1.4% | : |
| #214: | 3034642 | 0.9% | : |
| #215: | 3034642 | 0.9% | : |
| #216: | 4552423 | 1.4% | : |
| #217: | 3022530 | 0.9% | : |
| #234: | 3009498 | 0.9% | : |
| #235: | 3022530 | 0.9% | : |
| #236: | 4539949 | 1.4% | : |
| #240: | 3022168 | 0.9% | : |
| #241: | 3035562 | 0.9% | : |
| #242: | 3371365 | 1.1% | : |
| #243: | 2022819 | 0.6% | : |
| #244: | 2058873 | 0.6% | : |

Executions accounted for in the profile: 92.0%

APPENDIX 8: ERROR MESSAGES FROM **ee9**

The following headings introduce classes of error message. Each such message includes detailed diagnostic information.

LIV (LOCK-IN VIOLATION)

INVALID OPERATION ATTEMPTED IN DIRECTOR

These are invalid operations that were detected as such by the KDF9 hardware, and caused a RESET interrupt, or a LIV interrupt when running in problem program mode. LIV interrupt requests did *not* interrupt in Director mode, but are always treated by **ee9** as failing, because they signal states that do not permit emulation to continue successfully.

INVALID OPERAND

INVALID OPERAND IN DIRECTOR

These failures are caused by operands that cannot be correctly interpreted by **ee9**. They include incorrect OUT parameters that would have been detected and rejected by Director, and miscellaneous other errors that **ee9** detects and fails.

FEATURE NOT YET IMPLEMENTED

Presently, only unimplemented OUT numbers give rise to this error.

THE KDF9 OPERATOR MUST HAVE MADE A MISTAKE

These failures are caused by errors in the configuration of the emulated KDF9 that result from mistakes made in the invocation of **ee9**; e.g. by running it in the wrong working directory, so that some required file is absent.

INVALID PAPER TAPE FILE SUPPLIED

These failures probably result from the user not having set up an object program correctly in KDF9 paper tape code.

APOLOGIES FOR THIS DISMAL FAILURE

These are failures of internal consistency checks made by **ee9**. They should never happen, but are handled defensively, with a view to debugging **ee9** itself.

Messages from the `host_IO` package accompany an otherwise unhandled exception named `stream_IO_error`, and indicate that the execution environment is not compatible with running **ee9**. Each message includes a detailed diagnostic of the I/O stream concerned.

Messages from the `POSIX` package accompany an otherwise unhandled exception named `POSIX_IO_error`, and indicate that the execution environment is not compatible with running **ee9**.

OTHERS

The following is detected during diagnostic output at the end of a run. Should never happen. 8-)

```
Failure in finalize_ee9 ...
```

APPENDIX 9: OPERATING A KDF9 WITH THE TIME SHARING DIRECTOR

The following material draws heavily on the EE document ‘A1020 – Time Sharing Director – Mark I’, by A. Doust and M.R. Wetherfield, the authors of the Time Sharing Director program.

Commands from the computer operators to Director are known as ‘TINTs’, short for **Typewriter Interrupts**. They are initiated by pressing the interrupt button on the console Flexowriter. Director responds by typing **TINT**; and waiting for a command to be input. Each such command is terminated by typing ‘.→’. With **ee9**, interrupt by typing CTRL-C and answer the prompt with RETURN. For ‘→’, shown below, type ‘|’.

In the following, **dd** indicates a two-digit device (buffer) number; **tt** indicates a device type (see Table A4.2); **p** indicates a 12-character program name (also known as the PRN, or Program Reference Number); **n** is an octal number; **l** is a magnetic tape label; and **s** is a timesharing slot name (one of ‘P’, ‘Q’, ‘R’ or ‘S’).

A s.→

Terminate program in slot *s*, or terminate its loading.

A s+.→

Terminate program in slot *s* and type a basic diagnostic, showing the top of the SJNS and the NEST..

B s n.→

Read the octal integer *n* (up to 8 digits) and store its value into the less significant half of E0 of *s*. This can be used to convey options to the program at run time, separately from any tape or card data.

C dd.→

Load the magnetic tape on unit *dd*. Director reads the tape label, notes it, and positions the tape at the block immediately following, ready for allocation to a program that requests it by name, using OUT 4 or OUT 10.

D dd.→

Unload the magnetic tape on unit *dd*. The tape is rewound and disengaged from the deck, ready for removal.

E ddA.→ and **E ddB.→**

Nominate the magnetic tape loaded on unit *dd* for the input of A/B programs.

F .→

Dummy (used if interrupt key pressed in error).

G.→

Type the peripheral unit list.

H.→

Type a list of ‘wanted’ tape labels. These are tapes that programs have requested, but have not yet been loaded.

I s0.→

Even restart for program *s*, i.e. make it execute the jump in the first halfword of word 0. This, and the odd restart, are for use when a program fails in a manner that has been anticipated, and can recover from.

I s1.→

Odd restart for program *s*, i.e. make it execute the jump in the second halfword of word 0.

L dd/tt.→

Change the peripheral device unit *dd* to type *tt*. If *tt* = 0, the unit is deleted from the free list.

M x{s?}y.→

Output a store print in syllabic octal. *x* and *y* are both octal integers. *y* words are output, starting at address *x*: if *y* is omitted, 1 is understood. If {*s?*} is P, Q, R or S then the base address of *s* is added to *x*. Any other separator (e.g. ‘/’) gives the absolute (Director) address *x*.

R s.→

Resume *s* (after suspension).

S s.→

Suspend *s*.

T n/w.→

Load a B-program and give it priority level *n*, with a store limit of *w* words. Absence of *w* implies that the program may want the whole store. If the / is replaced by P the paper tape reader from which its call tape is read is pre-allocated to the program. A-programs are loaded on the initiative of Director, not the human operators. When the resources that are needed become available, Director says:

n tt P dd s

n APIU dd s

The operator must have presented the program’s call tape on the A-program input unit *dd*. Director reads it in and continues:

* *date time*

n s P p or n s M p

depending on whether the program itself is to be read from paper tape or magnetic tape.

U.→

For each program in the machine, type its slot letter (P, Q, R or S), 12 character identifier, priority, base address, and running and elapsed times so far.

V n/n' .→

Put program in priority level n into priority level n' , and vice versa.

Z dd .→

Relabel the magnetic tape on unit dd . Director issues the query **TN/ID**; to which the operator replies **N/l**.→, e.g.:

TN/ID;N/+DIRECTORBINWORK.→

Director confirms the change, e.g.:

10L12 /Iden<+DIRECTORBINWORK>,TSN -00-0552

WHEN THINGS GO WRONG

If something goes wrong while reading in a program, Director types:

n CRNP F x

where: CRNP means 'Can't Read New Program' and x is:

- 0: No paper tape reader is available for reading the A-block; this applies to B-programs only.
- 1: Parity failure in the A-block.
- 2: the A-block not in correct form.
- 3: C-block sum check failure.
- 4: Parity failure in the B-block.
- 5: E2 and E3 of the B-block are not the same as the first two words of the A-block.
- 6: Program's store requirement too large.
- 7: Incorrect fillers for a C-block.
- 8: Parity failure in a C-block.
- 9: the unit specified by the A-block is not available for reading B-blocks and C-blocks.

Program input can be terminated by giving a bogus A-block, thus inducing CRNP F2. B-program input can be terminated by the operator: if no reader is available, **TINT A s .→** causes CRNP F0, but after the A and B blocks have been read, and the program is waiting for core store, it causes CRNP F6.

In the event of a problem program failing, Director types:

$n s$ FAILS indicator [*SJNS, N1, N2 and NEST depth, where needed*]

REACT;

This gives the operator the opportunity to abandon, or to restart the run, using **A s .→**, **I $s0$.→**, or **I $s1$.→**. The *indicator* is taken from the following list of two or three digit codes:

- S** A Spurious interrupt, indicating a hardware (emulation) failure
- 00L** Lock-in violation
- 00N** Nest or SJNS over- or under-flow
- 00T** Time limit exceeded
- 01** Incorrect OUT number (it is still in N1)
- 02** Failure in OUT 5
- 03** Failure in OUT 6 or OUT 7
- 04** OUT 4 or OUT 10 requests an unavailable tape
- 05** OUT 1 obeyed with less than 3 items in nest
- 06** OUT 1 obeyed with incorrect program name
- 07** OUT 4 specifies incorrect identifier
- 11** OUT 10 specifies incorrect identifier
- 71** Closing OUT 8 stream without having written anything to it
- 72** Wrong terminator to output block in OUT 8
- 73** Incorrect character in OUT 8 block for the Flexowriter
- 74** Invalid stream number in OUT 8
- 75** No magnetic tape available for OUT 8
- 76** Parity failure in OUT 8 output
- 77** Invalid addresses for an OUT 8 block

The following failures do not give the option of a restart, i.e. **REACT**; is not typed:

- 10 CRNP failure in OUT 1
- 20 Incorrect program name in OUT 2
- 21 Time limit for OUT 2 absent or incorrect
- 22 OUT 2 obeyed with incorrect store limit in E1

NORMAL TERMINATION

When a program finishes without detected failure, the following message is typed out:

n p // e / run time / n.e.t. / elapsed time

where: *run time* is the CPU time used; *n.e.t.* is the ‘notional elapsed time’ which gives an estimate of the elapsed time would have been experienced had there been no delays due to multiprogramming; *elapsed time* is the ‘wall clock’ time since the program started; and *e* is the ‘ending number’, which gives the reason for termination, namely:

- 0: OUT 0
- 2: OUT 2
- 4: TINT A
- 5: CRNP in OUT 1
- 6: any failure in OUT 2
- 7: result of any response to **REACT**;

In the case of successful overlay by OUT 1, Director types the priority, slot and name of the new program:

n s OUT 1

n M p

‘DESCRIPTORS’

Messages of the form:

tt S dd s

indicate that unit *dd* is of type *tt* and has current status *S*. For units other than magnetic tape units, when the unit is unallocated *S* is the letter U. When the unit is pre-allocated to a program or allocated to a program, *S* is P or A respectively. *s* indicates the program to which the unit is (pre-)allocated. When a unit is allocated to Director (e.g. for TINT M), *S* is the letter D.

For magnetic tape units, these messages are only typed when the unit becomes loaded (L) or unloaded (U), except when the whole unit list is typed by TINT G). They then also include the Tape Serial Number (TSN) of the tape, e.g.:

10L12/Iden<PRINTEND>, TSN -20-0403

10L13/Ident<ZERO>, TSN -20-0284

When a list is typed by TINT G, the identifiers of tapes on loaded units only are typed, and the TSN is omitted, e.g.

10L12 PRINTEND

10L13 ZERO

When a unit is allocated or deallocated by a program, the descriptor is typed in the relevant column for P, Q, R or S. The only exceptions to this are the pre-allocation messages preceding A-program input, and messages concerning magnetic tape units. These are always typed in the Director column.

WAITING FOR ...

Messages of the form:

s WAITING FOR TYPE tt

mean that program *s* (which must in this case be a B-program) has attempted to allocate to itself a unit of type *tt*, but none is available. The operators have to decide whether or not to terminate program *s* (or another B-program), in order to free a device of type *tt*, or let it wait for one to be freed voluntarily.

APPENDIX 10: MAGNETIC TAPES IN **ee9**

Magnetic tapes are represented by Ada direct access files, using the `Ada.Direct_IO` library package, to allow selective overwriting of blocks. This is necessitated by the MWIPE and MGAP operations of the 1081-type tape deck. Tapes must be initialized (labelled) before any attempt is made to access them by a KDF9 problem program. (See **RLT** in Appendix 11.)

The “write permit ring”, which was a metal band inserted into the tape reel concentrically with the hub, depressed a switch to enable the deck’s write heads. It is modelled by the file’s access permission. Making the file read-only simulates an absent ring, allowing operations that do not change the contents of the tape, and failing those that do.

Each tape block, and each length of erased tape, is represented by one or more “slices”, a slice being a record in the direct access file. A slice has two components: a string and per-slice metadata. The string contains the Case Normal Latin-1 transliteration of all or part of a KDF9 tape data block. In the case of an erasure slice the string reserves space for possible future over-writing by data, but its contents are of no significance.

An emulated MT block is represented by a number of consecutive slices such that the total length of their contained strings is sufficient to encompass the KDF9 data block or tape erasure. The maximum string size has been set so that blocks of 256 words (as used by POST), and short blocks containing OUT 8 print-line images, both have a space efficiency of better than 95%. The maximum block size (not slice size) is 32KW, or 256K characters, that being the maximum size of the core store. No attempt is made to model either interblock gaps or the erased tape extending from the Beginning of Tape Window (BTW) to the start of the first block of data. However interblock gaps are taken into account when estimating the elapsed time of magnetic tape transfers. Ampex 7-track tape files are recorded in exactly the same way as KDF9-native tapes, with the addition of single-slice blocks representing the two kinds of tape mark. They read into core as #170000000000 in the single input word. Tape marks do not appear in KDF9-native tapes, they are for Ampex ‘IBM-compatible’ 7 track tapes only.

The metadata in each record is as follows.

- Byte 0—a code indicating whether the slice represents a **data** block (code ‘D’), a length of tape erased by the MWIPE operation (code ‘W’), a length erased by the MGAP operation (code ‘G’), an even parity tape mark (code ‘e’), or an odd parity tape mark (code ‘o’).
- Byte 1—a code made up as follows:
 - (a) if the block is ‘LBM’ marked; i.e. if it was written by a MLWQq or MLWEQq instruction instead of the normal MWQq and MWEQq instructions, and so responds positively to the MLBQq order: +64;
 - (b) if this is the last slice of a multi-slice block: +8; and
 - (c) if this is the first slice of a multi-slice block: +1.

Byte 1 therefore has the following possible values (decimal = octal = Latin-1):

```
00 = 000 = NUL  => no flags
01 = 001 = SOH  => first slice of block
08 = 010 = BS   => last slice of block
09 = 011 = HT   => only slice of block (first and last)
64 = 100 = @    => LBM flag
65 = 101 = A    => first slice of block with LBM flag
72 = 110 = H    => last slice of block with LBM flag
73 = 111 = I    => only (first and last) slice of block with LBM flag
```

- Byte 2—the length of the string in this slice.

This encoding makes the contents of a magnetic tape somewhat legible using the POSIX **od** command, but **mtp** usually offers an a more useful view.

THE **mtp** UTILITY

Convenient views of a tape file are obtainable using the **mtp** program. The command takes the form:

```
mtp {MT|ST}{01234567}[Tl{PQRS}{1357}{01234567}]
```

The nominated magnetic tape file is read and an interpretation of its content is written to the standard output. Any error messages are written to the standard error output.

- To despool a stream from an OUT 8 tape written by TSD, append the slot letter and stream number, e.g. **mtp MT0P30**:

```
Despooling OUT 8 stream 30 for slot P, written on 23/09/69 by WHETSTONEUPU
```

```
N=   0 J=   0 K=   0 X1=+1.00000000 X2=-1.00000000 X3=-1.00000000 X4=-1.00000000
N= 120 J= 140 K= 120 X1=-0.06834220 X2=-0.46263766 X3=-0.72971839 X4=-1.12397907
N= 140 J= 120 K= 120 X1=-0.05533645 X2=-0.44743656 X3=-0.71097339 X4=-1.10309806
N=3450 J=   1 K=   1 X1=+1.00000000 X2=-1.00000000 X3=-1.00000000 X4=-1.00000000
N=2100 J=   1 K=   2 X1=+6.00000000 X2=+6.00000000 X3=-0.71097339 X4=-1.10309806
N= 320 J=   1 K=   2 X1=+0.49040732 X2=+0.49040732 X3=+0.49039250 X4=+0.49039250
N=8990 J=   1 K=   2 X1=+1.00000000 X2=+1.00000000 X3=+0.99993750 X4=+0.99993750
N=6160 J=   1 K=   2 X1=+3.00000000 X2=+2.00000000 X3=+3.00000000 X4=-1.10309806
N=   0 J=   2 K=   3 X1=+1.00000000 X2=-1.00000000 X3=-1.00000000 X4=-1.00000000
N= 930 J=   2 K=   3 X1=+0.83466552 X2=+0.83466552 X3=+0.83466552 X4=+0.83466552
```

```
THAT TOOK 21.5 SECONDS, FOR 46.5 KWIPS
FINISHED ENDS 0
```

- If an OUT 8 stream is numbered in the 50-57 range it is taken to be written in Ferranti 5-hole paper tape code. In that case **mtp** attempts to emulate an original teleprinter transcription of the data. For example, this KDF9 code:

ABCDEFGHIJKLMNPOQRSTUVWXYZ}|\Ø

is transcribed thus in Figures Shift:

12*4 () 78±=-vlf , 0>» 3 | 56/×9+ .ncr

and thus in Letters Shift:

ABCDEFGHIJKLMNPOQRSTUVWXYZ. ?f

Note that the Ø is suppressed.

- If a magnetic tape contains only legible text in paper tape code, e.g. a Usercode object program as written out by the Kidsgrove Algol compiler, append a T to the tape deck name, e.g. **mtp MT3T**, to get its transcription into plain Latin-1.
- Invoked with just the deck name, e.g. **mtp MT0**, it gives a slice-by-slice analysis the tape file. Each character in a data block is displayed using its Case Normal Latin-1 transliteration. Each slice is displayed with its record number in the direct access file, the KDF9 data is enclosed in « » quotes, an asterisk flags a block written with a 'last block' marker, and complete blocks, possibly consisting of several slices, are separated by blank lines. Here is the analysis of the above OUT8 tape:

```
TAPE LABEL TSN '-00-1478', IDENTIFIER '+KOUTPUT/0023001'

2      * «0001ØØP"P000001©»
3      * «0001ØA&"©ØØØØP© »
4      «0003ØØ&"WHETSTONEUPU 23/09/69®»
5      «0001ØØ&" STR30®»
6      «0001ØØ&"©ØØØØP© »
7      «0023ØØ&"N?ØØØØØØ 00ØØØØ J?ØØØØØØ 00ØØØØ K?ØØØØØØ 00ØØØØ X1?ØØØØØ+1.00000000000000 »
8      «X2?ØØØØØ-1.00000000000000 X3?ØØØØØ-1.00000000000000 X4?ØØØØØ-1.000000000000000000®»
9      «0023ØØ&"N?ØØØØØØ 120ØØØØØ J?ØØØØØØ 140ØØØØØ K?ØØØØØØ 120ØØØØØ X1?ØØØØØ-0.06834220000000 »
10     «X2?ØØØØØ-0.46263766000000 X3?ØØØØØ-0.72971839000000 X4?ØØØØØ-1.1239790700000000000000®»
11     «0023ØØ&"N?ØØØØØØ 140ØØØØØ J?ØØØØØØ 120ØØØØØ K?ØØØØØØ 120ØØØØØ X1?ØØØØØ-0.05533645000000 »
12     «X2?ØØØØØ-0.44743656000000 X3?ØØØØØ-0.71097339000000 X4?ØØØØØ-1.1030980600000000000000®»
13     «0023ØØ&"N?ØØØØØØ0345000000 J?ØØØØØØ 100ØØØ K?ØØØØØØ 100ØØØ X1?ØØØØØ+1.00000000000000 »
14     «X2?ØØØØØ-1.00000000000000 X3?ØØØØØ-1.00000000000000 X4?ØØØØØ-1.0000000000000000000000®»
15     «0023ØØ&"N?ØØØØØØ0210000000 J?ØØØØØØ 100ØØØ K?ØØØØØØ 200ØØØ X1?ØØØØØ+6.00000000000000 »
16     «X2?ØØØØØ+6.00000000000000 X3?ØØØØØ-0.71097339000000 X4?ØØØØØ-1.1030980600000000000000®»
17     «0023ØØ&"N?ØØØØØØ 320ØØØØØ J?ØØØØØØ 100ØØØ K?ØØØØØØ 200ØØØ X1?ØØØØØ+0.49040732000000 »
18     «X2?ØØØØØ+0.49040732000000 X3?ØØØØØ+0.49039250000000 X4?ØØØØØ+0.4903925000000000000000®»
19     «0023ØØ&"N?ØØØØØØ0899000000 J?ØØØØØØ 100ØØØ K?ØØØØØØ 200ØØØ X1?ØØØØØ+1.00000000000000 »
20     «X2?ØØØØØ+1.00000000000000 X3?ØØØØØ+0.99993750000000 X4?ØØØØØ+0.9999375000000000000000®»
21     «0023ØØ&"N?ØØØØØØ0616000000 J?ØØØØØØ 100ØØØ K?ØØØØØØ 200ØØØ X1?ØØØØØ+3.00000000000000 »
22     «X2?ØØØØØ+2.00000000000000 X3?ØØØØØ+3.00000000000000 X4?ØØØØØ-1.1030980600000000000000®»
23     «0023ØØ&"N?ØØØØØØ 00ØØØØ J?ØØØØØØ 200ØØØ K?ØØØØØØ 300ØØØ X1?ØØØØØ+1.00000000000000 »
24     «X2?ØØØØØ-1.00000000000000 X3?ØØØØØ-1.00000000000000 X4?ØØØØØ-1.0000000000000000000000®»
25     «0023ØØ&"N?ØØØØØØ 930ØØØØØ J?ØØØØØØ 200ØØØ K?ØØØØØØ 300ØØØ X1?ØØØØØ+0.83466552000000 »
26     «X2?ØØØØØ+0.83466552000000 X3?ØØØØØ+0.83466552000000 X4?ØØØØØ+0.8346655200000000000000®»
27     «0001ØØ&"ØØØØØØØ®»
28     «0007ØØ&"THAT TOOK ØØØØØØ 21.5 ØØSECONDS~ FOR ØØØ 46.5 ØØKWIPSØØ®»
29     «0002ØØ&"FINISHED ENDS 0®»
30     * «0001ØZ&"©ØØØØP© »
31     * «}ØØØØØØØ»
32     WIPE of 1906 erased characters

EOF
```

The final 'EOF' is not from the tape; it is a confirmation by **mtp** that all of the data on the tape has been shown.

APPENDIX 11: ANCILLARY PROGRAMS FOR USE WITH **ee9**

This section gives specifications for the utility programs—some shell command files, some in KDF9 Usercode, and others in Ada 2012—that are provided with distributions of **ee9** to facilitate its use.

THE **a2b** UTILITY

a2b reads data from standard input in a stated code and writes it to standard output in another form. Conversions are available between raw bytes and paper tape code, between paper tape code and Latin-1, and from paper tape code to a legible display. The command takes the form:

```
a2b { -r2p | -L2p | -p2c [ F | D | M | P ] | -p2L | -p2t | -p2o | -p2r | -F2L }
```

Exactly one flag parameter must be given; it is actually case-insensitive. The effect is as follows:

| | |
|-------------|--|
| -r2p | Take the input to be ‘raw’ bytes, perhaps representing KDF9 syllables; read groups of 6 to form 48-bit words; output each such word as 8 KDF9 characters in paper tape code. |
| -L2p | Take the input to be 8-bit characters in Latin-1 code; transcribe them individually to KDF9 characters in paper tape code. |
| -p2L | Take the input to be KDF9 characters in paper tape code; transcribe them individually to 8-bit characters in Latin-1 code; ignore NULs (runout); report parity errors. |
| -p2c | Take the input to be a KDF9 object program in paper tape code and output a valid call tape for it, using the name extracted from words 2 and 3 of the program’s A block; report parity errors. If one of the parameters D, M, or P is given a call type of that kind is created. The parameter F (for file) makes a call tape for the medium specified in the A block of the program file, and this is the default. |
| -p2t | Like -p2L , but effect case shifting and ignore redundant or non-printing characters, so as to give a clean output text ; report parity errors. |
| -p2o | Take the input to be KDF9 characters in paper tape code; read groups of 8 to form 48-bit words; output each such word in octal half/word, Q-store, syllable and character formats; report parity errors and incomplete words. |
| -p2r | Take the input to be KDF9 characters in paper tape code; read groups of 8 to form 48-bit words; output each such word as 6 ‘raw’ bytes; report parity errors and incomplete words. |
| -F2L | Take the input to be characters in Ferranti paper tape code; transcribe them to 8-bit characters in Latin-1 code. |

THE **RLT** UTILITY

RLT is a Usercode program that reads a set of tape labels from TR1 and writes them in succession to the magnetic tape files MT0-MT5 and ST0, having erased a gap in which to write the new label on each tape. The data given in TR1 consists of one or more lines of text. The first 8 characters of the line give the ‘Tape Serial Number’ (TSN). The next 8 or 16 characters give the mnemonic ‘identifier’ of the tape. If the tape is intended to be a scratch work tape, its identifier must consist of 8 blank spaces (all zeros in KDF9 character code). A 16-character identifier must start with the character ‘+’. There must be an End Message character (‘|’ in **ee9**) after the last character of the identifier. A line starting with an End Message character terminates the data.

Here is an example, showing the sort of data that is used to label the tapes by **ee9**’s regression test suite:

```
-00-1234WHETLIST |
00000000 |
-00-0552EFPBEAAG |
77777777MS-DUMP. |
-00-2339+KOUTPUT/0023004 |
0-00-929PRINTEND |
0-00-777AMPEXTM4 |
|
```

For ease of running, the command file **rlt** is provided to set up the environment and the **ee9** mode parameters for **RLT**. **rlt** truncates the former contents of all of the tape files and then runs **RLT** in test program mode, so that it can access the physical tape buffers without having had them allocated by Director (which requires the tapes to be already labelled.)

rlt takes the new labels from the file **RLT_data.txt** by default. For a different set of labels, supply the name of an alternative file as a parameter.

THE `PLT` UTILITY (NOT YET AVAILABLE)

PLT is a Usercode program that generates POST-format program library tapes that are used by the Time Sharing Director to hold programs that can be loaded into store at the command of an M-type call tape. (See **a2b** and **call_tape** above.)

If given no data **PLT** claims a **ZERO** (scratch) work tape, relabels it +PROGRAM/LIBRARY, and writes the sentinel blocks that structure it as an empty library.

If given a KDF9 object program in TR1, it appends that program to the library.

For ease of running, the command file **plt** is provided to set up the environment and the **ee9** input mode parameters correctly for **PLT**. Among other things, **plt** runs the **RLT** command to label the tape files suitably prior to running **PLT**.

See the EE System Routine Library Manual, §22.1, 'Library Tape and Program Structure', 1965.

THE `to_9_from_1934` UTILITY

to_9_from_1934 reads the file `Data/wabbit_data_1900`, which must contain commands for the ICT 1934 plotter, converts them to KDF9 plotter commands, and writes them to the file `Data/wabbit_data_kdf9` in KDF9 8-track paper tape code. See ICT Technical publication 4003/C, 'System Manual Volume X: Visual Input/Output Equipment', 1966.

THE `kidopt` PROGRAM

kidopt takes in a list of symbolic Kidsgrove Algol compilation options and converts them to the bit patterns used to transfer options to the compiler. See Appendix 12.

THE `run_cr_tests` SHELL FILE

run_cr_tests runs a set of regression tests for card reader and card punch emulation.

THE `run_dr_tests` SHELL FILE

run_dr_tests runs a set of regression tests for drum store emulation.

THE `run_fd_tests` SHELL FILE

run_fd_tests run a set of regression tests for fixed disc emulation.

THE `run_kids_tests` SHELL FILE

run_kids_tests runs a set of regression tests for the Kidsgrove Algol compiler and runtime system

THE `run_liv_tests` SHELL FILE

run_liv_tests runs a set of regression tests for basic CPU error-detection functionality.

THE `run_mt_tests` SHELL FILE

run_mt_tests runs a set of regression tests for magnetic tape emulation.

THE `run_nouv_tests` SHELL FILE

run_nouv_tests runs a set of regression tests for basic CPU nesting store functionality.

THE `run_si_tests` SHELL FILE

run_si_tests runs a set of regression tests for standard interface buffer emulation.

THE `run_whet_tests` SHELL FILE

run_whet_tests runs the same set of regression tests as **run_kids_tests** but using Whetstone Algol

THE `ee9_reg_test` SHELL FILE

ee9_reg_test runs a comprehensive suite of regression tests of **ee9**. It includes most of the various **run_*** commands, and reruns the **OUT4A** magnetic tape test to check its signature. In addition it does extensive checks of fixed and floating point arithmetic and runs a variety of Whetstone Algol, Kidsgrove Algol and Usercode problem programs. It does not include any tests of boot mode, because running a Director forces user interaction.

APPENDIX 12: WORKING WITH THE WHETSTONE AND KIDSGROVE ALGOL 60 COMPILERS

The Algol 60 Report defines a ‘reference language’ that ignores the practicalities of implementation on the graphically impoverished computers of the 1960s. Indeed it uses symbols that are not trivially available even today, such as \uparrow , \times , \div , \supset , and \equiv . It further specifies that an implementation may work in a ‘hardware language’ that represents the reference language using a computer’s native character set. The Whetstone (‘WAlgol’) and Kidsgrove (‘KAlgol’) hardware languages are based on the Friden Flexowriter character set listed in Appendix 2A. Symbols not present there are synthesized, primarily by means of the non-escaping underline character, so that **begin**, for example, is prepared for input to a compiler as begin and \equiv as eqv. **ee9** uses the Latin-1 break character as its transliteration of the Flexowriter underline, so that begin appears thus: b_e_g_i_n. Another scheme, used on computers with even less flexible input than the KDF9, is the ‘stropped’ format: each reserved word is decorated with flag characters and *ad hoc* arrangements are made for other symbols. For example, many card oriented Algol systems, including EGDON Algol on the KDF9, represent **begin** as ‘begin’, with the word enclosed in apostrophes. The Eldon 2 Teletype-based interactive system for the KDF9 flags reserved words with an initial exclamation mark, thus: !begin, and this is the form I find easiest to use.

The 2020 input routines for the resurrected Kidsgrove system allow greater flexibility and convenience, with well-considered alternative lexical forms that are much nicer to type. The following table lists character transliterations and other hardware representations used with **ee9** for both the Whetstone and Kidsgrove compilers. The original Whetstone representations are accepted by the Kidsgrove compiler, but not vice versa; the Whetstone representations are the only ones accepted by the 1964-vintage Whetstone compiler. You may find it easiest to write a program in stropped format and convert it to original format, even if you only want to use the Whetstone compiler. See the **strop** and **ports** commands described in §1; they provide a quick and easy way of converting programs from one format to the other.

| Algol 60 | Flexowriter | ee9 and whet | additional kalgol forms |
|------------------|------------------|----------------------|--|
| \uparrow | \uparrow | \wedge | !up ‘up’ |
| \times | \times | \times | * |
| \div | \div | \div | % !div ‘div’ |
| \supset | \supset | \supset | ~ \ |
| \neq | \neq | \neq | # != !ne ‘ne’ |
| \geq | \geq | \geq | >= !ge ‘ge’ |
| \leq | \leq | \leq | <= !le ‘le’ |
| | \rightarrow | | **** |
| begin etc | <u>begin</u> etc | <u>b_e_g_i_n</u> etc | !begin ‘begin’ etc |
| ‘string’ | [string] | _[string_] | {string} (string in string quotes) |
| ‘ ’ | [*] | _[*_] | {_} {\$} (string blank space in string quotes) |
| \neg | <u>not</u> | <u>n_o_t</u> | !not ‘not’ |
| \wedge | <u>and</u> | <u>a_n_d</u> | !and ‘and’ |
| \vee | <u>or</u> | <u>o_r</u> | !or ‘or’ |
| \supset | <u>imp</u> | <u>i_m_p</u> | !imp ‘imp’ |
| \equiv | <u>eqv</u> | <u>e_q_v</u> | !eqv ‘eqv’ |

WHETSTONE ALGOL (WALGOL)

A selection of Algol source programs can be found in the directory `Testing/Whetstone`. I provide a shell command, **whet**, in the `Testing` directory, that makes it easy to compile and run Algol programs using WAlgol. It expects programs to be in text files named with the ‘.a60’ suffix. The suffix is optional in a name given as parameter to the **whet** command; if supplied, it must be correct; if omitted, it is automatically restored; so that, e.g.:

```
whet FLUID
```

compiles and runs `Whetstone/FLUID.a60`. There is some flexibility in the location of WAlgol source programs: see Appendix 1. A source program and its stream 20 data may both be kept in the same file. Alternatively, only the program need be held in that file, with its data being provided by the interactive input feature of **ee9**. (See §3.3.)

Additional *mode* and *miscellany* parameters are optional and as given in §1 for the **nine** command. More comprehensive options, as described in §5, may be specified in the `settings_1.txt` file. If you want to specify different options for the program run, as opposed to its compilation, put them in the second options file, `settings_2.txt`.

If either TP0 or LP0 is found to be non-empty at the end of a run, its content is displayed on the terminal.

The **whet** command sets up the FW0 file for the Whetstone system so that you do not need to type in any responses to its Flexowriter prompts. If the given replies are unsuitable, change the data in `FW0_for_Whetstone`.

A compilation listing is produced only if the response to the compiler’s **OUT**; prompt is an OUT 8 stream number: either 10. | or 30. |, rather than N. |. Stream 10 is directed to TP0; stream 30 goes to LP0. You may find that the listing disappoints: the source code is not included. Instead the compiler outputs a table relating source line numbers and object code addresses, which may later be quoted in runtime error messages. The line numbers are somewhat deceptive, as they seem to ignore blank lines and lines before the first **begin**.

When the WAlgol object program starts, it prompts **STREAM;** for the number of the output stream to be used; again, reply 10. | or 30. |. This should be the same as the stream number nominated for output in the source program. All of this is automated with the provided FW0_for_whetstone file, which suppresses the listing and sends output to stream 30.

You are likely to encounter both compilation errors and execution errors. They are explained in the documents *Whetstone Compilation Errors* and *Whetstone Runtime Errors*. Runtime errors may be accompanied by a ‘retrospective trace’ which lists the procedures called but not yet exited, the value of any failing operand, and a source code line number.

KIDSGROVE ALGOL (KALGOL)

The KAlgol system has been resurrected by David Holdsworth, David Huxtable (one of its original authors) and Brian Wichmann. It is something of a chimera. Several of its original components are lost and have been replaced with reverse engineered substitutes. The object program is generated in Usercode, which needs to be assembled. For these reasons running the Kidsgrove system is complex, and a little flaky. Nevertheless it is well worth the effort to see what a pioneering and very clever compiler was able to make of an intractable language like Algol 60 six decades ago.

A shell command, **kalgol**, in the **Testing** directory, hides this complexity and makes it easy to compile KAlgol programs. It has one parameter, the name of the program, taken from the directory **Testing/Kidsgrove**. Execution *mode* and *miscellany* parameters for the run of the compiler may be given in the environment variables KIDSMODE and KIDSMISC respectively. It is particularly useful to set KIDSMISC=w to suppress the compiler’s voluminous Flexowriter output, and this is the default. For example:

```
kalgol FLUID
```

compiles Kidsgrove/FLUID.a60.

A shell command, **kids**, in the **Testing** directory, combines a call of **kalgol** to compile a program and a call of **nine** to run it. It has one mandatory parameter: the name of the program. Additional parameters are taken to be *data*, *mode* and *miscellany* options for the run of the object program by **nine**. Mode and miscellany parameters for the run of the compiler may be given as for **kalgol**. For example:

```
export KIDSMODE=t; export KIDSMISC=rsw
kids FLUID FLUID_data f
```

After a successful compilation with **kids** or **kalgol** the Usercode object program is left in the **Assembly** directory. The KDF9 executable is left in the **Binary** directory and can be run with the **nine** command, e.g.:

```
nine FLUID FLUID_data f
```

There is actually considerable flexibility in the location of KAlgol source programs, object programs, their data files, and other components of the Kidsgrove compilation system provided with **ee9**: see Appendix 1.

Error messages are explained in the documents *Kidsgrove Compilation Errors* and *Kidsgrove Runtime Errors*.

KAlgol procedure bodies can be written in a version of Usercode that allows access to formal parameters. This is how the standard functions and the I/O libraries are implemented. See the document *Kidsgrove Code Procedures* and, for a simple example, the **PLOT** program in Kidsgrove.

The standard functions of Algol 60, and the KDF9 Algol I/O procedures, are incorporated into a program by means of the **library** (!library, ‘library’, l_i_b_r_a_r_y) directive, which is placed immediately after the first **begin** of a program and lists the (source code) libraries to be included. The document *Kidsgrove IO Libraries* names the libraries that were originally provided. The table below indicates the libraries (A0 through A15) that are available at the moment, and the procedures they contain. This is subject to occasional enhancements.

| | |
|-----|---|
| A0 | the standard functions of Algol 60: sqrt , ln , exp , sin , cos , arctan , entier , abs , sign |
| A1 | open and close ; all input must come from stream 20, and all output must go to stream 30 |
| A4 | read and read boolean (but read boolean is unlikely to work with A1 as yet) |
| A5 | write , output , format , write boolean |
| A6 | the union of A1, A4, A5, and A15 |
| A12 | newline , space , tab , gap |
| A13 | character I/O and Algol Basic Symbol I/O |
| A14 | copy text |
| A15 | write text |

It is an error to import duplicates, so that A6 should not be specified in combination with any of A1, A4, A5, and A15.

Kidsgrove compilation options, affecting the object code, e.g. by suppressing optimization, may be given on the command line, thus:

```
kalgol FLUID with NO_OPT DEBUG
```

or by setting an environment variable, thus:

```
export KIDSOPTS="NO_OPT DEBUG"
kalgol FLUID
```

(The “with ...” syntax is a nod to the **TRANSLATE** command of the KDF9’s POST software development system.)

To communicate compilation options to **kalgol** when using the **kids** command, which has an ample sufficiency of optional parameters, use KIDSOPTS, thus:

```
export KIDSOPTS="NO_OPT DEBUG"
kids FLUID FLUID_data
```

The presently available compilation options are as follows:

| NONE | #0 | apply default options |
|--------|------|---|
| DEBUG | #2 | enable assignment tracing (strangely invoked by 'WITHOUT TEST' within POST) |
| NO_OPT | #4 | suppress global optimisations |
| LABELS | #10 | enable label tracing (strangely invoked by 'WITH TEXT' within POST) |
| option | code | meaning |

- **NONE** specifies the compiler's default behaviour: an optimised, overflow-checking, assignment-tracing compilation with none of the other compile-time or run-time diagnostic outputs.

- **DEBUG** enables the generation of assignment tracing code. The compiler includes a call to a procedure that can print the value being assigned (in octal). The output from that procedure can be switched off and on dynamically using a procedure called **TRACE** (nothing to do with any **TRACE** option). If a compilation omits the **DEBUG** option all code related to assignment tracing is omitted from the object program.

- **NO_OPT** specifies the suppression of the compiler's global optimisations. The resulting program will probably run quite a bit slower. The optimiser is not completely reliable and may produce incorrect object code in difficult cases, but it is instructive to compare the Usercode produced with and without optimisation. Simple **for** loops, in particular, benefit enormously from optimisation.

- **LABELS** requests the inclusion of code to provide a control-flow trace that prints out the Usercode labels of instructions encountered as the object program executes. This option is useful only in conjunction with object program's Usercode assembly listing, which **kalgol** leaves in the **Assembly** directory on completion of a successful compilation.

Options are given to the compiler under **ee9** by means of the **P**, 'poke', flag in a settings file. The **kidopt** program takes in the list of symbolic options and outputs the corresponding **P** flag setting. **kalgol** copies **settings_for_kalgol.txt** into **settings_1.txt** and then appends the output from **kidopt**. This enables the user to set some persistent options for **ee9**'s runs of the compiler and allows them to be augmented with Kidsgrove-specific compilation options, per-run, by means of **kidopt**'s output. For more information about how **kalgol** works, see §7 of *ee9 Implementation Overview*.

N.B. This correspondence between option bits and object code effects is implemented in the early version of the Kidsgrove compiler that has been restored to working order and is now used with **ee9**. It is not entirely consistent with some surviving English Electric documentation, which is thought to support a later version of the compiler.

SEE ALSO

The Algol 60 language, and its usage on the KDF9 computer, are described in the following English Electric publications:

Report On The Algorithmic Language ALGOL 60

Ed. P. Naur; 1960. Available in: *Egdon System Reference Manual, Chapter 7, 'EGDON ALGOL'*.

Publication 103 550566; English Electric–Leo–Marconi Computers Limited; 1968.

KDF9 ALGOL Programming

Publication 1002 mm (R) 1000565, English Electric–Leo–Marconi Computers Limited; 1969.

The following papers describing the Kidsgrove and Whetstone systems were written by their original designers and implementers and constitute an invaluable historical resource:

KIDSGROVE

Implementation of ALGOL 60 for the English Electric KDF9

F. G. Duncan

Computer Journal, Vol.5, No.2, pp. 130–132; 1962.

Input and output for ALGOL 60 on KDF9

F. G. Duncan

Computer Journal, Vol.5, No.4, pp. 341–344; 1963.

A multi-pass translation scheme for ALGOL 60

E.N. Hawkins and D.H.R. Huxtable

Annual Review in Automatic Programming, Vol.3, pp. 163–205, Pergamon Press; 1963.

On writing an optimizing translator for ALGOL 60

D.H.R. Huxtable

Introduction to System Programming, APIC Studies in Data Processing, No.4, pp. 137–155, Academic Press; 1964.

WHETSTONE

The Whetstone KDF9 ALGOL Translator

B. Randell

Introduction to System Programming, APIC Studies in Data Processing, No.4, pp. 122–136, Academic Press; 1964.

ALGOL 60 Implementation

B. Randell and L.J. Russell

Academic Press; 1964.

These documents are available online, at time of writing, at www.findlayw.plus.com/KDF9.