F36P

MACRO ASSEMBLY PROGRAM

INTERNAL OPERATIONS MANUAL

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MACRO

ASSEMBLY PROGRAM

INTERNAL OPERATIONS MANUAL

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INTRODUCTION

MACRO FIO-DEC is based on MACRO III, an assembly program for the TX-O computer at the Massachusetts Institute of Technology. The TX-O was built at Lincoln Laboratory and is now on loan to the Electrical Engineering Department at MIT. Since the PDP-1 is very similar in its logical design to the TX-O, it was thought worthwhile to prepare a version of the MACRO assembly program for use on the PDP-1. The program was written in MACRO language, and originally was assembled on the TX-O. An elementary version of DDT (see DECUS distribution MIT-2) was also prepared and was used in debugging MACRO. The present version incorporates a number of improvements over the original, and has been in use in its present form for several months at MIT.

The program is a two-pass assembler, with a macro-instruction facility which generates words from encoded stored model statements. With one minor exception, it is a linear scan character processor, examining each character once in order on each pass. In order to reduce wear and tear on input-output equipment, both input and output are buffered. The tape reading routine has an optional parity check, but except for this, and stripping the parity bits, the tape handling routines are essentially transparent to the rest of the program. We shall begin our discussion with an investigation of these routines.

SECTION 1

INPUT TAPE HANDLER

Each time the main program requires a character, rch is called. Characters are stored three to a word, and fwd is a counter which indicates which of the three characters is to be read out next. When a word is exhausted, the next is picked up at rc8, and saved in fwb. Normally, control drops through the tests immediately following, fwd is reset to 3, and the next character is stripped off at rc1. The character is saved in t, rcp, and the AC. The subroutine then returns to the main program.

When the last word is fetched, special treatment is necessary, for as will be seen later, it may not have three characters in it. The precise number is to be found in nfc, from which fwd is set when the program reaches rc3.

The next time through rc8, it will be found that no more words remain in the buffer, and control passes to rfb. The buffer indices are reset, and the program commences reading. Tape will be read until a stop code is encountered, a carriage return is encountered during filling the last 24 words of buffer, or a parity error is found. Deletes are filtered out, but all other characters are stored. Sense switch 6 is examined to see if parity is to be checked, and if it is off, parity is checked. The character is planted in a rotate instruction, which rotates according to the number of ones in the instruction. Thus, executing this on a word of alternate ones and zeroes generates a parity. If an error is found, a diagnostic is printed, and the character as read is displayed in the IO. The type symbol subroutine (tys) is used for typing. Continue causes the character to be accepted by going to rfa. Start ignores the character by returning to the read instruction (rf2). Note that the action on Start, if not otherwise conditioned by the test word, is determined by sov. This will be dealt with in detail later.

The characters are assembled into words directly into storage. The previous contents of the buffer words are lost by being shifted off the end of the word at rf3. Next we check for whether the remaining stop conditions are met. Stop codes go to rf6, where the last word has its characters correctly aligned for the readout routine. The end checks are set up, and control returned to rc8. If the buffer is within 24 (octal) words of being full, rf4 is set to exit to rf6 on the next carriage return. Since, in the usual MACRO-language typescript, the next character after a carriage return is almost always an ignored tab, no great harm will be done if the reader cannot stop before the next character.

INITIALIZATION AND TITLE SEQUENCE

From ps2 to pte is initialization for starting or continuing a pass. Complete discussion of the initialization will mostly be confined to a general description, with specifics being related at the initialized routines.

The initial entry to the program is at ps5. The program stops at ps1-1, and on Continue goes through ps1, which sets for Pass 1; np1, which sets up to begin a pass; and through np2, which sets up to begin processing a single tape. At np2 is a sequence which detects whether there is a tape in the reader and the reader is turned on. An rpa is given without a wait, and if no character has appeared in the IO within about 80 milliseconds, the reader is assumed to be not ready and the program stops. When the reader is ready, the tape reading routine is initialized such that the buffer will appear completely empty, and tape will be read as soon as rch is called.

At pte, flag 5 is off iff (if and only if) a title is to be punched. If it is off, some blank tape is fed before anything else is done. Next the characters comprising the title are read. Leading stop codes are ignored; and also leading spaces, to prevent blank tape from being considered as spaces in the event that parity is not being checked. Leading carriage returns are also ignored. The first non-ignored character sets flag 6, so that spaces will no longer be ignored; and if the character is a middle dot, flag 5 is set to discontinue punching the title. The character is typed with completion requested but no in-out wait, and if the character is to be punched, this is done while the typewriter is typing. It has been found empirically that six lines can be punched during typing one character with negligible likelihood of the typewriter completion appearing before punching is done.

The carriage return following the title is detected at pt5, and when it has been found, pass 1 or pass 2 is typed out, followed by punching the input routine, if this is necessary. The input routine on the MACRO tape, as read into storage, is used as data. Some more tape is fed, and control passes to rst.

RESET SEQUENCE

The terminating character switches determine MACRO's treatment of the terminating characters tab, comma, equals, slash, and left parenthesis. The macro-instruction definition indicator mii determines the setting of these switches. If mii is on (-0), these switches are set to appropriate parts of the macro-instruction definition routine.

Indicators for each word are reset at rsk and rsw. At rsk, the left and right parenthesis switches are reset, and the dummy-symbol pushdown counter prs is set to 0. At rsw, the accumulated word value wrd is zeroed; the polysyllabic word indicator syl is turned off by clearing flag 5; the temporary storage nsm, asa, and amn is cleared (these are used by the slash routine for determining the symbolic location after a location assignment); the defined indicator def is turned on; and the dummy symbol indicator, flag 6, which is used by the macro definition routines, is turned off. At sp, the indicators for each syllable are cleared: the sign of the next syllable is set positive, the symbol letter indicator is cleared, and so are the overbar indicator, the syllable value num, the symbol storage sym, and the character counter chc. Control then falls into the main character processing loop, which begins at r.

SYMBOL GENERATOR

There are three kinds of symbols which are developed in the main character loop: integers, pseudo-instructions, and "symbols," which term we shall reserve for sequences of one, two, or three letters or numerals containing at least one letter. Letters and numerals are dispatched on at r and go to l and n respectively. Numerals are combined into num at n. The current radix control at n1 multiplies the preceding digits by eight or ten for octal or decimal. So that 777777 (octal) yields minus rather than plus zero, a check at n3 does a special treatment of zero. Letters turn on the letter indicator let and also letters-in-upper liu if in upper case. Letter and number flow combines at ln where the character count chc is stepped and the first three characters are combined into a symbol sym at l2. If a fourth character is encountered, let is checked; if a letter has occurred, it is a pseudo-instruction, and otherwise it is merely a number of four or more digits. Pseudo-instructions cause the P-I name to be saved in api for error printing purposes, and reset various indicators preparatory to picking up possible arguments. Additional characters are read until a break character (space, plus, minus, tab, or carriage return) is encountered, which ends the pseudo-instruction name, and the second three characters are saved in syn. At the break character, control is transferred to search for the pseudo-instruction name at spm.

SYMBOL PROCESSOR

Symbols are combined by addition or subtraction as indicated by plus or minus signs, which go to p and m on dispatching. All routines which are called at the end of a symbol go to evl, which evaluates any symbol and performs the indicated arithmetic.

The symbol system is based on the idea that a symbol will be defined relatively infrequently, but will be used quite often. It is reasonable to spend a relatively long time defining a symbol if this will make it possible to evaluate it quickly. The symbol table is therefore kept sorted at all times, and a binary or logarithmic search is used to evaluate symbols. For those not familiar with the idea, the remainder of this paragraph is devoted to a discussion of the principle. Consider a dictionary, in which it is desired to locate a word, say pen. First look in the center of the book, and determine whether the word found there is before pen, after pen, or pen itself. If the word is before pen, which is likely to be the case, look next in the center of the back half of the book. Suppose the word found to be tree. Now pen is known to be before tree, so we next look in the center of the preceding quarter. The process is repeated, dividing the word list by two each time until the word is found. It is apparent that if there are two to the nth words, a maximum of n lookups are required, and the average number will be n-1.

To secure an alphabetic ordering of the symbol table, it is necessary to modify the codes of the letters so that the concise code is converted to alphabetic order. The easiest way to do this is by "inverting the zone bits," i.e., complementing the highest bit of each character if the next highest is a 1. This is done at the permute zone bits subroutine per, which also complements the sign bit. The transformation is reciprocal, i.e., permuting a permuted symbol un-permutes it. This fact is used by the error print routine.

Returning to evl, we see the symbol permuted, followed by a check of the macro-instruction indicator mii. If it is on, control is transferred to wsp to check for dummy symbols. If it is off, let is checked; if it is on, a symbol table search is necessary, otherwise the number (integer) is combined into wrd. It is also combined into amn, which accumulates the numeric part, if any, of a word for determining the new symbolic location in the event of a location assignment.

Location assignments are also dealt with at el, where the symbol, if any, to be used in a symbolic location is determined. There is a three state indicator nsm, which is initially + 0, and is set to + 1 after the first symbol of a word, and to - 1 after any other symbol. It is also set to - 1 in the event of a symbol preceded by a minus sign, for such a symbol cannot be the symbolic part of a symbolic location. Further discussion of this point will be postponed until a complete investigation of location assignments.

The logarithmic search begins at e2. There is a shift counter t1 which constructs the repeated increments to the address in the symbol table. The table is stored from register 7750 down, with the symbols in even-numbered registers and values in the next higher odd-numbered registers. Register 7750 is called low and contains lac the lowest address in the symbol table. The first location examined is that contained in low, and hence the lowest entry in the table. Succeeding addresses are computed as necessary, but the contents thereof are not examined until it is determined that the address does in fact lie in the symbol table. The decision as to whether to go up or down is seen to involve the overflow indicator (initially cleared at e2+ 2). This is a consequence of the fact that the symbols can assume all possible arithmetic values. Here the reason for complementing the sign bit becomes apparent. The table is arranged in numerical order, with the most negative number, originally the smallest positive number, at the bottom. It will be seen that if an overflow occurred, the sign of the result will be exactly the opposite of what it should be to move the search in the correct direction. Thus we do a skip on no overflow, and overflow causes a complement. Next we do a three way branch to move the search up, down, or exit on finding the symbol in the table. The remaining portion of the routine at eqt is related to variables and will be discussed later.

It will be seen that the maximum size of the symbol table must be a power of 2, since the shift counter is halved at each iteration and the search must always move an integral number of registers. The maximum corresponding to the initial value of the shift counter will never be realized in practice, for the symbol table would first collide with the top of the macro-instruction or constant table. The top of the latter tables is kept in register hih, and a collision results in an alarm of storage capacity exceeded.

Also in evl is a subroutine ed whose purpose is to frustrate the PDP circuitry that filters out minus zeroes on addition. Additions to wrd are done through this subroutine. This assures that when an expression such as (777776+1) appears in a source program, minus zero and not plus zero will be the result.

SECTION 2

STORAGE WORDS

The storage word termination routine places words in the punch buffer, counts the location counter and determines when punching should take place. Control is passed to the punch routine on Pass 2 whenever the location gets to a multiple of 100. This results in convenient sized binary blocks. There is a subroutine sch which checks syl and chc to see whether anything occurred since the last tab, carriage return or other terminator; if something has, the next instruction is skipped; otherwise the terminator is redundant and is ignored, since the next instruction returns control to r.

This routine is used as a subroutine by the macro-instruction processor and constant routine.

LOCATION ASSIGNMENTS

The location assignment character </> enters at b. If preceded by a word terminator, it denotes the beginning of a comment, and control passes to itc to ignore characters until the next tab or carriage return. Otherwise, evl is called and the new location is set up. First the symbolic location is constructed according to the following rule: A symbolic location exists if the location can be expressed as symbol ± number, where the number may be 0. In the event that the assignment is expressed as the sum of symbols, the old symbolic location, if any, is retained. If the assignment is purely numeric, asi is turned off (-0) and asm and aml are cleared, since asa and amn will contain zero. Otherwise, the alarm symbol indicator is left on (+0), and asm contains the symbolic part of the location, and aml the numeric part.

If, on Pass 1, a location assignment contains an undefined symbol, the location is considered indefinite, which fact is denoted by a negative number in loc. If the location is definite, loc is set from wrd at bnp. The location is taken modulo machine size, while the sign bit is preserved to retain whether or not the location is definite.

On Pass 2, an undefined symbol in a location assignment causes an alarm, but the location does not become indefinite, for the undefined symbol is simply ignored. If the assignment is defined, or on recovery from an alarm stop, wrd is taken modulo machine size and compared with loc. If the two are identical, it is not necessary to start a new block, and the routine exits to bnp. If they are different, control passes to pun, with the new location saved in wrd while pun uses the old one to punch out the block.

At pun, the location is compared with the block origin to determine whether there are any words in the punch buffer. If there are not, it exits at once to bnp to set up the next block. It also exits if the punch indicator pun is off. If punching is to be done, the first and last address are punched, followed by the contents of the punch buffer, followed by a checksum which is the sum of all other words in the block. Register t is a counter which counts through the buffer, and the checksum is kept in ck1. Punching of each word is done by a subroutine pnb which displays the origin of each block in the AC as punching is done, enabling the operator to observe the progress of the assembly. Five lines of blank tape are punched at the beginning of each block.

After the block is completed, the new block origin is taken from wrd, where it was saved, and put into org. The punch buffer index ts is reset, and the routine normally exits to rnw.

VARIABLES AND SYMBOL DEFINITION

There are three basic ways to define symbols in MACRO: by parameter assignment, by address tag, and by variable definition. The appearance of a comma directs control to the address tag routine. If the location is indefinite, the routine exits at once; otherwise, evl is called. If the word preceding the comma is defined, its value is compared with the location counter; if they differ, an error is flagged at mdt. The symbol field on the error printout contains the tag if the tag consisted of one symbol; otherwise sym is cleared before the error is called. After return, or if the definition was correct, the new symbolic location is determined. In the event that the tag was polysyllabic, the old symbolic location is retained.

Should the word preceding the comma be undefined, the routine exits at once if the tag was polysyllabic; otherwise the symbol is defined at vsm, and the new symbolic location is determined as before.

Parameter assignments go to the parameter assignment routine at the occurrence of the equal sign. The expression to the left of the equal sign must consist of a single symbol which may not bear an overbar. If these requirements are met, the symbol is saved in scn (which is also used by the macro-instruction processor), and the terminating character switches (bt for bar (slash), qt for equal sign, ct for comma, tt for tab and carriage return) are set so that any terminator other than tab or cr causes an alarm. The routine then exits to rnw to await the expression for the value.

When the terminator occurs, the routine exits in the event nothing has appeared; and otherwise calls evl. If it is well defined, control passes to q2 which saves the value, and then sets up indicators so that evl may be used to determine whether the symbol on the left of the equal sign was defined. If it was, the new value replaces the old one. If it was not, it is defined by vsm and the routine goes to reset. If the expression on the right was undefined, the attempted definition is ignored on Pass 1, and causes an error comment on Pass 2.

Variables are handled at evl by a variety of routines. The logic is that we must first have a symbol. If the symbol is defined, nothing further is done unless it has an overbar. If it is defined as -0, on Pass 1 we act as if it were really undefined and exit, and on Pass 2 we redefine it to the correct value which is the sum of the variables origin (as determined by the location of the pseudo-instruction variables on Pass 1) and the variables counter, which counts the different variables as they are defined. If it is defined as other than -0, on Pass 1 we give an error alarm (for this implies it was defined in a conflicting manner elsewhere), and on Pass 2 we ignore it, assuming that a previous occurrence has caused it to be defined correctly. Thus, on Pass 1, we go defining all variables as -0, and on Pass 2 we redefine them to their correct values as they occur. The scheme avoids requiring a separate list of variables, as they are stored in the main symbol table at all times, but has the disadvantage that the first appearance must have an overbar, or the variable will be incorrectly evaluated as -0.

The actual defining of symbols is handled by the vsm routine. Since the symbol table is maintained sorted at all times, vsm must locate the correct place for the new symbol and move all lower symbols down two registers to make room for it. The routine starts at the bottom of the symbol table and works its way up, using the overflow indicator in the same way that it is used in the logarithmic search. At the outset a check is made to see whether all of storage has been used; if it has, an error comment is made.

PSEUDO-INSTRUCTIONS

The pseudo-instruction system uses a form of list structure in the principal table, which begins at mai. There are two relevant registers, mai and psi, which contain indices to the table. From mai+1 to npi-1 are the system pseudo-instructions arranged in a three-entry table. The first two entries are the name of the pseudo-instruction and the last is the location to which control is to be transferred in the event one is found. Index psi is a pointer to the last pseudo-instruction name in the table. If there are macro-instructions defined, it points to the last macro name. At npi the macro storage begins. Each macro block begins with three registers, of which again the first two contain the name, but the third entry is now a pointer back to the beginning of the previous macro or pseudo name. These pointers contain law in the instruction part, and the negative sign is used to distinguish these pointers from pseudo-instruction locations. These considerations dictate the form of the search for the pseudo or macro name.

First we load the I-O with mdi, which is an indicator which is on (negative) if this name is that of a macro-instruction to be defined. Then we look at the last name defined, via the pointer psi. If the first three characters match, the second three are checked. If these match also, we either go to the mdm alarm if we are trying to define a macro of this name, or go to the appropriate routine. If the sign of the pointer is negative, we have a macro name, compute the beginning of the macro information storage and go to mac. If it is positive, the pointer addresses the location containing the location to which control is to be transferred.

If the first three match but the second three do not, it is recorded in flag 2 that at least one approximation to the correct name has been found, and the location is retained in sp5. The search is continued until either the correct name is found or the table is exhausted. If no name is found, and the name being searched is the name of a macro being defined, control passes to dmi, define macro instruction; if an approximation has been found, we go to the appropriate routine as before. If all the preceding fail, the name is undefined and causes an alarm at ipi.

The various pseudo-instructions are fairly straightforward in their execution. Character and Flexo treat their arguments in an obvious manner. Text checks rqc, which is negative in the range of a repeat, and if it is off, sets up switches and picks up the terminating character, which is saved in t2. Register t1 counts the characters in each word. Until the terminating character is matched, complete words are sent to the storage word routine, or to the storage word part of the macro processor if in a macro definition. When the terminator is matched, the last word is filled out with zeros (spaces) as necessary, and after it is disposed of, the routine exits through the storage word routine to rnw.

The pseudo-instruction Repeat sets all terminating switches to illegal format except comma, tab, and carriage return and then exits to pick up the count. The termination of the count goes to rq1, which checks definiteness and for a positive or zero count. If all is well, the pointers for the readout of the flexo list are saved in private temporary storage, and carriage returns are arranged to trap. The routine exits to reset. Each succeeding carriage return is counted until the count runs out; until it does, the flexo pointers are restored to their old values and the character reader re-reads the characters. When the count runs out, the carriage return switch is restored and the routine exits. The reason Text is not allowed in a Repeat is to ensure that all characters required by the Repeat are in storage. Otherwise, rfb might have stopped reading tape on a carriage return in the Text (and therefore, inside the Repeat), and the trick of restoring the pointers would not work.

Start causes a complaint if it occurs in a repeat or macro definition and otherwise sets the terminating switches to pick up the starting address. The address termination returns to s, where on Pass 1 the program is stopped ready to begin Pass 2, and on Pass 2, if everything is definite, the address is saved and the punch buffer dumped. The origin for a continuation tape is set up from loc, and the program stops. Continue punches a start block if pch is on, preceded and followed by some blank tape. The program again stops, and Continue begins Pass 1 anew retaining all symbol definitions. The contents of sov control action on Start.

The variables pseudo-instruction is considered illegal if in a macro definition or in a region of indefinite location. Because of limited storage, variables may be used only once. If repeated usage were allowed, two entries would be required for each use; as it is, the two numbers are kept in va1 and va2 which are the beginning of, and the first free register after, the variables storage. Although a count of variables is kept on Pass 2, it is necessary to record the first free register, because in the event that the operator should desire to repeat Pass 2, the variables count would be zero as all variables would be correctly defined on the first Pass 2. On Pass 2, a check is made to see that the pseudo-instruction location agrees with that found on Pass 1, and if it does not, there is an alarm. If all is well, a location assignment is simulated to leave room for the variables, and the program continues.

The pseudo-instruction dimension causes symbols to be defined as variables, with the variables counter being advanced according to the size of the array. Terminating switches are set up so that commas are ignored, left parens save the symbol in tcn (and check flag 5 to make sure only one symbol appeared), and right parens do all the work. The array size is evaluated and checked for definiteness. The saved symbol is then looked up. On Pass 1 control goes to di3 which, if the symbol is undefined, defines it as -0. On Pass 2, the correct definition is constructed. On both passes, the variables counter is suitably advanced and the routine exits. The terminators are restored when a carriage return or tab is encountered.

The pseudo-instruction constants is quite similar to variables in its operation. The values of the constants are stored in order in the macro-instruction table above the last macro definition, starting at a register whose address is kept in con. On Pass 1, the location is advanced according to the total usage of parenthesis operators, whether or not any identical constants occur, and the location of the beginning of the constants storage is saved in the first entry of the constants origin table. On Pass 2, the stored constants are dumped into the punch buffer via the storage word routine. There is no ambiguity as to how far to advance the location counter, as the number of parentheses, which is kept in nca, must be the same on both passes. The number of different constant values is determined by nco, which will generally be less than nca. Storing the constants on top of the macro definitions has both advantages and disadvantages. The primary advantage is economy of space in the assembler, for all of the available table space must be used before the tables collide, and any saving in one table is automatically available to the others. The major disadvantage is that an unnecessarily large block of space may be reserved for constants in the assembled program. To avoid this, it would be necessary to save the values of constants on both Pass 1 and Pass 2, leaving one register in the reserved storage area for each constant which is undefined at its appearance on Pass 1, plus whatever is required for the defined ones. Since in general there will be constants used before all the macros are defined, putting the constants on top of the macro table is not feasible in this scheme. The constants are placed in the constants table by the constant table search routine which will be discussed later.

Although it is not done here, it is quite possible to check for agreement of location of the pseudo-instruction constants on Pass 1 and Pass 2. If they disagree, it is clear that the result on the assembled program would be disagreeable, as all preceding constant syllables would have been incorrectly assembled. It should be pointed out that the second entry in the cor table is set up on Pass 2 and is used only by the symbol package for printing out the constants areas.

CONSTANTS

Constants syllables are enclosed in parentheses. Left parentheses normally go to lp, and right parens go to rt from which they go to rp unless there is no matching left paren, in which case control goes to ilf. There is a four entry table (cv1-cv4) in which are stored the macro-instruction dummy symbol pushdown counter (described later), wrd, the sign preceding the left paren, and whether wrd is defined. There is a subroutine pi which handles the indices on the cv tables which is called here to move the pointers up one level. If the table overflows, control goes to tmc for an alarm. The first left paren saves all the terminating character switches in private temporary storage and sets them to go to the constant evaluating routine or ilf. In either case, control then goes to rsw to reset all storage associated with words and syllables. The value of the constant is then accumulated.

Right parens now go to rp, which evaluates the constant, and if not in a macro definition, calls co which files the constant in the constant list and returns the location in which it will be stored. The appropriate sign is applied, and the value is added to the previous value of wrd. Again pi is called, this time to move the pointers down one level. The indicators for syllables are then reset, and if the routine was entered from a right paren, the routine exits to process the next character in sequence. The word terminators comma, tab and cr also enter at rp, but when finished they go around again until the level is reduced to zero. The check for carriage return at rp3 is a patch that was put in to fix a bug in the repeat logic.

When the level is reduced to zero, the terminating character switches are restored to their original values and the routine exits to the appropriate switch.

The co routine is straightforward. The constants appearance counter nca is stepped, and on Pass 1 the routine exits at once returning -0. On Pass 2 def is checked, and if any undefined symbols appeared, an alarm is flagged. The search for a matching constant begins at the bottom of the constant table, to which con points. If a matching value is found, at co6 the position in the table is found, added to the current constant origin, and returned as the value of the syllable. If the search is exhausted unsuccessfully, the pointer to the top of the table nco is increased by one and, if there is any storage left, the new constant is added to the list. The value of the syllable is then constructed as before.

There is a fairly large amount of initialization for the constants routines at np1. The top of the macro instruction list is used to determine con, and nco points to it until there are constants in the table. The constants appearance counter nca is cleared, and the constant origin indices are set to zero. The pseudo-instruction constants also clears nca and nco and advances the constant origin indices.

SECTION 3

MACRO INSTRUCTIONS

The macro instruction facility in MACRO is both the strongest and weakest part of the program. It is the strongest in the sense that it is that part of the program which contributes most toward ease of programming, especially in setting up tables of specialized format. It is the weakest in that it is quite inflexible and does not incorporate any of the more significant improvements in assembler technology that have occurred since the logic was first written in 1957.

There are two frequently used ways of organizing macro instruction storage: either the input characters comprising the definition are stored away, with dummy symbols usually marked in some special way, or the input characters are partially assembled, and the assembled words are stored with provision for inserting the dummy symbol values when the macro is used. The first scheme requires a relatively large amount of storage for macro definitions and has considerable complication in the treatment of dummy symbols if macro calls are permitted within macro definitions. However, the rest of the assembler can be used as a subroutine when the macro is called, and considerable flexibility is available in the use of dummy symbols, since an entire character string can be inserted as, say, part of a macro to print a message on the on-line typewriter. The second scheme realizes some economies in macro instruction storage, particularly if macro calls within macro definitions are relatively infrequent, and has a slightly less involved treatment of dummy symbols. The principal disadvantage is that dummy symbols can not supply other than numerical values to the compiled instructions without a large amount of involved coding. It is the second scheme which is used here.

Before delving into the mechanics of macro operation, we should consider some implications of macro calls within macros. Firstly, a macro definition within a macro definition is not allowed. Macro calls within macro definitions are allowed, and dummy symbols from the definition are allowed to be used in the macro call. A macro call cannot have any effect on the macro being defined except possibly to insert additional storage words into the definition. Thus it is not possible to have a macro call a macro which does nothing but, say, double an argument of the first macro. Calling a macro within a macro definition causes the data for the called macro to be re-copied into the data for the macro being defined, with no change except such as may be required for the proper translation of dummy symbols. With this background, we can examine the macro processor in detail.

MACRO INSTRUCTION TABLES

The best place to start is with an examination of the macro-instruction table structure. The principal table is mai. After the pseudo-instruction data, the first word is a code word consisting of code bits which are read from left to right. The other entities in the table are identified by these bits. The code combinations are as follows:

0 denotes a storage word.

10 denotes a dummy symbol specification.

110 denotes a constant.

1110 denotes a dummy symbol parameter assignment.

1111 marks the end of the macro definition.

Subsidiary combinations are used after these identifiers as necessary.

The order of entities is as follows: First will appear any relevant dummy symbol specifications. Next will appear one of the other entities, with which all of the dummy symbol specifications are associated. Parameter assignments and storage words are the lowest order, and they may include constants. If a storage word or parameter assignment contains constants, and both the word or assignment and the constants contain dummy symbols, the dummy symbols within each constant appear first, followed by the constant designator, followed by dummy symbols for the word or assignment, followed by the word or assignment data.

Each dummy symbol specification code bit pair is immediately followed by seven more bits which specify the dummy symbol sign and the dummy symbol number. The six bits for the number are written in reverse order. All these bits are written into the table by sco and scz, store code bit one and store code bit zero. The writing of the dummy symbol specification uses an additional routine wro which calls sco and scz. There is a corresponding routine rro which reads dummy symbol specifications.

Storage words store one additional bit which is zero or one depending on whether the word is zero or non-zero, respectively. If the word is non-zero, it is stored in the macro instruction table.

Constants and parameter assignments are very similar in that both have associated a value and a dummy symbol number. The value is treated as it is in storage words. The dummy symbol number is treated as in dummy symbol specifications, except that the sign bit is used to tell whether this is a new dummy symbol (denoted by a 0) or a redefinition of an old one (denoted by a 1). Constants behave like parameter assignments in that their effect is to define a new dummy symbol whose value will ultimately be the location of the stored constant.

The net result in the mai table is an assortment of codewords and value words. The type of any particular word is determined by the preceding codeword in an elementary manner: the first word is a codeword, in which one writes bits until it is full; then one starts on a new codeword. Any value words which occur in the meantime are stored in order after the codeword, and the new codeword is put in the next available space. As there are routines for writing code bits, so is there a routine for testing them: tcb, which is used when a macro is called. Its operation will be considered later.

Also used by the macro processor is a set of erasable tables. First there is dsm, the dummy symbol table, which has the flexo codes of defined dummy symbols. Each dummy symbol has a number which is its position in this table. Dummy symbols are numbered sequentially in order of definition starting with R, which is always defined and is dummy symbol number 1.

Next there is dss, the dummy symbol specification table, which is used when defining a new macro-instruction in terms of an old one. The nth entry in dss, gives the dummy symbol in the macro being defined corresponding to dummy symbol n in the one previously defined. The first entry is always 1, since dummy symbol R always transforms into itself. An entry of -0 means that there is no dummy symbol in the new definition corresponding to one in the old definition because the value of the old dummy symbol has been determined by some means; for example, if first A had been defined, and second had been defined as first 1, there is no dummy symbol in second corresponding to A in first, because A now has a definite value, i.e., 1.

Next in the list is dsv, the dummy symbol value table. It contains the values of all the dummy symbols when a macro instruction is used.

Finally there is pdl, the dummy symbol pushdown list. The pdl table is used to ensure that the order of dummy symbols fed into the mai table corresponds to that described above. Pointers to this list occur in cvl. As constant levels build up because of left parentheses, pointers in cvl mark the beginning of each level. When left parentheses reduce the level, all the dummy symbol specifications down to the next level are stored and a constant assignment defines a single dummy symbol on the lower level whose value is the location of the constant. The dummy symbol specifications in pdl are stored by prs, prepare specifications; and all specifications at any one level are stored in mai by ss, store specifications.

Since we have doubtless by now left the reader in a sea of confusion, without further ado we will enter into a description of how all this is done in the hope that some clarity may yet be achieved. The reader is advised to construct some macro definitions and examine the resulting mai table in an actual assembly for further examples of how all of this works. An example is given here in Appendix 2.

MACRO INSTRUCTION DEFINITIONS

The appearance of the pseudo-instruction define marks the beginning of a macro definition. Control passes to dfn, where the first test is for whether a macro definition is already in progress. If it is not, terminating switches are set so that equals and comma are illegal, slash for anything other than a comment is illegal, and tab or carriage returns other than redundant ones are illegal. The location counter is saved in tlo and zeroed. The symbolic location is killed, and the macro define indicator mdi is turned on. The macro instruction pointer is boosted to leave room for the pseudo-instruction information, and the routine exits to rnw to await the name of the macro being defined. When this has been read and checked for multiple definition (see Search for Pseudo-instruction), control passes to dmi. Here the name and other pseudo-instruction data is set up, but psi is not stepped as yet as recursive definitions are not allowed. The macro define indicator is turned off, and the macro instruction indicator is turned on. The dummy symbol counter is set to zero, the specification pushdown counter is set to zero, and the terminators are set to pick up dummy symbols. Dummy symbols terminated by tab and carriage return go to pdl and pds, respectively. Checks are made to see that legitimate dummy symbols are used, and if all is well, the dummy symbol is filed in the dummy symbol table at dd. The last dummy symbol, followed by a carriage return, sets the define exit to go to reset terminating character switches. It is possible to check for duplicately defined dummy symbols, but it is not done in this version of the program.

Reset terminating character switches sets the switches to go to the appropriate macro definition routines. Dummy symbols appearing in expressions are detected at wsp, which is logically part of evl. Search for dummy symbol sds is called after the sign is set up, and the next instruction is skipped iff the symbol is defined. Subroutine pr enters the specification for the dummy symbol in the dummy symbol pushdown list.

Storage word terminators (tab and cr) go to sw. If there are undefined symbols in the word, there is an alarm, otherwise, the alarm location and location counter are stepped and control goes to ss, which stores the dummy symbols from the pushdown list, and then to smb to store the word after the code bits are written. Final exit is to rnw. Register tea is a temporary for subroutine exit addresses (hence the name).

The equal sign in a dummy symbol parameter assignment goes to da. If the symbol to the left of the equal sign is in good order it is saved in tcn and the terminators are set to pick up the expression for the value. The terminator traps to da1 where the usual checks are made. The saved symbol is then looked up in the dummy symbol table. If it is defined, a negative sign is attached to flag this as a redefinition; otherwise dd is called to define a new dummy symbol. Note that sds returns the dummy symbol in the IO where it is used by dd. Next mp is called, which writes the appropriate entries in the mai table. Final exit is to rst to reset the terminators.

Constants in a macro definition go to lp and rp as before, but are treated differently at rp. Instead of calling co, control passes to rp8, which first calls mc to write a constant entry in the mai table, and then defines a new dummy symbol (whose flexo name is zero) whose number is used to complete the entry in the mai table. A specification for the newly created dummy symbol is written on the specification pushdown list, from which it will be filed in the mai table preceding the entry for the entity in which the constant has been used. After this, we go back to rp5 to move the pointers and restore the terminators if necessary.

The macro definition is ended by the pseudo-instruction terminate. This is illegal if not in a macro definition. The location counter is restored, the symbolic location cleared, and the macro-instruction indicator turned off. The pseudo-instruction index is set to include the new definition, and four ones written into the codeword. The last codeword is rotated around into the correct position and stored in the mai table. The routine then exits to rst to set the terminating characters to normal assembly position.

To conclude this part of the macro definition procedure, let us turn to the code bit routines. The two entries sco and scz both save the return address, and save the bit to be stored in tc which cannot be in use at the same time. The bit counter scn is stepped, and until it overflows, control goes to sc4 where the new bit is added to the current codeword which is stored in scw. When a codeword overflows, it is stored in the mai table at sc3, and then sm, store word in mai is called. It does not store anything useful, however; it merely is used to locate the point in the mai table at which the NEXT codeword will be stored. The reason for this is of course that the codeword must precede any value words which may be associated with it. The lio i sc3 makes the code bit routine transparent to the IO, which fact is used by wro.

MACRO INSTRUCTION USAGE

We will defer until later any discussion of macro calls within a macro definition. Assume a macro has been called, and mii is off. The pseudo-instruction search routine goes to mac, where the address of the first word of macro data, as determined by spm, is saved in aw, which is the general pointer for reading out of the mai table. The terminating switches are set to pick up the arguments (if any), and the dsv table is cleared. Control now passes to r2 to pick up the arguments.

Commas terminating arguments go to ae1, from whence evl is called, and if the argument is defined, its value is stored in the dsv table at ae4. The routine exits at ae6 until the last argument is terminated, when control passes to am.

Assemble macro-instruction into program (am) reads and dispatches on the principal codebits. The codebit tester returns to one after the call if the codebit is a one, and goes to the address in the AC if the codebit is a zero. Storage words go to awm. There are two nested subroutines here: rw, read word, which gets the next word out of the mai table;

and ar, which checks the zero-nonzero codebit and calls rw if necessary. Note that rw leaves the number in the AC, the IO, and in t. It is added into wrd by the ed add routine, and if not in a macro definition, the complete word is filed in the punch buffer by the storage word routine.

Dummy symbol specifications go to as, where the dummy symbol number is read. The sign bit is saved in tc and used to set up the sign operation at as6. When not in a macro definition, the dummy symbol value is read next and added into wrd by ed. The routine then exits to am1 to read the next principal code bits.

Constants go to ac, where the value word is read and, if mii (which ar returns in the IO) is off, co is called and the location of the stored constant put in wrd. The new dummy symbol which represents this constant is then stored in the dsv table. The routine then exits to ami, which clears wrd. The expression in which the constant syllable was used will have a dummy symbol specification for the associated dummy symbol, and it is by this means that the correct value of the constant syllable will appear in the expression. This obtains complete generality with respect to usage of dummy symbols within and without constant syllables of arbitrary depth.

MACROS WITHIN MACROS

We are now prepared to deal with the question of macro calls within macro definitions. The macro being defined will in general have associated dummy symbols. The index to these symbols is saved in dsl as soon as control gets to mac. In addition to clearing the dsv table, we now clear the dss table in order to make the routines work in the event of unsupplied arguments, which are taken as zero. Now the arguments are picked up. These may contain dummy symbols, which by the time the terminator occurs, will have been entered on the pushdown list and will have set the dummy symbol indicator. If this has occurred, a new dummy symbol will be defined which represents the argument dummy symbol or symbols, and a parameter assignment will be written into the mai table to signify this fact by the routine at ae7. Furthermore, the number of this dummy symbol as it will be used in the macro being defined is entered in the dss table in the position corresponding to the dummy symbol used in the previously defined macro. If an argument contains no dummy symbols, the dss entry is made -0 to signify that no new dummy symbol need be included when reading specifications for old ones. The old dummy symbol may be said to be inactive. Constant syllables appearing in arguments are treated as elsewhere: a new dummy symbol is defined whose value will be that of the constant. This is taken care of by the lp and rp routines as we have seen before. Note that this is done whether or not the constant syllable contains dummy symbols. After the arguments are completed, control goes to am as usual.

At am, we insure that the specification pointer is reset and start reading codebits. Storage words go to mw instead of tb3 after reading out of mai, and thus get stored back into mai for the new definition. Arguments, after reading the sign and dummy symbol number, go through as8 instead of skipping to as5 and examine the dss entry. If it is zero, there is no new dummy symbol to worry about and the dummy symbol value is picked up as usual. If it is not zero, there is a dummy symbol, which has the proper sign applied and then is entered on the pushdown list. If the dummy symbol number is 1, then the value is added into wrd, as this is the only way that the location counter as used in the macro being defined can get into the macro being read. If it is anything else, the dummy symbol value must not be added in at this point, for it will be included when the macro being defined is ultimately used. To see this, recall that 1) if the argument included dummy symbols, a dummy symbol assignment was written which included the value, and 2) if the argument did not include dummy symbols, the dss entry is zero and the value will be added here.

Constants go to ac, where, after reading the value, we call mc to rewrite the value for the new definition and then go to ac1. Here we read the associated dummy symbol number which we will then look up in dss. If the sign is positive, this is a new dummy symbol and dd is called; the new dummy symbol number is then entered in the dss table. If the sign is negative this is a dummy symbol redefinition and the old dss entry is examined to determine whether this dummy symbol was active before. If it was, nothing more need be done, as the old dss entry is correct; if it was not, a new dummy symbol must be defined. In any case we leave cc with an active dummy symbol. The new dummy symbol number is then written in the mai table to complete the constant entry, and we return to ami. It would appear that the dummy symbol value should be entered in the dsv table, but in fact this is not necessary, as the dummy symbol will be referred to only once in whatever the constant is used in, and this reference will not refer to the dsv table since the corresponding dss entry is not 0 or 1. (See discussion of as above for elaboration of this point.)

Dummy symbol assignments read the dummy symbol value from the mai table, then enter it in the dsv table. If the dummy symbol defined includes no dummy symbols in its value, we go to aal where we clear the associated dss entry to signify this. If it does, we call cc as was done with constants to activate a suitable dummy symbol. A parameter assignment for this dummy symbol is then written into the mai table, and the routine exits to ami.

Encountering the code for the end of the macro definition restores the dummy symbol counter dsk to its old value, effectively undefining all dummy symbols associated with the called macro. Control then passes to rst to reset and continue with the definition.

SECTION 4

ERROR ALARMS

We have seen that a fairly large amount of error checking is done during the assembly process, and we should consider briefly the diagnostic routine. Most errors transfer control to an appropriate calling routine which determines the point to which to return, the particular routine to which to go, and the name of the error. The error routine proper has two entries, one for errors which print in the fifth field of the error listing and one for those which do not. The return point is put into sov and the name of the error picked up and printed out. Next the absolute location is printed if definite, or ind is printed if it is not. Next the alarm symbol indicator is tested, and if there is a symbolic location it is printed. Next the last pseudo-instruction used is printed. If there is a fifth field, it is printed at als. Completion of an alarm printout is followed by a carriage return. Next the test word is checked to see whether immediate continuation is desired, and if it is not the machine is stopped. Continuation returns to the appropriate routine. There is some extra coding to make sure that the columns line up correctly if the symbolic location or api fields are vacant.

START OVER SEQUENCE

The first routine in the program is the sequence that determines action on depressing the start key. We have seen that sov contains the address to which control is transferred on Start unless test word switch 0 is on. If it is on, the switches are placed in the IO and the first five registers of temporary storage are set in order to 1 or -0 depending on whether the associated switch is 1 or 0. If the continue pass bit was on, control goes to np2, otherwise control goes to ps1 or ps4 for Pass 1 or Pass 2, respectively.

SYMBOL PACKAGE

The symbol package is a six link chain. The routines sit in the temporary tables and use appropriate parts of the main program as necessary. The first link is symbol punch. If sense switch 1 is off or gets turned off, the routine exits to the input routine to read in the next link. If it is on, we first feed some tape and then listen for characters from the on-line typewriter. These are punched by the title puncher in the main program which returns control to ls. A tab termination goes to ls2 which listens for s or m for symbols or macros. If symbols are to be punched sps-1 will have jmp sps which will punch the symbol table and then go to the macro puncher if flag 5 is off signfying macros are wanted too. If just macros are wanted, we go at once to the macro routine.

Both the symbol and macro punchers use the end subroutine which copies the appropriate storage into the punch buffer and transfers control to pun+6 when the buffer is full or the end of the macro or symbol table is reached. When punching a block is done, control returns to pcb+1. Flag 4 gets set on the last block, and finding it on causes the subroutine to exit through psx.

The macro punch will punch macros only if some have been defined. If some have, end is called. At the end of the job some blank tape is fed, followed by punching a start block. Some more tape is fed, and the routine goes back to the input routine.

The next link contains a text printing subroutine, the initial symbol table, and the constants area printer which will run if either switch 2 or switch 3 is on. A pointer to the cor table is checked to see whether any constants areas were designated, and if none were, the routine exits to the input routine. Otherwise, pss is checked, and constants origins are dumped on Pass 1, and the entire cor table on Pass 2. Flag 5 is used as a pass indicator. When finished, control returns to the input routine.

The alphabetic symbol print is the next link, which runs if sense switch 2 is on. It uses the symbol table and text printer which remain in storage from the preceding link. Since the symbol table is ordered alphabetically, the logic is simple enough. Each symbol is looked for in the initial symbol table, and if it is not there, it is printed out. When done, the heading for numeric symbol print is written if switch 3 is on, and then control goes back to the input routine.

The numeric symbol print is the most complex part of the symbol package. A floor register (t1) and a ceiling register (t) are kept, with the floor initially containing zero. Successive passes are made through the symbol table comparing the value words with the floor and ceiling. If a symbol is less than the floor, it is discarded, and if it is equal, it is printed out if not in the initial symbol table. If it is larger than the floor, it is compared with the ceiling and if it is greater, it is discarded. If it is less, the ceiling is set from the symbol value. Thus at the end of each pass, the floor represents the value of the symbols just printed, and the ceiling represents the value of the symbol or symbols next in line to be printed. Therefore, the ceiling is moved into the floor and the ceiling is set to -0 (777777), and the process is repeated until -0 is found in the floor, which insures that all symbols have been printed.

Now let us follow the coding. Pointers to the initial symbol table sy3 and sy4 are set up, the ceiling (t) is zeroed, and a carriage return typed. We then drop into the main loop. The ceiling is moved to the floor, -0 put into the ceiling, and the symbol table pointers initialized. Now we start comparing values with the floor. Note that overflow will be a problem, for either number can vary over the whole range of values from 0 to 777777. Thus a simple subtraction will not yield a meaningful difference. Furthermore, it turns out not to be convenient to use the overflow indicator, which is better suited for use when the range of values is from 400000 (smallest) to 377777 (largest). Therefore we proceed in the following way. The numbers are xor'ed and the sign of the result examined. If it is positive, the numbers are of the same sign and a meaningful subtraction can be performed, and this is done at sq1. If it is negative, the number with the negative sign is the larger. In either event, going to syi discards the number, while going to sq2 starts doing precisely the same sort of comparison with the ceiling. Identity between the floor and value goes to syc where the check against the initial symbol table is made.

At syc the symbol location is put into syz for printing purposes. Now the value is compared with the value of the present symbol on the initial symbol list. If they are equal, the symbols are compared at syf, and if these are equal also, this is an initial symbol and control passes to syi. If the initial symbol value is less than or equal to the symbol table value, the initial symbol table pointers are moved upward until this is no longer true. Note that the initial symbol table is arranged in numerical order. Thus it is not necessary to compare the symbol table symbol with all the initial symbols, but only with the next one which it is expected that will be found.

At syi the main symbol table pointers are moved up. When the top of the symbol table is reached, the floor is checked for -0, and when this is found, the routine exits to the input routine after waiting for the last carriage return.

The next link in the chain is restore, called by sense switch 4. This routine resets the macro-instruction indices, then uses vsm and the initial symbol table to reconstruct the initial symbol table from scratch. When this is done, we go once again to the input routine to read the last link.

The final routine determines where to return control in the main program after the symbol package is done. If restore was run, control goes to ps5. Otherwise, pss and flag 6 are checked to return control to the appropriate place in the start routine, ready to begin or continue the assembly.

CONCLUSION

This completes our discussion of the MACRO assembly program. The version described here does not use sequence break and will run on any PDP-1. Enterprising programmers may wish to make changes to the routine to incorporate sequence break or make other improvements. It is hoped that this memo will facilitate this. We strongly suggest that no fundamental changes be incorporated, particularly those affecting the source language, for source language compatibility, and to a lesser extent, operating compatibility, are desirable goals. However, this should not be interpreted as ruling out any changes. We recognize that the program is not in any sense ideal or perfect. Nonetheless, it will give satisfactory service for its intended purpose.

APPENDIX 1

MACRO PROGRAM LISTING

MACRO FIO-DEC • part 1, 2-13-62

```
ncn=10    nfw=200    nds=30    ncd=20    ncl= 0

4240/                pbf,        /punch buffer
        pbf+101/     flx,        /flexo input buffer
        flx+nfw/     dsm,        /dummy symbols
        dsm+nds/     dss,        /argument translation indicators
        dss+nds/     dsv,        /m-i argument values
        dsv+nds/     pdl,        /dummy symbol specifications
        pdl+ncd/     cv1,        /constants dummy symbol levels
        cv1+ncl/     cv2,        /constants value levels
        cv2+ncl/     cv3,        /constant signs
        cv3+ncl/     cv4,        /constants definite on this level
        cv4+ncl/     cor,        /list of constant origins
        cor+ncn+1/
                     cr2,        /second constants origin
        cr2+ncn+1/
                     ck1,        /checksum
        ck1+1/       org,        /block origin
        org+1/       psi,        /pseudo instruction index
        psi+1/       mai,        /macro instruction storage
        7750/        low,        /symbol table end

        xy=1         one=(1

define
        error ROU,RET,NAM
        law RET
        jda ROU
        NAM
        terminate

0/
```

```
/start over entry

        lat
        sma
sov,    jmp xy

so1,    swap
        init so3,pss

so4,    ril 1s
        clc
        spi
        law 1
so3,    dac xy
        index so3,(dac pss+5,so4
        lac npa
        sma
        jmp np2

so5,    lac pss
        spa
        jmp ps1
        jmp ps4
```

```
/reset terminating character switches

rst,    law rsk
rsl,    dap rsx
        lio mii
        init bs,rnw
        init ct,c
        init dtb+57, lp
        spi
        jmp rsm
        dio mdi
        init bt,b
        init qt,q
        law tab
        jmp rs1

rsm,    init bt,df2
        init qt,da
        law sw
rs1,    dap tt
rsx,    jmp xy

/reset to convert next word

rsk,
rnw,    init lp1,cv1
        init prs,pdl
        init rt,ilf

rsw,    dzm wrd
        clf 5           /syl
        dzm nsm
        dzm amn
        dzm asa
        clf 6           /dsi
        law 1
        dac def
        law r

rss,    lio (opr

sp,     dio sgn
        dap spx
        dzm let
        clf 4           /liu
        dzm ovb
        dzm num
        dzm sym
        dzm chc
spx,    jmp xy
```

```
/read and dispatch on one character

r,      jsp rch
        add (dtb
        dap .+2
        clc
        jmp xy

/re-dispatch on last character read

r2,     lac rcp
        jmp r+1

/dispatch table

dtb,    jmp p       jmp n       /space, 1
        jmp n       jmp n       /2, 3
        jmp n       jmp n       /4, 5
        jmp n       jmp n       /6, 7
        jmp n       jmp n       /8, 9
        jmp il      jmp r       /i, stop code
        jmp il      jmp il
        jmp il      jmp il

        jmp n       bt,jmp      /space, +
        jmp l       jmp l       /s, t
        jmp l       jmp l       /u, v
        jmp l       jmp l       /w, x
        jmp l       jmp l       /y, z
        jmp il      jmp cqt     /i, comma
        jmp r       jmp r       /color
tt,     jmp 0       jmp il      /tab

        jmp il      jmp l       /middle dot, j
        jmp l       jmp l       /k, l
        jmp l       jmp l       /m, n
        jmp l       jmp l       /o, p
        jmp l       jmp l       /q, r
        jmp il      jmp il
        jmp pm      jmp rt      /+/-, )
        jmp ovr     jmp lp      /‾,(

        jmp il      jmp l       /a
        jmp l       jmp l       /b, c
        jmp l       jmp l       /d, e
        jmp l       jmp l       /f, g
        jmp l       jmp l       /h, i
        jmp rcd     jmp rl      /l. c., period
        jmp rcu     jmp il      /u. c., backspace
        jmp il      dtc,jmp tt          /car ret

rcu,    stf 3
        jmp r

rcd,    clf 3
        jmp r
```

```
/case dependent characters

cqt,    szf 3
qt,     jmp q
ct,     jmp c

pm,     szf 3
        jmp p
        jmp m

/process alphabetic or numeric character

l,      dac let
        szf 3                   /cas
        stf 4                   /liu
        jmp ln

l2,     lac sym
        ral 6s
        ior t
        dac sym
        jmp r

n,      law 17
        and t
        dac t1
n2,     lac num
        ral 3s
        xct .+1
n1,     xx                      /opr=octal, add num=decimal
        dac num
        add t1
        sza
        jmp n3
        lac t1
        xor num
n3,     dac num

ln,     idx chc
        sub (3
        spq
        jmp l2
        lac let
        sma
        jmp r
        dzm num
        dzm let
        dzm chc
        stf 5                   /syl
        lac sym
        dac api
```

```
/read three more characters for p-i or m-i

        lac t
        dac syn
        setup t1,3
        jsp rch

ln4,    sza i
        jmp spm          /space
        sad (54
        jmp spm          /minus
        sad (36
        jmp spm          /tab
        sad (77
        jmp spm          /cr
        sad (35
        jmp rch+1        /color change

ln3,    isp t1
        jmp .+2
        jmp rch+1
        lac syn
        ral 6s
        ior t
        dac syn
        jmp rch+1

/over bar indicator

ovr,    law 1
        dac ovb
        jmp r
```

```
/search for pseudo or macro instruction

spm,    clf 2
        lac psi
        lio mdi

sp2,    dap sp1
        lac sym

sp1,    sad .
        jmp sp3
        idx sp1

sp7,    idx sp1
        lac i sp1
        spa
        jmp sp2
        law i 5
        add sp1
        sas (sad mai-2
        jmp sp2
        spi
        jmp dmi
        szf 2
        jmp sp4
        jmp ipi

sp3,    stf 2
        idx sp1
        dap sp5
        lac syn

sp5,    sas .
        jmp sp7
        spi
        jmp mdm

sp4,    idx sp5
        dap sp8
        lac i sp5
        sma

sp8,    jmp i .
        idx sp5
        jmp mac
```

/address tag routine (comma)

```
c,      lac loc
        spa
        jmp rnw
        jsp evl              /def in io on return
        spi
        jmp c1
        lac loc
        sad wrd
        jmp c2
        szf 5                /syl
        dzm sym
        jsp mdt

c2,     szf 5
        jmp rnw
c3,     dzm asi
        dzm aml
        move sym, asm
        jmp rnw

c1,     szf 5
        jmp rnw
        lac loc
        dac t3
        jsp vsm
        jmp c3
```

```
/parameter assignment (equal sign)

q,      lac let
        szf 5                  /syl
        jsp ipa
        sza i
        jsp ipa
        lac ovb
        sza
        jsp ipa
        lio sym
        dio scn
        init bt,ilf
        dap qt
        dap ct
        init tt,qq
        jmp rnw

qq,     jsp sch
        jmp rst
        jsp evl                /def in io pss in ac
        spi i
        jmp q2
        spq
        jmp rst
        jsp usq

q2,     lio scn
        dio sym
        move wrd,scn
        clc
        dac let
        law 1
        dac def
        jsp evl
        lac def
        spq
        jmp q1
        lac scn
        dac i ea
        jmp rst

q1,     move scn,t3
        jsp vsm
        jmp rst

sch,    dap sck
        szf 5                  /syl
        jmp .+3
        lac chc
        szm
        idx sck
sck,    jmp xy
```

/evaluate syllable and accumulate word value

```
evl,      dap ex
          lac sym
          jda per
          dac sym
          lac mii
          spa
          jmp wsp

ev2,      lac let
          spa
          jmp el
          add num

sga,      xct sgn
          add amn
          dac amn
en,       lac num
sgn,      xx
          jda ed

evx,      lac pss
          lio def
ex,       jmp .

ndf,      clc
          dac def
          dac t3
          jda ed
          lio sym
          dio lus
          lac ovb
          sub pss
          sas one
          jmp evx
          jsp vsm
          idx vct
          jmp evx

el,       lac sgn
          sad (opr
          jmp el1

el2,      law i 1
          dac nsm
          jmp e2

el1,      lac nsm
          szm
          jmp el2                /if +1
          sza
          jmp e2                 /if -1
          law 1
          dac nsm
          move sym, asa
```

```
/evaluate symbol (logarithmic search)

e2,     law 4000
        dac t1
        clo
        lac low
        jmp e1+1

edn,    lac (sub
        dip e1
        lac t1
        rar 1s
        dac t1
        sad (1
        jmp ndf
        lac ea
e1,     t1
        dac ea
        sub low
        spa
        jmp eup
        lac ea
        sub (lac low-1
        sma+sza-skp
        jmp edn

ea,     lac .
        sub sym
        szo
        cma
        sma+sza-skp
        jmp edn

eqt,    sza
        jmp eup
        idx ea
        lac i ea
        dac num
        lac ovb
        sza i
        jmp en
        lac num
        lio pss
        cma
        sza
        jmp evk
        spi
        jmp ndv
        lac vct
        add vc1
        dac num
        dac i ea
        idx vct
        jmp en
```

```
eup,    lac (add
        jmp edn+1

ndv,    clc
        dac def
        move sym,lus
        jmp en

evk,    spi i
        jmp en
        move sym,lus
        error alu, en, flex mdv

ed,     0
        dap edx
        lac ed
        add wrd
        sza
        jmp ed1
        lac ed
        xor wrd
ed1,    dac wrd
edx,    jmp xy
```

/insert symbol in symbol table

```
vsm,      dap vsx
          law i 2
          add low
          dac low
          dap v1
          add one
          sad hih
          jsp sce
          clo

vs1,      lac v1
          dap v2
          add one
          dap v4
          add one
          dap v1
          add one
          dap v3
          sas (lio low+1
          jmp vs2
vs3,      lac sym
          dac i v2
          lac t3
          dac i v4
vsx,      jmp xy

vs2,      lac i v1
          sub sym
          szo
          cma
          spq-i
          jmp vs3

v1,       lio xy                    /low+2+I
v2,       dio xy                    /low+I
v3,       lio xy                    /low+3+I
v4,       dio xy                    /low+1+I
          jmp vs1
```

/pseudo-instruction repeat

```
rpt,    lac rqc
        spa
        jsp irp
        init bt,ilf
        dap qt
        init ct, rq1
        dap tt
        jmp rsk

rq1,    jsp evl
        spi
        jsp usr
        lac wrd
        spq
        jmp rq4
        cma
        dac rqc
        init dtc,rq2
        move fwd,rqx
        move rc8,rqy
        move fwb,rqz
        jmp rst

rq2,    count rqc,rq3
        init dtc,tt
        jmp tt

rq3,    move rqx,fwd
        move rqy,rc8
        move rqz,fwb
        jmp tt

rq4,    sza
        jmp irp
        jsp rch
        sas (77
        jmp rch+1
        jmp rst

irp,    error alm, rq4+2, flex ilr

rqc,    0
rqx,    0
rqy,    0
rqz,    0
```

/pseudo-instruction character

```
ch,         jsp rch
            lio (rar 6s
            sad (51
            jmp ch1               /r
            lio (opr
            sad (44
            jmp ch1               /m
            lio ch2
            sas (43
            jsp ilf               /l

ch1,        dio ch3
            jsp rch
ch2,        ral 6s
ch3,        xx
            dac num
            jmp r
```

/pseudo-instruction flexo

```
fx,         dzm num
            setup t1,3
            jsp rch
            lac num
            ral 6s
            ior t
            dac num
            count t1,rch+1
            jmp r
```

```
/pseudo-instruction text

txt,     lac rqc
         spa
         jsp ilf
         load txv;,law txq
         init txx,rch+1
         jsp rch
         dac t2

txq,     dzm wrd
         setup t1,3

txw,     jsp rch
         sad t2
         jmp txk

txa,     lac wrd
         ral 6s
         ior t
         dac wrd
         isp t1
txx,     jmp xy

txv,     xx
         dap bs
         lio mii
         spi
         jmp mw
         jmp tb3

txk,     load txv,law rnw
         init txx,txa
         init bs,rnw
         lac t1
         sad (-3
         jmp rnw
         dzm t
         jmp txa
```

```
/syllable separation characters (plus, minus, space)

p,        jsp sch
          jmp r

m,        jsp evl
          stf 5             /syl
          lac t
          lio (opr
          sza i
          jmp m1
          szf i 3
          lio (cma
m1,       law r
          jmp sp

/relative address syllable (.)

rl,       lac chc
          lio sgn
          sma
          lio (opr
          dio rl3
          lac loc

rl3,      xx                /opr or cma
          add wrd
          dac wrd
          stf 5             /syl
          lac mii
          sma
          jmp r
          rir 9s
          law 10
          rcr 3s
          jda pr
          jmp r
```

```
/storage word termination characters tab and carr ret)

tab,     jsp sch
         jmp rnw
         jsp evl
         spi+sma-skp
         jsp ust

tb3,     idx aml

tb4,     idx loc
tb2,     lac wrd
ts,      dac .
         idx ts
         lac loc
         dac wrd
         and (77
         szm
         jmp bs
         lac pss
         spq
         jmp bnp
         jmp pun

/location assignment termination character

b1,      lac def
         sma
         jmp bnp
         lac (400000
         jmp b3

b,       jsp sch
         jmp itc
         jsp evl
         lac nsm
         sad (-1
         jmp ba1
         dzm asi
         lio (-0
         sza i
         dio asi
         move asa, asm
         move amn, aml

ba1,     lac pss
         spq
         jmp b1
         lac def
         spq
         jmp usb

b5,      law 7777
         and wrd
         dac wrd
         sad loc
         jmp bs

start
```

Macro FIO-DEC part 2

```
/punch binary block

pun,    lac org
        sad loc
        jmp bnp
        lac pch
        spq
        jmp bnp
        cli
        repeat 5, ppa
        lac org
        add (dio
        dac ck1
        jda pnb
        lac loc
        add (dio
        jda pnb
        load t,dac pbf

pub,    lac i t
        jda pnb
        lac i t
        add ck1
        dac ck1
        idx t
        sas ts
        jmp pub
        lac ck1
        add loc
        add (dio
        jda pnb


/form origin for next block

bnp,    lac wrd
        and (407777
        dac org

b3,     dac loc
        init ts, pbf

bs,     jmp .

loc,    0
```

```
/pseudo-instruction start

sta,    lac mii
        ior rqc
        spa
        jsp ils
        init bt,ilf
        dap qt
        dap ct
        init tt,s
        jmp r2

s,      lac pss
        spa
        jmp 1st
        jsp evl
        spi
        jmp uss

s2,     move wrd,tcn
        init bs,s4
        move loc,wrd
        jmp pun

s4,     init sov,np2
        hlt+cla+cli+clf+6-opr-opr-opr
        lac pch
        spa
        jmp s6
        law i 40
        jda fee
        lac tcn
        add (jmp
        jda pnb
        law i 240
        jda fee

s6,     init sov,np2
        lio (-0
        hlt+clc+stf+6-opr-opr
        jmp ps1

1st,    init sov,np2
        hlt+cla+cli+stf+6-opr-opr-opr

        /  pss    flg 6   tag
        /  -0     0       s5
        /   1     0       s4
        /  -0     1       1st
        /   1     1       s6
```

```
/initialize for new pass

ps2,      law 1
          dac pss
          dac pch
          dac tit
          move ini,inp

ps4,      move psb,psi
          lac mai
          move psa, mai
          jmp np1

ps5,                                        /initial entry
ps3,      move mai,psa
          move psi,psb

s5,       init sov,ps2
          clc
          dac pss
          hlt+cli+clf+6-opr-opr

ps1,      clc
          dac pss
          dac pch
          law 1
          dac ini
          move psi,psb
          lac mai
          dac psa

np1,      dac hih
          add (sad-lac+1
          dac con
          dac nco
          dzm nca
          dzm asi
          law 4
          dac org
          dac loc
          law 1
          dac mii
          dzm vai
          dzm vct
          load n1, opr
          init cn6,cor
          init cn7,cr2
```

```
np2,     load t, -4000
         rpa-i
         spi i
         jmp .+5
         isp t
         jmp .-3
         hlt+clc+cli-opr-opr
         jmp np2
         dzm api
         dzm fwd
         init ts,pbf
         init rc8,flx+nfw+2
         dzm rqc
         init dtc,tt
         clc+clf 7+cli-opr-opr
         add pss
         add pch
         add tit
         sas (3
         stf 5
```

```
/print and punch title

pte,        law i 40
            szf i 5
            jda fee
            jmp pt1+1

pt1,        iot i                    /sync on typewriter
            jsp rch
            sad (13                  /stop code
            jmp rch+1
            sza
            jmp pt0
            szf i 6
            jmp rch+1
pt0,        sad (77
            jmp pt5
            stf 6
            sad (40
            stf 5
            ral 1s
            add (ftp
            dap pt2
            dap pt3
            idx pt3

pt1,        lio t
            iot 4003                 /tyo with nac but no ioh .
            szf 5
            jmp pt1

pt2,        lac .
            repeat 3, jda pt6
pt3,        lac .
            repeat 3, jda pt6
            jmp pt1

pt6,        0
            dap pt7
            lac pt6
            cli
            rcl 6s
            ppa
pt7,        jmp .

pt5,        szf i 6
            jmp pt1+1
            dzm tit
```

```
/print pass 1 and 2

pps,    jsp spc
        lac (723554                     /lc,red, -
        jda tys
        jsp spc
        lac (flex pas
        jda tys
        tyo
        jsp spc
        law 1               / 1
        add pss
        jda tys
        law 3477            /black carret
        jda tys

/punch input routine

        law i 1
        add pss
        add pch
        spq
        jmp rst

pf2,    law i 40
        jda fee
        lac inp
        spq
        jmp rst

pi2,    load pt6,dio 7751

pi3,    lac pt6
        jda pnb
        lac i pt6
        jda pnb
        index pt6,(dio 7776,pi3
        lac (jmp 7751
        jda pnb
        dzm inp
        jmp pf2

spc,    dap .+3
        cli
        tyo
        jmp .
```

/pseudo instruction terminate

```
ter,    lac mii
        spq-i
        jsp ilf
        lac tlo
        dac loc
        clc
        dac asi
        law 1
        dac mii
        lac dm3
        dap psi
        jsp sco
        jsp sco
        jsp sco
        jsp sco
        lio scw
        jmp .+2
        ril 1s
        isp scn
        jmp .-2
        dio i sc3
        jmp rst
```

/pseudo instruction define

```
dfn,    lac mii
        spq
        jsp ilf
        law ilf
        dap qt
        dap ct
        law df1
        dap tt
        law df2
        dap bt
        lio loc
        dio tlo
        dzm loc
        clc
        dac asi
        dac mdi
        idx mai
        dap dm3
        idx mai
        dap dm1
        idx mai
        dap dm2
        sub low
        sma
        jmp sce
        jmp rnw

df1,    jsp sch
        jmp r
        jsp ilf

if2,    jsp sch
        jmp itc
        jsp ilf
```

/define macro instruction

```
dmi,      lio sym
dm3,      dio .
          lio syn
dm1,      dio .
          clc+clf 4-opr         /liu
          clf 5                 /syl
          dac mii
          dzm sym
          dzm scw
          law 1
          dac mdi
          lac psi

dm2,      dac .
          idx mai
          dap sc3
          law i 23
          dac scn
          init prs, pdl
          init dsk, dsm+1
          init ddx, rsk
          init ct, pd1
          init tt, pds
          jmp r2
```

/pick up dummy symbol

```
pds,      law rst               /tab
          dap ddx
          lac chc
          spq
          jmp rst

pd1,      lac sym               /comma
          jda per
          dac sym
          szf 5                 /syl
          jmp pd2-1
          lac let
          sza i
          jmp pd2-1
          szf i 4               /liu
          jsp ids

pd2,      lio sym
          jmp dd+1
```

```
/search for dummy symbol

sds,     0
         dap sdx
         dap sdy
         idx sdy
         init sd1,dsm
sd2,     lac sds
sd1,     sad xy
         jmp sd4
         index sd1,dsk,sd2
         lio sds
sdx,     jmp xy

sd4,     lac sd1
         sub (sad dsm-1
sdy,     jmp xy

/define new dummy symbol

dd,      dap ddx
         dio i dsk
         idx dsk
         sad (sad dsm+nds-1
         jsp tmp
         sub (sad dsm
ddx,     jmp .

/macro instruction constant

mc,      dap tea
         dzm num
         stf 6                  /dsi
         jsp ss
         jsp sco
         jsp sco

mca,     law smb
         jmp scz

/macro instruction storage word

sw,      jsp sch
         jmp rnw
         jsp evl
         sma+spi-skp
         jsp usm
sw2,     law rnw
mw,      dap tea
         idx aml
         idx loc
         law mca
         jmp ss
```

/dummy symbol assignment

```
da,     szf i 4         /liu
        jsp ilf
        szf 5           /syl
        jsp ipa
        lac sym
        jda per
        dac tcn
        init bt,ilf
        dap qt
        dap ct
        init tt,da1
        jmp rnw

da1,    jsp sch
        jmp rnw
        jsp evl
        sma+spi-skp
        jsp usd
da3,    lac tcn
        jda sds
        jmp dab
        add (400000

daa,    jda mp
        jmp rst

mp,     0
        dap mpx
        jsp ss
        jsp sco
        jsp sco
        jsp sco
        jsp scz
        init tea,mp1
        jmp smb

mp1,    lac mp
        jda wro
mpx,    jmp xy

dab,    law daa         /if undef
        jmp dd
```

/macro instruction usage

```
mac,    dap aw
        move dsk,dsl
        init bt,ilf
        dap qt
        dzm tcn
        init tt,aev
        init ct,ae1
        init ae6,rsk
        init ae4,dsv
        clear dsv,dsv+nds-1
        lac loc
        dac dsv
        lac mii
        sma
        jmp r2
        clear dss+1,dss+nds-1
ma1,    jmp r2
```

/evaluate macro instruction arguments

```
aev,    init ae6,am
ae1,    jsp evl
        sma+spi-skp
        jsp usp

ae3,    idx ae4
        add (dss-dsv
        dap ae5
        sad (dio dss+nds-1
        jsp tmp
        lio wrd
ae4,    dio xy              /dsv
        szf i 6             /dsi
        jmp ae5-1
        lac mii
        spq
        jmp ae7
        clc
ae5,    dac xy
ae6,    jmp xy

ae7,    cli
        jsp dd
        dac i ae5
        jda mp
        jmp ae6
```

```
/assemble M-I into program

am,     lac pss
        dac def
        init prs,pdl
ami,    clf 6               /dsi
        dzm wrd
am1,    law awm
        jda tc
        law as
        jda tc
        law ac
        jda tc
        law aa
        jda tc
am5,    lac dsl
        dap dsk
        jmp rst

/assemble M-I storage word into progr. or mai

awm,    law aw3

ar,     dap ary
        law ar5
        jda tc
        law ar1

rw,     dap rwx
aw,     lio xy              /mai
        idx aw
        dio t
        lac t
rwx,    jmp xy

ar1,    jda ed
ar5,    lio mii
ary,    jmp xy

aw3,    law ami
        spi
        jmp mw
        dap bs
        jmp tb3
```

/assemble argument (dummy symbol) into M-I word

```
as,     jsp rro
        add (dsv-1
        dap as5
        add (dss-dsv
        dap as8
        and (777000
        dac tc
        lio (cma
        sma
        lio (opr
        dio as6
        lio mii
        spi i
        jmp as5

as8,    lac xy                  /dss
        szm
        jmp as7
as5,    lac xy                  /dsv
as6,    xx          /sgn
        jda ed
        jmp am1

as7,    xor tc
        jda pr
        lac i as8
        sas one
        jmp am1
        jmp as5
```

```
/assemble constant

ac,     jsp ar
        law ac1
        spi
        jmp mc
        jsp co
        dac wrd
        law ami

sv,     dap svx
        jsp rro
        add (dsv-1
        dap sv1
        lio wrd
sv1,    dio xy
        sub (dsv-1
svx,    jmp xy

ac1,    jsp rro
        jda cc
        jda wro
        jmp ami

cc,     0
        dap ccx
        lac cc
        add (dss-1
        dap cc2
        spa
        jmp cc1

cc5,    cli
        jsp dd

cc2,    dac xy
ccx,    jmp xy

cc1,    lac i cc2           /dss
        spq
        jmp cc5
        add (400000
        jmp ccx
```

```
/assemble assignment

aa,     jsp ar
        jsp sv
        lio mii
        spi i
        jmp ami
        szf i 6         /dsi
        jmp aa1
        jda cc
        jda mp
        jmp ami

aa1,    add (dss-1
        dap aa2
        clc

aa2,    dac xy          /dss
        jmp ami

/write dummy symbol specification

wsp,    szf i 4         /liu
        jmp ev2
        lac (-200000
        xct sgn
        sub (-200000
        dac t1
        lac sym
        jda sds
        jsp uds
        add t1
        jda pr
        jmp evx


/prepare dummy symbol specifications

pr,     0
        lio pr
prs,    dio .
        dap prx
        idx prs
        sad (dio pdl+ncd
        jsp tmp
        stf 6           /dsi
prx,    jmp xy
```

```
/store dummy symbol specification

ss,       dap ssx
          lac prs
          dap sst
          lac i lp1
          dap prs
          sub one
          dap ss1
          jmp ss2

ss3,      jsp sco
          jsp scz

ss1,      lac xy                /pdl
          jda wro
ss2,      index ss1,sst,ss3

ssx,      jmp xy

sst,      lac xy

/store word in mai

smb,      lac wrd
          sza
          jmp sm7
          lac tea
          jmp scz
sm7,      jsp sco
          lio wrd
          lac tea

sm,       dap smx
          idx mai
          dio i mai
          lio pss
          spi i
          jmp sm2
          dac hih
          sad low
          jsp sce

sm2,      cla
smx,      jmp .
```

```
/encode dummy symbol specification

wro,     0
         dap wrx
         lio wro
         law i 7
         dac t3

wr0,     law wr2
         spi
         jmp sco
         jmp scz
wr2,     rir 1s
         isp t3
         jmp wr0

wrx,     jmp .

/decode dummy symbol specification

rro,     dap rrx
         dzm t2
         setup t3,7

rr0,     law rr1
         jda tc
         law 100
rr1,     add t2
         rar 1s
         dac t2
         isp t3
         jmp rr0
         lac t2
         lio t2

rrx,     jmp xy
```

```
/store code bit

sco,    dap scx
        lac (400000
        jmp sc1

scz,    dap scx
        cla
sc1,    dac tc
        isp scn
        jmp sc4
        lac scw
sc3,    dac .
        lac tc
        ral 1s
        dac scw
        jsp sm
        lac mai
        dap sc3
        lio i sc3
        setup scn,22
        jmp scx-1

sc4,    lac tc
        ior scw
        ral 1s
        dac scw
        cla

scx,    jmp xy

/test code bit

tc,     0
        dap tcx
        isp tcn
        jmp tc3
        jsp rw
        setup tcn,22
        jmp tc5

tc3,    lio tcc
        ril 1s

tc5,    dio tcc
        cla
        spi

tcx,    jmp xy
        jmp i tc

start
```

Macro FIO-DEC part 3

```
/set to pick up constant

lp,         jsp evl
            law 1
            jda pi
            sad (dio cv4+ncl
            jsp tmc
            lio prs
lp1,        dio xy
            lio wrd
lp2,        dio xy
            lio sgn
lp3,        dio xy
            lio def
lp4,        dio xy
            sas (dio cv4+1
            jmp rsw
            move tt,ttt
            move ct,tct
            move qt,tqt
            move bt,tbt
            init tt,rp
            dap rt
            dap ct
            init qt,ilf
            dap bt
            jmp rsw

ttt,        0
tct,        0
tqt,        0
tbt,        0
```

```
/save constant and reduce level

rt,         jmp xy

rp,         jsp evl
            lac mii
            spq
            jmp rp8
            jsp co

rp5,        xct i lp3
            add i lp2
            dac wrd
            law 1
            dac def
            law i 1
            jda pi
            sas (dio cv4
            jmp rp3
            move ttt,tt
            move tct,ct
            move tqt,qt
            move tbt,bt
            init rt,ilf
            stf 5                  /syl

rp3,        jsp rss
            lac t
            sad (55                /right paren
            jmp r
            sas (77
            jmp r2
            jmp tt

rp8,        jsp mc
            jsp dd
            jda wro
lac (-200000
            xct i lp3
            sub (-200000
            add wro
            jda pr
            cla
            jmp rp5

pi,         0
            dap pix
            lac pi
            add lp1
            dap lp1
            add (cv2-cv1
            dap lp2
            add (cv3-cv2
            dap lp3
            add (cv4-cv3
            dap lp4
pix,        jmp xy
```

/constant table search

```
co,         dap cox
            idx nca
            lac pss
            spq
            jmp co8
            lac def
            spq
            jsp usc
            lac con
            dap co3
 jmp co4+1

co2,        lac wrd
co3,        sad xy
            jmp co6
co4,        index co3, nco, co2
            add one
            dac nco
            add (lac-sad+1
            dac hih
            sad low
            jsp sce
            lio wrd
            dio i co3

co6,        lac co3
            sub con
            add i cn6          /cor table (first)
            and (7777
co8,        dac num
cox,        jmp xy
```

/pseudo-instruction constants

```
cns,        lac mii
            spq
            jsp ilf
            lac loc
cn6,        dac xy                  /cor table (first)
            dac tlo
            lac nca
            add aml                 /aml is "alarm location"
            dac aml
            lac pss
            spq
            jmp cn5
            init bs,cn4
            lac con
            dap cn3
            jmp cn8
cn3,        lac xy                  /const. list
            dac wrd
            jmp tb4

cn4,        idx cn3
            add (sad-lac
cn8,        sas nco
            jmp cn3
            lac loc
cn7,        dac cr2                 /sto cor table (second)
cn5,        lac tlo
            add nca
            dac wrd
            init bs,cn1
            jmp ba1

cn1,        init bs,rnw
            move con,nco
            dzm nca
            idx cn6
            index cn7,(dac cr2+ncn,rnw

tmc,        error alm, alh, flex tmc
```

/pseudo-instruction "dimension"

```
dim,        init rt, di2
            init dtb+57, di1
            init ct, rsw
            init bt, ilf
            dap qt
            init tt, rst
            jmp rsw

di1,        move sym, tcn
            szf 5
            jsp ilf
            jmp rsw

di2,        jsp evl
            spi
            jsp usp
            move tcn, sym
            move wrd, tcn
            clc
            dac let
            jsp evl
            spa
            jmp di3
            spi
            jmp mdd
            lac vct
            add vc1
            dac i ea

di4,        lac vct
            add tcn
            dac vct
            jmp rsw

di3,        spi i
            jmp mdd
            dac t3
            jsp vsm
            jmp di4

mdd,        move sym, lus
            error alu, rsw, flex mdd
```

/pseudo-instruction variables

```
var,        lac mii
            spa
            jmp ilf
            lac loc
            spa
            jmp ilf
            lio vai
            spi
            jmp tmv
            load vai, -0
            lio pss
            spi
            jmp vaa
            sas vc1
            jmp vld

vac,        lac vc2
            dac wrd
            jmp b5

vaa,        dac vc1
            add vct
            dac vc2
            lac aml
            add vct
            dac aml
            jmp vac
```

/read characters from flexo buffer

```
rch,        dap rcz
            isp fwd
            jmp rc1

rc8,        lio xy              /flx list
            dio fwb
            idx rc8
            sub rf3
            sza i
            jmp rc3
            sma
            jmp rfb             /refill buffer
            law i 3
rc4,        dac fwd

rc1,        lio fwb
            cla
            rcl 6s
            dio fwb
            dac t
            dac rcp
rcz,        jmp xy

rc3,        lac nfc
            jmp rc4

rcp,        0
```

```
/refill flexo buffer

rfb,        init rc8,flx
            dap rf3
            law rf4+1

rf5,        dap rf4
rf1,        setup nfc,3
rf2,        rpa
            dio t
            rir 7s
            spi
            jmp rf2             /7th code=delete
            sense 6
            jmp rfa
            lac t
            sza i
            jmp rf2
 add (1000
            dap .+2
            law 5252
            rar                 /check parity
            spa
            jmp ilp

rfa,        cla
            lio t
            rcr 6s
rf3,        lio xy              /flx list
            rcl 6s
            dio i rf3
            rcr 6s
            sad (130000         /stop code
            jmp rf6
            sad (770000         /car ret
rf4,        jmp xy              /.+1 or rf6
            count nfc,rf2
            index rf3,(lio flx+nfw-24,rf1
            law rf6
            jmp rf5

rf6,        rcl 6s
            isp nfc
            ril 6s
            isp nfc
            ril 6s
            dio i rf3
            law i 2
            sub nfc
            dac nfc
            idx rf3
            jmp rc8

ilp,        law 7143
            jda tys
            law 4777
            jda tys
            init sov, rf2
            lio t
            hlt+clc-opr
            jmp rfa
```

```
/pseudo-instructions octal, decimal, expunge and noinput

oct,        lac (opr
            jmp dec+1
dec,        lac (add num
            dac n1
de2,        clf 5                  /syl
            jmp r2
noi,        clc
            dac ini
            jmp de2

xp,         lio pss
            law low
            spi
            dap low
            jmp de2

/ignore to tab or car ret

itt,        jsp rsl

itc,        clf 5
            dzm wrd
            jsp rss
            lac rcp
            jmp .+2

it1,        jsp rch
            sad (36
            jmp itx
            sas (77
            jmp it1
itx,        jmp r2
```

```
/feed subroutine

fee,        0
            dap fex
            cli
            ppa
            isp fee
            jmp .-2
fex,        jmp .

/punch routine

pnb,        0
            lio pnb
            dap pnx
            lac loc
            ppb
            ril 6s
            ppb
            ril 6s
            ppb
pnx,        jmp .

/oct7znt subroutine

opt,        0
            dap opx
            lio (100000
            lac opt
            clf 1
op1,        rcr 9s
            rcr 6s
            sza
            jmp op2
            law 20
op3,        swap
            szf 1
            tyo
            sad (10000
            stf 1
            cli
            sas (100000
            jmp op1
opx,        jmp xy

op2,        stf 1
            jmp op3
```

```
/type subroutine

tys,        xx
            dap tyx
            law i 3
            dac opt

tyl,        lac tys
            and (770000
            sza i
            jmp tyc
            rcl 6s
            tyo

tyc,        lac tys
            ral 6s
            dac tys
            isp opt
            jmp tyl
tyx,        jmp .

/tab typer

tb,         dap .+3
            law char r                      /tab
            jda tys
            jmp .

/permute zone bits

per,        0
            dap pex
            lac per
            cli
            rcr 6s
            sza
            jmp .-2
            dio per
            lac per
            and (202020
            ral 1s
            xor per
            xor (400000
pex,        jmp .
```

```
/error print routines

ust,        error alu,tb3,flex usw

usb,        error alu,b5,flex usl

usq,        error alu,rst,flex usp

uss,        error alu,s2,flex uss

usm,        jda alu
            flex usm

usc,        jda alu
            flex usc

usr,        error alu,rst,flex usr

usp,        jda alu
            flex usa

usd,        jda alu
            flex usd

uds,        dio lus
            error alu,evx,flex uds

il,         error alm,r,flex ich

ilf,        error alm,itt,flex ilf

ipi,        error alm,itc,flex ipi

mdt,        move sym,lus
            error alu,rnw,flex mdt

mdm,        error alm,dmi,flex mdm

ipa,        error alm,itt,flex ipa

ids,        dzm sym
            jda alm
            flex ids

ils,        error alm,alh,flex ils

sce,        error alm,alh,flex sce

tmp,        error alm,alh,flex tmp

vld,        error alm,rnw,flex vld

tmv,        error alm,rnw,flex tmv
```

/error print routine

```
alu,        0
            move alu,alm
            jmp alb

alm,        0
            dzm lus
alb,        dap .+3
            lac alm
            dap sov
            lac xy
            jda tys
            jsp tb
            lac loc
spa
            jmp al1
            jda opt
            jmp al2

al1,        lac (flex ind
            jda tys

al2,        jsp tb
            lac asi
            spa
            jmp al6
            lac asm
            jda per
            jda tys
            lac aml
            sza i
            jmp al6
            lio aml
            lac (flex +
            spi
law char r-
            jda tys
            lac aml
            spa
            cma
            jda opt

al6,        lac api
            sza i
            jmp al9
```

```
al7,    jsp tb
        lac api
        jda tys
        lac syn
        jda tys
        lac lus
        sza i
        jmp al8

als,    jsp tb
        lac lus
        jda per
        jda tys

al8,    law 77                  /c.r.
        jda tys
        lat
        rar 1s
        lio (-0
        sma

alh,    clc+hlt-opr
        dio pch
        jmp sov

al9,    lac lus
        sza i
        jmp al8
        jsp tb
        jmp als
```

```
/title punch table

ftp,        0         0         /space
            004277    400000    /1
            625151    514600    /2
            224145    453200    /3
            141211    771000    /4
            274545    453100    /5
            364545    453000    /6
            010171    050300    /7
            324545    453200    /8
            065151    513600    /9
            0         0
            0         0
            0         0
            0         0
            0         0
            0         0
            364141    413600    /zero
            000077    000000    //
            224545    453000    /s
            010177    010100    /t
            374040    403700    /u
            073060    300700    /v
            376014    603700    /w
            412214    224100    /x
            010274    020100    /y
            615141    454300    /z
            0         0
            141414    141400    /=
            0         0
            0         0
            0         0
            0         0
            0         0
            204040    403700    /j
            771014    224100    /k
            774040    404000    /l
            770214    027700    /m
            770214    207700    /n
            364141    413600    /o
            771111    110600    /p
            364151    215600    /q
            771111    314600    /r
            0         0
            0         0
            101010    101000    /-
            000041    221400    /)
            101074    101000    +
            001422    410000    /(
            0         0
            761111    117600    /a
            774545    453200    /b
            364141    412200    /c
            774141    413600    /d
            774545    414100    /e
            770505    010100    /f
            364151    513000    /g
            771010    107700    /h
            004177    410000    /i
            010300    010300    /close quotes
            000060    600000    /.
            030200    030200    /open quotes
```

```
/Indicators and variable storage

vai,        0          /variables pseudo-instruction indicator
vc1,        0          /beginning of variables
vc2,        0          /end of variables
vct,        0          /variables counter
ovb,        0          /overbar indicator, 1= on, 0= off
pss,        0          /-0 = pass 1, +1 = pass 2
npa,        0          /-0 = begin pass, +1 = continue pass
pch,        0          /-0 = do not punch, +1 = punh if pass 2
inp,        0          /-0 = suppress input routine, +1 = punch input routine
tit,        0          /-0 = suppress title, +1 = punch title
psa,        0          /end of psuedo-instruction list) at beginning
psb,        0          /end of macro-instruction list ) of pass 1
ini,        0          /aux. input routine indicator
hih,        0          /upper limit of macro instruction and constant list
nfc,        0          /test word for end of flexo word list
lus,        0          /last undefined symbol
fwd,        0          /flexo word from input tape
fwb,        0          /flexo word from list
wrd,        0          /partial sum of syllables of word
num,        0          /number = value of syllable.
sym,        0          /symbol = flexo word for symbol.
def,        0          /-0 = indefinite word, +1 = definite
chc,        0          /character count of characters in syllable
let,        0          /0 = no letters in syllable, -0 = at least one letter
api,        0          /last psuedo-instruction for error stop
asi,        0          /relative location•+0 = yes, -1 = no
asm,        0          /alarm symbol for relative location
aml,        0          /location relative to above symbol (asm)
nsm,        0          /(for establishing above symbolic relative
asa,        0          /(location from location
amn,        0          /(assignment
con,        0          /current address in constant list
nco,        0          /number of distinct constant values
nca,        0          /number of constant syllables
tlo,        0          /temporary for current location
mii,        0          /macro instruction mode indicator
mdi,        0          /define indicator
syn,        0          /second three characs of M-I name
tea,        0          /temporary subroutine exit address
scn,        0          /(temporaries
scw,        0          /(for code
tcn,        0          /(word
tcc,        0          /(subroutines
dsk,        sad xy     /dummy symbol count
dsl,        0          /temporary for dum sym count

t,          0          t1,        0          /temporary
t2,         0          t3,        0          /registers
```

```
constants

/pseudo instruction list and macro names and definitions

psi/        law npi-3

mai/        lac npi+1

            text .repeat.        rpt
            text .charac.        ch
            text .fle xo.        fx
            text .tex  t.        txt
            text .sta rt.        sta
            text .termin.        ter
            text .define.        dfn
            text .consta.        cns
            text .oct al.        oct
            text .decima.        dec
            text .noinpu.        noi
            text .expung.        xp
            text .variab.        var
            text .dimens.        dim
npi,

dss/        1
dsm/        110000
cv1/        pdl

low/        lac low

            start ps5
```

SYMBOL PACKAGE - macro fio-dec

```
/MACRO P SYMBO PUNCH·10-27-61

flx/

lsb,        clf 5
            senses 1001
            jmp 7751
 law i 20
            jda fee
ls,         listen
            swap
            senses 1001
            jmp 7751
            sad (77
            jmp ls3
            sas (36
            jmp pt1-5

ls2,        listen
            swap
ls3,        senses 1001
            jmp 7751
            lio (jmp sps
            sad (char rm
            lio (jmp mps
            sad (char rs
            stf 5
            dio sps-1
            lio ls3+2
            dio .-2
            sas (77
            jmp ls2
            law i 40
            jda fee
            lac end-1
            jda pnb
            law i 40
            jda fee
            xx
sps,        lac low
            dap bpp
            law low+1
            jda end
            szf 5
            jmp pse
            law i 40
            jda fee

mps,        law psi
            dap bpp
            add (2
            jda end
            init bpp,npi
            lac mai
            add (law-lac+1
            sad .-4
```

```
        jmp pse
        dap end
        jsp pst

pse,    law i 30
        jda fee
        lac (jmp ps5
        jda pnb
        law i 240
        jda fee
        jmp 7751

end,    0
pst,    dap psx
        clf 4
bpp,    law xy
psr,    dac org
        dap sor
        and (-77
        add (100
        dac loc
        law pbf
        dap .+2
psu,    lac i sor
        dac .
        idx .-1
        dap ts
        idx sor
        sad end
        jmp .+4
        sad loc
        jmp psc
        jmp psu
        dac loc
        stf 4

pcb,    jmp psc
        szf 4
psx,    jmp xy
        lac loc
        jmp psr

psc,    senses 1001
        jmp 7751
        jmp pun+6

sor,    xy

constants

bnp/    jmp pcb+1
pt1/    jmp pt1+4
pt6-1/  jmp ls

        start lsb
```

RESTORE

```
bnp/        lac wrd
pt1/        lio t
pt6-1/      jmp pt1


/Text printer

pbf/

txp,        0
            dap txu

txu,        lio .
            ril 6s
            tyo
            ril 6s
            tyo
            ril 6s
            tyo
            idx txu
            sub (lio
            sas txp
            jmp txu
            jmp i txp

            constants
```

```
/init. sym. val

ist,        flex  1s   1
            flex  2s   3
            flex  3s   7
            flex  4s   17
            flex  5s   37
            flex  6s   77
            flex  7s   177
            flex  8s   377
            flex  9s   777

            char li    10000

            flex and   020000
            flex ior   040000
            flex xor   060000
            flex xct   100000
            flex jfd   120000
            flex cal   160000
            flex jda   170000
            flex lac   200000
            flex lio   220000
            flex dac   240000
            flex dap   260000
            flex dip   300000
            flex dio   320000
            flex dzm   340000
            flex add   400000
            flex sub   420000
            flex idx   440000
            flex isp   460000
            flex sad   500000
            flex sas   520000
            flex mus   540000
            flex dis   560000
            flex jmp   600000
            flex jsp   620000

            flex skp   640000
            flex szf   640000
            flex szs   640000

            flex sza   640100
            flex spa   640200
            flex sma   640400
            flex szo   641000
            flex spi   642000
```

```
        flex ral   661000
        flex ril   662000
        flex rcl   663000
        flex sal   665000
        flex sil   666000
        flex scl   667000
        flex rar   671000
        flex rir   672000
        flex rcr   673000
        flex sar   675000
        flex sir   676000
        flex scr   677000

        flex law   700000
        flex iot   720000
        flex tyi   720004
        flex rrb   720030
        flex cks   720033
        flex lsm   720054
        flex esm   720055

        flex cdf   720074
        flex cfd   720074

        flex rpa   730001
        flex rpb   730002
        flex tyo   730003
        flex ppa   730005
        flex ppb   730006
        flex dpy   730007

        flex clf   760000
        flex nop   760000
        flex opr   760000

        flex stf   760010
        flex cla   760200

        flex hlt   760400
        flex  xx   760400

        flex cma   761000
        flex clc   761200
        flex lat   762200
        flex cli   764000

iyi,    -0         -0
```

/CONSTANTS PRINTER

```
yc,         szs i 30
            szs 20
            jmp ych
            jmp 7751

ych,        lac cn7
            sad (dac cr2
            jmp 7751
            dap yct
            law yc2
            jda txp
            357774    /red, c.r., u.c.
            637246    /c, l.c., o
            text .nstants area.

yc2,        lac pss
            spa
            jmp yc3
            law yc4
            jda txp
            text /, inclusive
from        t/        char lo+3477

yc4,        stf 5

yc7,        law cor
            dap ycm
            law cr2

ycr,        dap ycn
ycu,        sad yct
            jmp 7751

ycm,        lac .                 /cor
            spa
            jmp ycp
            jda opt
            szf i 5               /set to print
            jmp ycq
            law 36
            jda tys
            law i 1

ycn,        add .                 /cr2
            jda opt

ycq,        law 77
            jda tys
yck,        idx ycm
            idx ycn
            jmp ycu

yc3,        law yc6
            jda txp
            text / origi/         flex ns +34         77

yc6,        clf 5
            jmp yc7
```

```
yct,        add .

ycp,        law yco
            jda txp
            357145    /red, i, n
            flex def
            char l:+3477
yco,        jmp yck

            constants

            start yc
```

ALPHA SYMBOL PRINTER

```
yc/
ycs,        szs i 20
            jmp syx
            law ycl
            jda txp
            3577
            text /Defined Symbols ALPHA/
            3477
ycl,        lac low
            sad .-1
            jmp syx
            dap yc8
            lio (77
            iot 4003
ycy,        law ist
            dap yca

yca,        lac .       /ist
            jda per
yc8,        sad .       /symbol
            jmp ycb
            idx yca
            idx yca
            sas (lac iyi
            jmp yca
            clf 5

ycz,        iot i
            szs i 20
            jmp syx
            lac i yc8             /symbol
            jda per
            jda tys
            jsp tb
            idx yc8
            lac i yc8             /value
            jda opt
            szf i 5               /set if print
            jmp yc1
            jsp tb
            lac i yca
            jda opt
yc1,        lio (77
            iot 4003
            jmp ycv
```

```
ycb,        idx yc8
            idx yca
            lac i yc8
            sad i yca          /value
            jmp ycc
            stf 5
            law i 1
            add yc8
            dac yc8
            jmp ycz

ycc,
ycv,        idx yc8
            sas (sad low
            jmp ycy
            iot i

syx,        szs i 30
            jmp 7751
            law syy
            jda txp
            357777
text /Defined Symbols NUMERIC/
            3477
syy,        jmp 7751

            constants

            start ycs
```

NUMERIC SYMBOL PRINT

```
yc/
sy,         szs 30 i
            jmp 7751
            dzm t
            init sy3,ist
            init sy4,ist+1
            lio (77
            tyo-4000

sya,        lac t
            dac t1
            clc
            dac t
            lac low
            dap syb
            idx syb

syb,        lac xy                  /value
            lio i syb
            xor t1
            spa
            jmp sq5
            sza i
            jmp syc
            xor t1
            sub t1
sq1,        spa
            jmp syi

sq2,        lac t
            xor i syb
            spa
            jmp sq3
            lac i syb
            sub t
sq4,        spa
            dio t

syi,        idx syb
            idx syb
            sas (lac low+1
            jmp syb
            lac t1
            cma
            sza
            jmp sya
            iot i
            jmp 7751

sq5,        lac t1
            jmp sq1
```

```
sq3,        lac t
            jmp sq4

syc,        law i 1
            add syb
            dap syz

syg,
sy4,        lac xy                    /ist value
            xor i syb
            spa
            jmp sy5
            sza i
            jmp syf
            lac i syb
            sub i sy4
sy1,        spa
            jmp syp

syd,        idx sy4
            dap sy3
            idx sy4
            jmp syg

sy5,        lac i sy4
            jmp sy1

syp,        iot i
            szs i 30
            jmp 7751
syz,        lac xy                    /mai symbol
            jda per
            jda tys
            jsp tb
            lac i syb
            jda opt
            lio (77
            tyo-4000
            jmp syi

syf,
sy3,        lac xy                    /ist table
            jda per
            sas i syz
            jmp syp
            idx sy4
            dap sy3
            idx sy4
            jmp syi

            constants

            start sy
```

```
/restore macro

dsm/
rm,             szs 40 i
jmp 7751
                load mai,lac npi-1
                load psi,law npi-3
                load low,lac low
                init rm2,ist-2

rm4,            idx rm2
                idx rm2
                add (1
                dap rm3
rm2,            lac xy
                sad iyi
                jmp 7751
                jda per
                dac sym
rm3,            lac xy
                dac t3
                jsp vsm
                jmp rm4

                constants

                start rm
```

```
/final "where to go routine"

dsm/        110000                  /permuted char lr
            szs 40
            jmp ps5
            lac pss
            sma+szf 6-skp
            jmp s6
            sma
            jmp s4
            szf 6
            jmp 1st
            jmp s5

dss/        1
cv1/        pdl

            start dsm+1
```

APPENDIX 2

MACRO INSTRUCTION EXAMPLE

Appendix 2: Macro Instruction Example

The sample program on the next page is analyzed in detail to illustrate most of the features of the macro processor. We illustrate first how a programmer might analyze the macros. Each successive level of macro expansion is indented one column from its predecessor.

On the next page is listed an English transliteration of the macro structure from MACRO's point of view. Internal dummy symbol numbers correspond to the letters used as shown by the chart below. The most important changes to the dss table are shown also, but the reader should remember that any dummy symbol parameter assignment will in general alter the dss table. Note particularly how the extra argument of second is lost.

Finally there is an octal and binary dump of the mai table for these macros. The octal numbers are in the left hand column, and on the right appear the binary forms of the same numbers divided off according to their significance. Numbers in parentheses are value words associated with the zero-nonzero indicator bits immediately preceding them. Periods represent word boundarys, and semicolons represent statement boundarys. Each statement corresponds precisely with one entry in the mai table as listed on the preceding page. The pseudo-instruction data is shown also.

Table of Dummy Symbols

1	R
2	A
3	B
4	C
5	D
6	E
7	F
10	G
11	H
12	J
13	K
14	L

Sample program: June, 1962, RAS.

```
define   first A, B, C
         law A
         add B
         dac C
         term

define   second X, Y
         Z=105
         dac Z
         X=X+(Y
         first 1, (X, X+X
         lac Z
         Z=X
         add Z
         term

define   third J, K
         second 100, J+(K+200, K
         term

a,       first a, b, c
         second 1, 2
         third 10000, (40000
         dac d
         hlt
b,       0
c,       0
d,       0

const

start a
```

Expansion of Sample Program

```
Source tape            Intermediate results                  Word         Location

a,        first 4, 25, 26
                                                              law 4        4
                                                              add 25       5
                                                              dac 26       6

          second 1, 2
                       z=105
                       dac z                                  dac 105      7
                       x=1+(2)
                       x=1+30
                       x=31
                       first 1, (31), 62
                       first 1, 31, 62
                                                              law 1        10
                                                              add 31       11
                                                              dac 62       12

                       lac z                                  lac 105      13
                       z=x
                       z=31
                       add z                                  add 31       14

          third 10000, (40000)
          third 10000, 32
                       second 100, 10000+(32+200), 32
                       second 100, 10000+33, 32
                       second 100, 10033, 32
                                 z=105
                                 dac z                        dac 105      15
                                 x=100+(10033)
                                 x=100+34
                                 x=134
                                 first 1, (134), 270
                                 first 1, 35, 270
                                                              law 1        16
                                                              add 35       17
                                                              dac 270      20

                                 lac z                        lac 105      21
                                 z=x
                                 z=134
                                 add z                        add 134      22

          dac d                                               dac 27       23
          hlt                                                 hlt          24
b,        0                                                   0            25
c,        0                                                   0            26
d,        0                                                   0            27

const                                                         2            30
                                                              31           31
                                                              40000        32
                                                              232          33
                                                              10033        34
                                                              134          35
```

Sample Program Macros as Seen by MACRO

```
English input       Read from mai                       Stored into mai

define    first A, B, C
          law A                                          A+700000
          add B                                          B+400000
          dac C                                          C+240000
term

define    second A, B
          C=105                                          C=105
          dac C                                          C+240000
          A=A+(B)                                        D=(B+0)
                                                         A=A+D+0

          first 1, (A), A+A                   sets dss[2] to 0
                                                         E=(A+0)
                                                         F=E+0
                                              sets dss[3] to 7 [F]
                                                         G=A+A+0
                                              sets dss[4] to 10 [G]

                    A+700000                             700001
                    B+400000                             F+400000
                    C+240000                             G+240000

          lac C                                          C+200000
          C=A                                            C=A+0
          add C                                          C+400000
term

define    third A, B
          second 100, A+(B+200), B            sets dss[2] to 0
                                                         C=(B+200)
                                                         D=A+C+0
                                              sets dss[3] to 5 [D]
                                                         E=B+0
                                              sets dss[4] to 6 [E]

                    C=105                     sets dss[4] to 0
                    C+240000                             240105
                    D=(B+0)                              F=(D+0)
                    A=A+D+0                              G=F+100
                                              sets dss[2] to 10 [G]

                    E=(A+0)                              H=G+0
                    F=E+0                                J=H+0
                    G=A+A+0                              K=G+G+0
                    700001                               700001
                    F+400000                             J+400000
                    G+240000                             K+240000
                    C+200000                             200105
                    C=A+0                                L=G+0
                    C+400000                             L+400000
term
```

Octal and Binary Dump of mai Table

```
        FIRST
667151  fir
002223   st
705026  [pointer]
420314  10 0010000 0 1(700000); 10 01100.00
700000
060417  0 1(400000); 10 0001000 0 1(240000); 111.1/
400000
240000
400000

        SECOND
226563  sec
464564  ond
705031  [pointer]
721041  1110 1(105) 0001000; 10 0001.000
   105
031414  0 1(240000); 10 0110000 110 0.(0)
240000
242102  0101000; 10 0010000 10.
243450  0101000 1110 0(0) 101000.0;
210303  10 0010000 110 0(0) 0011.000;
043070  10 0011000 1110 0(0) 0.111000;
704204  10 0010000 10 0.010000
207004  1110 0(0) 0000100.;
316060  0 1(700001); 10 0111000 0 1(400000); 10 000.0100
700001
400000
214163  0 1(240000); 10 0001000 0 1(200000);
240000
200000
041622  1.0 0010000 1110 0(0) 10010.00;
102076  10 0001000 0 1(400000); 1111/
400000
```

```
        THIRD
237071  thi
005164   rd
705042  [pointer]
460642  10 0110000 110 1(200) 00010.00;
   200
104102  10 0010000 10 00010.00
161211  1110 0(0) 0101000; 10 01.10000
416060  1110 0(0) 0011000;
624307  0. 1(240105); 10 0101000 110 0(0) 0111.000;
240105
047072  10 0111000 1110 1(100) 0.000100;
   100
044046  10 0000100 110.
111111  0(0) 0100100; 10 0100100
605101  1.110 0(0) 0010100; 10 00001.00
101161  10 0000100 1110 0(0) 01.10100;
506121  0 1(700001); 10 0010100 0 1.(400000);
700001
400000
464260  10 0110100 0 1(240000); 0 1(200105);
240000
200105
234062  10 000.0100 1110 0(0) 0001100;
061740  10. 0001100 0 1(400000); 1111/
400000
```

extended pdp-1 ops and macros, jan 1962

```
lap=cla 100
ioh=iot i
clo=651600
spq=650500
szm=640500

define
          sensewitch A
          repeat 3, A=A+A
          szs A
          term

define
          initialize A, B
          law B
          dap A
          term

define
          index A, B, C
          idx A
          sas B
          jmp C
          term

define
          listen
          cla+cli+clf 1-opr-opr
          szf i 1
          jmp .-1
          tyi
          term

define
          swap
          rcl 9s
          rcl 9s
          term

define
          load A, B
          lio (B
          dio A
          term

define
          setup A, B
          law i B
          dac A
          term

define
          count A, B
          isp A
          jmp B
          term
```

```
define
            move A, B
            lio A
            dio B
            term

define
            clear A, B
            init .+2, A
            dzm
            index .-1, (dzm B+1, .-1
            term

start
```