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| Abstract | This paper describes a debugging system which has been developed on such a combined system of a minicomputer and a microprocessor that is microprogrammable for the user, and aims at an effective debugging of the errors that will be detected during the execution of the program written in a low-level language. The multiprocessor organization, adoption of firmware monitor and special hardwares yield such advantageous features as bilateral tracing, procedure extraction, eight kinds of event monitors, etc., which come to be effective for debugging. Debugging is performed in an interactive mode so that the program can be tested and modified easily by various kinds of editing and debugging commands. This system has four modes, that is, assemble, edit, debug, and test, which allow it to perform the debug processing consistently. |
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AN INTERACTIVE DEBUGGING SYSTEM COMPOSED OF A MINICOMPUTER AND A MICROPROCESSOR

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ABSTRACT

This paper describes a debugging system which has been developed on such a combined system of a minicomputer and a microprocessor that is microprogrammable for the user, and aims at an effective debugging of the errors that will be detected during the execution of the program written in a low-level language. The multiprocessor organization, adoption of firmware monitor and special hardwares yield such advantageous features as bilateral tracing, procedure extraction, eight kinds of event monitors, etc., which come to be effective for debugging. Debugging is performed in an interactive mode so that the program can be tested and modified easily by various kinds of editing and debugging commands. This system has four modes, that is, assemble, edit, debug, and test, which allow it to perform the debug processing consistently.

1. Introduction

In contrast to the drastic reduction of the recent hardware prices, software cost in the computer system tends to rather increase its rate, since the software productivity will not largely be improved. [1] One of the factors that suppress the improvement of software productivity lies in the difficulty of program debugging; [9] especially, debugging the errors detected in the execution of programs is an urgent problem, and thus many researches for the debuggers have been studied up to the present. [2] [3] [4] [5] [6] [8].

It can be considered that the requirements for such a debugger include (1) an interactive processing, (2) time-sharing processing, (3) high-performance efficiency, (4) acquisition of high-level information, (5) feasible usage, and so forth. At the time of developing the currently proposed debugging system that can satisfy the above requirements, the following principles are established:

- (1) Its object is laid in the assembly language, and is to debug the errors detected in the execution of user program.
- (2) It is realized on the multiprocessors to distribute their functions and also to suppress the occurrence of secondary errors which might be made through debugging.
- (3) It should employ a firmware monitor.
- (4) The debugging is proceeded in an interactive mode, and thus the time-sharing system is not taken into account because the object is limited to a minicomputer only.

Following the above statement, a debugging system which is realized on the combined system composed of a HITAC-10 minicomputer and a mCOM-16 microprocessor is described, which is shown in Figure 1, where the console for debugging use and various I/O units are also illustrated. [7]

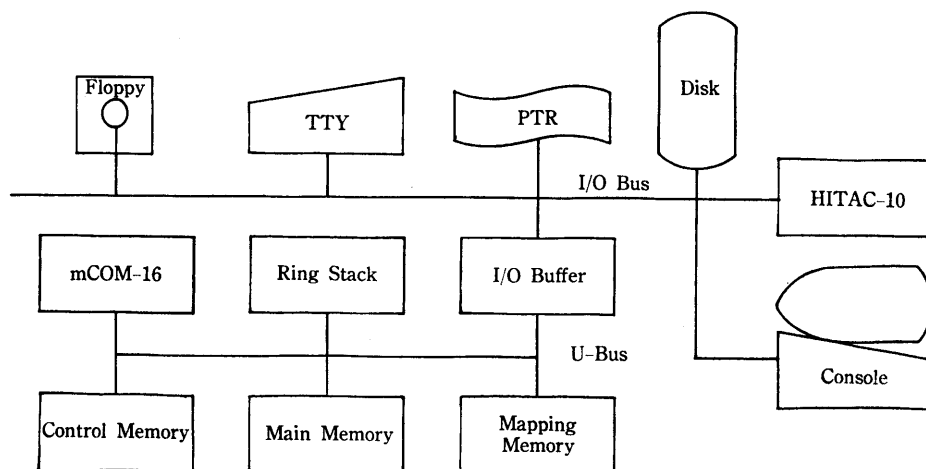


Figure 1. Hardware configuration.

2. Debugger

The debugger's software is composed of the processing programs of both the minicomputer side (nearly 4500 steps of the HITAC-10 assembly language) and the microprocessor side (about 2500 steps of the mCOM-16 microprogram), and collects and displays the debugging information obtained in the execution of the program in accordance with the commands delivered from the user. The user program is stored in the main memory of the mCOM-16 and carried out through the firmware monitor (three kinds of firmware monitors are registered in the disk and transferred to the mCOM-16 control memory). Since the mCOM-16 is controlled and managed by the HITAC-10, the user needs not be conscious of the existence of the mCOM-16. On the other hand, the processing program in the HITAC-10 is

divided into three; namely, (1) the command processing part which processes and analyzes the user's commands, (2) the debugging information part which arranges and displays the information obtained from the firmware monitor, and (3) the I/O service part which is prepared for the mCOM-16 providing no I/O units.

2.1 Firmware Monitor

For the purpose of collecting effective and high-level information without introducing any disturbances at the debug processing, the following are set as the monitor :

- (1) Execution of instructions by the specified number of steps.
- (2) Execution of the specified instructions by the specified number of times.
- (3) Execution of the instruction at the specified location by the specified number of times.
- (4) Execution of instructions at the specified area of the memory.
- (5) Read out from the specified location or area.
- (6) Write into the specified location or area.
- (7) Comparison of the contents of the memory with the constants.
- (8) Comparison of the contents between two different memory locations.

The multiple monitors can be designated simultaneously for those events, and even when only one of them is specified during the execution of user program, the execution is halted to display it to the user. Thus the user can recognize the executing state at the time when the individual conditions have been satisfied.

Furthermore, the following are prepared as the back-up functions in order to proceed the debug processing smoothly :

- (1) Restoring function of the initial state :

Since the user program stored in the disk is transferred to the main memory of the mCOM-16, and at the same time the initialization of the firmware monitor is carried out, the reexecution of the user program can be made from the initial state arbitrarily.

- (2) Read and write functions for the registers and memory :

The contents of all the registers and memory of the emulated machine can be read or written.

- (3) Procedure extraction function :

A series of processes which affect a particular location are taken out as a unit of procedure. Namely, this is such a function that since a sequence of instructions composed of a program has a pattern that it may start with a transfer instruction and then end at another transfer instruction after processed by some arithmetic instruction(s), such a sequence is picked up from the program to display as a unit of procedure. It will be a powerful tool for the user in a debugging operation to recognize a series of instructions that affect the location, the value of which is found to be inadequate.

- (4) Backtrack function :

Backtracking, which proceeds the execution of user program in the reverse direction, can be realized by stacking and monitoring the data information, which comprises the contents of memory and registers that

will be destroyed during the forward execution of the program and the address information concerning the program flow at the Jump, Call, Return instructions and the like in the ring stack. The number of steps that can be backtracked amounts to approximately 1000 steps at present, which will be determined by the ring stack capacity.

(5) Trace function :

This function provides a means of displaying the contents of the respective registers and effective addresses everytime when the specified operations, specified operands, or the instructions in the specified area are carried out, and consequently can catch the consecutive state transitions of user program. During the trace, both collection of the trace information due to the firmware monitor on the mCOM-16 and its display to the user through the HITAC-10 are performed in parallel.

(6) I/O change function :

This permits the change of the I/O units used in the user's program without altering its construction. Presently the TTY and PTR are provided.

(7) Disk dump function :

This allows the user program to be saved in the disk at any time and to return to that point, and comes to be effective to realize a check point and restart function.

These functions as well as the designation of events to be monitored are carried out using the commands, and the HITAC-10 generates the Reference Table which will be mentioned later in accordance with the given commands. The firmware monitor refers to the Reference Table and proceeds the execution of user program, collecting the useful information only. Events are checked at the following three processing parts :

- (1) Fetch part, where the execution address, the number of steps, and the kind of instructions are checked.
- (2) Address computation part, where the memory access is checked.
- (3) Execution part, where the executed results are checked.

The result of individual checking, if an event specified by the user comes into existence, will be informed to the HITAC-10, which then displays the generated event, the contents of individual registers, and the contents of consecutively seven locations of the program placing the approved location in the center of them.

The following three kinds of runs are registered in the firmware monitor: (1) Emulation run, which proceeds the execution of user program while monitoring the event specified by the user's commands; (2) preparation run, where the stacking operation for backtrack use is added to the emulation run; and (3) back run, which executes the program in the reverse direction while monitoring the event. Those are stored in the disk and transferred to the control memory of the mCOM-16 through user commands, and also the mapping memory is rewritten. Figures 2 and 3 depict these three kinds of monitor flows.

2.2 Commands and Reference Table

For the purpose of easy input and of getting abundant, useful information, the commands listed in Table 1 are prepared. As the operand of command, one

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can freely use the symbolic names in the user program, the direct address designation by decimal or hexadecimal representation, and the mnemonic names of registers. Multiple commands input from the console for debugging use are rearranged and compiled to generate the Reference Table.

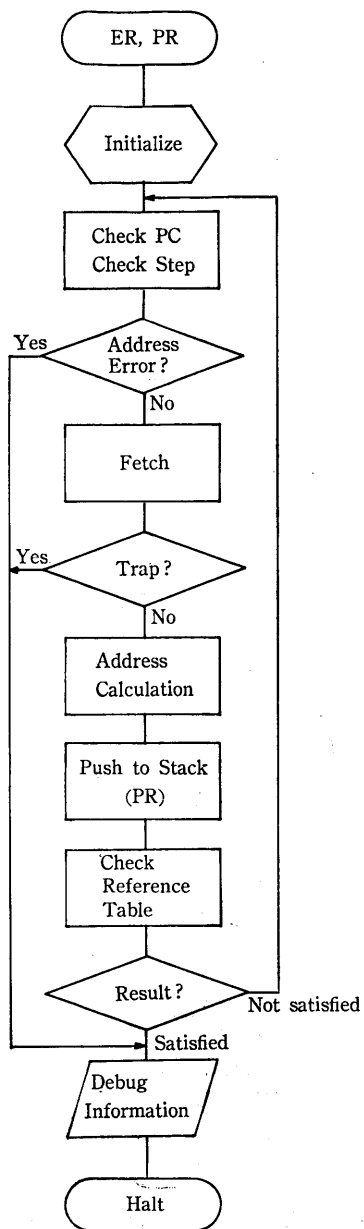


Figure 2. Flow of the firmware monitor (ER, PR).

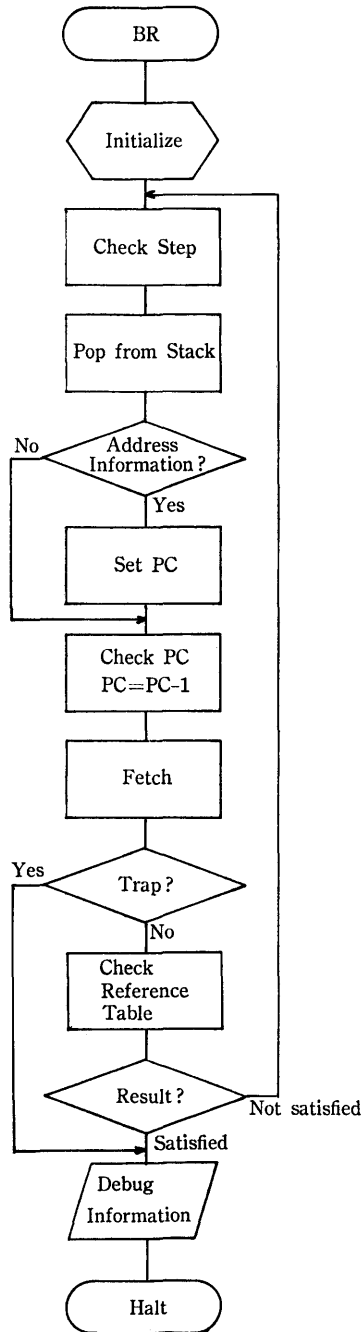


Figure 3. Flow of the firmware monitor (BR).

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Table 1. Command of the debugger.

| Format | Function |
|----------------|------------------------|
| I | Initialize |
| DD v | Dump to disk |
| DM v | Dump to memory |
| SR n v — | Set register |
| SM a v — | Set memory |
| GR n v — | Get register |
| GM a v — | Get memory |
| BP a v — | Break point |
| PC r — | Program counter |
| ST v | Step |
| OC c v — | Operation code |
| OR a v / r — | Operand refer |
| OM a v — | Operand modify |
| CC a o v — | Compare with constant |
| CV a o a' — | Compare with variable |
| E a | Extract |
| IO i | I/O change |
| CIO | Cancel I/O change |
| RA a / r — | Reverse assemble |
| T a / r / c — | Trace |
| UT a / r / c — | Untrace |
| ER | Emulation run |
| PR | Preparation run |
| BR | Back run |
| F | Finish |
| (ESC) | Go to command waiting |
| (Control-P) | Cancel current command |

- r: range
address—address
- a: address
decimal number, hexadecimal number, or label
- n: register name
PC, AC, EC, CAR, or IR
- v: value
decimal number, or hexadecimal number
- o: operator
EQ, GT, GE, LT, LE, or NE
- c: operation code
- i: I/O device name
PTR or TTY
- : repeatable

| | | | |
|--------------------|-------------|------------------|----------------------|
| Step | Total Step | | |
| Execution Area | Top Address | Last Address | |
| Trace Area | Top Address | Last Address | |
| Break Point | Address | Iteration Number | |
| Operand | Address | Flag | Iteration Number |
| Memory Access Area | Top Address | Last Address | |
| Comparison | Address | Operator | Address/ Constant |
| Operation | Flag | Iteration Number | |
| Extraction | Working | Address | |
| I/O Change | I/O Device | | |

Figure 4. Format of the Reference Table.

The Reference Table determines the operation of the firmware monitor and has 10 kinds of formats which keep the following information, as given in Figure 4:

- (1) Number of steps to be executed.
- (2) Location or area where the execution is prohibited.
- (3) Location or area to be traced.
- (4) Number of times of executing a location till the time of activating the breakpoint and/or break mechanism.
- (5) Specified number of accesses to a location and the necessity of tracing.
- (6) Memory area where the access is to be monitored.
- (7) 'Compare' operator and two locations to be compared or a location and a constant.
- (8) Specified number of times of executing macroinstructions and the necessity of tracing.
- (9) A location to be noticed by the procedure extraction function.
- (10) Names of two I/O devices to be changed each other.

In the above stated Reference, (1), (9), and (10) include only one item each; (8) will have the same number of items as that of the macroinstructions; and (2)

through (7) will keep the necessary number of entries for themselves. This Reference Table will be transferred to the special area of the main memory of the mCOM-16 through the execution (run) commands of the user program.

2.3 Processing of the Minicomputer Side

While the firmware monitor on the mCOM-16 executes the user's program, the processing that the minicomputer performs in the debugger includes the following:

- (1) Input of the user commands from the console.
- (2) Analysis of the commands, generation and updating of the Reference Table.
- (3) Read out from and write into the registers and the memory of the mCOM-16.
- (4) Transfer of the microprogram to the control memory of the mCOM-16 and its initiation.
- (5) I/O services for the mCOM-16.
- (6) Rearrangement and display of the debugging information resulted from the firmware monitoring.
- (7) Mode change of the system.

Figures 5 and 6 show the flow of processing by the minicomputer of the

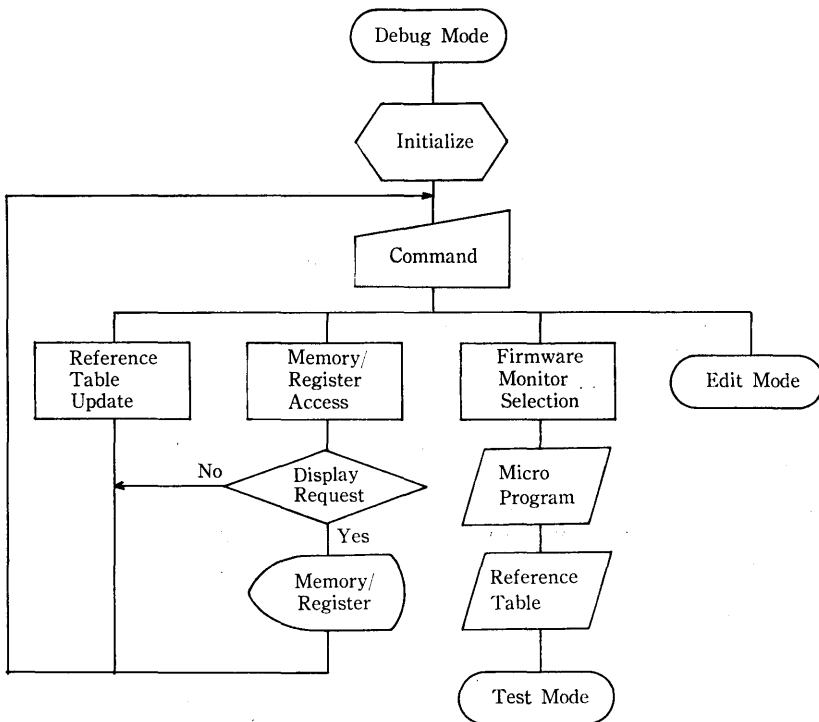


Figure 5. Flow of the debugger in debug mode.

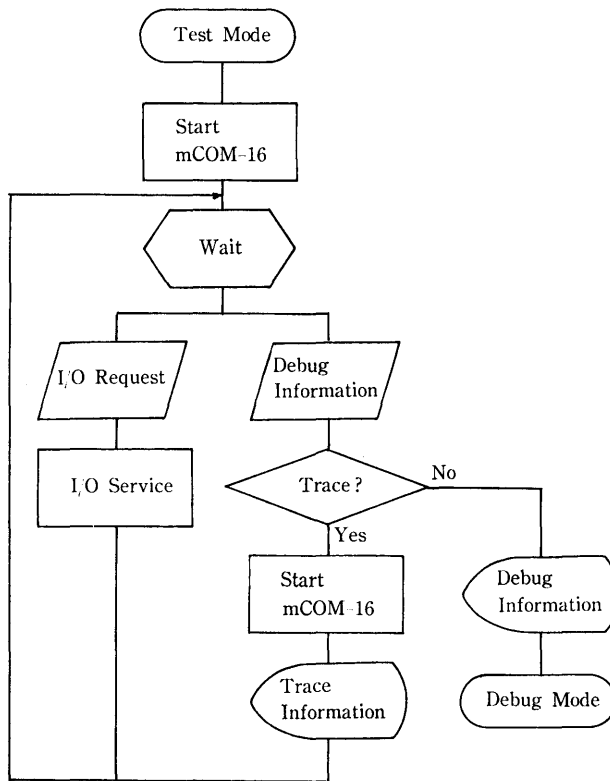


Figure 6. Flow of the debugger in test mode.

debugger.

This system has the four operation modes as follows :

- (1) Assemble mode that converts the user's program to the object one.
- (2) Edit mode that performs the program compilation and the file processing.
- (3) Debug mode that arranges the condition for the debug processing and displays the debug information.
- (4) Test mode that the firmware monitor performs the execution of user program.

Table 2 lists up the contents of the respective memory area in those four modes. On the HITAC-10, the assembler for debugging use runs in assemble mode, the text editor runs in edit mode, and the debugger runs in either debug or test mode; the distinction between them depends upon whether or not the firmware monitor in the control memory of the mCOM-16 is operating.

The role of the assembler for debugging use is to convert the user program to the object one and it is provided as the debugging version after having modified the macro-assembler delivered from the manufacturer. The principal modification is in that the address designation by symbols while debugging the program can be performed by way of saving the symbol table in a safety area at the end of assembling.

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Table 2. Contents of the specified memories for four system modes.

| | Edit Mode | Assemble Mode | Debug Mode | Test Mode |
|---------------------------|-----------|---------------|--------------------|---------------------|
| HITAC-10 Main Memory | Editor | Assembler | Debugger | Debugger |
| Common Area | — | — | Reference Table | Reference Table |
| mCOM-16 Main Memory | — | — | Object | Object |
| mCOM-16 Control Memory | — | — | — | Firmware Monitor |

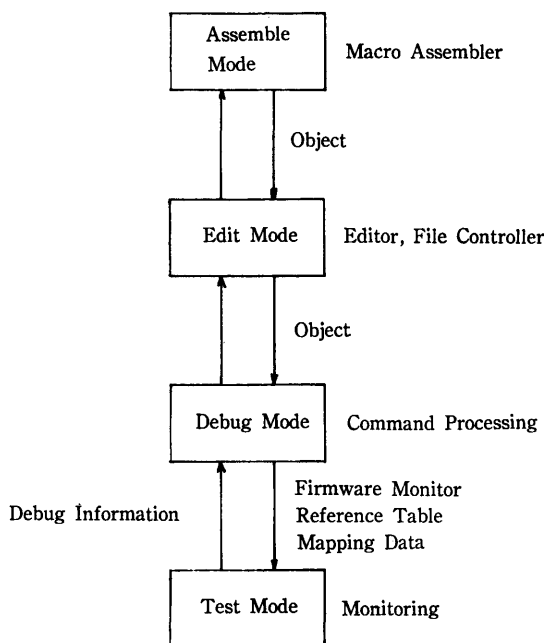


Figure 7. Mode transition.

The text editor has the function of various kinds of compilation and file processing, and is capable of linking the assembler with the debugger.

Figure 7 gives the operation and transition of these four modes, where the transition from assemble mode to edit is initiated automatically after terminating the assembling; the transition from test mode to debug is due to the generation of a specified event, and the other transitions are generated by the user's commands. In debug and test modes the following data transfer is carried out between the HITAC-10 and the mCOM-16.

- (1) From HITAC-10 to mCOM-16,
 - (a) object codes of the user's program (in debug mode),

- (b) firmware monitor (in debug mode),
 - (c) data to the mapping memory (in debug mode),
 - (d) Reference Table (in debug mode), and
 - (e) I/O service information (in test mode).
- (2) From mCOM-16 to HITAC-10,
- (a) debug information (in test mode), and
 - (b) I/O service request (in test mode).

These data transfer will be performed through the two buffer registers connecting the I/O Bus of the HITAC-10 with the U-Bus of the mCOM-16.

3. Examples of Debug Processing

This chapter describes some examples concerning the actual debug processing by making use of the results obtained from the execution of a sample program (see Appendix) through the debugger. The program is to convert a 4-digit hexadecimal (4 bytes) number of the character format to the decimal, using the TTY as an I/O unit. Each input hexadecimal digit of 1 byte is converted to a 4-bit hexadecimal digit after echobacking and stored in a word of 16 bits packed to the lefthand side, where the most significant bit is considered to be the sign. The 4-bit hexadecimal number thus obtained is output after converting it to the character type decimal number. The following lists are the output results obtained from the execution of the sample program with several kinds of commands picked out of those in this debugger. (\$\$ indicates the mode change, ** gives the system message in debug mode, mark # shows the address where the program is stopped after the HLT instruction has been carried out or some condition has been satisfied.)

- (1) From edit to debug mode by Z command. First, initialization is carried out. (See List 1.)

List 1.

```

$$ TTY - EDITOR $$
>Z
$$ HITAC-10 DEBUGGER $$

#I

```

- (2) The output results obtained from the normal execution without any input of the commands for event monitor use. (See List 2.)

The Program Counter is set to the starting location and the user program is executed by the ER command. Since the input routines from the TTY (X'2005' to X'200A') is in the user program, the operation will be at the state of queue. When 0800 is input at this point, =_02048 (_ indicates a space) is output by the user program, and the debugger informs the user that the HLT instruction has been carried out. The indicated information includes the following: the location and the instruction in it at the time its execution ended, the contents of Accumulator (AC), Extended Accumulator (EC), Carry Register (CAR), Effective Address (EA) and its contents ((EA)) as well as the location where the instruction just finished

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List 2.

```
#SR PC X"2000"

#ER
0000= 02048
** I'VE JUST EXECUTED "HLT" INSTRUCTION. **

LOC IR AC EC CAR EA (EA)
2033 6F00 000A 0000 0

          2030 5266 KCT ADR2 **054 #2066
          2031 5259 KCT **040 #2059
          2032 422E B *-004 #202E
* 2033 6F00 HLT
          2034 0A6B L X20 **055 #206B
          2035 3A5E ST BUFF **041 #205E
          2036 4200 B BGN *-054 #2000

** CONTINUE ? **
```

List 3.

```
#CC M7+1 EQ 0
** THE SPECIFIED LOCATION HAS THE APPOINTED VALUE NOW.**

#BP BGN+1

#ER
** I'VE JUST DONE THE SPECIFIED LOCATION.**

LOC IR AC EC CAR EA (EA)
2001 5259 205E 0000 0 2059 FFFB => FFFA

          1FFE F1C4 STE Z 472 #01C4
          1FFF 9156 SRA 342 #0176
          2000 4A37 BGN BAL INIT **055 #2037
* 2001 5259 KCT **088 #2059
          2002 5259 KCT **087 #2059
          2003 5259 KCT **086 #2059
          2004 5266 KCT ADR2 **098 #2066

#CC M7+1 EQ 0

#ER
FFFB
** THE SPECIFIED LOCATION HAS THE APPOINTED VALUE NOW.**

LOC IR AC EC CAR EA (EA)
201D 5259 FFFB 0000 0 2059 FFFF => 0000

          201A 8804 SLL 004 #0004
          201B 325B O HEXA **064 #205B
          201C 3A5C ST PACK **064 #205C
* 201D 5259 KCT **060 #2059
          201E 4205 B READ *-025 #2005
          201F 6864 KPA
          2020 4A51 BAL NEG1 **049 #2051

#GR AC
CONTENT OF AC ;#FFFB

#GM PACK
CONTENT OF LOCATION #205C IS # FFFB
```

List 4.

```
#BP X"2021"

#T NEG,NEG+6

#ER

LOC  IR  AC  EC  CAR EA  (EA)
2052 2A50 0004 0000 0  2050 FFFF
      2052 2A50          X          *-002 #2050

LOC  IR  AC  EC  CAR EA  (EA)
2053 3A5E 0004 0000 0  205C FFFB => 0004
      2053 3A5C          ST          PACK **+009 #205C

LOC  IR  AC  EC  CAR EA  (EA)
2054 525C 0004 0000 0  205C 0004 => 0005
      2054 525C          KCT         PACK **+008 #205C

LOC  IR  AC  EC  CAR EA  (EA)
2055 0A6A 002D 0000 0  206A 002D
      2055 0A6A          L           X2D  **+021 #206A

LOC  IR  AC  EC  CAR EA  (EA)
2056 3A5E 002D 0000 0  205E 0020 => 002D
      2056 3A5E          ST          BUFF **+008 #205E

LOC  IR  AC  EC  CAR EA  (EA)
2057 4651 002D 0000 0  2021 0A5A
      2057 4651          B   I       NEG  *-006 #2051

** I'VE JUST DONE THE SPECIFIED LOCATION.**

LOC  IR  AC  EC  CAR EA  (EA)
2021 0A5A 003D 0000 0  205A 003D
      201E 4205          B           READ *-025 #2005
      201F 6864          KPA
      2020 4A51          BAL         NEG  **+049 #2051
* 2021 0A5A          L           EQ   **+057 #205A
      2022 4A48          BAL         WRTE **+038 #2048
      2023 4A3D          BAL         CUVD **+026 #203D
      2024 2710          N   I       **+236 #2110
```

its execution and the inversely assembled results of seven locations (2030—2036). At the end of the HLT instruction, the 'CONTINUE' message is issued and will start the execution of program from the next location when 'C' is input from the TTY. In case where the characters except 'C' are input, the debugger will be at the state of accepting the commands of debug mode.

- (3) List 3 is an example to confirm that the 4-byte input data are packed and stored in the PACK location.

Since location M7+1 is a counter of the input characters, the command to halt is input when the contents of location M7+1 has come to be zero

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List 5.

```

#BP X"202D"

#ER
=
** I'VE JUST DONE THE SPECIFIED LOCATION.**

LOC  IR.  AC   EC   CAR EA  <EA>
202D 4A37 0035 0000 0   2037 2001 => 202E

      202A 000A
      202B 4A3D      BAL      CVHD **018 #203D
      202C 0001
* 202D 4A37      BAL      INIT **010 #2037
      202E 0E66      L      I   ADR2 **056 #2066
      202F 4A48      BAL      WRTE **025 #2048
      2030 5266      KCT      ADR2 **054 #2066

#GM BUFF,BUFF+5
CONTENT OF LOCATION #205E IS # 002D
CONTENT OF LOCATION #205F IS # 0030
CONTENT OF LOCATION #2060 IS # 0030
CONTENT OF LOCATION #2061 IS # 0030
CONTENT OF LOCATION #2062 IS # 0030
CONTENT OF LOCATION #2063 IS # 0035

```

(input of 4 characters finished). The message that the conditions have already been satisfied is issued (which will be checked before executing the CC and CV commands), so that the program is executed to the location where the initialization of it completed. Here again the command to halt is input when the contents of location M7+1 come to be zero and then the program is executed. As the the result, such a message is output that the conditions are satisfied after the input of hexadecimal date 'FFFB' of 4-byte form. It can be confirmed that the input data in the character format are stored in the form of hexadecimal numbers after reading the contents of the AC and PACK locations.

- (4) List 4 gives an example to confirm the state transition that the minus datum FFFB stored in the PACK location is converted to a form of 2's complement.

While the program is executed to location X'2021', the command to trace locations NEG7 to NEG7+6 (conversion subroutine to the 2's complement) is input. It can be confirmed below that the contents 'FFFB' of the PACK location comes to be 0005 and the minus code X'2D' is embedded in the BUFF location.

- (4) List 5 is an example to confirm that the converted data to the decimal numbers are stored in locations BUFF to BUFF+5 in the character format.

Such a command is input that executes the program till the time when embedding the character type decimal data to the BUFF is completed. It can be confirmed that the contents of locations BUFF to BUFF+5 are read and '-00005' is embedded.

- (6) Examples of the re-initialization setting, modify, step, and extract.

By making use of the I command, it is possible to execute the program again from its initial state at any arbitrary point of it. The program can

be executed by the input of the command to halt and by proceeding the stacking for the back trace use after the WORK location has been modified. At the state of input queue (due to the user program), when '8' is input, the message is output, which indicates that the read-in data X'38' has been stored in the WORK location. (See List 6.)

The following shows the results after executing 4 steps of the program

List 6.1.

```
#I
#SR PC X"2000"
#OM WORK
#PR
8
** I'VE MODIFIED THE SPECIFIED LOCATION. **
LOC IR AC EC CAR EA (EA)
200E 3A67 0038 00B8 1 2067 0000 => 0038
      200B 4A48 BAL WRTE **061 #2048
      200C 8809 SLL 009 #0009
      200D 8009 SRL 009 #0009
* 200E 3A67 ST WORK **089 #2067
      200F 1A69 S X40 **090 #2069
      2010 6864 KPA
      2011 4215 B **004 #2015
```

List 6.2.

```
#ST 4
#PR
** I'VE DONE THE NUMBER OF STEPS YOU ORDERED. **
LOC IR AC EC CAR EA (EA)
2015 0A67 0038 00B8 1 2067 0038
      2012 0A67 L WORK **085 #2067
      2013 1268 A **085 #2068
      2014 4216 B **002 #2016
* 2015 0A67 L WORK **082 #2067
      2016 880C SLL 012 #000C
      2017 800C SRL 012 #000C
      2018 3A5B ST HEXA **067 #205B
```

List 6.3.

```
#E WORK
#BR
LOC IR AC EC CAR EA (EA)
2009 7074 205E 00B8 0
      2009 7074 RTI C
      200C 8809 SLL 009 #0009
      200D 8009 SRL 009 #0009
      200E 3A67 ST WORK **089 #2067
```

while stacking.

The following gives the results obtained after extracting a series of instructions that affect the WORK location while restoring the program inversely from the X'2015' location.

The extract instruction halts at the time when restoring the transfer instruction that affects the specified location. Accordingly, this example shows that the contents of the AC, EC, and CAR were X'205E', X'00B8', and 0, respectively, before executing the RTI C instruction.

To edit mode by the F command that follows,

List 6.4.

```
#F
$$ TTY - EDITOR $$
```

4. Conclusion

Since the program used in the previous examples of debug processing is so much simple and required some hand manipulation of the user that the reduction of execution efficiency by the firmware monitor has not been found at all. Therefore, when a program that has no I/O instructions to compute the factorial of 1000 is carried out under the following three conditions, the execution time is as follows:

- (1) Execution by the HITAC-10—42.0 msec.
- (2) Execution by the emulator—420.1 msec.
- (3) Execution by the firmware monitor—2032.0 msec.

These figures indicate that the result by the firmware monitor introduced approximately 50 times of speed reduction composed with that by the hardware, but the principal cause of it is due to the low performance of the microprocessor mCOM-16 and also the lack of the hardware such as multiplication, division, shifter, or the like. The evaluation of the overhead by means of supplementing the debugging function should be composed with the usual emulator, where the speed reduction amounts to about 5 times. In fact when this system was operated, the processing time for debugging information at the user side has come to be extremely large, and thus the decrease in execution speed of the program in the minicomputer does not give much trouble to the user. The most essential factor is that the profitable debugging information is obtained and thus the modification and testing of the program can easily be carried out. This system provides a simple mode change, many edit functions as well as monitor ones, which have all used to accomplish the purpose of debugging from the standpoint of improving the overall performance of the system.

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An Interactive Debugging System Composed of a Minicomputer

Appendix

```

0000I
0800 0800G

////////////////////////////////////
/  CONVERT HEXADECIMAL TO DECIMAL  /
////////////////////////////////////

0000I
2000 2000G      ORG      X"2000"
2000 4A370      BGN     BAL      INIT
2001 52590      KCT     M7+1
2002 52590      KCT     M7+1
2003 52590      KCT     M7+1
2004 52660      KCT     ADR2
2005 6D000      READ   RIM      / READ HEXADECIMAL NUMBER
2006 70620      STI
2007 70610      KTI
2008 42070      B        *-1
2009 70740      RTI,C
200A 6C000      SIM
200B 4A480      BAL     WRTE    / ECHO BACK
200C 88090      SLL     9       / REMOVE PARITY
200D 80090      SRL     9
200E 3A670      ST      WORK
200F 1A690      S        X40    / A B C D E F ?
2010 68640      KPA
2011 42150      B        *-4
2012 0A670      L        WORK
2013 12680      A        WORK+1
2014 42160      B        *-2
2015 0A670      L        WORK
2016 880C0      SLL     12
2017 800C0      SRL     12     / REMOVE ZONE CODE
2018 3A5B0      ST      HEXA
2019 0A5C0      L        PACK
201A 88040      SLL     4
201B 325B0      O        HEXA
201C 3A5C0      ST      PACK    / STORE INTO ONE WORD
201D 52590      KCT     M7+1
201E 42050      B        READ
201F 68640      KPA
2020 4A510      BAL     NEGT    / WHEN NEGATIVE
2021 0A5A0      L        EQ
2022 4A480      BAL     WRTE    / PRINT CHAR. =
2023 4A3D0      BAL     CUHD
2024 27100      DC      10000
2025 4A3D0      BAL     CUHD
2026 03E80      DC      1000
2027 4A3D0      BAL     CUHD
2028 00640      DC      100
2029 4A3D0      BAL     CUHD
202A 000A0      DC      10
202B 4A3D0      BAL     CUHD
202C 00010      DC      1
202D 4A370      BAL     INIT
202E 0E660      L,I    ADR2
202F 4A480      BAL     WRTE    / PRINT DECIMAL NUMBER
2030 52660      KCT     ADR2
2031 52590      KCT     M7+1
2032 422E0      B        *-4
2033 6F000      HLT
2034 0A6B0      L        X20
2035 3A5E0      ST      BUFF
2036 42000      B        BGN

```

KEN'ICHI OKADA, TAIKI MATSUO and MISAO KITAGAWA

```

2037 00000 INIT DC / INITIALIZE
2038 0A580 L M7
2039 3A590 ST M7+1
203A 0A650 L ADR1
203B 3A660 ST ADR2
203C 46370 B , I *-5
/
203D 00000 CUHD DC / CONVERT
203E 88000 SLL
203F C25C0 LE PACK
2040 EE3D0 D , I *-3
2041 3A5C0 ST PACK / REMAINDER --> PACK
2042 A8000 SLDL
2043 125D0 A X30
2044 3E660 ST , I ADR2 / QUOTIENT --> (ADR2)
2045 52660 KCT ADR2
2046 523D0 KCT CUHD
2047 463D0 B , I CUHD
/
2048 00000 WRTE DC / PRINT ONE CHAR.
2049 6D000 RIM
204A 70860 WTO
204B 70810 KTO
204C 42480 B *-1
204D 70820 CTO
204E 6C000 SIM
204F 46480 B , I WRTE
/
2050 FFFF0 DC X"FFFF"
2051 00000 NEG1 DC
2052 2A500 X NEG1-1
2053 3A5C0 ST PACK
2054 525C0 KCT PACK / TWO'S COMPLEMENT
2055 0A6A0 L X2D
2056 3A5E0 ST BUFF
2057 46510 B , I NEG1
/
2058 FFF90 M7 DC -7
2059 0001K DS 1
205A 003D0 EQ DC C"="
205B 0001K HEXA DS 1
205C 00000 PACK DC
205D 00320 X30 DC X"30"
205E 00200 BUFF DC X"20"
205F 0005K DS 5
2064 000A0 DC X"0A"
2065 205E0 ADR1 DC BUFF
2066 0001K ADR2 DS 1
2067 0001K WORK DS 1
2068 00090 DC 9
2069 00400 X40 DC X"40"
206A 002D0 X20 DC X"2D" / MINUS -
206B 00200 X20 DC X"20" / SPACE
F352I
00B9 00B90
00B9 3FC00
00BA 3FC00
7F00I
009F 009FG
009F 00000
0000I
2000H END BGN

```