Microprogramming in psychology

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This paper describes the concept of application microprogramming. The major areas discussed are a definition of microprogramming, the invocation of microprograms from ordinary programming languages, the development cycle of a microprogram from initial design to final implementation, and the data processing tasks suitable for microprogramming. A calculation of "variance" with and without microcode enhancement is used for demonstration.

DEFINITION OF MICROPROGRAMMING

The application-oriented definition of microprogramming is the addition of customized instructions to a CPU so as to achieve reduced execution time and/or special capabilities. Information on the history and more theoretical aspects of microprogramming may be found in Husson (1970).

As an illustration of this definition, and of the power of microprogramming, consider the problem of calculating the variance of data. Ordinarily, this calculation is performed by executing a long series of assembler instructions, some of which are for general arithmetic calculations, none of which are specifically for calculating variance. By designing a customized assembler instruction to calculate variance (i.e., writing a variance calculating microprogram), the CPU is altered from a general purpose computer to one specifically "designed" to calculate variance. This variance programming problem is used as an example throughout the paper. The speed and facilities advantages of customized instructions (i.e., microprograms) over ordinary assembler instructions are due to the following: (1) Reduction of memory fetches required. (2) The per instruction execution time advantage of a microinstruction. (Microinstructions typically execute 5 to 10 times faster than assembler instructions.) (3) The greater number of registers available at the microcode level. (4) The greater number of arithmetic and logical operations available at the microcode level.

It should be noted that microcode execution is performed at the most basic level of computation and therefore precludes all interrupt processing. To avoid losing interrupts, a periodic check must be made (in the microcode) with interrupt servicing at appropriate condition detection.

INVOCATION OF MICROPROGRAMS FROM ORDINARY PROGRAMMING LANGUAGES

Suppose one were to code a Fortran WRITE statement. The Fortran compiler would generate a series of assembler instructions to perform the WRITE function.

These assembler instructions reside in, and execute out of, main memory. In a microprogrammed CPU, each assembler instruction invokes a series of microinstructions that reside in, and execute out of, control store. This, then, is the hierarchy in a microprogrammed CPU: high-level language to assembler language to microcode.

Figure 1 illustrates this fundamental hardware architectural innovation. In conventional computer design, the control store module is either not present or it is inaccessible. To access a user written microprogram from an assembler language program, a machine language operation code is selected that will "map" to the control store area containing the desired microprogram.

Figure 1.

To access a user written microprogram from Fortran (i.e., any high-level language), a CALL is coded which results in generation of an assembler jump-to-subroutine instruction. Ordinarily, execution of the CALL invokes a software subroutine that performs some desired function. Instead, a short "swap" routine is substituted for the software subroutine. The swap routine replaces the jump-to-subroutine assembler instruction with the machine language operation code necessary to "map" to the control store area containing the desired microprogram. The swap routine then jumps to this machine language operation code, thereby causing execution of the microprogram (see Figure 2). Note that after the initial swap, the microprogram executes directly without any further swap routine overhead.

DEVELOPMENT CYCLE OF A MICROPROGRAM FROM INITIAL DESIGN TO INITIAL IMPLEMENTATION

After selecting the part or parts of programs to be microcoded and writing the microcode, the microprogram is microassembled and loaded into a dynamically modifiable section of control store known as WCS (Writable Control Store). Use of WCS to check out and debug microcode is invariably desirable. It is also desirable to use the facilities of an editor specifically designed to load WCS and monitor microcode execution. For example, Hewlett-Packard has a standard piece of software known as MDE (Micro Debug Editor) which serves this purpose.

Figure 2.

Figure 3.

After the microprogram is checked out and operational, one decision remains; should the microprogram be kept in WCS or should it be permanently fixed in a nonmodifiable section of control store, i.e., a PROM (Programmable Read Only Memory)? The advantages of keeping the microprograms in WCS are: (1) WCS may be re-used for many microprograms for many different users. (2) A user may dynamically alter WCS to suit his several application requirements.

The disadvantages of keeping microprograms in WCS are: (1) If power is removed from WCS, the microprograms are lost and must be reloaded. (2) Microprograms in WCS can be destroyed by errant user programs. The advantage of PROM chips is that the microprograms are permanently part of the CPU. The disadvantage of PROM chips is that, if microprograms are updated, new PROM chips must be burned.

PROMs are available for standard applications, such as floating point mathematics, and Fortran code execution.

It shall be noted that selection of what to microcode is extremely important and is not necessarily a trivial task. Three techniques are: (1) Attaching program

analysis devices to the CPU—most accurate and most expensive. (2) Running program analysis programs on the CPU almost as accurate and considerably cheaper than hardware program analysis devices. (3) Manual periodic halting of the CPU, noting the program counter, and compiling an activity profile—tedious, but minimal material cost. The Hewlett-Packard solution is a program known as ACP (Activity Profile Generator) which programmatically compiles an activity profile representing the percentage of time spent in user specified areas-to-be-analyzed (i.e., blocks of memory). The activity profile is correlated to the programs in these blocks of memory by means of program load maps generated during standard operating system loader procedures. This procedure is shown in Figure 4.

DATA PROCESSING TASKS SUITABLE FOR MICROPROGRAMMING

Any iterative CPU tasks are prime candidates for microcode. A few examples are: (1) statistical analysis—variance, standard deviation, correlation, . . . ; (2) trans-

MAIN PROGRAM

```

0001   PTH,L,M
0002   PROGRAM PSYCH
0003   DIMENSION K(500)
0004   C
0005   C INITIALIZE N & K'S
0006   100 READ (1,*) N,IREPS
0007   DO 10 I=1,N
0008   10 K(I) = I - N/4
0009   C
0010   C START ACTIVITY PROFILE GENERATION
0011   CALL ACP
0012   C
0013   C CALCULATE VARIANCE
0014   DO 20 I=1,IREPS
0015   20 CALL VRNCE (N, K, IANS)
0016   C
0017   C END ACTIVITY PROFILE GENERATION
0018   CALL ACPO
0019   C
0020   C DISPLAY VARIANCE
0021   WRITE (1,1) IANS
0022   1 FORMAT (/," VARIANCE = ",I6,/)
0023   GO TO 100
0024   FND

```

** NO ERRORS**   PROGRAM = 00590   COMMON = 00000

LOAD MAP

RELOCATING LOADER

NAME	PROG ROUNDS	BP ROUNDS

PSYCH		
*PSYCH	14000	
*BAU.	15116	00560
*MPY	15116	
*DIV	15123	
*DLD	15130	
*DST	15135	
*FMTIO	15166	00565
*RIO.	15432	
*RIO.	15420	
*RIO.	15447	
*IAY.	15605	
*RAY.	15636	
*IAY.	15647	
*DIO.	15755	
*BIO.	16050	
*IOI.	15555	
*IOR.	15514	
*IAR.	15702	
*RAR.	15660	
*DMA.	16136	
*NEWIO	16066	
*OLDIO	16073	
*CIRIO	16417	00663
*CIRIO	16417	
*ACP	16422	00663
*ACP	16426	
*ACPO	16652	
*ACPTN	17122	
*VRNCE	17214	00666
*VRNCE	17217	
*DUMRX	17326	00666
*SLIBR	17326	
*SLIBX	17353	
*FLUN	17406	00666
*FLUN	17406	
*FLIB	17427	00667
*FLIB	17427	
*EAD	17436	
	17445	

COARSE ANALYSIS

CONSOLE RUN SHEET

```

50,5000
LOWER ADDRESS OF RANGE (OCTAL)? 14000
RESOLUTION (WORDS, DECIMAL)? 123
DEVICE SELECT CODE (OCTAL)? 12

```

VARIANCE = 208

ACTIVITY PROFILE

ADDRESS	NUMBER	FREQ	CUMULATIVE
BELOW RANGE	0	.0%	.0%
15000-15177B	49	.2%	.2%
17200-17377B	21312	96.5%	96.8%
23200-23377B	714	3.2%	100.0%
ABOVE RANGE	0	.0%	100.0%

TOTAL: 22075

FINE ANALYSIS

CONSOLE RUN SHEET

```

50,5000
LOWER ADDRESS OF RANGE (OCTAL)? 17200
RESOLUTION (WORDS, DECIMAL)? 16
DEVICE SELECT CODE (OCTAL)? 12

```

VARIANCE = 208

ACTIVITY PROFILE

ADDRESS	NUMBER	FREQ	CUMULATIVE
BELOW RANGE	0	.0%	.0%
17220-17237B	5907	26.8%	26.8%
17240-17257B	2831	12.0%	39.6%
17260-17277B	10637	48.2%	87.8%
17300-17317B	1761	8.0%	95.8%
17340-17357B	274	1.2%	97.1%
17360-17377B	44	.2%	97.3%
ABOVE RANGE	606	2.7%	100.0%

TOTAL: 22060

Figure 4.

cidental functions—sine, cosine, tangent, square root, . . . ; (3) table search—linear, binary, link-list, . . . ; (4) sort—bubble, shell, radix-interchange, . . . ; (5) FFT (Fast Fourier Transform). Data gathering functions including (1) pseudo-DMA I/O and (2) privileged I/O are also highly suitable for microcode enhancements. Cold start and special loaders should be considered.

Typical improvements realized through microcode en-

hancement vary depending on the CPU; for Hewlett-Packard's 21MX, 5 : 1 speed reductions are typical.

Statements of CPU tasks in algorithm form (i.e., microcodable form) may be found in many references, for example:

Hart, J. F., et al. *Computer approximations*. New York: Wiley, 1968.

Knuth, D. E. *The art of computer programming* (3

vols.). Reading, Massachusetts: Addison-Wesley, 1968-1973.

The Association for Computing Machinery, Inc. All publications. Address: 1133 Avenue of the Americas, New York, New York 10036.

The Institute of Electrical and Electronics Engineers, Inc. All publications. Address: 345 East 47th Street, New York, New York 10017.

CALCULATION OF "VARIANCE" WITH AND WITHOUT MICROCODE ENHANCEMENT

Variance, $(\text{summation } (K-KAVG)^2)/N$, is typical of the types of functions that may be profitably micro-coded. Using a Fortran subroutine to calculate variance of integer data, run time for 50 data points (5,000 repetitions) was 25 sec. Substituting microcode for the variance subroutine, the run time was reduced to 5 sec. In another calculation, 500 data points were used and

the result of the integer calculation performed in the Fortran subroutine was incorrect as the intermediate sums exceeded the integer maximum capacity. However, the microcode routine, being specifically designed to handle double-integer intermediate sums, correctly calculated the variance.

Thus, by using microcode, a customized instruction (variance calculation) achieving reduced execution time (25 sec to 5 sec total run time) and special capability (integer calculations requiring intermediate results $> 32K$) has been developed. Those interested in learning more about microprogramming may attend Hewlett-Packard's 5-day course, given monthly at Cupertino, California.

REFERENCE

HUSSON, S. S. *Microprogramming Principles and practices*. Englewood Cliffs, New Jersey: Prentice-Hall, 1970.