Micromanaging time: Measuring and controlling timing errors in computer-controlled experiments

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Computer-controlled experiments present a number of potential sources of error in timing the presentation of events, including video refresh rate, keyboard scanning rate, and disk I/O times. A terminate-and-stay-resident routine implementing multiple millisecond-accuracy timers is presented. Interfaces permitting use of the timer with several higher level languages (C, FORTRAN, Pascal, and QuickBASIC) are described, as is a design for a two- to four-button response system using the computer's printer port. A general strategy is described for using multiple timers to control and measure variation in critical experimental events. A C language program is provided to benchmark variation in the time required to perform common experimental tasks (screen refreshing, switching video pages, disk I/O, loop calculations), and results are summarized for several representative computers that use the IBM design.

Since at least the time of Donders (1868/1969), a standard psychological procedure has involved presenting subjects with visual stimuli and measuring the time they take to produce some response. The advent of microcomputers has greatly facilitated studies based on this general paradigm, but it has also introduced a number of potential errors in timing the events that are under experimental control.

The term *micromanagement* (LeMay, Lerner, & Taylor, 1988) was coined in the 1970s (Barnhart, 1984) to refer to the detailed planning of local operations by a central executive, a practice that can have the consequence of leaving little room for local initiative. Using personal computers to obtain precise timing of events requires a sort of micromanagement, in which the timing of events is not affected by ongoing computational processes. The present paper describes: (1) sources of timing errors in computer-controlled experiments, (2) an implementation of millisecond-level timing that is both flexible and modular, (3) a strategy for using the timing routine to measure and minimize timing errors, and (4) a benchmark program for comparing the performance of experimentally relevant tasks on different IBM PC computers.

Sources of Timing Errors

Where timing errors are constant across trials, they may be of little experimental significance, although variations in stimulus onset asynchrony (SOA) in priming experi-

ments of as little as 100 msec can be of theoretical importance (Posner, 1978).

Time to generate stimuli. The largest timing errors result from ignoring the time required to generate complex experimental stimuli. Preparing a visual display on an IBM AT can easily take several hundred milliseconds. This error is likely to be constant across trials, but it is large enough to affect the meaning of SOAs.

Video refresh rate. Computer displays are changed by a cyclical process in which each horizontal line is updated in turn. The mechanics of screen updating pose problems for presenting a new stimulus at a predetermined time (Paredes, Miller, & Creeger, 1990). In particular, failure to start timing when the stimulus is actually presented (immediately following vertical retraces) can result in maximum timing errors equal to the screen refresh interval (16.7 msec on an EGA display). One solution to the problem of synchronizing stimulus presentation to screen refreshes is to draw the stimulus during the interval (about 1.7 msec on an EGA) when vertical retracing occurs (Dlhopolsky, 1989). For stimuli too complicated to be created in 1.7 msec, this problem can be minimized by writing stimulus information to an invisible graphics "page" and then making that page visible in synchrony with the start of the next screen refresh cycle. The PSYBENCH program takes advantage of this technique, which is described in detail in Paredes, Miller, and Creeger (1990).

Disk I/O. The time required to read and write information to a hard disk depends on the arrangement of data on the disk. The operating system (MS-DOS) assigns data to physical disk locations; it frequently breaks up files and writes sectors wherever space is available. As the results of the benchmark testing reported below indicate, disk I/O results in the largest source of variable error of those described in this section. Careful program design usually

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allows disk-intensive operations to be performed during portions of the experiment that are not time-critical.

Keyboard and button I/O. IBM PCs and compatibles use a scanned matrix keyboard with a serial data connection from the keyboard to the computer. Scanning the entire keyboard takes 8 msec, which results in a variable error of ± 4 msec in measured response times and a negative bias of at least 9.2 msec in recorded times (keyboard scanning time plus a constant transmission time of 1.2 msec). Graves and Bradley (1987) tested an IBM PC keyboard and reported a mean error of 18.3 msec, with a standard deviation of 4.3 msec.

In contrast to the keyboard, the state of the parallel port can be read directly by the PC without the concomitant scanning and transmission delays. Thus a more accurate measure of subjects' response times can be obtained using switches connected to a parallel port. When four or fewer switches are required, a PC-compatible printer port can provide the necessary interface. A schematic diagram for a simple switch box for use with a printer port is presented in Figure 1. The switches are debounced using simple resistor-capacitor integrators. This form of debouncing results in a constant negative bias of 7 msec in recorded times. A four-button version is presented; versions with two or three buttons can be constructed by simply ignoring the portion of the diagram connecting to pins 17 (for three buttons) or 16 and 17 (for two buttons) of the printer port.

Figure 1. Schematic diagram for a general-purpose response switch that can be used to connect up to four response buttons to the printer port of an IBM PC computer. The switch features built-in debouncing of button presses, and it may be used with a variety of actual buttons or other devices.

TIMER.COM: A Flexible, Transparent Implementation of Multiple Millisecond Timers

PC-family computers use a 16-bit counter (one third of an Intel 8253/8254 timer chip or an equivalent custom circuit) to generate hardware interrupts at a constant rate. The counter is loaded with a known value and allowed to count down at a fixed rate. When the count reaches 0, a hardware interrupt is issued and the counter reloads itself to repeat the process. In order to maintain constant timing independent of processing speed, all PC computer timers count at 1.190 MHz. Normally, the timer interrupt is used by DOS to schedule time-dependent tasks—typically, updating the time-of-day clock and controlling floppy disk drive motor shutoff. PC BIOS timer routines use a timer value of 65536, the maximum value that can be stored in a 16-bit counter. This provides an interrupt rate of 55.2 msec.

TIMER is an assembly-language program that implements a number of useful timing functions on IBM PC computers (see Listing 1). It is a terminate-but-stay-resident (TSR) program. The software interface to TIMER uses the DOS function call mechanism; thus TIMER can be used with any high-level language that can generate system calls.

TIMER increases the timer interrupt rate to one per millisecond by decreasing the value loaded into the timer chip from 65536 to 1193. Allowing the operating system timer interrupt service routine (ISR) to run at the increased rate would affect the other time-dependent operations described above, which assume that timer interrupts will occur at the standard rate. TIMER solves this problem by emulating the standard timer interrupt. It passes control to the operating system timer ISR at nearly the expected rate (55 vs. 55.2 msec).

Running TIMER.COM from the DOS prompt installs TIMER's resident code and inserts its ISRs in the system timer and DOS function interrupt chains. The resident portion of TIMER occupies approximately 1K of memory. For most high-level languages, access to TIMER is easiest and fastest using a language-specific assembly-language interface module, which translates function calls from the calling convention of the high-level language into the format required by TIMER.

TIMER implements five timers with 1-msec resolution. Two are general-purpose 32-bit timers; two implement periodic repeating interval functions (such as A/D conversion at a regular rate); and one provides timing for parallel-port connected switches and for programmed pauses. Each can be started and read independently. TIMER and its interface modules provide the following: (1) the ability to start and stop TIMER completely; (2) access to two independent, 32-bit millisecond timers, whose maximum timable period is about 2.3 million seconds; (3) repeating interval timers, which are used to schedule regularly repeating events; (4) the ability to measure response time using switches attached to a printer

port; and (5) programmed pauses of specified duration. These functions have proved to be adequate for a variety of experimental tasks in our laboratory, including running standard chronometric and semantic priming experiments and managing external devices such as videotape controllers.

Interface modules have been developed for five widely used programming languages. Listings 2-5 present interface modules and corresponding function-definition files for use with Microsoft C, Microsoft FORTRAN, Microsoft QuickBASIC, and Borland Turbo Pascal.¹ All but the Turbo Pascal interface, which is written in Turbo Pascal, are written in assembly language.

Comparison with previous programs. A number of approaches to obtaining millisecond resolution timing on IBM PC computers have been described previously. Some approaches require additional hardware (Segalowitz, 1987, 1988). Crosbie (1989) has described a very different approach, based on directly reading the value of the latched timer, which could theoretically produce timing to accuracies of about a microsecond. For most purposes, timing resolution of 1 msec is a reasonable standard that avoids the added complexity of dealing with large values and inconvenient units of time.

The strategy of reprogramming the system timer to produce millisecond-level interrupts has been described previously. Several programs exist that reprogram the timing interrupts as TIMER does, but they do not pass the expected 55-msec interrupt back to the operating system (Bührer, Sparrer, & Weitkunat, 1987; Dlhopsky, 1988; Graves & Bradley, 1987, 1988). This can cause difficulties for other routines that expect timing interrupts to occur at the standard rate (e.g., this interrupt is used to turn off power to the floppy disk drive's motor after read/write operations), as well as cause unnecessary processing to occur. The entire DOS timer ISR is executed every millisecond rather than every 55 msec. TIMER overcomes these problems by limiting the processing that occurs each millisecond, and by passing control to the operating system ISR at the expected interval. Previous timing programs have also tended to be language-specific, to BASIC (Bührer, Sparrer, & Weitkunat, 1987; Graves & Bradley, 1987, 1988), Turbo Pascal (Crosbie, 1989), or C (Dlhopsky, 1988). TIMER's design allows it to be readily used with any language that can call operating system services, either through an assembly-language routine or by using facilities native to the language itself. TIMER's TSR design allows it to be isolated from the user's program. Because it is nearly impossible for the higher level program to disrupt TIMER, timing functions and system integrity are not vulnerable to bugs in user programs.

In the remainder of the paper, we will describe two uses of TIMER. The first involves a strategy for measuring and minimizing errors in the timing of events that takes advantage of the availability of multiple timers. The second consists of a benchmark program for measuring the time a given computer takes for performing a variety of tasks relevant to controlling psychological experiments,

and reports results for a number of different computers using the basic IBM PC design.

A Strategy for Measuring and Minimizing Timing Errors

Experimental tasks, particularly those involving small intervals between the presentation of successive stimuli (SOAs), consist of both stimulus processing tasks that must be accomplished and intervals that must be timed. Often both must be accomplished at the same time, and the experimenter must adjust time intervals to take into account time required to generate stimuli. Listing 6 presents an example of how one might accomplish this, using TIMER from a higher level language. The example program, MICROMAN.C, is written in C, although the same strategy could be used with other higher level languages. The basic procedure involves (1) starting both timers; (2) performing some work in preparing a stimulus display; (3) reading the first timer; (4) waiting for an interval that represents the best estimate of the remaining time to stimulus display [(desired interval) - (elapsed time) - (screen refresh interval)/2]; (5) presenting the stimulus on the next screen refresh; and (6) recording the actual elapsed time by reading the second timer.

The last step—recording the actual elapsed time—may seem redundant, and in most cases it will prove to be so. It is a simple and useful precaution, however, which can be used to provide better control over the interval used in Step 4 above if this is desired. The screen refresh rate imposes limits on the values that can be used for SOAs. In the worst case, in which the total elapsed time is within the range of variation of screen retraces, it is possible that the actual SOA will vary by one screen refresh interval (16.7 msec on PC ATs with EGA graphics). The interval used in Step 4 can be adjusted to eliminate any problem of synchronization between SOAs and screen refresh times. Because of the limitations imposed by screen refresh rates, actual SOAs will vary by as much as one refresh interval from the nominal rate imposed by the experimenter. Recording this rate will reveal if there is any problem of variation in SOAs across trials, as discussed above, and will indicate what the constant error is between desired and actual SOA.

MICROMAN.C introduces a random variation of 100 msec in the interval between presentation of successive screens, then uses TIMER to adjust for this variation. In 100 trials on an 8-MHz IBM AT, with a desired SOA of 300 msec, the actual SOA varied from 299 to 300 msec. The same test on a PS/2 Model 80 produced a consistent SOA of 304 msec.

PSYBENCH: A Benchmark Program for Experimentally Relevant Processes

The second application of TIMER described here is a C program, PSYBENCH.C, which measures the time required to perform a number of tasks relevant to present computer-controlled experiments. These are: (1) loop computation (a basic measure of integer processing speed,

Table 1
PsyBench Results for a Variety of Computers Based on the IBM PC Design

Computer	Processor	Clock Speed (MHz)	SI (Norton) (PC-units)	Loop Computation		Screen Refresh Interval		Screen Drawing		Writing File		Reading File	
				Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
<i>8088-based</i>													
IBM PC-XT	8088	4.77	1.0	637.0	630-644	16.8	16-17	974.9	971-987	3097.4	3007-3136	2902.0	2868-2921
<i>80286-based</i>													
IBM PC-AT	80286	6	7.4-7.5	170.8	170-171	16.8	16-17	857.9	857-858	898.0	814-937	815.8	808-828
IBM PC-AT	80286	8	8.3-8.4	158.8	158-159	16.7	16-17	796.0	796-797	854.4	802-909	740.0	733-747
IBM PC-AT	80286	10	10.4-10.5	125.7	125-126	16.8	16-17	633.9	633-634	612.0	601-657	624.9	617-633
IBM PS/2 mod 50	80286	10	10.7	126.9	126-127	14.3	14-15	591.7	591-592	784.3	772-863	655.2	645-661
<i>80386-based</i>													
IBM PS/2 mod 80	80386	16	15.4-15.5	52.0	51-53	14.3	14-15	402.2	401-403	507.0	423-549	385.8	375-393
Compaq 386-20	80386	20	24.2-24.3	34.4	34-35	16.8	16-17	404.6	404-405	258.0	246-312	180.2	167-189
Identity 386-25	80386	25	28.9-30.1	27.4	27-28	16.8	16-17	353.2	353-354	148.4	140-155	146.0	143-150

Note—All units are milliseconds, except where noted, and are based on tasks timed to the nearest 1 msec.

Description of tasks:

SI: System information program from Norton (1988). Units are multiples of the computation power of the original IBM PC. (Results from 20 trials.)

Loop computation: Sieve of Eratosthenes algorithm to determine all primes < 16,381. (Results from 200 trials.)

Screen refresh interval: Time between successive vertical retraces. (Results from 100 trials.)

Screen drawing: Drawing a full-screen multicolor pattern resembling a mountain scene using ellipses and polygons. (Results from 20 trials.)

Writing file: Writing 1,000 lines each containing one integer. (Results from 20 trials.)

Reading file: Reading the file described above (1,000 lines containing one integer each). (Results from 20 trials.)

using the sieve of Eratosthenes procedure for finding prime numbers, with code from Gilbreath and Gilbreath (1983); (2) screen retrace interval (interval between successive screen retraces); (3) stimulus generation (time to generate a variety of graphics screens varying in complexity); and (4) file I/O (time to read and write standard files). PSYBENCH is presented in Listing 7. It requires an IBM PC computer (including most clones) supporting EGA graphics (including VGA graphics devices and a number of other systems that emulate EGA graphics). PSYBENCH has two main uses. First, it can ensure that a particular computer can perform these tasks with reasonable speed and reliability, which may be important in selecting a computer for experimental use. Second, it provides a meaningful benchmark of the time a particular computer requires relative to others in performing the kinds of tasks required for running psychological experiments. PSYBENCH results for a number of computer systems available at the Psychology Department of the University of Texas are presented in Table 1. All computers were running MS-DOS Version 3.3. For purposes of comparison, results from the system information program (SI.COM) from Version 4.5 of the Advanced Edition of the Norton utilities (Norton, 1988) are presented. This is comparable to the loop routine in PSYBENCH in being a measure of basic processing speed, but note that SI provides a speed index rather than a time measurement. PSYBENCH prints out additional information about specific subtasks; these results are provided with the program.

Results from running PSYBENCH on a number of different computers show that in general the tasks assessed vary substantially between different systems, but that they tend to be reliable to within measurable limits ($\pm .5$ msec) on any particular computer. The obvious exception to this result concerns disk I/O. This is not very surprising, given the flexibility with which data sectors can be assigned to physical disk locations in PC-compatible computers. It is worth noting as a general point that although these benchmark tasks are similar to tasks used in many psychological experiments, these results might not be predictive for any given experimental program and computer. This is particularly true for the file I/O results, which can be greatly affected by the overall state and capacity of the disk at the time that I/O occurs.

IBM PC computers have become a ubiquitous tool for experimental psychologists. The design of these devices causes problems for experimenters desiring to control the presentation of experimental events accurately, but they are also designed such that it is possible to measure and minimize discrepancies between desired and actual times of these events. The capacity of computers sharing this general design has also evolved substantially (as the results in Table 1 demonstrate). Strategies for ensuring comparability of the timing of experimentally important events

across computers differing in speed and capability will become, if anything, more critical over time.

Program Availability

A disk containing source and executable versions of the programs described here, additional documentation for TIMER and more detailed benchmark results can be obtained by sending a check for \$15 to Kevin F. Miller. A version of TIMER that works with Microsoft Windows will also be included upon request. Please specify disk format (3.5 or 5.25 in.). Individuals who have access to electronic mail can receive copies from Kevin F. Miller at kmiller@emx.utexas.edu or PSHU654@UTA3081.

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NOTE

1. Interface modules for IBM Professional FORTRAN and IBM/Microsoft Pascal are not presented, but are included with the other modules on the disk available from the authors.

Listing 1: TIMER.asm

Comment /*

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This Program may be distributed with out charge for any no-profit use
 but may not be sold.

No Warranty, expressed or implied applies to this program.

Timer is accessed using Dos function calls. Parameters and return values are passed to Timer by Language interface routines. These routines are supplied as object modules and are linked with the user code. Executing Timer.Com installs Timer code, inserts the timer service routine and Timer's timer action interrupt service routine into their respective interrupt chains. The resident portion of timer occupies about 1.2 kbytes of memory. When active (no timers enabled), the timer action interrupt service routine consumes about 5% of cpu time on a stock AT. The language interface routines and the timer service interrupt service routine use the following parameter passing convention:

AH = Extended Dos Timer Function code (0f0 hex).
 AL = Call: Timer function number.
 Return: Characters or switch numbers.
 BX = Timer values sent and returned.
 CX = Call: Device number.
 Return: Error Code
 DX = High order word for 32 bit time values.

Timer provides the following function groups and functions:

TIMER CONTROL FUNCTIONS:

START, function number 1

Activates the Timer's Interrupt Service Routine and sets the system clock interrupt period to 1 mS. Setup must be called before any other timing routines are used.
 Parameters: none.
 Return: none.

STOP, function number 2

Undoes what start does. Restores the system timing routines to normal. This routine should be called before the program exits or the system time be somewhat inaccurate.
 Parameters: none.
 Return: none.

ACKNOWLEDGE, function number 3

Timer uses this function to determine whether it has already been installed.
 Returns Offh in AL, 0 in AH.

REPEATING INTERVAL TIMER (Type 2 Timer) FUNCTIONS:

DINIT, function number 4

Start a repeating timed period and return. Two timers are available, 1 and 2.
 Parameters: Device selected in CX, Time in BX
 Return : illegal device returns 2 in cx.

WAIT, function number 5

Holds execution until the end of the next repeating interval of a Type 2 timer.
 Parameters: CX = device number.

Listing 1 (Continued)

Return: Error 2, bad device number, error 3, selected delay timer has not been initialized by dinit, error 8 wait over-run.

REPORT_FLAG, function number 6

Get a Type 2 timer's event flag, I.E. has the next interval elapsed or not.

Parameters: CX = device number.

Return : 16 bit logical flag in dx, same errors as function WAIT.

CONTINUOUS TIMER (Type 1 Timer) FUNCTIONS:

START_T, function number 7

Initializes a 32 bit timer, clears the timer and resets the overflow flag.

Parameters: Device number in CX.

Returns: Error on illegal timer number.

TIMER, function number 8

Returns the present value of the specified 32 bit timer.

Parameters: Device number in CX.

Returns a 32 bit integer time value in DX:BX. Errors, bad timer number and timer overflow.

ASSORTED TIMING FUNCTIONS

STIME, function number 9

Measure response time to a switch press. Switches are attached to a printer port.

Parameters: Time-out value in BX.

Returns : response time in BX, switch number in al. Cx = 4 means no switch press was detected (Timed out).

PAUSE, function number 10

Function: Delay for the time specified in parameter.

Parameters: Delay, in BX, time to wait in milliseconds.

Return: none.

SET_SWITCH_PORT, function number 11

Select the printer port used by stime (LPT1 - LPT3). The default port is LPT1.

Parameters : Cx is set to LPT# (1-3 allowed).

Returns : Error 2, illegal port #, error 9, requested port not installed.

TIMER ERROR RETURNS:

The following error are reported:

cx = 1, Timer not installed. This error code is returned by the interface routine. Timer returns AH = 0. The interface routine detects AH = 0 returns the error code.

cx = 2, invalid device error

cx = 3, wait, call to un initialized timer.

cx = 4, stime timed out

cx = 5, timer overflow

cx = 6, bad function number

cx = 7, Timer not started

cx = 8, wait over-run.

cx = 9, bad device number in call to set_switch_port.

end of comment */

Listing 1 (Continued)

```

;-----

; Con_string displays a string to the console, using dos function 9

con_string macro string
    mov     dx, offset string
    mov     ah, 9
    int     21h
endm

;-----

set_vect macro int_no, old_vect, service
    mov     al, int_no
    mov     ah, 35h
    int     21h
    mov     word ptr old_vect, bx
    mov     word ptr old_vect[2], es
    mov     dx, offset service
    mov     al, int_no
    mov     ah, 25h
    int     21h
endm

;-----

; this macro tests the device number in the CL register. If
; it is neither 1 or 2, cx loaded with 2, the bad device error code
; and the carry flag is set.
; if the device number is valid the offset of either the 1st or 2nd
; is loaded into the SI register, the carry flag and the CX register
; are cleared.

GetDevData macro data1, data2
    local dev_bad, do_2, get_end

    cmp     cl, 2
    jg      dev_bad
    cmp     cl, 1
    jl      dev_bad

    jne     do_2
    mov     si, offset data1
    cld
    xor     cx, cx                ; clear the error return
    jmp     short get_end
do_2:
    mov     si, offset data2
    cld
    xor     cx, cx                ; clear the error return
    jmp     short get_end
dev_bad:
    mov     cx, 2                ; 2 = invalid device error code
    stc
get_end:
endm

```


Listing 1 (Continued)

```

;-----
    true    equ        1
    false   equ        0
    num_functions equ    11
    cr      equ        0dH
    lf      equ        0ah

;-----
;   Timer Data Structures

delay  struc                      ; Type 2 timers
    val          dw      ?
    count        dw      ?
    flag         db      false
    late_flag    db      false
    initd       db      false
delay  ends

clock  struc                      ; Type 1 timers
    time         dd      ?
    ovfl_flag    db      false
clock  ends

code   segment public 'code'
    assume cs: code, ds: code
    org 100h

Entry: jmp Initialize

;   permanent data area.
    timer_running db      false
    delay_1      delay <>          ; type 2 timers
    delay_2      delay <>
    timer_1      clock <>          ; type 1 timers
    timer_2      clock <>
    up_count     dw      ?          ; pause and stime
    clock_count  db      ?          ; down counter for sys clock
    old_timer_vector dd      ?
    old_dos_vector dd      ?
    port         dw      ?

;   function dispatcher jump address table
even
jump_table  dw      ?              ; blank address, no function #0
            dw      offset START
            dw      offset STOP
            dw      offset ACKNOWLEDGE
            dw      offset DINIT
            dw      offset _WAIT
            dw      offset REPORT_FLAG
            dw      offset START_T
            dw      offset TIMER
            dw      offset STIME
            dw      offset PAUSE
            dw      offset set_switch_port

```

Listing 1 (Continued)

```

;*****
;      Timer Function Dispatcher
;*****

;   This routine intercepts all dos function calls. Calls to Timer
;   calls are directed to the timer code, normal system calls are
;   passed on.

Service:
    sti
    pushf
    cmp     ah, 0f0h
    je      Start_service      ; timer function, do it.
    popf                    ; not timer function, pass it on.
    assume  ds:nothing
    jmp     old_dos_vector
    assume  cs: code, ds: code

Start_service:
    popf
    push    si
    push    di
    push    es
    push    ds
    push    cs
    pop     ds

    cmp     al, 1              ; no timer not running error
    je      ok                 ; when starting the timers (funct 1)
    jl      error_exit         ; function less than 1 illegal
    cmp     timer_running, true
    je      ok
    mov     cx, 7
    jmp     exit

OK:      cmp     al, num_functions
    jg      error_exit         ; illegal function number
    shl     al, 1              ; fun. num times 2 for word offset
    push    ax
    cbw
    mov     si, ax
    pop     ax
    call    jump_table[si]     ; jump to function

exit:    mov     ah, 0          ; indicates Timer installed.
    pop     ds
    pop     es
    pop     di
    pop     si
    iret

error_exit:
    mov     cx, 6              ; bad function number
    jmp     exit

```

Listing 1 (Continued)

```

;*****
; Timer Action Interrupt Service Routine
;*****
;
; This routine, manages all Timer actions which happen in response to
; the system timer interrupt. It updates any virtual timers that are
; enabled. When Timer is enabled, the clock interrupt rate is
; raised to 1 mS. When this is done, this routine passed control to the
; existing Timer interrupt service routine 1 time in 55, thus maintaining the
; proper system clock interrupt rate.

ISR:
    sti                ; re-enable interrupts
    push    ax         ; save and setup
    push    ds
    mov     ax, cs
    mov     ds, ax
    cmp     timer_running, true
    je      running
    jmp     inactive_exit

running:
    inc     up_count           ; up counter for stime and pause
    inc     word ptr timer_1.time ; type 1 timers
    jnz     do_timer_2
    inc     word ptr timer_1.time + 2
    jnz     do_timer_2
    mov     timer_1.ovfl_flag, true

do_timer_2:
    inc     word ptr timer_2.time ; timer 2
    jnz     end_timer
    inc     word ptr timer_2.time + 2
    jnz     end_timer
    mov     timer_2.ovfl_flag, true

end_timer:
    cmp     delay_1.initied, true ; type 2timers
    jne     d_2
    cmp     delay_1.flag, true
    jne     not_late
    mov     delay_1.late_flag, true

not_late:
    dec     delay_1.count
    jnz     d_2
    mov     ax, delay_1.val ; reload
    mov     delay_1.count, ax
    mov     delay_1.flag, true ; set event flag (fortran true)

d_2:
    cmp     delay_2.initied, true
    jne     end_delay
    cmp     delay_2. flag, true
    jne     not_late2
    mov     delay_2.late_flag, true

not_late2:
    dec     delay_2.count
    jnz     end_delay
    mov     ax, delay_2.val ; reload

```

Listing 1 (Continued)

```

        mov     delay_2.count, ax
        mov     delay_2.flag, true           ; set event flag (fortran true)
end_delay:

        dec     clock_count                 ; decrement system clock counter
        jnz     end_ISR                     ; not time for sys clock
        mov     clock_count,55

inactive_exit:                             ; chain to old timer isr
        pop     ds                           ; restore stack
        pop     ax

assume ds:nothing
        jmp old_timer_vector
assume ds:code

end_ISR:                                   ; non-chained exit
        mov     al,20h                       ; signal end of interrupt to pic
        out     20h,al
        pop     ds                           ; restore stack
        pop     ax
        iret

;*****

;subroutine:  dinit (delay)
public dinit
        dinit  proc near

                GetDevData delay_1 delay_2
                jc      dinit_exit

load_timer:
        cli
        mov     [si].val, bx                 ; load time value into value and counter
        mov     [si].count, bx
        mov     [si].flag, false
        mov     [si].inited, true
        mov     [si].late_flag, false
        sti
dinit_exit:
        ret

dinit  endp

;*****

; subroutine: wait

public _wait
_wait  proc near

        GetDevData delay_1 delay_2
        jc      wait_exit

        cmp     [si].inited, true

```

Listing 1 (Continued)

```

        je      no_init_error
        mov     cx, 3                      ; uninited timer error code
        ret
no_init_error:
        cmp     [si].late_flag, true      ; test for late
        jne     again
        mov     [si].late_flag, false
        mov     cx, 8
        ret
again:
        cli
        mov     bl, [si].flag
        sti
        cmp     bl, true                  ; test for set
        jnz     again                   ; jump if not set
        cli
        mov     [si].flag, false          ; clear the event flag
        sti
        ret
wait_exit:
        ret
_wait     endp

;*****

public Report_flag
Report_flag  proc near

        GetDevData delay_1 delay_2
        jc      report_exit

        cmp     [si].inited, true
        je      get_flag
        mov     cx, 3                      ; uninited timer error
        ret
get_flag:
        cli
        mov     bl, [si].flag
        mov     bh, 0
        mov     [si].flag, false          ; clear the event flag
        sti

report_exit:
        ret
report_flag  endp

;*****

;  subroutine pause
PAUSE  proc   near
        public PAUSE
        cli
        mov     up_count, 0
        sti
not_yet:
        cli
        mov     ax, up_count

```

Listing 1 (Continued)

```

        sti
        cmp     ax, bx
        jl      not_yet
        mov     cx, 0
        ret
pause   endp

;*****
;   subroutine start_t
;   starts a continuous millisecond timer.
;   present time returned by subroutine timer.

start_t proc    near
        public  start_t

        GetDevData timer_1 timer_2
        jc      start_t_exit

        mov     word ptr [si].val, 0
        mov     word ptr [si].val+2,0
        mov     [si].flag, false                ;Fortran false

start_t_exit:
        ret

start_t endp

;***** Subroutine Timer *****

;   returns the time, in milliseconds, since the latest
;   call to start_t for the specified timer. Time is a 32 bit integer.
;   Timer flag is a 16 bit logical which is set to indicate
;   overflow of the timer.

timer   proc    near
        public  timer

        GetDevData timer_1 timer_2
        jc      start_t_exit

        mov     bx, word ptr [si].val
        mov     dx, word ptr [si].val+ 2
        mov     cl, [si].flag
        cmp     cl, true
        je      error_ret
        ret

error_ret:
        mov     cx, 5                ; overflow error code
        mov     bx, 0                ;0 time on error
        mov     dx, 0

timer_exit:
        ret
timer   endp

;*****

```

Listing 1 (Continued)

```

; subroutine STIME

; This routine measures the elapsed from the time the routine call
; to the time of detection of a switch press.
; The routine returns the time (long integer) and switch number.

public stime
stime proc near
    mov     up_count, 0           ; zero the counter
    mov     dx, port             ; printer control port
    mov     al, 20                ; int disable, bit 3 hi.....
    out     dx, al               ; output lines high for pull up

read_switch:
    mov     dx, port             ; printer control port
    in      al, dx
    and     al, 15                ; mask off all but low 4 bits
    xor     al, 4                 ; invert 3rd bit because of the port
    mov     cx, 1                 ; counter for switch check loop
    mov     dl, 1                 ; mask value for switch check

next_bit:
    cmp     al, dl
    jz      got_switch
    shl     dl, 1                 ; set mask to next bit position
    inc     cx                     ; loop counter (also switch number)
    cmp     cx, 4
    jle     next_bit
    cmp     bx, up_count           ; check for time out
    jg      read_switch           ; if no time out, keep checking switches
    mov     cx, 4                 ; else return timed out error.
    ret

got_switch:
    mov     al, cl                ; switch number in al
    mov     ah, 0
    mov     cx, 0                 ; clear error return
    cli                     ; read the counter

    mov     bx, up_count
    mov     dx, 0
    sti                     ; let it count again
    ret

stime endp

;*****

; subroutine STOP
; This routine resets the system timer interrupt rate
; to defaults values.

public STOP
STOP proc near
    mov     timer_running, false
    cli

; Reset sys clock interrupt rate.
; The divisor for the clock will be 0 (same as 10000H)
    mov     al, 34h               ; set control word
    out     43h, al               ; store ctrl word at port location
    nop

```

Listing 1 (Continued)

```

        mov     al, 00h                ; store low byte of counter divisor
        out     40h, al
        nop
        mov     al, 00h                ; store high byte of counter divisor
        out     40h, al
        sti
        mov     cx, 0
        ret
STOP    endp

```

```

;*****

```

```

public START
START proc near

```

```

; This routine sets the system clock interrupt rate to 1 mS and
; initializes various (sorry 'bout that) timer variables.

```

```

        cmp     timer_running, true
        je      start_exit

;   set system clock interrupt rate to 1 mS.
;   The divisor is 4a9h. The control word is 34h.
        mov     al, 34h                ; set timer control word
        out     43h, al
        nop
        mov     al, 0a9h               ; don't rush the poor timer!
        out     40h, al                ; store low byte of counter divisor
        nop
        mov     al, 04h                ; store high byte of counter divisor
        out     40h, al
        sti
        mov     delay_1.inited, false
        mov     delay_2.inited, false
        mov     delay_1.flag, false
        mov     delay_2.flag, false
        mov     delay_1.late_flag, false
        mov     delay_2.late_flag, false
        mov     timer_1.flag, false
        mov     timer_2.flag, false
        mov     timer_running, true
start_exit:
        mov     cx, 0                  ; clear error return
        ret
START endp

```

```

;*****

```

```

public ACKNOWLEDGE
ACKNOWLEDGE proc near
        mov     al, 0ffh
        mov     ah, 0
        mov     cx, 0
        ret
ACKNOWLEDGE endp

```


Listing 1 (Continued)

```

;*****

; subroutine set_switch_port selects which printer port to use for
; switch press detection.

set_switch_port proc    near
public  set_switch_port
    cmp     cl, 3                ; test for valid device number
    jg      bad_port_num
    cmp     cl, 1
    jl      bad_port_num
    shl     cl, 1                ; port num * 2
    add     cl, 6                ; plus 6 = offset in BIOS Data Area
    mov     ax, 40h              ; BIOS Data Area Segment
    mov     es, ax
    mov     ch, 0
    mov     bx, cx
    mov     ax, es:[bx]
    cmp     ax, 0
    je      un_installed_port
    add     ax, 2
    mov     port, ax
    mov     cx, 0                ; no error.
    ret

bad_port_num:
    mov     cx, 2                ; invalid device error
    ret

un_installed_port:
    mov     cx, 9                ; port not installed.
    ret

set_switch_port endp

;*****

Initialize:
    jmp     end_temp_data
error      db      lf, 'Error: Timer System already installed', cr, lf, '$'
version    db      lf, 'Timer Sub_system version 3.21', cr, lf, '$'
normal     db      lf, 'timer system installed normally', cr, lf, '$'
stime_warning db      lf, 'timer system detects no printer ports', cr, lf, '$'
res_flag   dw      ?

end_temp_data:
    call test_installed          ; sets res_flag if installed already
    con_string version
    cmp     res_flag, true
    jne     install
    con_string error
    int     20h                  ; terminate

install:
    con_string normal
    mov     ax, ds:2ch            ; deallocate the environment block.
    mov     es, ax

```

Listing 1 (Continued)

```

mov     ah, 49h
int     21h

set_vect 21h, old_dos_vector, service    ; set int21 vector

set_vect 8, old_timer_vector, ISR        ; set int8 (timer) vector

mov     ax, 040h                        ; get LPT1 port address
mov     es, ax
mov     ax, es:8
cmp     ax, 0
jne     port_ok
con_string stime_warning
mov     ax, 0
port_ok:
add     ax, 2                          ; offset from port base to status port
mov     port, ax

mov     ds, bx
mov     dx, offset initialize            ; lowest available mem.
int     27H                            ; terminate and stay resident

;*****
test_installed proc    near
    public test_installed
;   this routine uses DOS' ability to detect an unimplemented DOS
;   function to detect previously installed versions of TIMER.

    mov     ax, 0f0f0h
    int     21h                        ;timer function ACKNOWLEDGE
    cmp     al, 0
    jne     resident                    ; set installed flag
not_resident:
    mov     res_flag, false
    ret
resident:
    mov     res_flag, true
    ret
test_installed endp

code    ends
end     entry

```

Listing 2: Microsoft C Language Interface for TIMER

1. timing.h - header file to be included in C programs that use TIMER.

```

short start(void);
short stop(void);
short dinit(short, short);
short wait(short);
short report_flag(short, short *);
short start_timer(short);
short stime (short *, short *);
short read_timer(short, long *);
short stall(short);

```

Listing 2 (Continued)

2. ctimer.asm - Microsoft C interface for TIMER.

```

; Copyright <c> 1989
; Carl Creeger
; 202 Pickle Rd
; Austin, Tx 78704
; This Program may be distributed with out charge for any no-profit use but may not be sold.
; No Warranty, expressed or implied applies to this program.

; Use with the header file "TIMING.H"
; Functions implemented:
;   start, function number 1
;   stop, function number 2
;   acknowledge, function number 3
;   dinit, function number 4
;   wait, function number 5
;   report FLAG, function number 6
;   start_timer, function number 7
;   read_timer, function number 8
;   stime, function number 9
;   stall, function number 10
;   set_switch_port, function number 11
;
; CTIMER uses the file 'CMACROS.INC' version 1.06 or 5.0. At compile time this file
; must be in the current directory or in a directory pointed to by
; the "include" environment variable. 'CMACROS.INC' is included with the
; Microsoft C compiler.
;
; 'Cmacros' allow this module to produce code for any memory model,
; depending on the command line used:
;   small model:  masm /D?memS=1 /Mx ctimer,,;
;   medium model: masm /D?memM=1 /Mx ctimer,,;
;   compact model: masm /D?memC=1 /Mx ctimer,,;
;   large model:  masm /D?memL=1 /Mx ctimer,,;

; All functions return 0 if successful, otherwise a TIMER error.
; See TIMER.ASM for a list of TIMER errors.

; the following warning is normal and can be ignored:
;   ctimer.ASM(99): warning A4016: Reserved word used as symbol: WAIT

; definitions to control Cmacros:
?PLM=0           ; NOT PLM (pascal and fortran) calling conventions.
?WIN=0           ; NOT Windows callable.
.xlist           ; don't list all the macros.
include cmacros.inc
.list

;-----
DoTimer macro fnum      ; code common to all timer interface functions.
LOCAL proc_exit
    mov     ah, 0f0h      ; TIMER's "DOS" function #
    mov     al, fnum      ; sub function code.
    int     21h

```

Listing 2 (Continued)

```

        cmp     ah, 0
        je      proc_exit      ; TIMER installed
        mov     cx, 1          ; TIMER not installed code
proc_exit:
        mov     ax, cx          ; return error
endm

;-----

createSeg _TEXT, code, word, public, CODE, <>
sBegin code
assumes cs,code

;-- start ----- Enable the TIMER.

cProc  start,<PUBLIC>,<>
cBegin
    DoTimer 1
cEnd

;-- Stop ----- disable TIMER

cProc  stop,<PUBLIC>,<>
cBegin
    DoTimer 2
cEnd

;-- dinit ----- initialize a repeat interval timer.

cProc  dinit,<PUBLIC>,<di,si>
    parmW timer_number
    parmW period
cBegin
    mov     bx, period
    mov     cx, timer_number
    DoTimer 4
cEnd

;-- wait ----- wait 'til end of next repeated interval

cProc  wait,<PUBLIC>,<di,si>
    parmW timer_number
cBegin
    mov     cx, timer_number
    DoTimer 5
cEnd

;-- report_flag ---- report status of repeated interval timer

cProc  report_flag,<PUBLIC>,<si,ds>
    parmW timer_number
    parmDP stat_ptr
cBegin
    mov     cx, timer_number
    DoTimer 6
if sized
                                ; Data pointers for are far
    mov     dx, seg_stat_ptr

```

Listing 2 (Continued)

```

        mov     ds, dx
        mov     si, off_stat_ptr
else
        mov     si, stat_ptr
endif
        mov     [si], bx
cEnd

;-- start_timer  -----  start a timer.
cProc  start_timer,<PUBLIC>,<di,si>
        parmW timer_number
cBegin
        mov     cx, timer_number
        DoTimer 7
cEnd

;-- read_timer  -----  return current value of timer.

cProc  read_timer,<PUBLIC>,<si, ds>
        parmW timer_number
        parmDP timer_value
cBegin
        mov     cx, timer_number
        DoTimer 8
if sized
        mov     si, seg_timer_value      ; if large data model
        mov     ds, si                  ; get seg of timer_value
        mov     si, off_timer_value      ; offset of timer parameter
else
        mov     si, timer_value          ; offset of timer parameter
endif
        mov     [si], bx                ; return time lsw
        mov     [si + 2], dx            ; return time msw
cEnd

;-- Stime  -----  measure switch response time

cProc  stime,<PUBLIC>,<di,si,ds>
        parmDP time_value
        parmDP switch_number
cBegin
if sized
        mov     si, seg_time_value
        mov     ds, si
        mov     si, off_time_value      ; offset of time parameter
else
        mov     si, time_value          ; offset of time parameter
endif
        mov     bx, [si]

        mov     ah, 0F0h
        mov     al, 9                    ; stime's function number.
        int     21h
        cmp     ah, 0
        je      stime_exit
        mov     cx, 1                    ; Timer not installed code
stime_exit:
        mov     [si], bx                ; return time value

```

Listing 2 (Continued)

```

if sized
    mov     si, seg_switch_number
    mov     ds, si
    mov     si, seg_switch_number    ; address of switch parameter
else
    mov     si, switch_number        ; address of switch parameter
endif
    mov     ah, 0
    mov     [si], ax
    mov     ax, cx                    ; return error code
cEnd

;--  Stall -----  pause.

cProc  stall,<PUBLIC>,<di,si>
    parmW time_val

cBegin
    mov     bx, time_val              ; get the time value
    mov     dx, 0
    DoTimer 10
cEnd

;--  set_port -----  Select printer port to user with stime.

cProc  set_port,<PUBLIC>,<di,si>
    parmW port_num

cBegin
    mov     cx, port_num
    DoTimer 11
cEnd
sEnd
end

```

Listing 3: Microsoft FORTRAN Language Interface for TIMER

1. timer.fi - FORTRAN include file for programs that use TIMER.

```

interface to function start()
    integer*2 start
end

interface to function stopti()
    integer*2 stopti
end

interface to function dinit(NumTi, rate)
    integer*2 dinit
    integer*2 NumTi
    integer*2 rate
end

interface to function wait(NumTi)
    integer*2 wait
    integer*2 NumTi [reference]
end

```

Listing 3 (Continued)

```

interface to function report(NumTi, flag)
    integer*2 report
    integer*2 NumTi
    logical*2 flag
end

interface to function startt(NumTi)
    integer*2 startt
    integer*2 NumTi
end

interface to function stime (time, NumSw)
    integer*2 stime
    integer*2 time
    integer*2 NumSw
end

interface to function timer(NumTi, time)
    integer*2 timer
    integer*2 NumTi
    integer*4 time
end

interface to function stall(time)
    integer*2 stall
    integer*2 time
end

interface to function swport(portnum)
    integer*2 swport
    integer*2 portnum

```

2. timer.fd - FORTRAN function definition file to be included in subroutines.

```

integer*2 start[EXTERN]
integer*2 stopti[EXTERN]
integer*2 dinit[EXTERN]
integer*2 wait[EXTERN]
integer*2 report[EXTERN]
integer*2 startt[EXTERN]
integer*2 stime [EXTERN]
integer*2 timer[EXTERN]

```

3. msftimer.asm - TIMER interface for Microsoft FORTRAN.

```

;      Copyright <c> 1989
;      Carl Creeger
;      202 Pickle Rd
;      Austin, Tx  78704

;      This Program may be distributed with out charge for any no-profit use
;      but may not be sold.

;      No Warranty, expressed or implied applies to this program.

;      interface from Microsoft Fortran to the "Timer" timing system .

```

Listing 3 (Continued)

```

;      for information on TIMER's interface, see timer.asm.
;      Use with interface definition file TIMER.FI in each module that uses TIMER,
;      and TIMER.FD in each subroutine that calls TIMER functions.

; Assemble :
;      masm msftimer,;;

; the following warning is normal:
;      msftimer.ASM(85): warning A4016: Reserved word used as symbol: WAIT

.model large          ; for use with large (default) memory model programs.
.code

;-----

entry macro
    push    bp
    mov     bp, sp
    push    ds
    push    si
    push    di
endm

exit macro size
    pop     di
    pop     si
    pop     ds
    pop     bp
    ret     size
endm

err_ret MACRO
LOCAL proc_exit
    cmp     ah, 0
    je      proc_exit          ; Timer installed
    mov     cx, 1              ; Timer not installed code
proc_exit:
    mov     ax, cx              ; return error
ENDM

DoTimer macro fnum
    mov     ah, 0f0h           ; Timer's "DOS" function code
    mov     al, fnum            ; sub function code.
    int     21h
    err_ret
endm

;-----

start proc              ; start the timer
public start
    DoTimer 1
    ret
start endp

```


Listing 3 (Continued)

```

;-----

stopti proc
public stopti                                ; stop the Timer.
    DoTimer 2
    ret
stopti endp

;-----

dinit proc                                ; initialize a delay timer.
public dinit
    entry
    lds    si, [bp + 10]
    mov    cx, [si]                        ; timer number
    lds    si, [bp + 6]
    mov    bx, [si]                        ; time value (16 bits incoming)
    mov    dx, 0                          ; clear msb of 32 time returns

    DoTimer 4
    exit   8
dinit endp

;-----

wait proc
    public wait
    entry
    lds    si, [bp + 6]
    mov    cx, [si]                        ; timer number

    DoTimer 5
    exit   4
wait endp

;-----

report proc
    public report
    entry
    lds    si, [bp + 10]
    mov    cx, [si]                        ; timer number
    DoTimer 6

    lds    si, [bp + 6]
    mov    [si], bx
    exit   8
report endp

;-----

startt proc
    public startt
    entry
    lds    si, [bp + 6]
    mov    cx, [si]                        ; timer number

```

Listing 3 (Continued)

```

        DoTimer 7
        exit    4
startt endp

;-----

timer proc
    public timer
    entry
    lds    si, [bp + 10]
    mov    cx, [si]          ; timer number

    DoTimer 8
    lds    si, [bp + 6]
    mov    [si], bx          ; return time value lsw
    mov    [si + 2], dx      ; return time value msw
    exit   8
timer endp

;-----

stime proc
    public stime
    entry
    mov    ah, 0f0h          ; timer's DOS function code
    mov    al, 9             ; function number
    mov    di, bx

    lds    si, [bp + 10]
    mov    bx, [si]          ; timeout value
    int    21h

    err_ret                  ; test and return error
    lds    si, [bp + 6]
    mov    [si], bx          ; return time value lsw
    mov    word ptr[si + 2], 0 ; return time value msw
    lds    si, [bp + 10]
    mov    ah, 0
    mov    [si], ax
    exit   8
stime endp

;-----

stall proc
    public stall
    entry
    lds    si, [bp + 6]
    mov    bx, [si]          ; time value (16 bits incoming)
    mov    dx, 0             ; clear msw of 32 time returns

    DoTimer 10
    exit   4
stall endp

```

Listing 3 (Continued)

```

;-----
swport proc                                ; select switch port.
public swport
    entry
    lds    si, [bp + 6]
    mov    cx, [si]                        ; port number

    DoTimer 11
    exit    4
swport endp

end

```

Listing 4: Microsoft QuickBASIC Language Interface for TIMER

1. timer.bi - QuickBASIC include file

```

'--- TIMER.BI : Timer system interface Include File ---
'
'    Copyright <c> 1989
'    Carl Creeger
'    202 Pickle Rd
'    Austin, Tx 78704
'
'    This Program may be distributed with out charge for any no-profit use
'    but may not be sold.
'
'    No Warranty, expressed or implied applies to this program.
'
'    This include file defines the functions used to interface
'    to the timing system "TIMER.COM". It provides the DECLARE
'    statements for the assembly language routines  START,
'    STOPTI, DINIT, MS_WAIT, REPORT_FLAG, START_TIMER, TIME,
'    READ_TIMER, STALL, and SET_PORT
'
'-----

DECLARE FUNCTION START%

DECLARE FUNCTION STOPTI%

DECLARE FUNCTION DINIT% (BYVAL devnum AS INTEGER, BYVAL dtime AS INTEGER)

DECLARE FUNCTION MSWAIT% (BYVAL wtime AS INTEGER)

DECLARE FUNCTION REPORTFLAG% (BYVAL devnum AS INTEGER, SEG flag AS INTEGER)

DECLARE FUNCTION STARTTIMER% (BYVAL devnum AS INTEGER)

DECLARE FUNCTION STIME% (SEG swnum AS INTEGER, SEG time AS INTEGER)

DECLARE FUNCTION READTIMER% (BYVAL devnum AS INTEGER, SEG time AS LONG)

DECLARE FUNCTION STALL% (BYVAL time AS INTEGER)

DECLARE FUNCTION SETPORT% (BYVAL portnum AS INTEGER)

```

Listing 4 (Continued)

2. qbtimer.asm - TIMER interface for Microsoft QuickBASIC

```

; qbtimer.asm
; Microsoft QuickBasic v4.5 interface to the "Timer" timing system.
;
;   Copyright <c> 1989
;   Carl Creeger
;   202 Pickle Rd
;   Austin, Tx  78704
;
;   This Program may be distributed with out charge for any no-profit use
;   but may not be sold.
;   No Warranty, expressed or implied applies to this program.
;
; use with include file 'TIMER.BI'

; Functions implemented:
;   FUNCTION START%
;   FUNCTION STOPTI%
;   FUNCTION DINIT% (BYVAL START AS INTEGER, BYVAL dtime AS INTEGER)
;   FUNCTION MSWAIT% (BYVAL wtime AS INTEGER)
;   FUNCTION REPORTFLAG% (BYVAL tinum AS INTEGER, SEG flag AS INTEGER)
;   FUNCTION STARTTIMER% (BYVAL tinum AS INTEGER)
;   FUNCTION STIME% (SEG swnum AS INTEGER, SEG time AS INTEGER)
;   FUNCTION READTIMER% (BYVAL tinum AS INTEGER, SEG time AS LONG)
;   FUNCTION STALL% (BYVAL time AS INTEGER)
;   FUNCTION SETPORT% (BYVAL portnum AS INTEGER)

      public start, stopti, dinit, mswait, reportflag
      public starttimer, readtimer, stime, stall, setport

; Assemble :
;   masm qbtimer,.,;

;-----
entry macro
    push    bp
    mov     bp, sp
    push    ds
    push    si
    push    di
endm

exit macro size
    pop     di
    pop     si
    pop     ds
    pop     bp
    ret     size
endm

DoTimer macro fnum
LOCAL proc_exit
    mov     ah, 0f0h          ; Timer's "DOS" function #
    mov     al, fnum          ; sub function code.
    int     21h

```

Listing 4 (Continued)

```

        cmp     ah, 0
        je      proc_exit          ; Timer installed
        mov     cx, 1              ; Timer not installed code
proc_exit:
        mov     ax, cx              ; return error
endm

.model medium
.code

;-----

start proc
    DoTimer 1
    ret
start endp

;-----

stopti proc
    Dotimer 2
    ret
stopti endp

;-----

dinit proc
    entry
    mov     cx, [bp + 8]           ; timer number
    mov     bx, [bp + 6]           ; time value (16 bits incoming)
    mov     dx, 0                  ; clear msw of 32 time returns
    DoTimer 4
    exit    4
dinit endp

;-----

mswait proc
    entry
    mov     cx, [bp + 6]           ; timer number

    Dotimer 5
    exit    2
mswait endp

;-----

reportflag proc
    entry
    mov     di, bx
    mov     cx, [bp + 10]          ; timer number
    DoTimer 6

    lds     si, [bp + 6]
    mov     [si], bx
    exit    6
reportflag endp

```

Listing 4 (Continued)

```

;-----
starttimer proc
    entry
    mov     cx, [bp + 6]          ; timer number
    Dotimer 7

    exit    2
starttimer endp

;-----

readtimer proc
    entry
    mov     di, bx
    mov     cx, [bp + 10]        ; timer number
    Dotimer 8

    lds     si, [bp + 6]
    mov     [si], bx             ; return time value lsw
    mov     [si + 2], dx         ; return time value msb
    exit    6
readtimer endp

;-----

stime proc
    entry
    mov     ah, 0f0h             ; Timer's DOS function code
    mov     al, 9                ; function number
    lds     si, [bp + 10]
    mov     bx, [si]             ; timeout value
    int     21h
    cmp     ah, 0                ; Timer installed
    je      stime_exit
    mov     cx, 1                ; Timer not installed code
stime_exit:
    lds     si, [bp + 10]
    mov     [si], bx             ; return time value lsw
    lds     si, [bp + 6]
    mov     ah, 0
    mov     [si], ax
    mov     ax, cx               ; return error code
    exit    8
stime endp

;-----

stall proc
    entry
    mov     bx, [bp + 6]         ; time value (16 bits incoming)
    mov     dx, 0               ; clear msb of 32 time returns
    DoTimer 10
    exit    2
stall endp

```

Listing 4 (Continued)

```

;-----
setport proc
    entry
    mov     cx, [bp + 6]      ; port number
    DoTimer 11

    exit    4
setport    endp
;-----
end

```

Listing 5: TPTIMER.PAS: Turbo Pascal Interface to TIMER

1. TPTIMER.PAS

```

unit tptimer;
{This is an interface to the millisecond timing routine "timer"
See the file timer.doc for details.

```

```

    Copyright <c> 1989
    Carl Creeger
    202 Pickle Rd
    Austin, Tx 78704

```

```

    This Program may be distributed with out charge for any no-profit use
    but may not be sold.

```

```

    No Warranty, expressed or implied applies to this program. )

```

```

(*****)

```

```

interface

```

```

uses dos;

```

```

{ Functions implemented: }

```

```

    FUNCTION start : integer;
    FUNCTION stop : integer;
    FUNCTION dinit(dev_num, delay_value : integer) : integer;
    FUNCTION wait(dev_num : integer) : integer;
    FUNCTION report_flag(device_num : integer; var status : boolean)
        : integer;
    FUNCTION start_timer(device_num : integer) : integer;
    FUNCTION read_timer(device_num : integer; var timer_value : longint)
        : integer;
    FUNCTION stime (var time, switch_number : integer) : integer;
    FUNCTION stall(stall_time : integer) : integer;
    FUNCTION set_port(port : integer) : integer;

```

```

implementation

```

```

(-----)

```

Listing 5 (Continued)

```

FUNCTION start : integer;

var
    regs : registers;

begin
    regs.ah := $0f0;           { timer systems "DOS" function # }
    regs.al := 1;             { sub function code. }
    intr ($21, regs);

    if (regs.ah <> 0) then begin
        start := 1;
    end else begin
        start:= regs.ax;
    end;
end;

{-----}

FUNCTION stop : integer;

var
    regs : registers;

begin
    Regs.al := 2;
    regs.ah := $f0;

    intr ($21, regs);

    if (regs.ah <> 0) then begin
        stop := 1;
    end else begin
        stop:= regs.ax;
    end;
end;

{-----}

FUNCTION dinit(dev_num, delay_value : integer) : integer;
var
    regs : registers;

begin
    regs.cx := dev_num;       { device number }
    regs.bx := delay_value;
    regs.dx := 0;

    Regs.al := 4;
    regs.ah := $f0;

    intr ($21, regs);

    if (regs.ah <> 0) then begin
        dinit := 1;
    end;
end;

```


Listing 5 (Continued)

```

        end else begin
            dinit:= regs.ax;
        end;
    end;

    {-----}

    FUNCTION wait(dev_num : integer) : integer;
    var
        regs : registers;

    begin
        regs.cx := dev_num;
        Regs.al := 5;
        regs.ah := $f0;

        intr ($21, regs);

        if (regs.ah <> 0) then begin
            wait := 1;
        end else begin
            wait:= regs.ax;
        end;
    end;

    {-----}

    FUNCTION report_flag(device_num : integer; var status : boolean)
        : integer;

    var
        regs : registers;

    begin
        regs.cx := device_num;           { device number }
        Regs.al := 6;
        regs.ah := $f0;

        intr ($21, regs);

        if (regs.bx = 0) then begin
            status := false;
        end else begin
            status := true;
        end;

        if (regs.ah <> 0) then begin
            report_flag := 1;
        end else begin
            report_flag:= regs.ax;
        end;
    end;

    {-----}

    FUNCTION start_timer(device_num : integer) : integer;

```

Listing 5 (Continued)

```

var
  regs : registers;

begin
  regs.cx := device_num;
  Regs.al := 7;
  regs.ah := $f0;

  intr ($21, regs);

  if (regs.ah <> 0) then begin
    start_timer := 1;
  end else begin
    start_timer := regs.ax;
  end;
end;

{-----}

FUNCTION read_timer(device_num : integer; var timer_value : longint)
  : integer;

var
  regs : registers;

begin
  regs.cx := device_num;
  Regs.al := 8;
  regs.ah := $f0;

  intr ($21, regs);

  if (regs.ah <> 0) then begin
    read_timer := 1;
  end else begin
    read_timer := regs.ax;
  end;

  timer_value := regs.bx;
end;

{-----}

FUNCTION stime (var time, switch_number : integer) : integer;

var
  regs : registers;

begin
  regs.ah := $0f0;
  regs.al := 9;
  regs.bx := time;

  intr ($21, regs);

```

Listing 5 (Continued)

```

        if (regs.ah <> 0) then begin
            stime := 1;
        end else begin
            stime := regs.ax;
        end;

        time := regs.bx;

        switch_number := regs.ax;
    end;

    {-----}

    FUNCTION stall(stall_time : integer) : integer;

    var
        regs : registers;

    begin
        regs.bx := stall_time;
        regs.dx := 0;
        Regs.al := 1;
        regs.ah := $f0;
        intr ($21, regs);

        if (regs.ah <> 0) then begin
            stall := 1;
        end else begin
            stall := regs.ax;
        end;
    end;

    {-----}

    FUNCTION set_port(port : integer) : integer;

    var
        regs : registers;

    begin
        regs.cx := port;
        Regs.al := 1;
        regs.ah := $f0;

        intr ($21, regs);

        if (regs.ah <> 0) then begin
            set_port := 1;
        end else begin
            set_port := regs.ax;
        end;
    end;
end;
end.
```

Listing 6: MicroMan.C: A Strategy for Measuring and Minimizing Timing Errors

```

#include <stdio.h>
#include <stdlib.h>
#include <graph.h>
#include <time.h>

/***** declarations for timing routines *****/
short far start(void);
short far stop(void);
short far start_timer(short);
short far read_timer(short, long *);
short far stall(short);
/***** color code definitions *****/
#define RED          4
#define MAGENTA      5
#define BROWN        6
#define WHITE         7
#define LT_WHITE     15

#define SOA           300L /* intended SOA */
#define REFRESH       16.7 /* average screen refresh time for EGA */
#define DUMMY_RESPONSE_TIME 120

/***** poll port for change in retrace status *****/
void retrace()
{
    while(!(inp(0x3da) & 8)) ;
    while( inp(0x3da) & 8) ;
}

/***** generate dummy priming stimulus *****/
void draw_priming_stim(int page)
{
    _setactivepage(page);
    _setcolor(BROWN);
    _rectangle(_G_FILLINTERIOR, 256, 140, 384, 210);
    _setcolor(LT_WHITE);
    _rectangle(_G_FILLINTERIOR, 266, 150, 374, 200);
}

/***** generate dummy target stimulus *****/
void draw_target_stim(int page)
{
    _setactivepage(page);
    _setcolor(MAGENTA);
    _rectangle(_G_FILLINTERIOR, 256, 140, 384, 210);
    _setcolor(WHITE);
    _rectangle(_G_FILLINTERIOR, 266, 150, 374, 200);
    _settextcolor(RED);
    _settextposition(12,37);
    _outtext("XXXXXXX");
    _settextposition(13,37);
    _outtext("0000000");
    _settextposition(14,37);
    _outtext("XXXXXXX");
}

```

Listing 6 (Continued)

```

/***** simulate response *****/
void get_response()
{
    stall(DUMMY_RESPONSE_TIME);
}

time_t clocktime;    /* for seeding random number generator */
main()
{
    long time1, time2, time3;

    time(&clocktime);    /* get seed */
    srand(clocktime);    /* seed */
    start();              /* initialize timer setup */
    _setvideomode(_ERESCOLOR); /* set graphic mode */
    draw_priming_stim(0);
    start_timer(1);
    start_timer(2);
    stall(rand()%100);    /* add random time (0-100 msec) to overhead */
    draw_target_stim(1);  /* generate target stimulus off screen */
    read_timer(1,&time1); /* get overhead time */
    stall(SOA-time1-REFRESH/2); /* wait intended SOA minus overhead minus
                                1/2 refresh rate */
    retrace();            /* wait for beginning of refresh cycle */
    _setvisualpage(1);    /* display target stimulus */
    read_timer(2,&time2);  /* get actual soa interval */
    start_timer(1);
    get_response();
    read_timer(1,&time3);
    stop();               /* stop timing routines */
    _setvideomode(_DEFAULTMODE); /* return to text mode */
    printf("\nIntended SOA = %ld Actual SOA = %ld", SOA, time2);
    printf("\nOverhead = %ld", time1);
}

```

Listing 7: PsyBench.c: A Benchmark Program for Experimentally Relevant Tasks

```

/*-----
* PsyBench.c: Benchmark program for recording elapsed times for...
*       Screen Refreshing
*       Generating Graphical Displays
*       Disk (File) I/O (Writing/Reading)
*       Computing (Eratosthene's Sieve for Finding Primes)
*
* History:   Specifications: August, 1989, Kevin Miller, University of Texas at Austin
*           Written September, 1989, David Paredes, U. T. Austin
*           Assembly language timer modules (ctimer.obj & timer.com)
*           written by Carl Creeger, U. T. Austin
*
* Compiler:  Microsoft C version 5.0
*           Compile statement: CL -c psybench
* Linked:    Ctimer.obj
*           Link statement: link /NOE psybench ctimer;
*

```

Listing 7 (Continued)

```

* Hardware:   IBM PC or PS/2 with EGA or VGA (or compatible)
*
* Dependency: timer.com must be invoked before program execution
*
* Output:     times.out
*-----*/
#include <stdio.h>
#include <stdlib.h>
#include <graph.h>
#include <math.h>
#include <bios.h>
#include <timing.h>

#define LOOP      20    /* number of main loops */
#define MAXLINE   1000  /* maximum # of read-write lines for disk i-o test */
#define STALLTIME 5000  /* stall time to read intro & test timer */
#define ESC       1     /* scan code for escape key */

#define PutText(row,col,string) _settextposition((row),(col)); _outtext((string))

#define T_BLACK    0 /* color code definitions */
#define T_BLUE     1
#define T_GREEN    2
#define T_CYAN     3
#define T_RED      4
#define T_MAGENTA  5
#define T_BROWN   6
#define T_WHITE    7
#define T_GRAY     8
#define T_LT_BLUE  9
#define T_LT_GREEN 10
#define T_LT_CYAN  11
#define T_LT_RED   12
#define T_LT_MAGENTA 13
#define T_YELLOW   14
#define T_LT_WHITE 15

/* global arrays for storing times */
double retraces[5], screen1[5], screen2[5], screen3[5], screen4[5], sieves[5];
double write1[5], write2[5], write3[5], read1[5], read2[5], read3[5];

enum stat { N, MIN, MAX, SUM, SUMSQ }; /* mnemonics for variables to be stored */
FILE *outfile, *tmp1, *tmp2, *tmp3; /* output & temporary files */
/***** Fatal Error Exit *****/
void ErrExit(ErrMsg)
    char * ErrMsg;
{
    _setvideomode(_DEFAULTMODE);

    printf("\n%s", ErrMsg);
    exit(1);
}
/***** check for escape key *****/
void check_esc()
{
    if(kbhit())
        if(((bios_keybrd(_KEYBRD_READ) & 0xff00) >> 8)==ESC)
            ErrExit("\nProgram terminated by user.");
}

```

Listing 7 (Continued)

```

}
/***** Accumulate timing values. *****/

void AccumStats (data, time)
    double data[];
    long time;
{
    data[N]++;
    if(data[N]==1) data[MIN]=time;
    data[MIN]=min(data[MIN],time);
    data[MAX]=max(data[MAX],time);
    data[SUM]=data[SUM]+(time);
    data[SUMSQ]=data[SUMSQ]+(time*time);
}
/***** test timing *****/
void test_timer(timeout)
    int timeout;
{
    long time;

    start_timer(1);
    stall(timeout);
    read_timer(1,&time);
    if((time-timeout) > 1 || (timeout-time) > 1)
        ErrExit ("\\nError: Time.com not invoked or not running correctly.");
}
/***** open output & temp files *****/
void open_files()
{
    if((outfile=fopen("times.out","w"))==NULL)
        ErrExit ("ERROR: Could not open output file");

    if((tmp1=fopen("tmp1","w"))==NULL)
        ErrExit ("ERROR: Could not open temporary file #1");

    if((tmp2=fopen("tmp2","w"))==NULL)
        ErrExit ("ERROR: Could not open temporary file #2");

    if((tmp3=fopen("tmp3","w"))==NULL)
        ErrExit ("ERROR: Could not open temporary file #3");
}
/***** wait for change in retrace status *****/
void retrace()
{
    while(!(inp(0x3da) & 8)) ; /* waits for a retrace on */
    while( inp(0x3da) & 8) ; /* waits for a retrace off */
}
/***** time between retraces: screen refresh rate *****/
void do_retrace()
{
    long time;

    retrace();
    start_timer(1);
    retrace();
    read_timer(1,&time);
    AccumStats (retraces, time);
}

```

Listing 7 (Continued)

```

/***** construct introduction screen *****/
void draw_intro (page)
    int page;
{
    _setactivepage(page);
    _setcolor(T_BLUE);
    _rectangle(_G_FILLINTERIOR,0,0,640,350);
    _setbkcolor(_BLUE);
    PutText (2,32,"MICRO MANAGING TIME");
    PutText (6,34,"Carl Creeger");
    PutText (8,33,"Kevin F. Miller");
    PutText (10,32,"David R. Paredes");
    PutText (14,24,"The University of Texas at Austin");
}
/***** generate display # 1 *****/
void draw_screen1 (page)
    int page;
{
    unsigned char * mask={"x20x08x20x08x20x08x20x08"};
    long time;

    start_timer(1);
    _setactivepage(page);
    _setcolor(T_RED);
    _setfillmask(mask);
    _rectangle(_G_FILLINTERIOR,0,0,640,350);
    _setfillmask(NULL);
    PutText (25,35," SCREEN 1 ");
    read_timer(1,&time);
    AccumStats (screen1, time);
}
/***** generate display # 2 *****/
void draw_screen2 (page)
    int page;
{
    long time;

    start_timer(1);
    _setactivepage(page);
    _setcolor(T_BLUE);
    _rectangle(_G_FILLINTERIOR,0,0,640,350);
    _moveto(0,350);
    _setcolor(T_LT_BLUE);
    _lineto(80,300);
    _lineto(140,325);
    _lineto(240,280);
    _lineto(300,300);
    _lineto(320,295);
    _lineto(340,300);
    _lineto(500,270);
    _lineto(640,330);
    _lineto(640,350);
    _lineto(0,350);
    _floodfill(1,1,T_LT_BLUE);
    _setcolor(T_YELLOW);
    _ellipse(_G_FILLINTERIOR,370,90,485,170);

```


Listing 7 (Continued)

```

    _setcolor(T_WHITE);
    _ellipse(_GFillInterior,200,150,450,160);
    _ellipse(_GFillInterior,430,130,600,140);
    PutText (25,35," SCREEN 2 ");
    read_timer(1,&time);
    AccumStats (screen2, time);
}
/***** generate display # 3 *****/

void draw_screen3(page)
    int page;
{
    long time;

    start_timer(1);
    _setactivepage(page);
    _setcolor(T_MAGENTA);
    _rectangle(_GFillInterior, 256, 140, 384, 210);
    _setcolor(T_WHITE);
    _rectangle(_GFillInterior, 266, 150, 374, 200);
    _settextcolor(T_RED);
    PutText (12,37,"XXXXXXX");
    PutText (13,37,"0000000");
    PutText (14,37,"XXXXXXX");
    PutText (25,35," SCREEN 3 ");
    read_timer(1,&time);
    AccumStats (screen3, time);
}
/***** generate display # 4 *****/
/* (copy stimulus from display # 3 to memory & write it 25 */
/* times to the active page */
/*****
void draw_screen4(source_page,dest_page)
    int source_page, dest_page;
{
    int x, y;
    char *ibuffer;
    long time;

    start_timer(1);
    _setactivepage(source_page);
    ibuffer = malloc((unsigned int)_imagesize(256, 140, 384, 210));
    if (!ibuffer)ErrExit ("ERROR: Not enough memory to copy image");
    _getimage(256, 140, 384, 210,ibuffer);
    _setactivepage(dest_page);
    for(y=0;y<=350;y+=69) {
        for(x=0;x<=640;x+=127)
            _putimage(x,y,ibuffer,_GPSET);
    }
    free(ibuffer);
    PutText (25,35," SCREEN 4 ");
    read_timer(1,&time);
    AccumStats (screen4, time);
}
/***** write black box to entire page *****/
void clr_page(page)
    int page;

```

Listing 7 (Continued)

```

_setactivepage(page);
_setcolor(T_BLACK);
_rectangle(_GFillInterior,0,0,640,350);
}
/***** generate dummy data for file write & read *****/
long avar[MAXLINE], bvar[MAXLINE], cvar[MAXLINE];
void generate_data()
{
    int i;

    for(i=0;i<MAXLINE;i++)
        avar[i]=i; bvar[i]=i+i; cvar[i]=i*i;
}
/***** write dummy data to file # 1 *****/
void write_file1()
{
    long time;
    int i;

    start_timer(1);
    for (i=0;i<MAXLINE;i++)
        fprintf(tmp1,"%ld\n",avar[i]);
    read_timer(1,&time);
    AccumStats (write1, time);
}
/***** write dummy data to file # 2 *****/
void write_file2()
{
    long time;
    int i;

    start_timer(1);
    for (i=0;i<MAXLINE;i++)
        fprintf(tmp2,"%ld %ld\n",avar[i],bvar[i]);
    read_timer(1,&time);
    AccumStats (write2, time);
}
/***** write dummy data to file # 1 *****/
void write_file3()
{
    long time;
    int i;

    start_timer(1);
    for (i=0;i<MAXLINE;i++)
        fprintf(tmp3,"%ld %ld %ld\n",avar[i],bvar[i],cvar[i]);
    read_timer(1,&time);
    AccumStats (write3, time);
}
/***** rewind temporary files for reading or rewriting *****/
void rewind_files()
{
    rewind(tmp1);
    rewind(tmp2);
    rewind(tmp3);
}

```

Listing 7 (Continued)

```

/***** read file 1 *****/
void read_file1()
{
    long time,tmpnum1;

    start_timer(1);
    while((fscanf(tmp1,"%ld\n",&tmpnum1)) != EOF) ;
    read_timer(1,&time);
    AccumStats (read1, time);
}
/***** read file 2 *****/
void read_file2()
{
    long time,tmpnum1,tmpnum2;

    start_timer(1);
    while((fscanf(tmp2,"%ld %ld\n",&tmpnum1,&tmpnum2)) != EOF) ;
    read_timer(1,&time);
    AccumStats (read2, time);
}
/***** read file 3 *****/
void read_file3()
{
    long time,tmpnum1,tmpnum2,tmpnum3;

    start_timer(1);
    while((fscanf(tmp3,"%ld %ld %ld\n",&tmpnum1,&tmpnum2,&tmpnum3)) != EOF) ;
    read_timer(1,&time);
    AccumStats (read3, time);
}
/***** use DOS command to delete temp files *****/
int system(const char *);
void delete_files()
{
    system("del tmp?");
}
/***** time computations: adapted from */
/*      Eratosthenes Sieve Prime Number Program in C, Byte January 1983. */
/*      The code has been corrected to produce primes correctly.      */
#define TRUE    1
#define FALSE   0
#define SIZE    8190

char flags[SIZE+1]={0};

void run_sieve()
{
    register int i,k;
    int count;
    long time;

    start_timer(1);
    count = 0;
    for( i = 0; i <= SIZE; i++) flags[i] = TRUE; /* set all flags true */

```

Listing 7 (Continued)

```

for( i = 2; i <= SIZE; i++ ) {
    if ( flags[i] ) {                                /* found a prime */
        for ( k = i + i; k <= SIZE; k += i )
            flags[k] = FALSE;                        /* Cancel its multiples */
        count++;
    }
}
read_timer(1,&time);
AccumStats (sieves, time);
}
/***** calc. mean and Std_dev and Print one line of the report. *****/
void DoPrint (file, szLabel, data, flag)
    FILE * file;
    char * szLabel;
    double data[];
    short flag;                                     /* one prints to screen and file, 0 only to screen. */
{
    double Mean, Std;
    static char Fmt[] = "\n%-14.14s   %3.0f   %5.0f   %5.0f   %8.2f   %6.2f";

    Mean = data[SUM] / data[N];
    Std = sqrt((data[SUMSQ] / data[N]) - (Mean) * (Mean));
    fprintf(file, Fmt, szLabel, data[N], data[MIN], data[MAX], Mean, Std);
    if (flag) printf(Fmt, szLabel, data[N], data[MIN], data[MAX], Mean, Std);
}
/***** calculate totals & write to screen and output file *****/
void write_report()
{
    double mean, std, screentime, writetime, readtime, tot_time;
    static char label[] = "   Test           N           Min           Max           Mean           STD";

    screentime = screen1[SUM] + screen2[SUM] + screen3[SUM] + screen4[SUM];
    writetime = write1[SUM] + write2[SUM] + write3[SUM];
    readtime = read1[SUM] + read2[SUM] + read3[SUM];
    tot_time = retraces[SUM] + screentime + writetime + readtime + sieves[SUM];

    printf("\n\n\n\n-----REPRESENTATIVE STIMULI GENERATION & DISK I/O TIMES-----");
    fprintf(outfile, "----- STIMULI GENERATION & DISK I/O TIMES-----");
    printf("\n -- TIMES ARE IN MILLISECONDS --\n");
    fprintf(outfile, "\n -- TIMES ARE IN MILLISECONDS --\n");
    printf("\n%s", label);
    fprintf(outfile, "\n%s", label);

    DoPrint(outfile, "Loop Compute", sieves, mean, std, 1);
    DoPrint(outfile, "Screen Refresh", retraces, mean, std, 1);
    DoPrint(outfile, "Screen1", screen1, mean, std, 0);
    DoPrint(outfile, "Screen2", screen2, mean, std, 1);
    DoPrint(outfile, "Screen3", screen3, mean, std, 0);
    DoPrint(outfile, "Screen4", screen4, mean, std, 0);
    DoPrint(outfile, "Write File1", write1, mean, std, 1);
    DoPrint(outfile, "Write File2", write2, mean, std, 0);
    DoPrint(outfile, "Write File3", write3, mean, std, 0);
    DoPrint(outfile, "Read File1", read1, mean, std, 1);
    DoPrint(outfile, "Read File2", read2, mean, std, 0);
    DoPrint(outfile, "Read File3", read3, mean, std, 0);
}

```

Listing 7 (Continued)

```

printf("\n\nTOTAL OF TEST TIMES (IN MINUTES): %-8.4f",tot_time/60000);
fprintf(outfile,"\n\nTOTAL OF TEST TIMES (IN MINUTES): %-8.4f",tot_time/60000);
printf("\n-----");
fprintf(outfile,"\n-----");
printf("\n\nAdditional information is recorded on file times.out\n");
}
/***** MAIN PROGRAM *****/
main()
{
    short mainloop, i;

    start();          /* initialize timing routines */
    _setvideomode(_ERESCOLOR); /* color display 640 x 350 pixels */
    draw_intro(0);
    test_timer(STALLTIME);
    check_esc();
    open_files();

    for(mainloop=0; mainloop < LOOP; mainloop++) {
        do_retrace();
        check_esc();
        draw_screen1(1);
        do_retrace();
        _setvisualpage(1);
        check_esc();
        generate_data();
        write_file1();
        check_esc();
        draw_screen2(0);
        do_retrace();
        _setvisualpage(0);
        check_esc();
        write_file2();
        for(i=0; i<10; i++) run_sieve();
        clr_page(1);
        draw_screen3(1);
        check_esc();
        do_retrace();
        _setvisualpage(1);
        clr_page(0);
        check_esc();
        write_file3();
        rewind_files();
        read_file3();
        check_esc();
        draw_screen4(1,0);
        do_retrace();
        _setvisualpage(0);
    }
}

```

Listing 7 (Continued)

```
    read_file1();
    check_esc();
    read_file2();
    rewind_files();
    clr_page(1);
}
delete_files();
stop(); /* stop timing routines */
_setvideomode(_DEFAULTMODE);
write_report();
}
```

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