System Programming
(ELEC462)

Event-Driven Programming

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Contents

Introduction

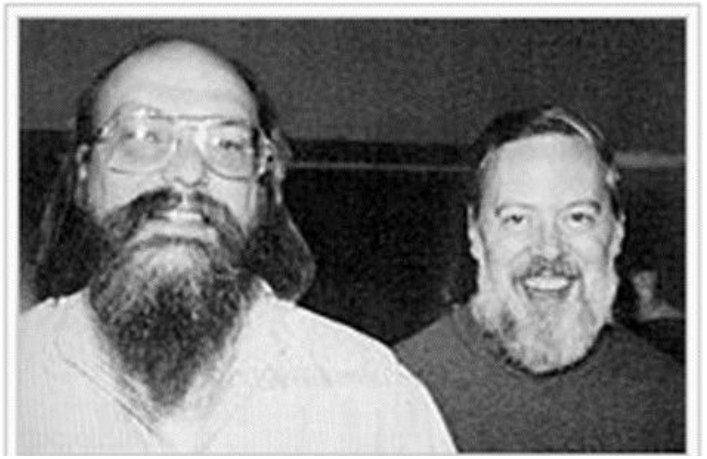
- Writing programs driven by asynchronous (unblocking) events
- The `curses` library: purpose and use
- Alarms and interval timers
  - `alarm(), setitimer(), getitimer()`
- Reliable signal handling, critical sections, and inter-process communication
  - `(u)sleep(), pause(), sigaction(), sigprocmask(), kill()`

Introduction (cont.)

- Featuring
  - screen control
  - tty control
  - time
  - doing two things at once
- General remarks
  - Writing space travel led to Unix
  - Video games are fun to write and use
  - Character-based games are sort of like graphics games, just with fatter pixels
  - Video games lead to important ideas about how to do several things at once. Kind of like multi-tasking

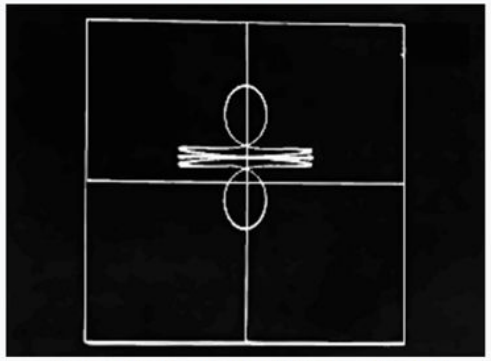
Video Games

- Space Travel
  - An early video game developed by Ken Thompson in 1969 that simulates travel in the solar system



< Ken Thompson (left) &
Dennis Ritchie (right) >

Space Travel



Gameplay image of *Space Travel*

Developer(s)	Ken Thompson
Designer(s)	Ken Thompson
Platform(s)	Multics, GECOS, PDP-7
Release	1969
Genre(s)	Simulation game
Mode(s)	Single-player

A modified PDP-7 under restoration in Oslo, Norway

Manufacturer	Digital Equipment Corporation
Product family	Programmed Data Processor
Type	Minicomputer
Release date	1965; 55 years ago
Introductory price	US$72,000 (equivalent to $584,135 in 2019)

Video Games (cont.)

- Space Travel (cont.)
  - Creates images of planets, asteroids (minor planets), spaceships, and others, and keeps those images moving
  - Each object
    - Has properties: speed, position, direction, momentum, and other attributes
    - Interacts: e.g., An asteroid may face a spaceship or another asteroid.
  - The player
    - Flies their ship around a 2D-scale model of the solar system,
    - Attempts to land on various planets and moons, with no specific purpose,
    - Can move and turn the ship, and
    - Adjusts the overall speed by adjusting the scale of the simulation.
  - The spaceship
    - Affected by the single strongest “gravitational pull” of the astronomical bodies

How a Video Game Works

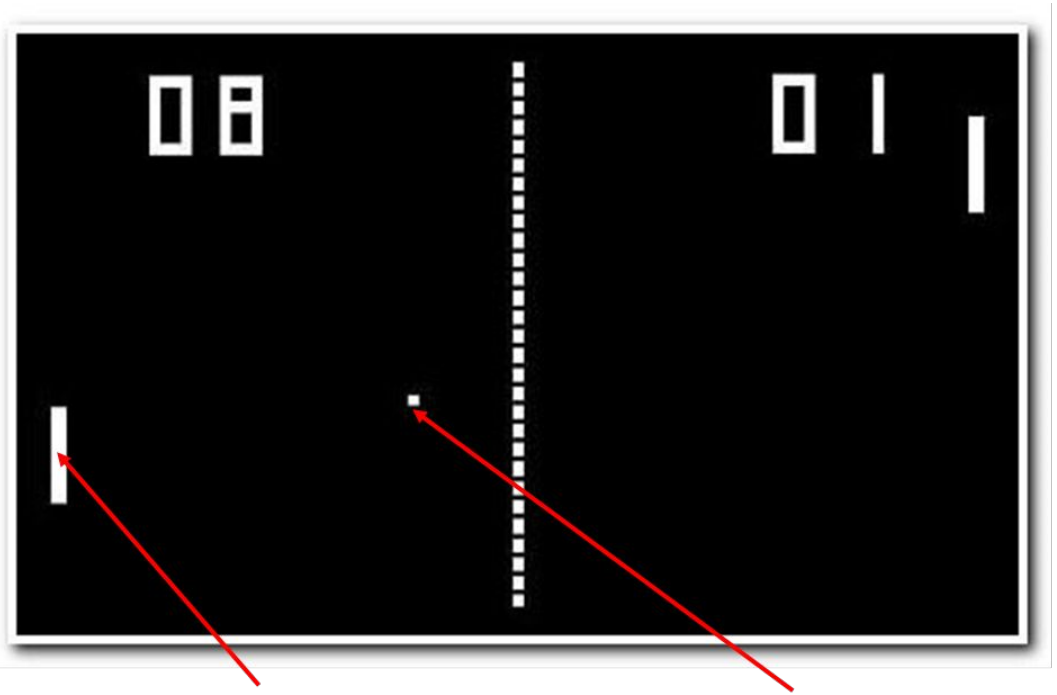
- A video game combines several basic ideas and principles
- Four major aspects:
  - 1) Space
    - The game has to draw images at specific locations on the screen
  - 2) Time
    - Images move across the screen at different “speeds”
    - Changes in position occur at certain “intervals”
  - 3) Interruptions
    - The program moves objects smoothly across the screen
    - Users can send input (causing interrupts) whenever they like
  - 4) Doing several things
    - The game has to keep “several objects moving” and also respond to “interruptions” at the same time (so called, support of multitasking)

Operating Systems Address Similar Questions

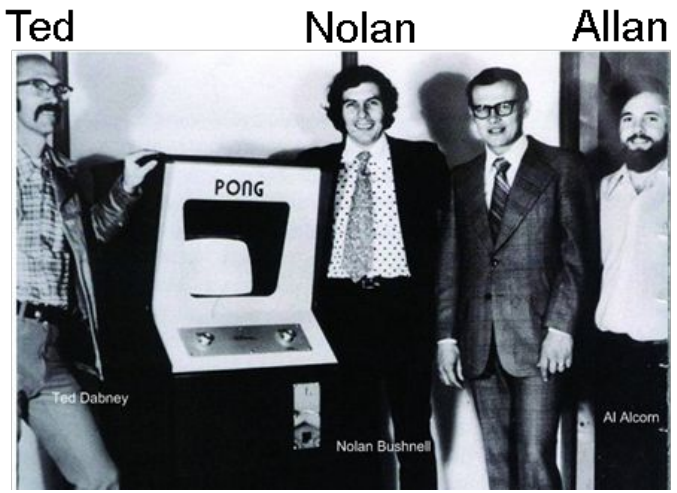
- Kernel
  - Loads programs into memory space and keeps track of the location of each program
  - Schedules programs to run for “short intervals” and also internal tasks to be done at “specific times”
  - Has to respond to quickly when users and other external devices send input at “unpredictable” times
- Question: How does the kernel keep data from becoming disordered and confused?
  - Doing several things at once may be very CHALLENGING

“PONG”

- One of the earliest arcade video game (in 1972)
  - Originally manufactured by Atari (Co-founder: Ted & Nolan)



Paddle: user control *Ball: bounces around the screen*



The Project: Write Single-Player `pong`

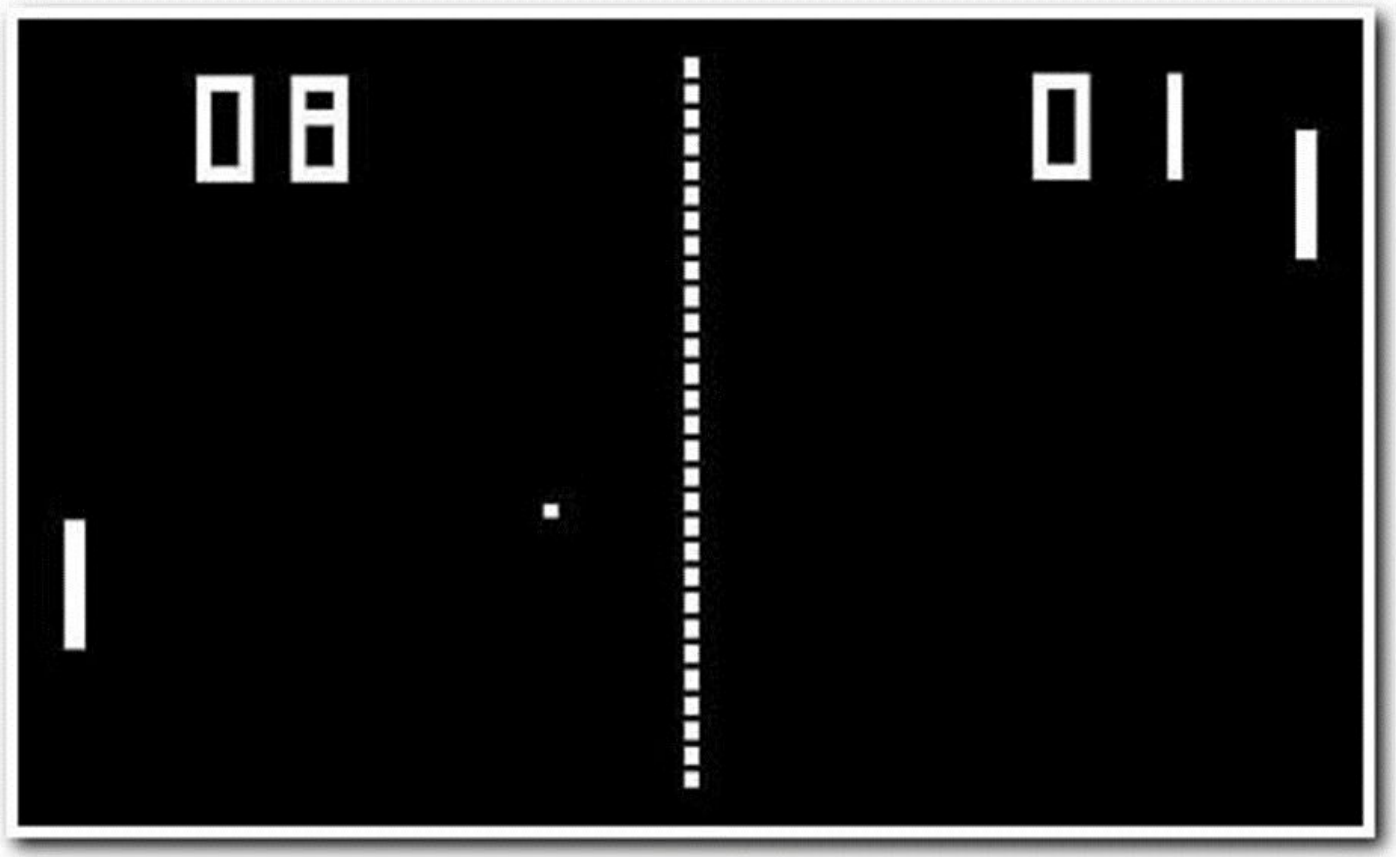
- General outline
  - Ball keeps moving at some speed
  - Ball bounces off walls and paddle
  - User presses keys to move paddle up and down
- Skills we need to learn
  - a) Draw stuff on screen at specific positions
  - b) Draw stuff at particular times
  - c) Use a) and b) to do animation
  - d) How to get user input without stopping action

The Project: Write Single-Player `pong` (cont.)

- Towards writing a video game
  - 1. **Space Programming**: Drawing images
  - 2. **Time Handling**: Making animated effects
  - 3. **Signal Handling**: Moving the bar when keyboard input
  - 4. **Inter-Process Communication**: Sending a signal to another process from a process

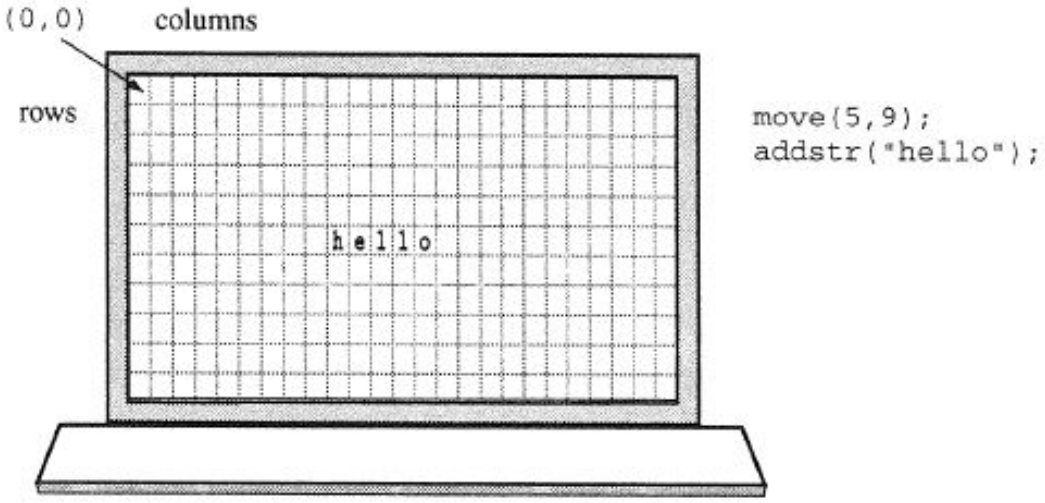
Space Programming: The `curses` Library

- How to draw images at specific location on the screen?



Space Programming: The `curses` Library (cont.)

- "Terminal control" library
  - Consists of a set of functions
    - Allowing a programmer to (i) set the position of the cursor and (ii) control the appearance of text on a terminal screen
  - Used by most programs controlling the terminal screen
- The terminal screen?
  - A grid of character cells
  - The origin – upper left corner of the screen



< The three standard file descriptors >

Space Programming: The `curses` Library (cont.)

- Includes functions to
  - Move the cursor to any cell on the screen: `move()`
  - Add chars to and erase chars from the screen: `addstr()`
  - Set visual attributes of chars (e.g., color, brightness, …): `standout()`
  - Create and control windows and other regions of text: `initscr(), endwin(),`…

Basic Curses Functions

`initscr()`	Initializes the curses library and the tty
`endwin()`	Turns off curses and resets the tty
`refresh()`	Makes screen look the way you want
`move(r,c)`	Moves cursor to screen position (*r*,*c*)
`addstr(s)`	Draws string *s* on the screen at current position
`addch(c)`	Draws char *c* on the screen at current position
`clear()`	Clears the screen
`standout()`	Turns on **standout** mode (usually reverse video)
`standend()`	Turns off **standout** mode

Space Programming: The `curses` Library (cont.)

- Where to find the curses library?
  - What if it is not installed? Try the following command:
  - `$ sudo apt install libncurses5-dev libncursesw5-dev`
  - `$ less /usr/include/curses.h`

Curses Example 1: `hello1.c`

- Compile with `curses` library
  - `$ gcc -o hello1 hello1.c -lcurses`
  - `-lcurses`: Link `curses` library

```c
/* hello1.c
 *      purpose  show the minimal calls needed to use curses
 *      outline  initialize, draw stuff, wait for input, quit
 */

#include        <stdio.h>
#include        <curses.h>

int main()
{
        initscr() ;             /* turn on curses       */

                                /* send requests        */
        clear();                        /* clear screen */
        move(10,20);                    /* row10,col20  */
        addstr("Hello, world");         /* add a string */
        move(LINES-1,0);                /* move to LL   */

        refresh();              /* update the screen    */
        getch();                /* wait for user input  */

        endwin();               /* turn off curses      */

        return 0;
}
```

```
Hello, world
```

Curses Example 2: `hello2.c`

```c
/* hello2.c
 *      purpose  show how to use curses functions with a loop
 *      outline  initialize, draw stuff, wrap up
 */

#include        <unistd.h>
#include        <curses.h>

int main()
{
        int     i;

        initscr();                      /* turn on curses       */
        clear();                        /* draw some stuff      */
        for(i=0; i<LINES; i++ ){                /* in a loop    */
                move( i, i+i );
                if ( i%2 == 1 )
                        standout();
                addstr("Hello, world");
                if ( i%2 == 1 )
                       standend();
        }

        refresh();                      /* update the screen    */
        sleep(3);                       /* wait for 3 seconds   */
        endwin();                       /* reset the tty etc    */

        return 0;
}
```

```
Hello, world
  Hello, world
    Hello, world
      Hello, world
        Hello, world
          Hello, world
            Hello, world
              Hello, world
                Hello, world
                  Hello, world
                    Hello, world
                      Hello, world
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                                                        Hello, world
                                                          Hello, world
                                                            Hello, world
                                                              Hello, world
```
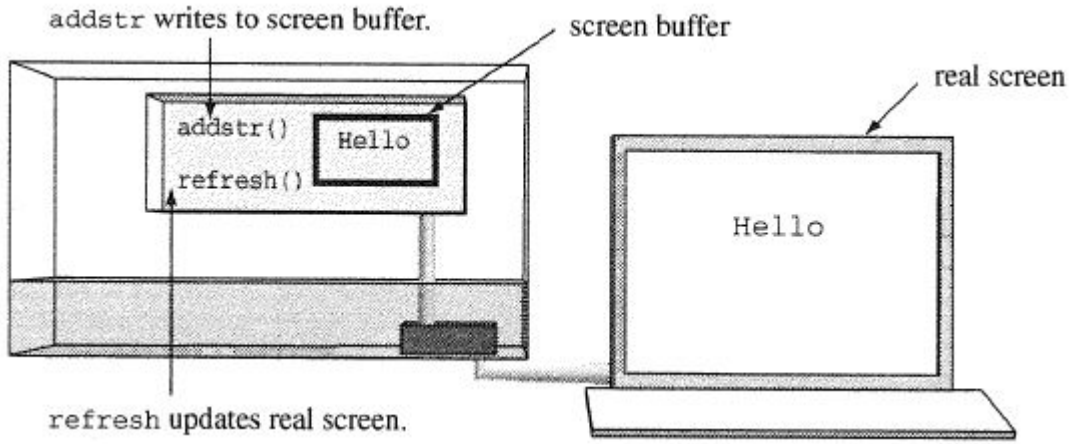

Curses Internals: Virtual and Real Screens

- What does the `refresh` function do?
  - Let's do an experiment
    - Comment out that line, recompile and run the program
    - Then what can you see on the (real) screen?

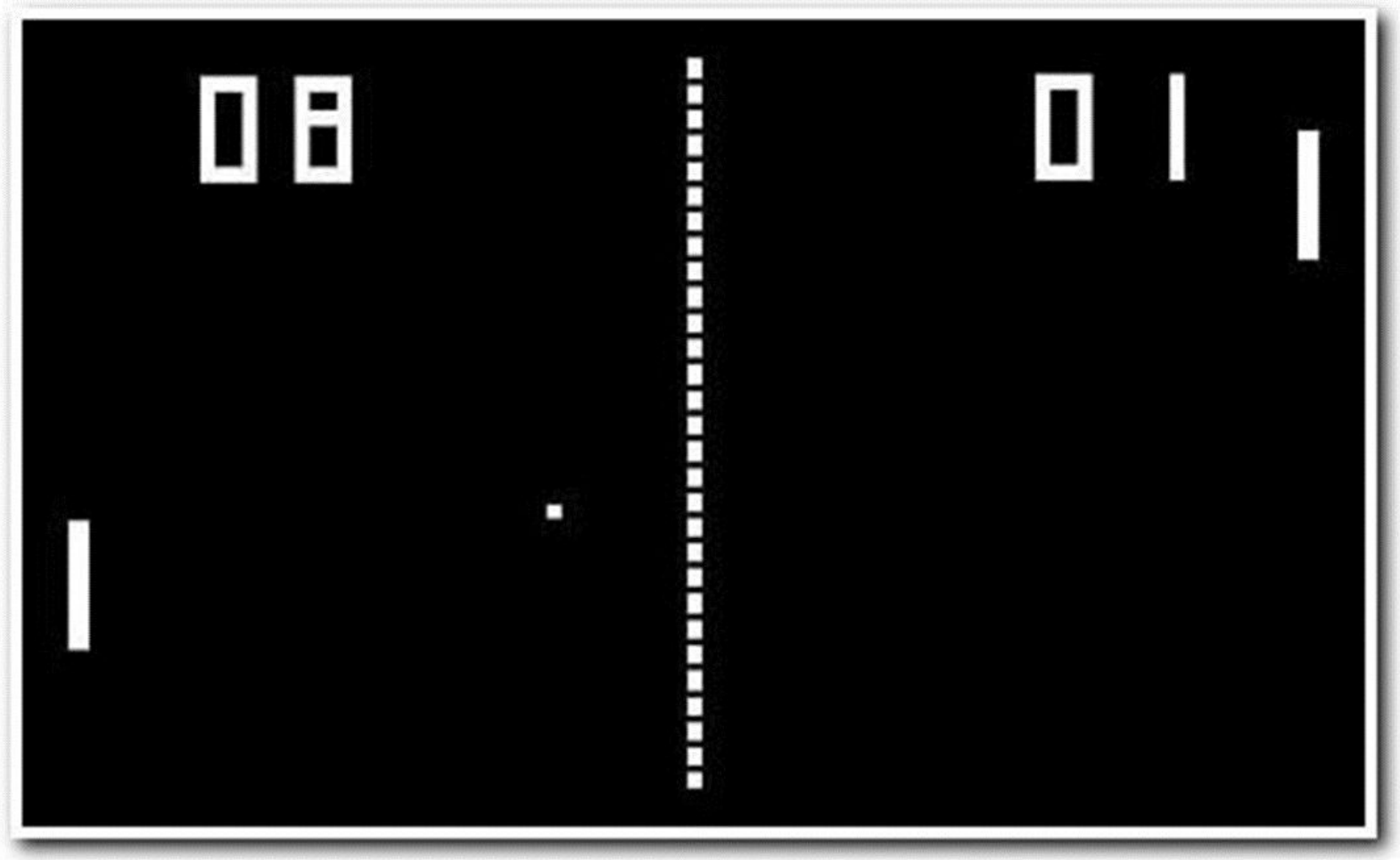


< Curses keeps a copy of the real screen >

- `curses` is designed to update your text screen
  - Minimizes data flow by working with virtual screens
- The `refresh` function
  - Compares the workspace screen to the copy of the real screen
  - Sends out through the terminal driver characters and screen control codes needed to make the real screen match the working screen, like "disk buffering"!

Time Handling

- How to move or to show “animated effects” on the images?



Time Programming: `sleep`

- To write a video game, we have to put images at specific places at specific times
  - Add time to our programs
  - For this, we use the system `sleep` function

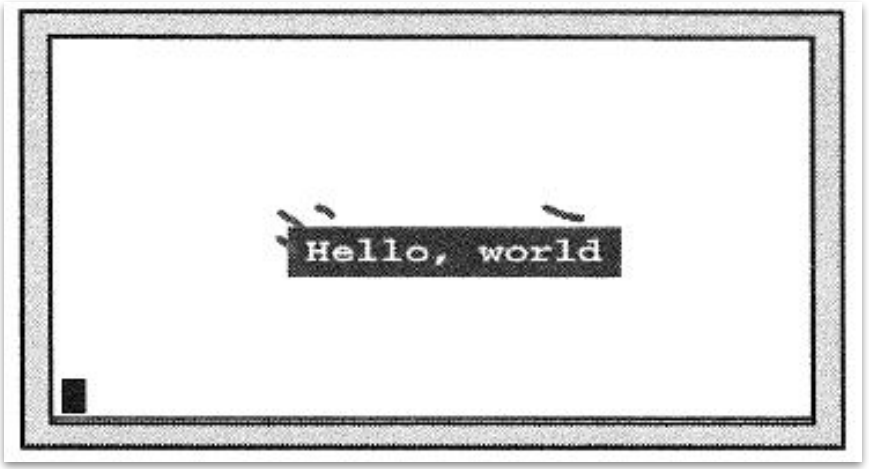
Animation Example 1: `hello3.c`

```c
/* hello3.c
 *      purpose  using refresh and sleep for animated effects
 *      outline  initialize, draw stuff, wrap up
 */
#include        <stdio.h>
#include        <unistd.h>
#include        <curses.h>

int main()
{
        int     i;

        initscr();
           clear();
           for(i=0; i<LINES; i++ ){
                move( i, i+i );
                if ( i%2 == 1 )
                        standout();
                addstr("Hello, world");
                if ( i%2 == 1 )
                        standend();
                sleep(1);
                refresh();
           }
        endwin();

        return 0;
}
```

```
Hello, world
  Hello, world
    Hello, world
      Hello, world
        Hello, world
          Hello, world
```

Animation Example 2: `hello4.c`

```c
/* hello4.c
 *      purpose show how to use erase, time, and draw for animation
 */
#include        <stdio.h>
#include        <unistd.h>
#include        <curses.h>

int main()
{
        int     i;

        initscr();
           clear();
           for(i=0; i<LINES; i++ ){
                move( i, i+i );
                if ( i%2 == 1 )
                        standout();
                addstr("Hello, world");
                if ( i%2 == 1 )
                        standend();
                refresh();
                sleep(1);
                move(i,i+i);                    /* move back    */
                addstr("             ");        /* erase line   */
           }
        endwin();

        return 0;
}
```



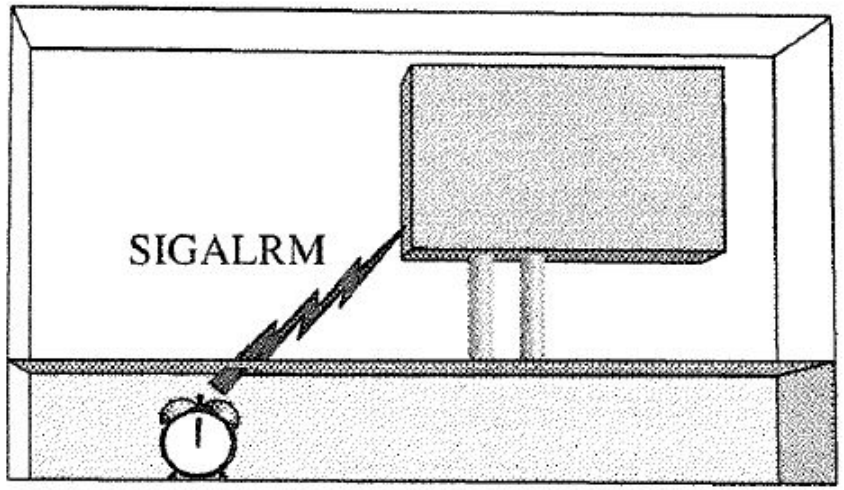
< A message drifts slowly down the screen >

Animation Example 3: `hello5.c`

```c
/* hello5.c
 *    purpose  bounce a message back and forth across the screen
 *    compile  cc hello5.c -lcurses -o hello5
 */
#include        <unistd.h>
#include        <curses.h>

#define LEFTEDGE        10
#define RIGHTEDGE       30
#define ROW             10

int main()
{
        char    message[] = "Hello";
        char    blank[]   = "     ";
        int     dir = +1;
        int     pos = LEFTEDGE ;

        initscr();
        clear();
        while(1){
                move(ROW,pos);
                addstr( message );              /* draw string          */
                move(LINES-1,COLS-1);           /* park the cursor      */
                refresh();                      /* show string          */
                sleep(1);
                move(ROW,pos);                  /* erase string         */
                addstr( blank );
                pos += dir;                     /* advance position     */
                if ( pos >= RIGHTEDGE )         /* check for bounce     */
                        dir = -1;
                if ( pos <= LEFTEDGE )
                        dir = +1;
        }
        return 0;
}
```

Programming with Time I: Alarms

- Adding a delay: `sleep`
  - `sleep(n)`: suspends the current process for *n* seconds or until an unignored signal (like `SIGINT`) arrives
- How `sleep()` works: using alarms in Unix (Linux)
  - Set an alarm for # secs you wish for a program to sleep
  - Pause until the alarm goes off



Every process has its own timer.

How the sleep function works:

```
signal(SIGALRM,handler);
alarm(n);
pause();
```

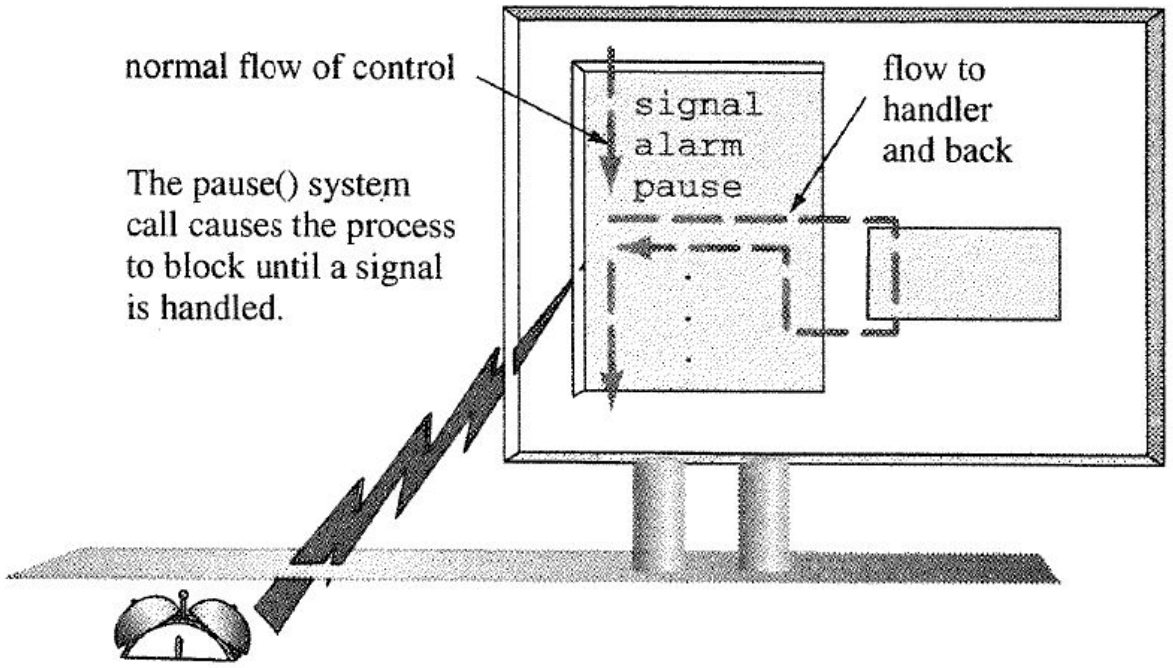
< A process sets an alarm then suspends execution >

Alarm Example 1: `sleep1.c`

```c
/* sleep1.c
 *      purpose show how sleep works
 *      usage   sleep1
 *      outline sets handler, sets alarm, pauses, then returns
 */
#include        <stdio.h>
#include        <unistd.h>
#include        <signal.h>
// #define      SHHHH

int main()
{
        void    wakeup(int);

        printf("about to sleep for 4 seconds\n");
        signal(SIGALRM, wakeup);                /* catch it     */
        alarm(4);                               /* set clock    */
        pause();                                /* freeze here  */
        printf("Morning so soon?\n");           /* back to work */

        return 0;
}

void wakeup(int signum)
{
#ifndef SHHHH
        printf("Alarm received from kernel\n");
#endif
}
```

Programming with Time I: Alarms (cont.)

- How `sleep()` works: using alarms in Unix (Linux) (Cont.)
  - After 4 secs pass on the alarm timer, the kernel sends `SIGALRM` to the process, causing control to jump from the pause to the signal handler



< Flow of execution into handler >

Programming with Time I: Alarms (cont.)

alarm	
PURPOSE	Set an alarm timer for delivery of a signal
INCLUDE	#include <unistd.h>
USAGE	unsigned old = alarm(unsigned seconds)
ARGS	seconds how long to wait
RETURNS	-1 if error old time left on timer

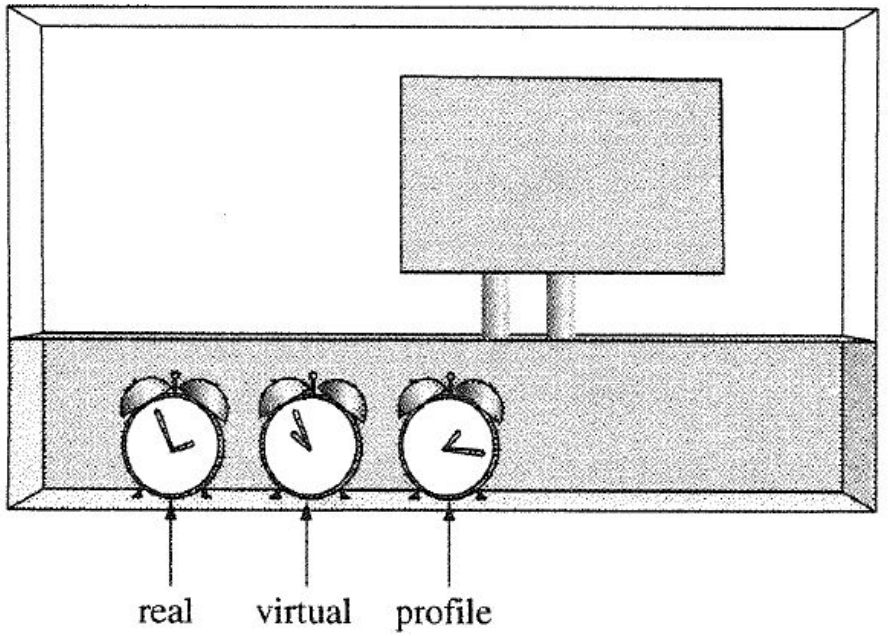
pause	
PURPOSE	Wait for signal
INCLUDE	#include <unistd.h>
USAGE	result = pause()
ARGS	no args
RETURNS	-1 always

Programming with Time II: Interval Timers

- Why do we want to need an interval timer?
  - e.g., Taxi meter device
    - The basic fare is 3,300 won for 3 mins. (initial)
    - It increases 100 won every 30 secs. (repeat)
    - There is a NEED to set a timer at “regular intervals.”
  - Or what other cases??
- What if we want to set a finer-grained delay?
  - e.g., The ball is getting faster every 10.5 seconds
  - For a finer delay: can use `usleep()`
  - `usleep(n)`
    - Suspends the current process n microseconds (1/1,000,000 sec)

Programming with Time II: Interval Timers (cont.)

- Every process has three timers
- Each timer has two settings:
  - (1) The time until the first alarm
  - (2) The interval between repeating alarms



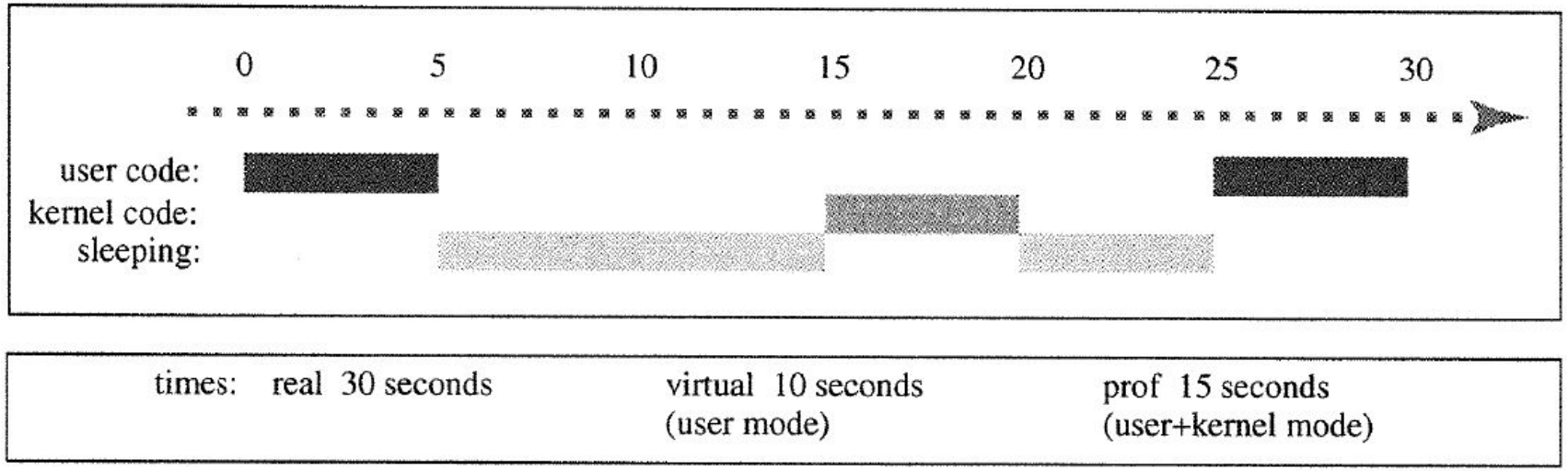
Every process has three timers.

Each timer has two settings: the time until the first alarm and the interval between repeating alarms.

< Every process has three timers >

Programming with Time II: Interval Timers (cont.)

- Three kinds of timers: real, process (virtual), and profile
  - e.g., Consider a program, terminating in 30 seconds after running
    - Total (real): 30 seconds
    - User mode: 10 seconds
    - Profile (user + kernel (or system)) mode: 15 seconds (i.e., program time)



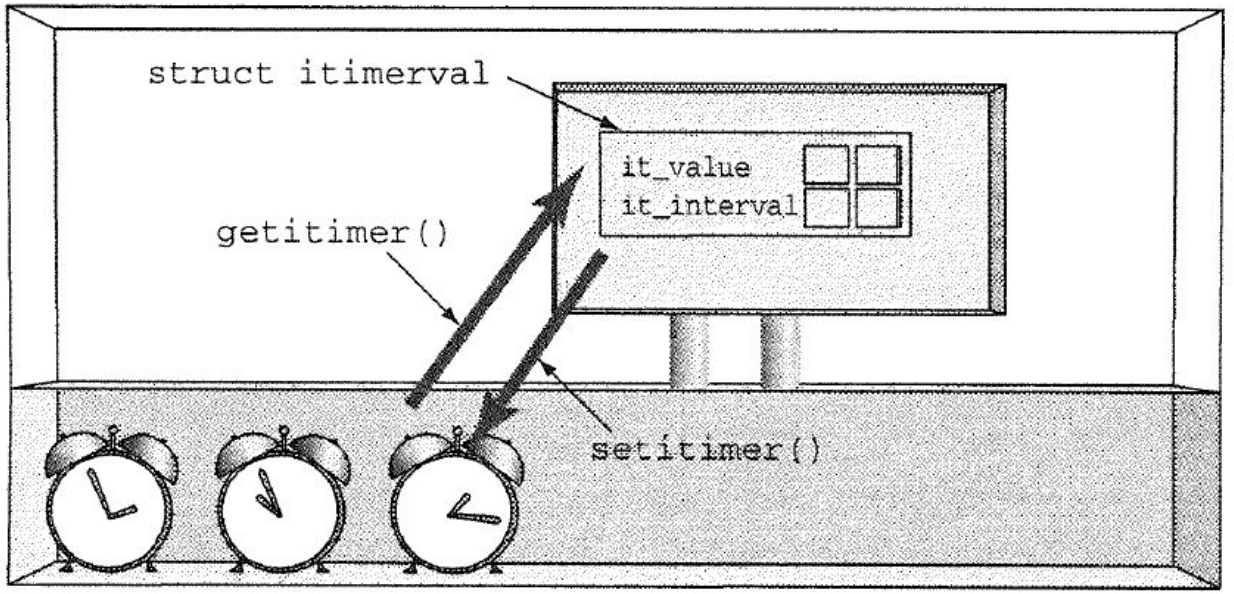
< Where does the time go? >

Programming with Time II: Interval Timers (cont.)

- The kernel provides timers to measure each of these types
  - `ITIMER_REAL`
    - Ticks in “real time” (wall clock time)
    - Send `SIGALRM` if this (real) timer expires
  - `ITIMER_VIRTUAL`
    - Ticks “only when the process runs in user mode” (like an NBA game)
    - Send `SIGVTALRM` if this (virtual) timer expires
  - `ITIMER_PROF`
    - Ticks when the process runs in user mode and when the kernel is running system calls made by this process
    - Send `SIGPROF` if this (profile) timer expires

Programming with Time II: Interval Timers (cont.)

- Programming with the interval timers
  - 1. Decide on an initial interval and a repeating interval
  - 2. Set values in a struct `itimerval`: Initial interval (ex. `it_value` <- 1 hr) and repeating interval (ex. `it_interval` <- 4 hrs)
  - 3. Pass the `itimerval` to the timer by calling `setitimer`



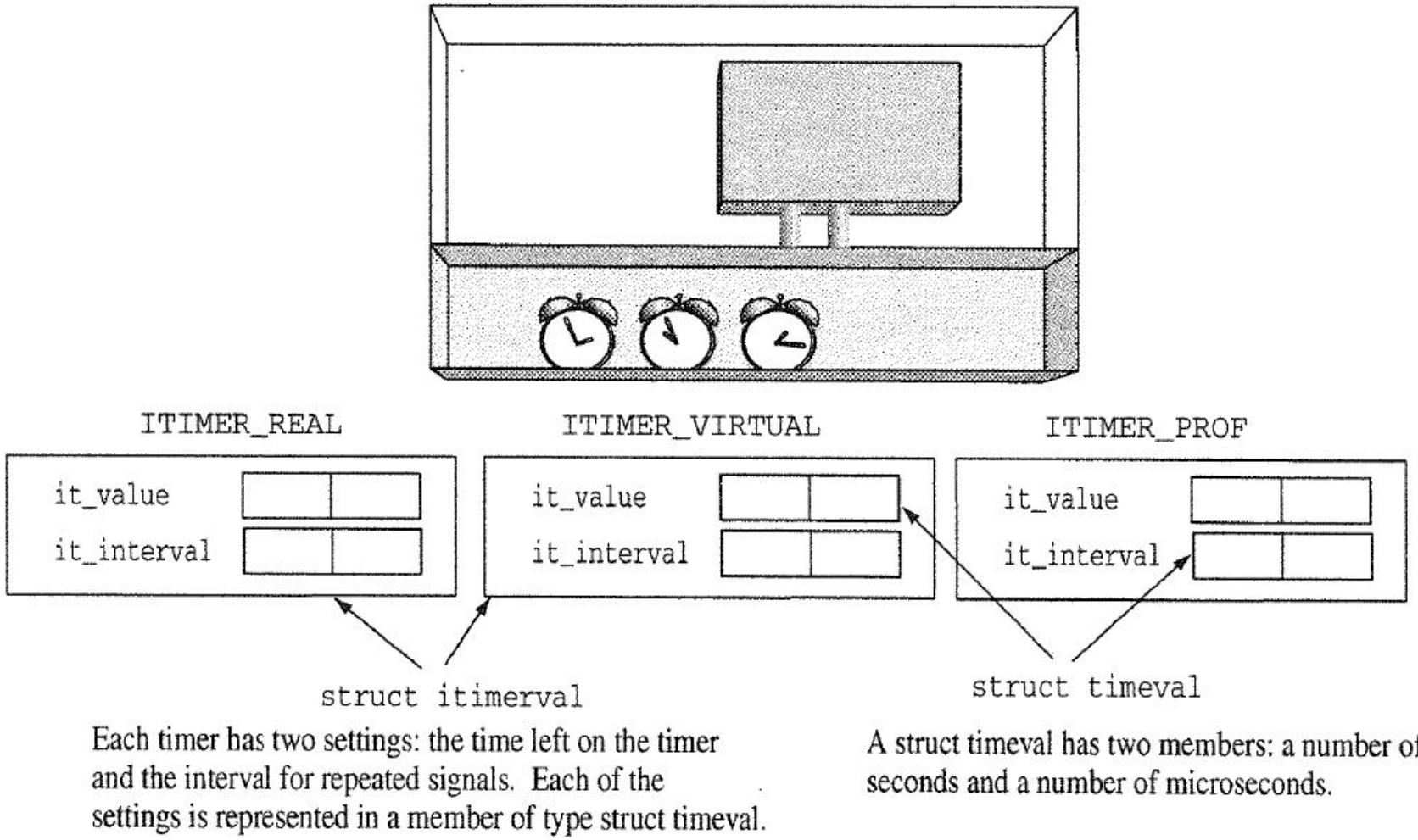
< Reading and writing timer settings >

Programming with Time II: Interval Timers (cont.)

- More details about the data structures

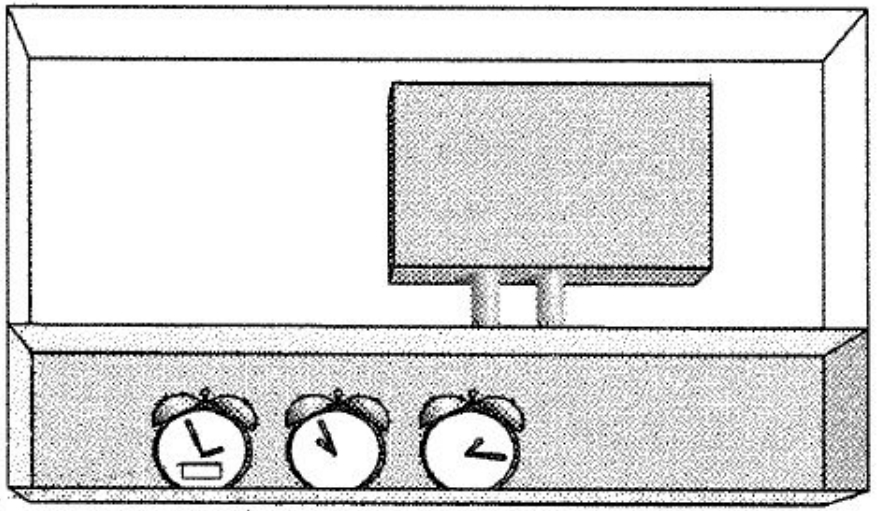
```
struct itimerval{
     /* time to next timer expiration */
     struct timeval it_value;
     /* reload it_value with this  */
     struct timeval it_interval;
};


struct timeval{
     time_t tv_sec;           /* seconds */
     suseconds_t       tv_usec; /* and microseconds
*/
};
```

Programming with Time II: Interval Timers (cont.)



< Inside the interval timers >

Programming with Time II: Interval Timers (cont.)



ITIMER_REAL

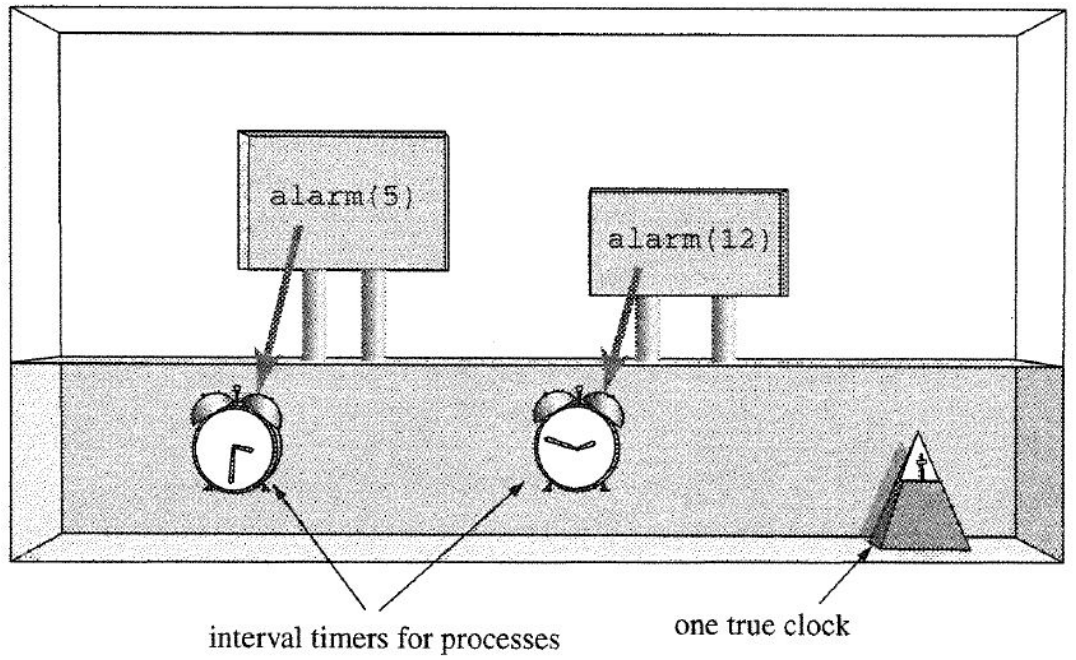
	tv_sec	tv_usec
it_value	60	500000
it_interval	240	250000

This example sets the real time interval timer to send a signal in 60.5 seconds and then to send signals every 240.25 seconds.

< Seconds and microseconds >

Programming with Time II: Interval Timers (cont.)

- How many clocks does the computer have?
  - Every process on the system have three separate clock?!
  - Actually, the system needs only one clock to set the tempo (for ticking)
  - Each process sets its private timer by calling alarm
  - The kernel updates all process timers at each signal from its clock
    - When the counters reach zero, then SIGALRM is fired



Each process sets its private timer by calling `alarm`. The kernel updates all process timers at each signal from its clock.

< Two timers, one clock >

System Call Summaries

getitimer,setitimer	
PURPOSE	Get or set value of interval timer
INCLUDE	`#include <sys/time.h>`

USAGE	`result = getitimer( int which,`
	`struct itimerval *val);`
	`result = setitimer( int which,`
	`const struct itimerval *newval,`
	`struct itimerval *oldval);`

ARGS	`which` timer being read or set `val` pointer to current settings `newval` pointer to settings to be installed `oldval` pointer to settings being replaced
RETURNS	`-1` on error `0` on success

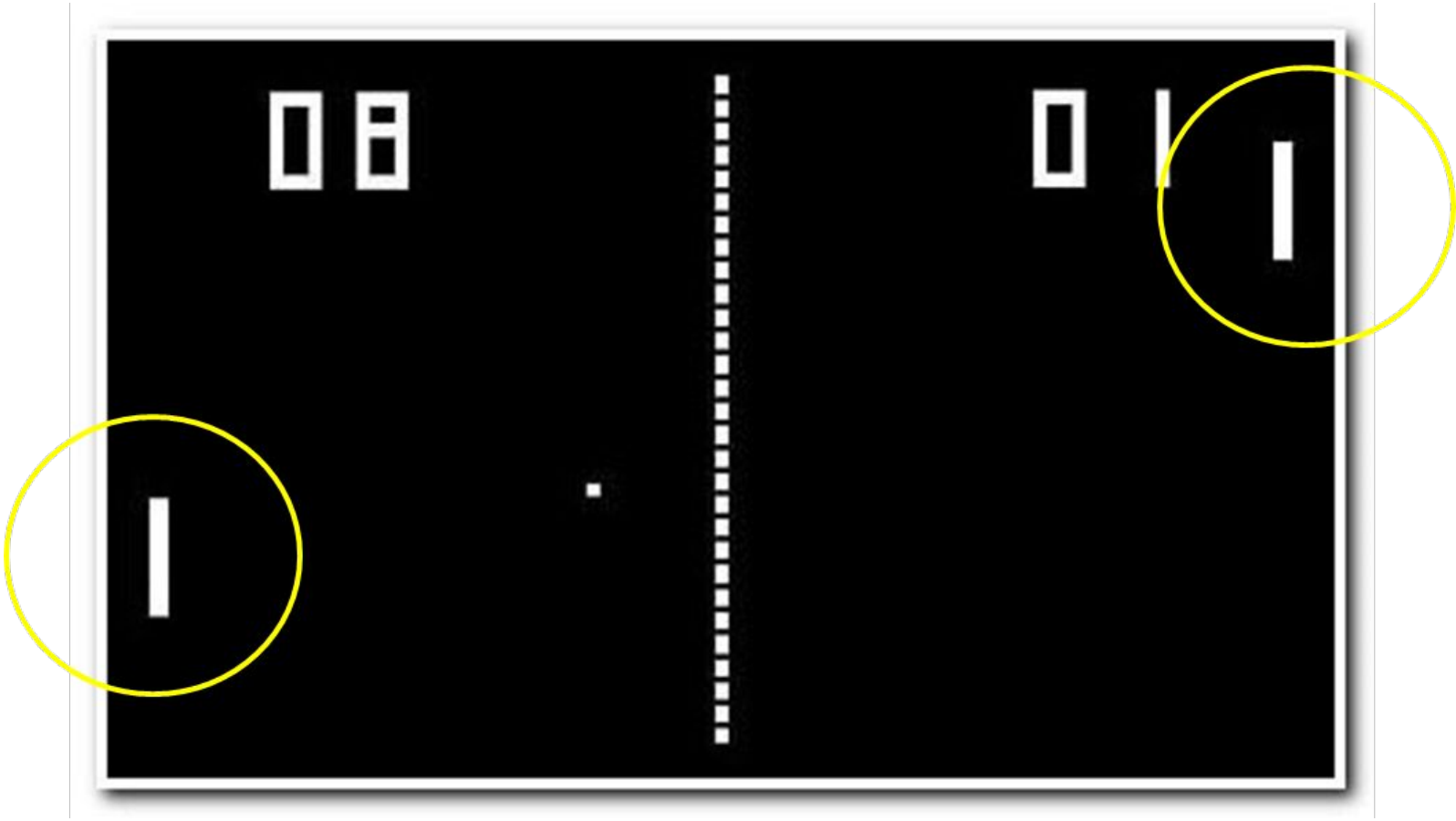
Interval Time Example 1: `ticker_demo.c`

```c
/* ticker_demo.c
 *    demonstrates use of interval timer to generate regular
 *    signals, which are in turn caught and used to count down
 */

#include        <stdio.h>
#include        <sys/time.h>
#include        <unistd.h>
#include        <stdlib.h>
#include        <signal.h>

int set_ticker(int);
void countdown(int);

int main()
{
        void    countdown(int);

        signal(SIGALRM, countdown);
        if ( set_ticker(500) == -1 )
                perror("set_ticker");
        else
                while( 1 )
                        pause();
        return 0;
}
```

```c
void countdown(int signum)
{
        static int num = 10;
        printf("%d ..", num--);
        fflush(stdout);
        if ( num < 0 ){
                printf("DONE!\n");
                exit(0);
        }
}

/* [from set_ticker.c]
 * set_ticker( number_of_milliseconds )
 *      arranges for interval timer to issue SIGALRM's at regular intervals
 *      returns -1 on error, 0 for ok
 *      arg in milliseconds, converted into whole seconds and microseconds
 *      note: set_ticker(0) turns off ticker
 */

int set_ticker( int n_msecs )
{
        struct itimerval new_timeset;
        long    n_sec, n_usecs;

        n_sec = n_msecs / 1000 ;                /* int part     */
        n_usecs = ( n_msecs % 1000 ) * 1000L ;  /* remainder    */

        new_timeset.it_interval.tv_sec  = n_sec;        /* set reload       */
        new_timeset.it_interval.tv_usec = n_usecs;      /* new ticker value */
        new_timeset.it_value.tv_sec     = n_sec  ;      /* store this       */
        new_timeset.it_value.tv_usec    = n_usecs ;     /* and this         */

        return setitimer(ITIMER_REAL, &new_timeset, NULL);
}
```

Signal Handling

- How to move the bar when users type the keyboard?
  - Such interruptions (by keyboard) should be properly handled by the game

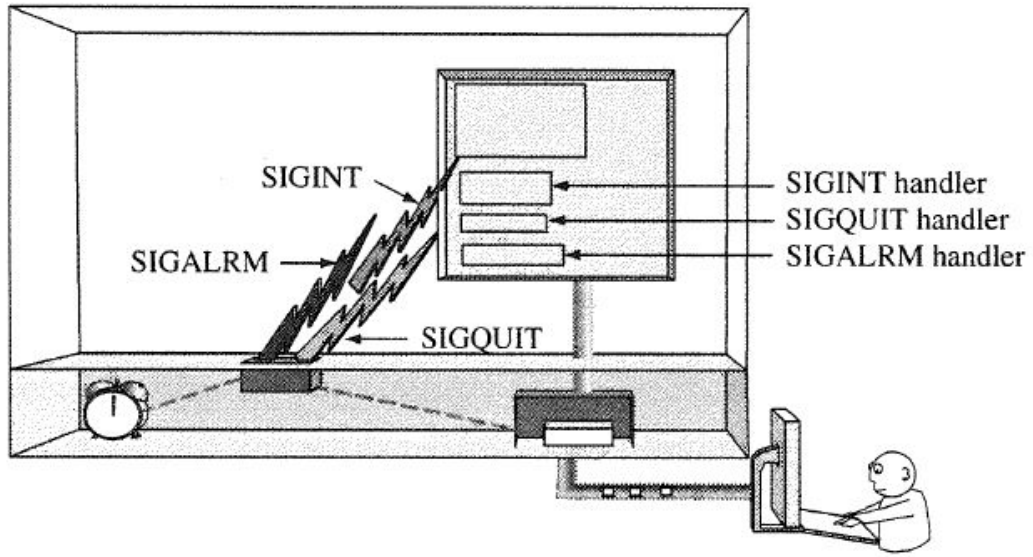


Signal Handling I: Using `signal`

- The kernel sends signals to a process to respond to a variety of events:
  - (i) Certain user keystrokes, (ii) illegal process behaviors, and (iii) elapsed timers, etc.
- Old-style signal handling (covered last class)
  - Default action (usually termination)
    - `signal(SIGALRM, SIG_DFL)`
  - Ignore the signal
    - `signal(SIGALRM, SIG_IGN)`
  - Invoke a (user-defined) function
    - `signal(SIGALRM, handler)`

Signal Handling I: Using `signal` (cont.)

- Handling multiple signals
  - If only one single arrives, then the original signal model works OK!
  - But what if a process receives multiple signals??
    - "Termination or ignore" (obvious) vs. "invoke a function" (not clear)
  - Q1. Is this handler disabled after each use?
  - Q2. What happens if a SIGY arrives while the process is in the SIGX handler?
  - Q3. What happens if a second SIGX arrives while the process is still in the SIGX handler? Or a third SIGX?
  - Q4. What happens if a signal arrives while the process is blocking on input in getchar() or read()?



< A process receiving multiple signals >

Multiple Signals Example 1: `sigdemo3.c`

```c
/* sigdemo3.c
 *      purpose:   show answers to signal questions
 *      question1: does the handler stay in effect after a signal arrives?
 *      question2: what if a signalX arrives while handling signalX?
 *      question3: what if a signalX arrives while handling signalY?
 *      question4: what happens to read() when a signal arrives?
 */

#include        <stdio.h>
#include        <unistd.h>
#include        <string.h>
#include        <signal.h>

#define INPUTLEN        100

void inthandler(int);
void quithandler(int);

int main(int ac, char *av[])
{
        void    inthandler(int);
        void    quithandler(int);
        char    input[INPUTLEN];
        int     nchars;

        signal( SIGINT,  inthandler );          /* set handler */
        signal( SIGQUIT, quithandler );         /* set handler */

        do {
                printf("\nType a message\n");
                nchars = read(0, input, (INPUTLEN-1));
                if ( nchars == -1 )
                        perror("read returned an error");
                else {
                        input[nchars] = '\0';
                        printf("You typed: %s", input);
                }
        }
        while( strncmp( input , "quit" , 4 ) != 0 );

        return 0;
}
```

```c
void inthandler(int s)
{
        printf(" Received signal %d .. waiting\n", s );
        sleep(2);
        printf("  Leaving inthandler \n");
}

void quithandler(int s)
{
        printf(" Received signal %d .. waiting\n", s );
        sleep(3);
        printf("  Leaving quithandler \n");
}
```

Multiple Signals Example 1: `sigdemo3.c` (cont.)

- Experiment for four questions:
  - Q1) Is the handler disabled after each use?

    (`^C` → `(handler)` → `^C`)

    - Each time handler must be reset after invoke.
    - Don't kill the process. Why?

```
dynam@DESKTOP-Q4IJBP7:~/lab8$ ./sigdemo3

Type a message
^C Received signal 2 .. waiting
  Leaving inthandler
^C Received signal 2 .. waiting
  Leaving inthandler
```

  - Q2) What happened if a SIG_INT arrived while the process is in the SIG_QUIT handler? (`^\` → `^C` → `^\`)

    - Back to the normal after jumping to the `quithandler`, `inthandler`, and back to `quithandler`

```
dynam@DESKTOP-Q4IJBP7:~/lab8$ ./sigdemo3

Type a message
^\ Received signal 3 .. waiting
  Leaving quithandler
^C Received signal 2 .. waiting
  Leaving inthandler
^\ Received signal 3 .. waiting
  Leaving quithandler
```

Multiple Signals Example 1: `sigdemo3.c` (cont.)

- Q3) What happened if a second SIG_INT arrived while the process is still in the SIG_INT handler? Or a third SIG_INT? (`^C → ^C → ^C`)
  - Recursively, calling the same handler
  - Ideally, better to block later signals…
- Q4) What happens if a signal arrives while the program is blocking on input? (`^\ → ^C → Enter`)
  - Back to the normal; somewhat strange...

Signal Handling I: Using `signal` (cont.)

- Besides, the original signal system has two other weaknesses.
  - W1) You don't know why the signal was sent
  - Tells the handler which signal invoked it (using signum)
    - inthandler is invoked with SIGINT, and quithandler with SIGQUIT.
  - However, it does not tell the handler why the signal was generated

Signal Handling I: Using `signal` (cont.)

- W2) You cannot safely block other signals while in a handler
  - Say our program wants to ignore `SIGQUIT` when answering `SIGINT`
  - A modified version looks like the one below. Any problem??

```
void inthandler(int s)  // A handler for SIGINT
{
    int rv ;
    void (*prev_qhandler)();                /* holds prev handler */
    prev_qhandler = signal(SIGQUIT, SIG_IGN); /* ignore QUIT's */
    ...
    signal( SIGQUIT, prev_qhandler );        /* restore handler */
}
```

  - Prob. 1: Handling each signal happens in sequence. Both should happen at the same time.
  - Prob. 2: Do not want to ignore SIGQUIT; want to block it until SIGINT processed

Signal Handling II: `sigaction`

- `sigaction`: the POSIX replacement for `signal`
  - POSIX (Portable Operating System Interface): a family of standards specified by IEEE for maintaining compatibility between operating systems (from Wiki)
    - Defines API, along with command line shells and utility interfaces, for software compatibility with variants of Unix/Linux and perhaps other operating systems
    - Tries to minimize any incompatibility issue that might occur to a system program that would run on a different operating system
  - Specifies “which” signal to handle and “how” to respond to that signal

Signal Handling II: `sigaction` (cont.)

- `sigaction`: the POSIX replacement for `signal`
  - `struct sigaction`: a struct to support customized signal handling; specifies how to invoke an old- or new-style handler

sigaction	
PURPOSE	Specify handling for a signal
INCLUDE	`#include <signal.h>`

USAGE	`res = sigaction(int signum,`
	`const struct sigaction *action,`
	`struct sigaction *prevaction);`

ARGS	`signum` signal to handle `action` pointer to struct describing action `prevaction` pointer to struct to receive old action
RETURNS	`-1` on error `0` on success

Signal Handling II: `sigaction` (cont.)

- Customized Signal Handling: Use `struct sigaction`

Only one between these

```
struct sigaction{ // struct, not a function
   /* use only one of the following two */
   void (*sa_handler)(int); // OLD: SIG_DFL, SIG_IGN, or function
   void (*sa_sigaction)(int, siginfo_t *, void *);// NEW handler

   sigset_t sa_mask; // signals to block while handling
   int sa_flags;     // enable various behaviors
}
```

Using an old-style handler	Using a new-style handler

`struct sigaction action;`
`action.`**`sa_handler`** `=`
`handler_old``;`
	`struct sigaction action;`
	`action.`**`sa_sigaction`** `=`
	`handler_new``;`

- How do you tell the kernel you are using the new-style handler?
  - Easy, just set the `SA_SIGINFO` bit in (`sigaction.`)**`sa_flags`**

Signal Handling II: `sigaction` (cont.)

- sa_flags
  - A set of bits that control how the handler answers about the four questions

Flag	Meaning
SA_RESETHAND	Reset the handler when invoked. This enables mousetrap mode.
SA_NODEFER	Turn off automatic blocking of a signal while it is being handled. This allows recursive calls to a signal handler.
SA_RESTART	Restart, rather than return, system calls on slow devices and similar system calls. This enables BSD mode.
SA_SIGINFO	Use the value in `sa_sigaction` for the handler function. If this bit is not set, use the value in `sa_handler`. If the `sa_sigaction` value is used, that handler function is passed not only the signal number, but also pointers to structs containing information about why and how the signal was generated.

- sa_mask: an important technique for data corruption prevention
  - Decide if we would like to block any other signal while in the handler
  - Contains a set of signals to block

Signal Handling II: `sigaction` (cont.)

```c
/* sigactdemo.c
 *               purpose: shows use of sigaction()
 *               feature: blocks ^\ while handling ^C
 *                        does not reset ^C handler, so two kill
 */

#include        <stdio.h>
#include        <unistd.h>
#include        <signal.h>
#define INPUTLEN        100

void inthandler(int);

int main()
{
        struct sigaction newhandler;            /* new settings         */
        sigset_t         blocked;               /* set of blocked sigs */
        void             inthandler();          /* the handler          */
        char             x[INPUTLEN];

        /* load these two members first */
        newhandler.sa_handler = inthandler;      /* handler function    */
        newhandler.sa_flags = SA_RESETHAND | SA_RESTART;  /* options    */

        /* then build the list of blocked signals */
        sigemptyset(&blocked);                   /* clear all bits      */
        sigaddset(&blocked, SIGQUIT);            /* add SIGQUIT to list */

        newhandler.sa_mask = blocked;            /* store blockmask     */

        if ( sigaction(SIGINT, &newhandler, NULL) == -1 )
                perror("sigaction");
        else
                while( 1 ){
                        fgets(x, INPUTLEN, stdin);
                        printf("input: %s", x);
                }

        return 0;
}
```

- `sigactdemo.c`

```c
void inthandler(int s)
{
        printf("Called with signal %d\n", s);
        sleep(s);
        printf("done handling signal %d\n", s);
}
```

Protecting Data from Corruption

- Critical Sections
  - A section of code that modifies a data structure if interruptions to that section of code can produce incomplete or damaged data
    - e.g., A postal office with interrupting telephone calls and knocks on the door
- You must determine which parts of code are critical sections and arrange to protect those sections
  - When you write your code with signals
- Note that critical sections are “not always” in signal handlers
  - Actually, many of them are in regular flow of a program
- What is the “simplest” way to protect critical sections?
  - “ignoring” or “blocking” signals that call handlers that use or change the data

Blocking Signals: `sigprocmask()` and `sigsetops`

- We can block signals (i) at the signal-handler level and (ii) at the process level.
- How can we block signals in a "signal handler"? --- (i)
  - Set the `sa_mask` member
- How can we block signals for a "process"? --- (ii)
  - A process has a set of its blocking signals, called signal mask.
  - To modify that set of blocked signals, use `sigprocmask()`:
    - Takes a set of signals, and
    - Uses (in an atomic operation, such that no other process can alter the mask) that set to change the current set of blocked signals

How to Modify the Signal Mask?

- `sigprocmask()` modifies the present signal mask with the signals in `*sigs` as specified by a how value.
- `sigset_t`: defines a set of signals to be added or deleted for mask

sigprocmask		
PURPOSE	Modify current signal mask	
INCLUDE	`#include <signal.h>`	

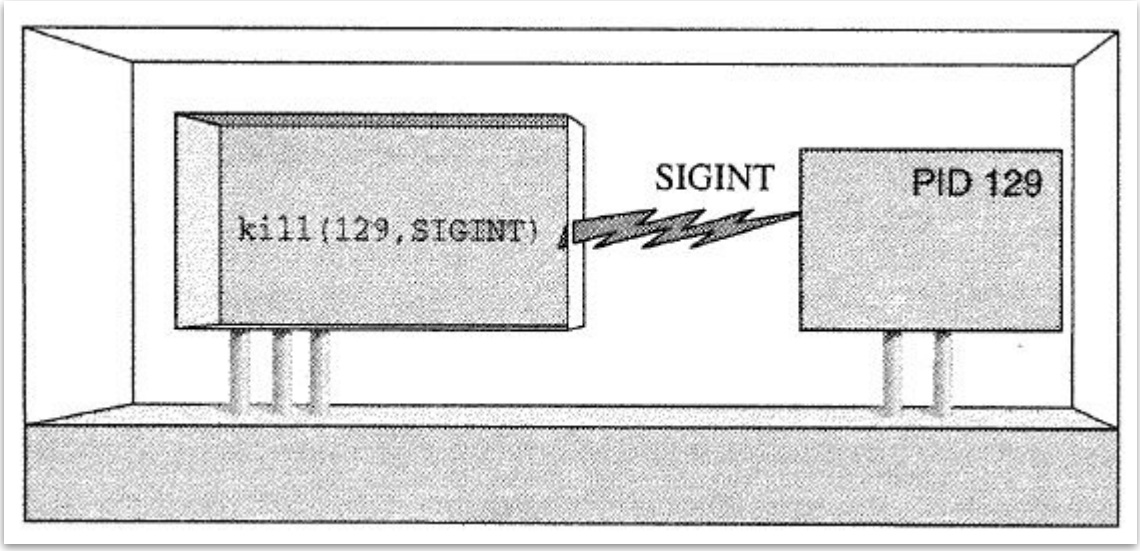
USAGE	`int res = sigprocmask( int how,`
	`const sigset_t *sigs,`
	`sigset_t *prev);`	

ARGS	how	how to modify the signal mask
	sigs	pointer to list of signals to use
	prev	pointer to list of previous signal mask (or NULL)
RETURNS	-1	on error
	0	on success

Building Signal Sets with `sigsetops` (Signal Set Operations)

- `sigset_t`
  - Abstract set of signals that has methods for signal addition or removal
  - `sigaddset(sigset_t* setp, int signum)`
    - Add `signum` to the set pointed by `setp`
  - `sigdelset(sigset_t* setp, int signum)`
    - Remove `signum` from the set pointed to by `setp`
  - `sigfillset(sigset_t* setp)`
    - Add all signals to the list pointed to by `setp`
  - `sigemptyset(sigset_t* setp)`
    - Clear all signals from the list pointed to by `setp`

`kill`: Sending Signals from a Process



< A process uses kill() to send a signal >

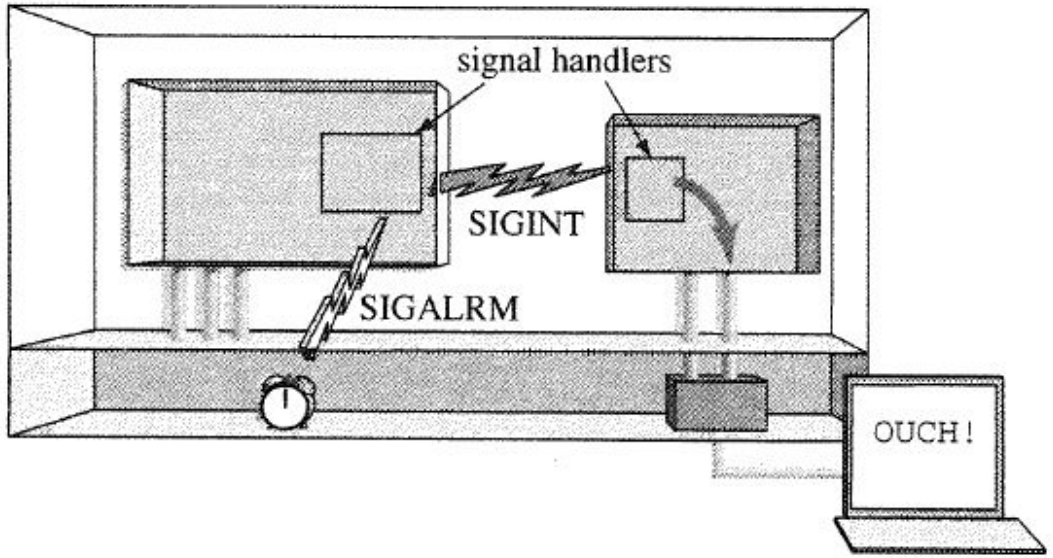
- Signals arise from many different objects:
  - Interval timers, the terminal driver, the kernel, and processes
- A process can send a signal to another process. How?
  - By using the kill system call

`kill`: Sending Signals from a Process (cont.)

- Lessons
  - The process sending the signal must have the same user ID as the target process
  - Or the sending process must be owned by the superuser
  - The kill program is used at inter-process communication (IPC) (on the local machine)

kill		
PURPOSE	Send a signal to a process	
INCLUDE	#include <sys/types.h> #include <signal.h>	
USAGE	int kill(pid_t pid, int sig)	
ARGS	pid sig	process id of target signal to throw
RETURNS	-1 0	on error on success

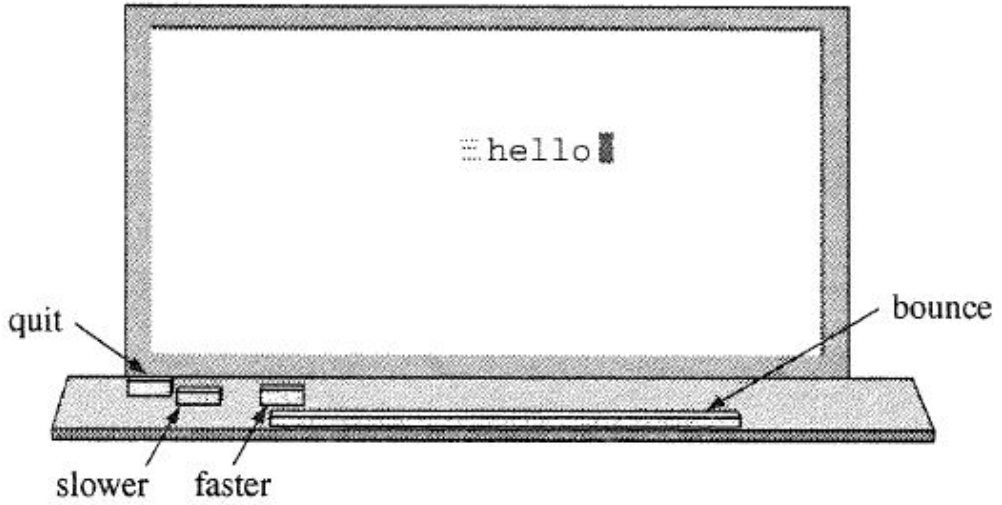
`kill`: Sending Signals from a Process (cont.)



< Complex use of signals >

- Implications for Interprocess Communication
  - Suppose that P1 sets its interval timer, which after the specified interval generates a signal, or SIGALRM, and calls a signal handler receiving it
  - P1's signal handler then sends SIGINT to P2 using kill().
  - P2 with a signal handler for SIGINT, receives it and prints out "OUCH!"

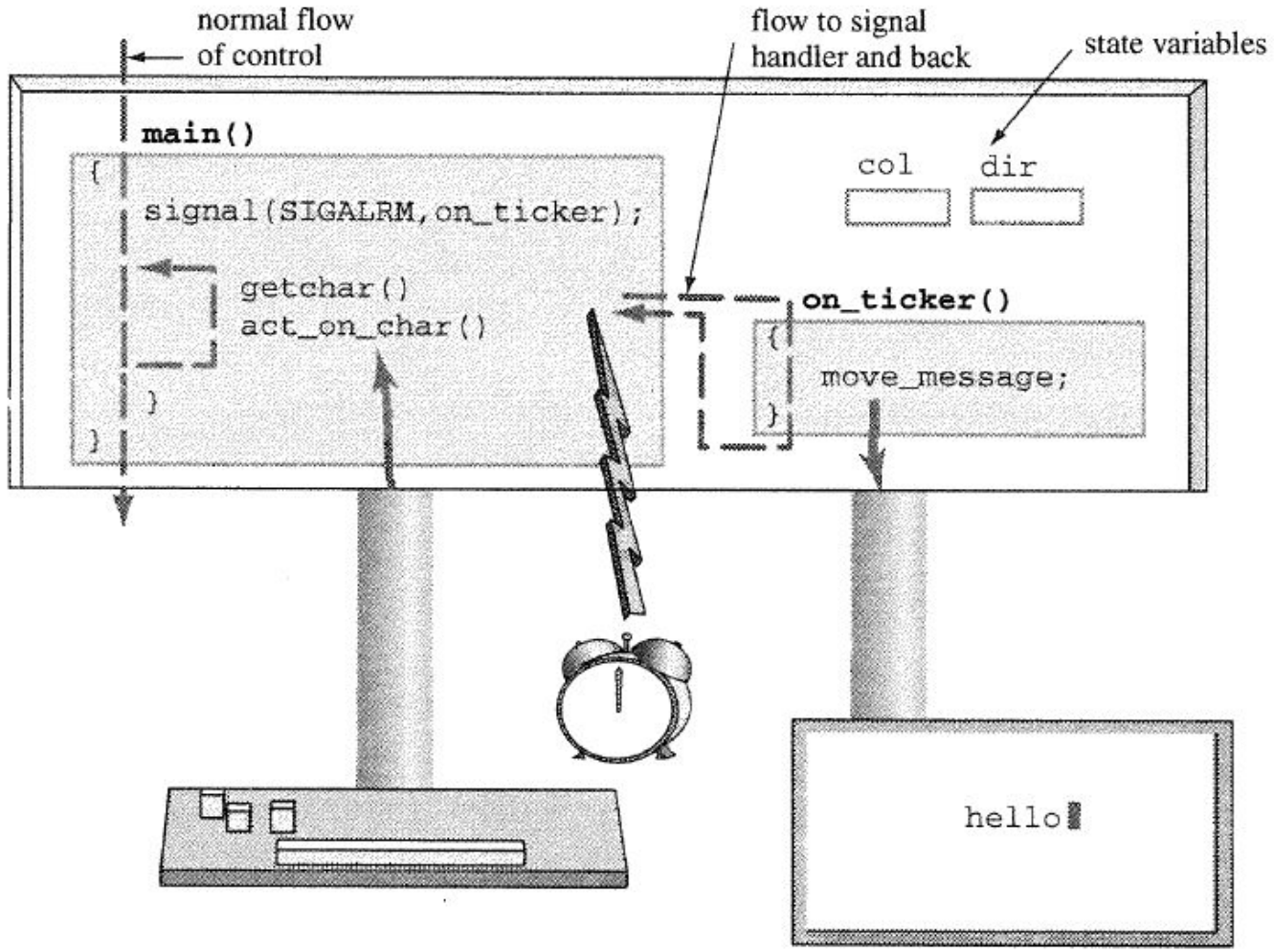
Using Timers and Signals: Video Games



< `bounce1d` in action: user-controlled animation >

- This program moves a single word smoothly across the screen.
  - Space bar: the message reverses direction.
  - “s” and “f”: make the message move slower and faster, respectively.
  - “Q” : quits the game
  - Besides, two variables for direction (“left” or “right”) and speed of motion (causing a “long” or “short” delay the interval between timer ticks)
- Let’s add user control of direction and speed to the program
  - State variables and event handling come into play for this extra work

Using Timers and Signals: Video Games (cont.)



< User input changes values. Values control action. >

bounce1d.c: Controlled Animation on a Line

```c
/* bounce1d.c
 *      purpose animation with user controlled speed and direction
 *      note    the handler does the animation
 *              the main program reads keyboard input
 *      compile cc bounce1d.c set_ticker.c -lcurses -o bounce1d
 */
#include        <stdio.h>
#include        <curses.h>
#include        <signal.h>
#include        <string.h>

/* some global settings main and the handler use */

#define MESSAGE "hello"
#define BLANK   "     "

void move_msg(int);
int set_ticker(int);

int     row;    /* current row          */
int     col;    /* current column       */
int     dir;    /* where we are going   */
```

```c
int main()
{
        int     delay;          /* bigger => slower     */
        int     ndelay;         /* new delay            */
        int     c;              /* user input           */
        void    move_msg(int);  /* handler for timer    */

        initscr();
        crmode();
        noecho();
        clear();

        row   = 10;             /* start here           */
        col   = 0;
        dir   = 1;              /* add 1 to row number  */
        delay = 200;            /* 200ms = 0.2 seconds  */

        move(row,col);          /* get into position    */
        addstr(MESSAGE);        /* draw message         */
        signal(SIGALRM, move_msg );
        set_ticker( delay );

        while(1)
        {
                ndelay = 0;
                c = getch();
                if ( c == 'Q' ) break;
                if ( c == ' ' ) dir = -dir;
                if ( c == 'f' && delay > 2 ) ndelay = delay/2;
                if ( c == 's' ) ndelay = delay * 2 ;
                if ( ndelay > 0 )
                        set_ticker( delay = ndelay );
        }
        endwin();
        return 0;
}
```

`bounce1d.c`: Controlled Animation on a Line (cont.)

```c
void move_msg(int signum)
{
        signal(SIGALRM, move_msg);      /* reset, just in case  */
        move( row, col );
        addstr( BLANK );
        col += dir;                     /* move to new column   */
        move( row, col );               /* then set cursor      */
        addstr( MESSAGE );              /* redo message         */
        refresh();                      /* and show it          */

        /*
         * now handle borders
         */
        if ( dir == -1 && col <= 0 )
                dir = 1;
        else if ( dir == 1 && col+strlen(MESSAGE) >= COLS )
                dir = -1;
}
```

```
$ gcc -o bounce1d bounce1d.c
set_ticker.c -lcurses
```

```c
#include        <stdio.h>
#include        <sys/time.h>
#include        <signal.h>

/*
 *      set_ticker.c
 *          set_ticker( number_of_milliseconds )
 *                  arranges for the interval timer to issue
 *                  SIGALRM's at regular intervals
 *          returns -1 on error, 0 for ok
 *
 *      arg in milliseconds, converted into micro seoncds
 */


int set_ticker( int n_msecs )
{
        struct itimerval new_timeset;
        long    n_sec, n_usecs;

        n_sec = n_msecs / 1000 ;
        n_usecs = ( n_msecs % 1000 ) * 1000L ;

        new_timeset.it_interval.tv_sec  = n_sec;        /* set reload  */
        new_timeset.it_interval.tv_usec = n_usecs;      /* new ticker value */
        new_timeset.it_value.tv_sec     = n_sec  ;      /* store this   */
        new_timeset.it_value.tv_usec    = n_usecs ;     /* and this     */

        return setitimer(ITIMER_REAL, &new_timeset, NULL);
}
```

Summary

- A video game responds to time and to user input
  - OS also reacts to time and to input from external devices
- The `curses` library is a set of functions that programs can call to manage the appearance of a text screen
- A process schedules events by setting “timers”; each set to ring once or at regular intervals
  - Each process can run three separate timers; real, virtual, and profile

Summary (cont.)

- Handling a single signal is easy while doing multiple ones is more complicated
  - A process can ignore or block signals; it should determine how to react to them
  - Should tell the kernel which signals to block or ignore at which times
- Some functions perform uninterruptable operations (in critical section)
  - A program can protect them via careful use of signal masks