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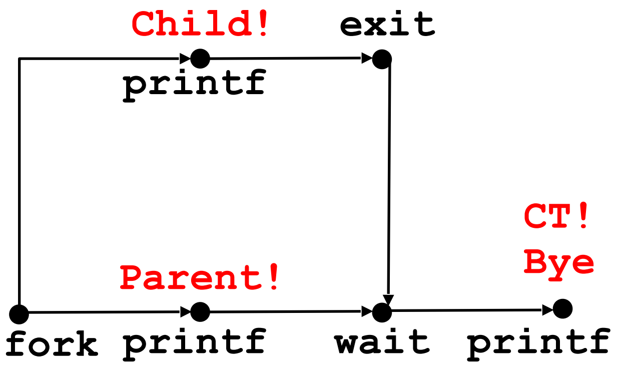
Process Control *con't*

+ `wait()`: Synchronizing with Children

- **Parent reaps a child by calling the wait function**
- **`int wait(int *child_status)`**
  - Suspends current process until one of its children terminates
  - Return value is the pid of the child process that terminated
  - If child_status != NULL, then the integer it points to will be set to a value that indicates reason the child terminated and the exit status.
    - See textbook for more details.

+ wait(): Example

```
void fork9() {
    int child_status;

    if (fork() == 0) {
        printf(“Child!”);
       exit(0);
    } else {
        printf(“Parent!);
        wait(&child_status);
        printf(“CT!”);
    }
    printf("Bye\n");
}
```



Feasible output:
Parent!
Child!
CT!
Bye

Infeasible output:
Parent!
CT!
Bye
Child!

Another wait() Example

- If multiple children completed, will take in arbitrary order
- Use WIFEXITED and WEXITSTATUS to get exit status

```
void fork10() {
    int pid[N];
    int i, child_status;

    for (i = 0; i < N; i++)
        if ((pid[i] = fork()) == 0)
            exit(100+i); /* Child */

    for (i = 0; i < N; i++) { /* Parent */
        int child_pid = wait(&child_status);
        if (WIFEXITED(child_status))
            printf("Child %d terminated with exit status %d\n",
                   child_pid, WEXITSTATUS(child_status));
        else
            printf("Child %d terminate abnormally\n", child_pid);
    }
}
```

waitpid(): Waiting for a Specific Process

- `int waitpid(pid_t pid, int &child_status, int options)`
  - Suspends current process until specific process terminates
  - Various options (see textbook)

```
void fork11() {
    int pid[N];
    int i, child_status;

    for (i = 0; i < N; i++)
        if ((pid[i] = fork()) == 0)
            exit(100+i); /* Child */

    for (i = N-1; i >= 0; i--) {
        int child_pid = waitpid(pid[i], &child_status, 0);
        if (WIFEXITED(child_status))
            printf("Child %d terminated with exit status %d\n",
                   child_pid, WEXITSTATUS(child_status));
        else
            printf("Child %d terminate abnormally\n", child_pid);
    }
}
```

+ execve(): Loading and Running Programs

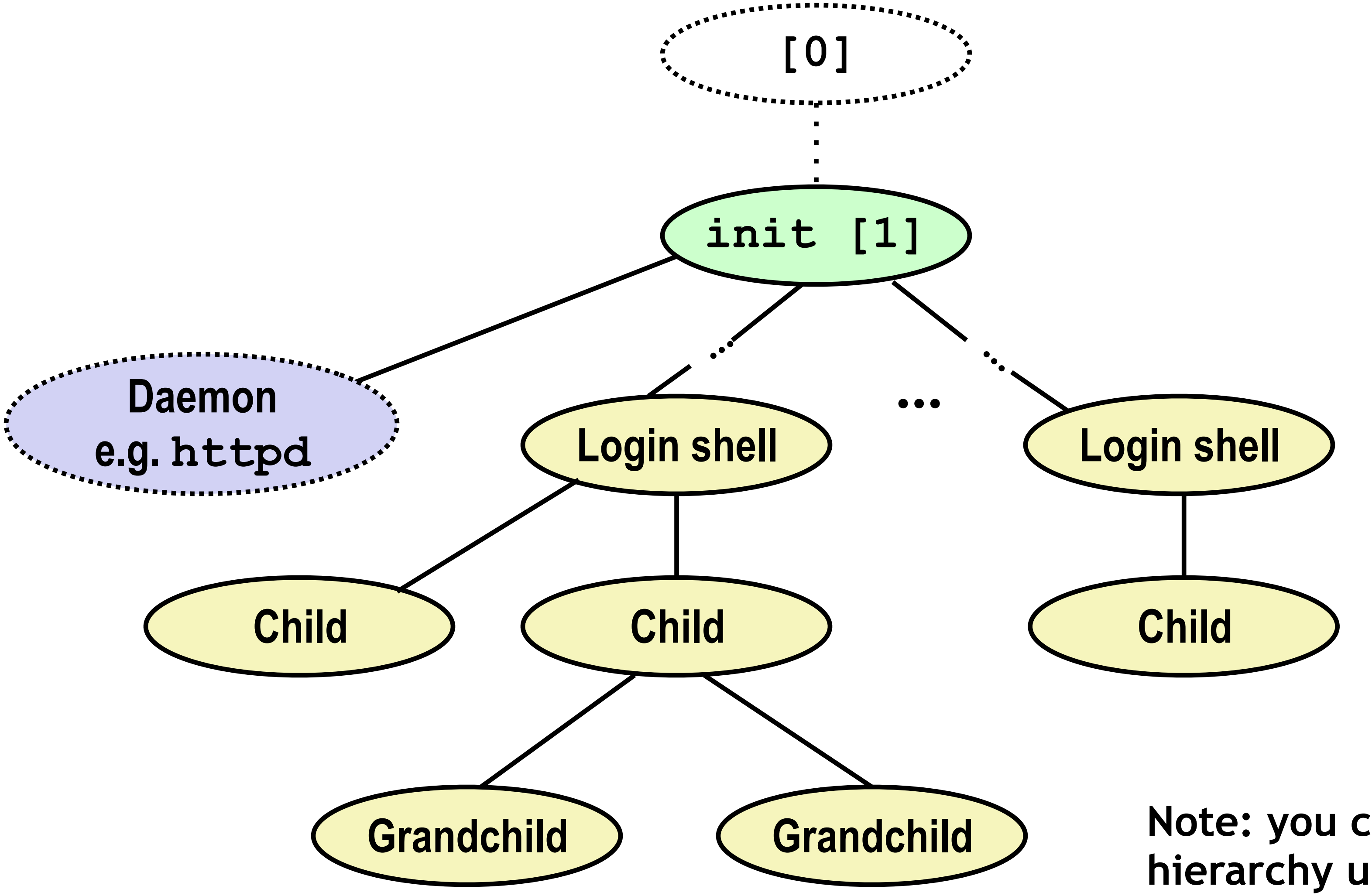
- `int execve(char* filename, char* argv[], char* envp[])`
- **Loads and runs in the current process:**
  - Executable file `filename`
  - Argument list `argv`
  - Environment variable list `envp`
    - "name=value" strings (e.g., `USER=rshepherd`)
    - `getenv(), putenv(), printenv()`
- **Overwrites code, data, and stack**
  - Retains PID, open files and signal context
- **Called once and never returns**
  - …except if there is an error
- **See book for more details.**

+ Summary

- **Creating processes**
  - Call `fork`
  - One call, two returns
- **Process completion**
  - Call `exit`
  - One call, no return
- **Reaping and waiting for processes**
  - Call `wait` or `waitpid`
- **Loading and running programs**
  - Call `execve`
  - One call, (normally) no return

Signals

+ Linux Process Hierarchy



Note: you can view the hierarchy using the Linux `pstree` command

Shell Programs

- A shell is an application program that runs programs on behalf of the user.
  - **sh** Original Unix shell (Stephen Bourne, AT&T Bell Labs, 1977)
  - **bash** "Bourne-Again" Shell (default Linux shell)
  - **csh**, **zsh**… many others

```
int main()
{
    char cmdline[MAXLINE]; /* command line */

    while (1) {
        /* read */
        printf("> ");
        fgets(cmdline, MAXLINE, stdin);
        if (eof(stdin))
            exit(0);

        /* evaluate */
        eval(cmdline);
    }
}
```

Execution is a sequence of read/evaluate steps

+ Simple Shell eval Function

```
void eval(char* cmdline)
{
    char* argv[MAXARGS]; /* Argument list for program to be run*/
    int bg;              /* Should the job run in bg or fg? */
    int pid;             /* Process id */

    bg = parseline(cmdline, argv); /* Extract arguments and set bg */

    if ((pid = Fork()) == 0) {   /* Child runs user job */
       if (execve(argv[0], argv) < 0) {
           printf("%s: Command not found.\n", argv[0]);
           exit(0);
       }
    }

    /* Parent waits for foreground job to terminate */
     if (!bg) {
        int status;
        if (waitpid(pid, &status, 0) < 0)
           printf("waitfg: waitpid error %d”, status);
    } else {
        printf("%d %s", pid, cmdline);

    }


    return;
}
```

+ Problem with Simple Shell Example

- **Our example shell correctly waits for and reaps foreground jobs**
- **But what about background jobs?**
  - Will become zombies when they terminate
  - Will never be reaped because shell (probably) will not terminate
  - Will create a memory leak that could run the kernel out of memory

+ Solution: Exceptional control flow

- **We can leverage exceptional control flow from our programs**
  - The kernel will interrupt regular processing to alert us when a background process completes
  - In Unix, the mechanism is called a **signal**

+ Signals

- **A signal is a small message that notifies a process that an event of some type has occurred in the system**
  - Akin to exceptions and interrupts
  - Sent from the kernel (sometimes at the request of another process)
  - Signal type is identified by integer ID's (1-30)
  - Only information in a signal is its ID and the fact that it arrived

ID	*Name*	*Default Action*	*Corresponding Event*
2	SIGINT	Terminate	User typed ctrl-c
9	SIGKILL	Terminate	Kill program (cannot override or ignore)
11	SIGSEGV	Terminate	Segmentation violation
17	SIGCHLD	Ignore	Child stopped or terminated

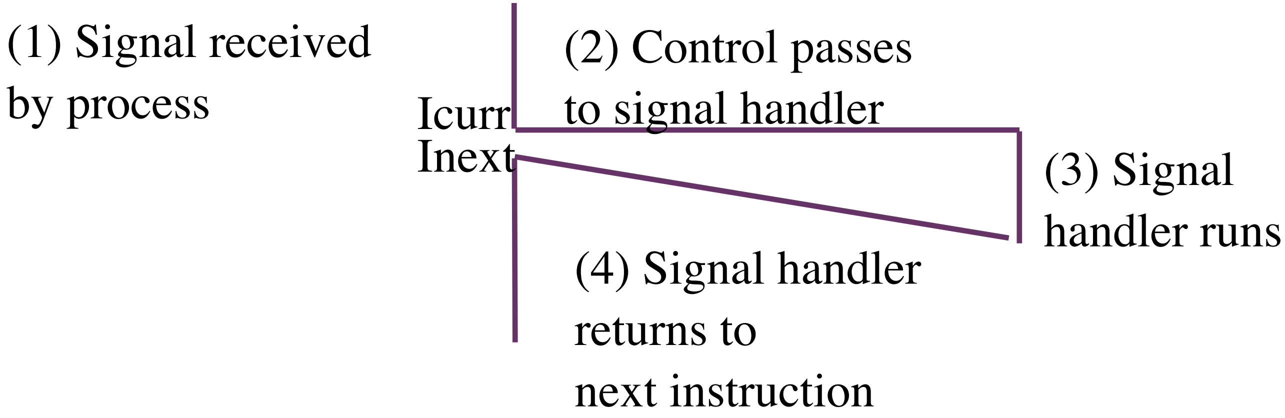
+ Signal Concepts: Sending a Signal

- **Kernel sends (delivers) a signal to a destination process by updating some state in the context of the destination process**

- **Kernel sends a signal for one of the following reasons:**
  - Kernel has detected a system event such as the termination of a child process (SIGCHLD)
  - Another process has invoked the `kill` system call to explicitly request the kernel to send a signal to the destination process

+ Signal Concepts: Receiving a Signal

- **A destination process receives a signal when it is forced by the kernel to react in some way to the delivery of the signal**
- **Some possible ways to react:**
  - *Ignore* the signal
  - *Terminate* the process
  - *Catch* signal by executing a user-level function called *signal handler*
    - Like exception handler called in response to an async interrupt



+ Signal Concepts: Pending & Blocked

- **A signal is *pending* if *sent* but not yet *received***
  - There can be at most one pending signal of any particular type
  - Important: Signals are not queued
    - If a process has a pending signal of type k, then subsequent signals of type k that are sent to that process are discarded

- **A process can *block* the receipt of certain signals**
  - Blocked signals can be delivered, but will not be received until the signal is unblocked
  - Cannot block SIGKILL or SIGSTOP

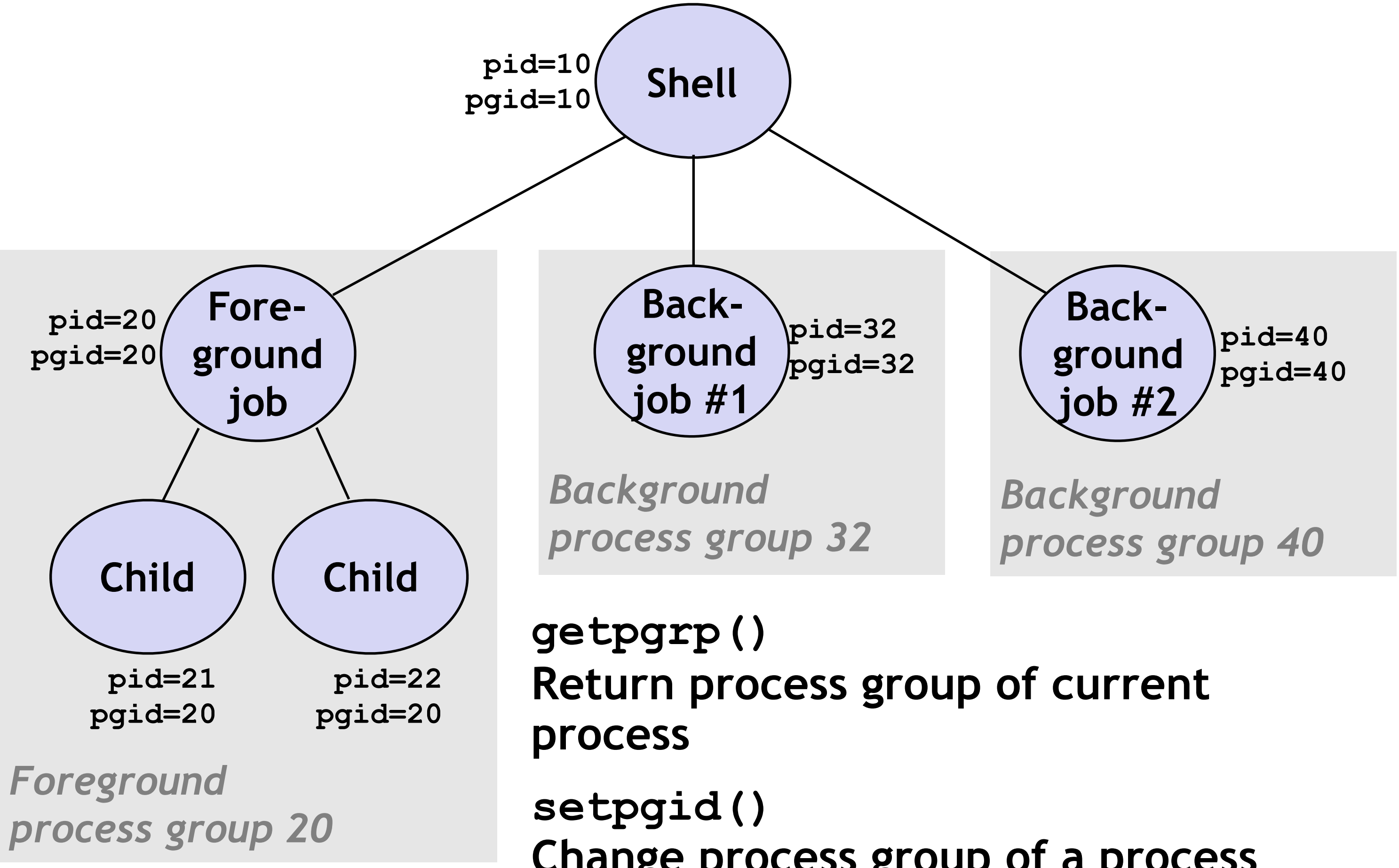
- **A *pending* signal is received at most once**

+ Signal Concepts: Pending/Blocked Bits

- **Kernel maintains `pending` and `blocked` bit vectors in the context of each process**
  - **`pending`**: represents the set of pending signals
    - Kernel sets bit k in pending when a signal of type k is delivered
    - Kernel clears bit k in pending when a signal of type k is received
  - **`blocked`**: represents the set of blocked signals
    - Can be set and cleared by using the `sigprocmask` function
    - Also sometimes referred to as the "`signal mask`".

Sending Signals: Process Groups

- Every process belongs to exactly one process group



`getpgrp()`
Return process group of current process

`setpgid()`
Change process group of a process (see text for details)

+ Sending Signals with /bin/kill Program

- **`/bin/kill` program sends specified signal to a process or process group**

- **Examples**
  - `/bin/kill -9 24818`
    Send SIGKILL to process 24818
  - `/bin/kill -9 -24817`
    Send SIGKILL to every process in process group 24817

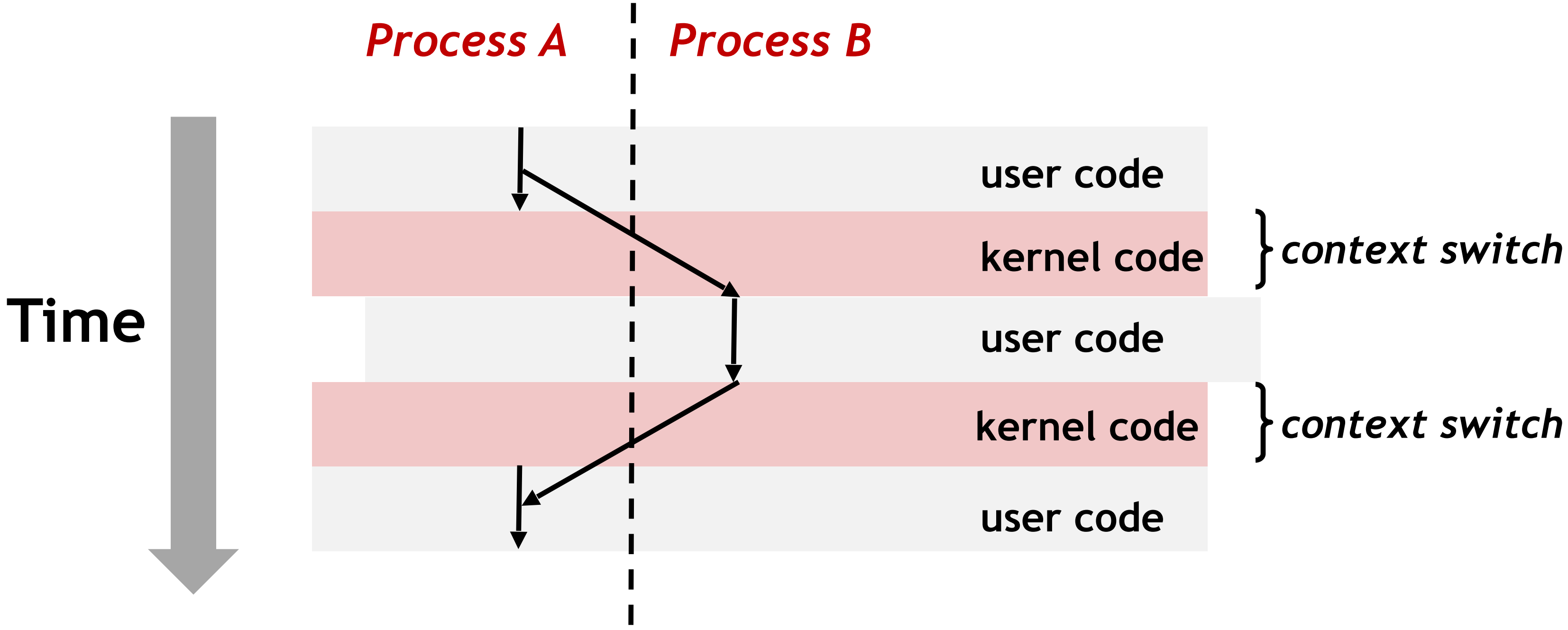
```
linux> ./forks 16
Child1: pid=24818 pgrp=24817
Child2: pid=24819 pgrp=24817

linux> ps
  PID TTY          TIME CMD
24788 pts/2    00:00:00 tcsh
24818 pts/2    00:00:02 forks
24819 pts/2    00:00:02 forks
24820 pts/2    00:00:00 ps
linux> /bin/kill -9 -24817
linux> ps
  PID TTY          TIME CMD
24788 pts/2    00:00:00 tcsh
24823 pts/2    00:00:00 ps
linux>
```

Sending Signals with `kill` Function

```c
void fork12()
{
    pid_t pid[N];
    int i;
    int child_status;

    for (i = 0; i < N; i++)
        if ((pid[i] = fork()) == 0) {
            /* Child: Infinite Loop */
            while(1) {}
        }

    for (i = 0; i < N; i++) {
        printf("Killing process %d\n", pid[i]);
        kill(pid[i], SIGINT);
    }

    for (i = 0; i < N; i++) {
        int wpid = wait(&child_status);
        if (WIFEXITED(child_status))
            printf("Child %d terminated with exit status %d\n",
                   wpid, WEXITSTATUS(child_status));
        else
            printf("Child %d terminated abnormally\n", wpid);
    }
}
```

+ Receiving Signals

- **Suppose kernel is returning from an exception handler and is ready to pass control to process *B***



Receiving Signals *con't*

- **Suppose kernel is returning from an exception handler and is ready to pass control to process B**

- **Kernel computes pnb = pending & ~blocked**
  - The set of pending nonblocked signals for process B

- **If (pnb == 0)**
  - Pass control to next instruction in the logical flow for B

- **Else**
  - Choose nonzero bit k in pnb and force process B to receive signal k
  - The receipt of the signal triggers some action by B
  - Repeat for all nonzero bits in pnb
  - Pass control to next instruction in logical flow for B

+ Default Actions

- **Each signal type has a predefined default action, which is one of:**
  - The process terminates
  - The process stops until restarted by a SIGCONT signal
  - The process ignores the signal
- **What if we do not like the default action?**
  - *Signal handlers*

+ Installing Signal Handlers

- **The signal function modifies the default action associated with the receipt of signal `signum`:**
  - `handler_t* signal(int signum, handler_t* handler)`

- **Different values for handler (macros for commons cases):**
  - `SIG_IGN`: ignore signals of type `signum`
  - `SIG_DFL`: revert to the default action for signals of type `signum`
  - Otherwise, handler is the address of a user-level *signal handler*
    - Called when process receives signal of type `signum`
    - When the handler executes its return statement, control passes back to instruction in the control flow of the process that was interrupted by receipt of the signal.

- **Returns the previous value of the signal handler, or SIG_ERR on error.**

+ Signal Handling Example

```
void sigint_handler(int sig) /* SIGINT (ctrl+c) handler */ {
    printf(“You want me to quit???\n”);
    sleep(2);
    exit();
}

int main(){
    /* Install the SIGINT handler */
    if (signal(SIGINT, sigint_handler) == SIG_ERR)
        unix_error("signal error");

    /* Wait for the receipt of a signal */
    pause();

    return 0;
}
```