Exceptions, Processes and Signals

Computer Systems Organization (Spring 2017)
CSCI-UA 201, Section 3

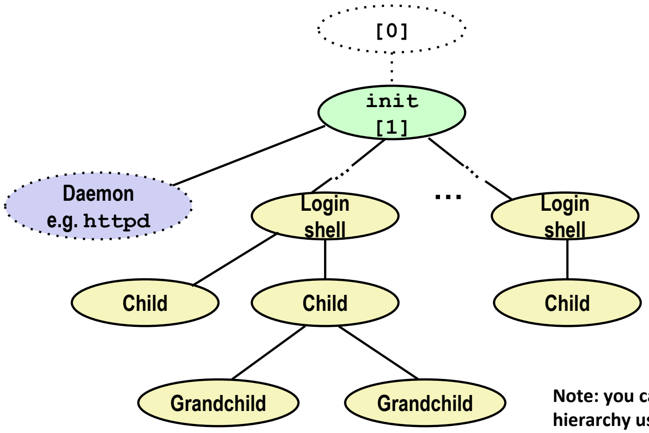
Instructor: Joanna Klukowska

Slides adapted from
Randal E. Bryant and David R. O'Hallaron (CMU)
Mohamed Zahran (NYU)

Shells

See https://en.wikipedia.org/wiki/Shell_(computing)

Linux Process Hierarchy



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

Shell Programs

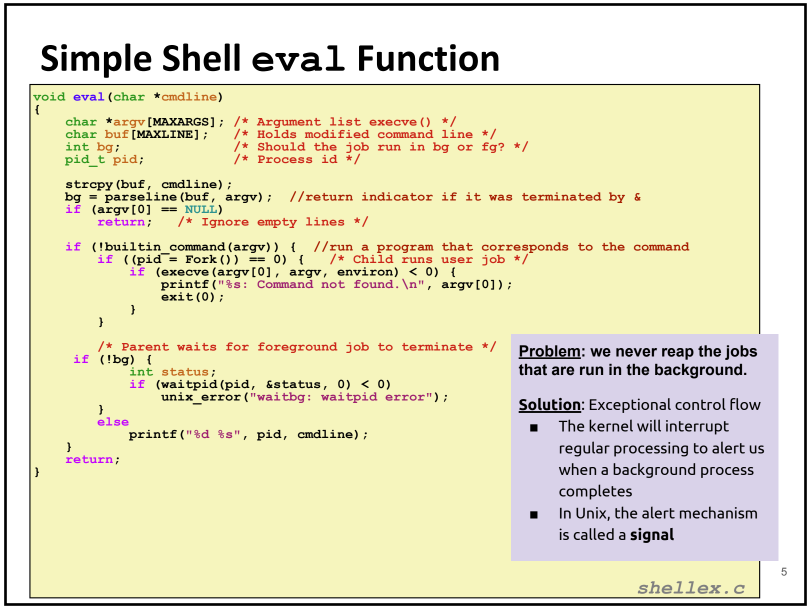
A **shell** is an application program that runs programs on behalf of the user.

- **sh** Original Unix shell (Stephen Bourne, AT&T Bell Labs, 1977)
- **csh/tcsh** BSD Unix C shell
- **bash** "Bourne-Again" Shell (default Linux shell)

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

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

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

shellex.c

Execution is a sequence of read/evaluate steps



Simple Shell `eval` Function

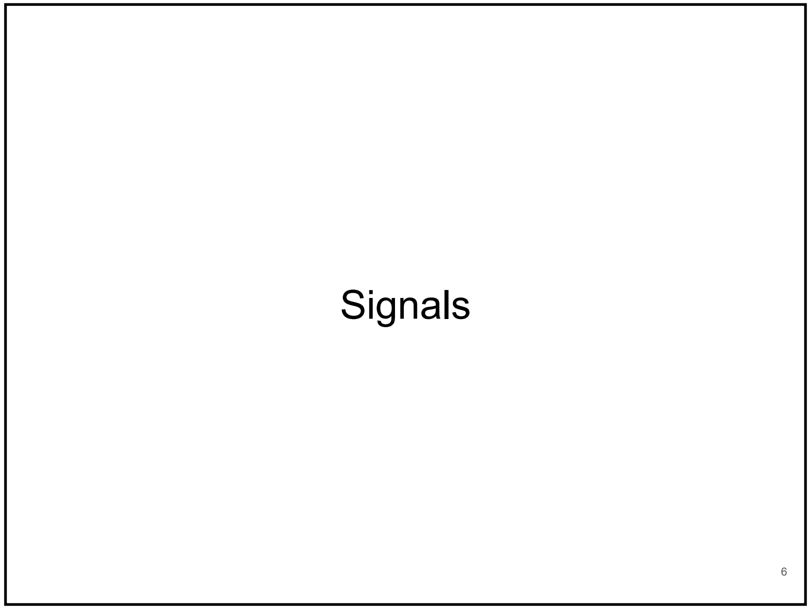
```
void eval(char *cmdline)
{
    char *argv[MAXARGS]; /* Argument list execve() */
    char buf[MAXLINE];   /* Holds modified command line */
    int bg;              /* Should the job run in bg or fg? */
    pid_t pid;           /* Process id */

    strcpy(buf, cmdline);
    bg = parseline(buf, argv);  //return indicator if it was terminated by &
    if (argv[0] == NULL)
        return;   /* Ignore empty lines */

    if (!builtin_command(argv)) {  //run a program that corresponds to the command
        if ((pid = Fork()) == 0) {   /* Child runs user job */
            if (execve(argv[0], argv, environ) < 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)
                unix_error("waitbg: waitpid error");
        }
        else
            printf("%d %s", pid, cmdline);
    }
    return;
}
```

Problem: we never reap the jobs that are run in the background.

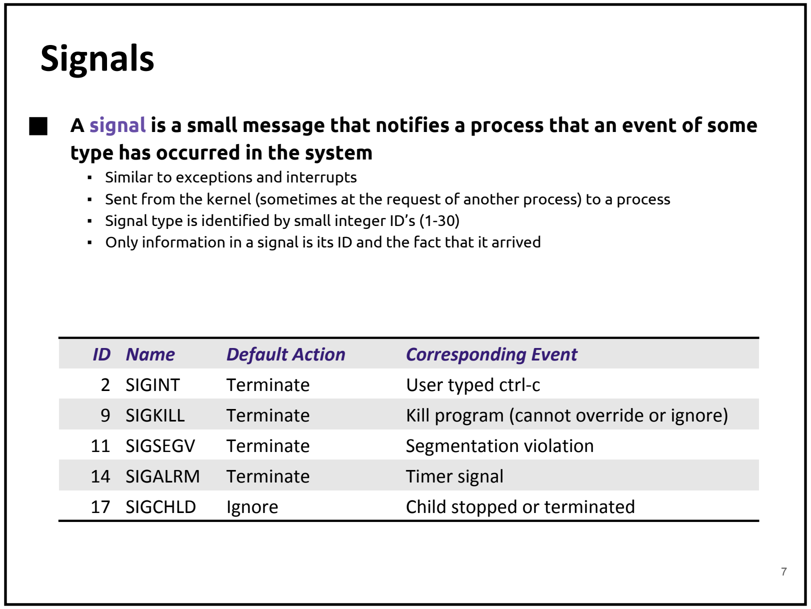
Solution: Exceptional control flow

- The kernel will interrupt regular processing to alert us when a background process completes
- In Unix, the alert mechanism is called a **signal**

shellex.c



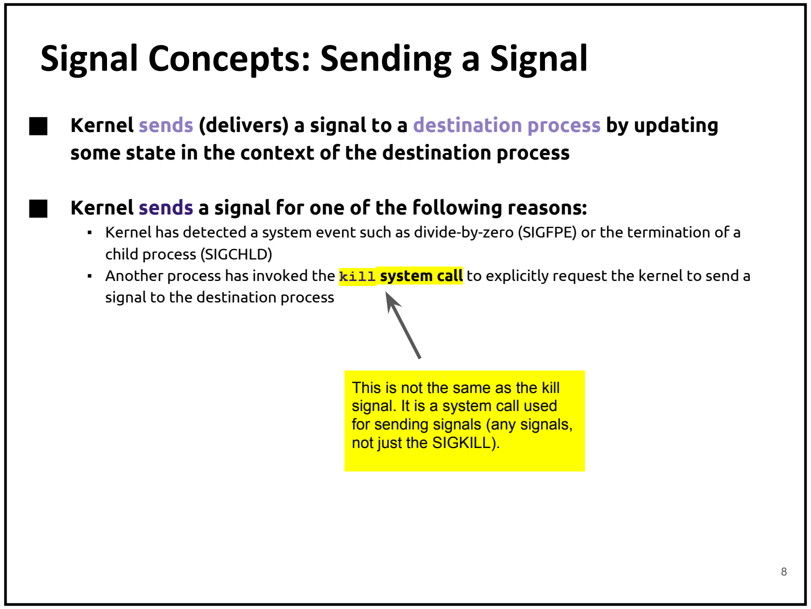
Signals



Signals

- **A signal is a small message that notifies a process that an event of some type has occurred in the system**
  - Similar to exceptions and interrupts
  - Sent from the kernel (sometimes at the request of another process) to a process
  - Signal type is identified by small 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
14	SIGALRM	Terminate	Timer signal
17	SIGCHLD	Ignore	Child stopped or terminated



Signal Concepts: Sending a Signal

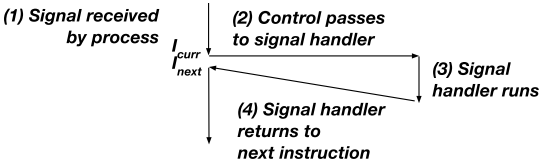
- **Kernel sends (delivers) a signal to a destination process by updating some state in the context of the destination process**
- **Kernel sends a signal for one of the following reasons:**
  - Kernel has detected a system event such as divide-by-zero (SIGFPE) or the termination of a child process (SIGCHLD)
  - Another process has invoked the **`kill` system call** to explicitly request the kernel to send a signal to the destination process

This is not the same as the kill signal. It is a system call used for sending signals (any signals, not just the SIGKILL).

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 (do nothing)
  - **Terminate** the process (with optional core dump)
  - **Catch the signal** by executing a user-level function called **signal handler**



(1) Signal received by process
(2) Control passes to signal handler
(3) Signal handler runs
(4) Signal handler returns to next instruction
I_{curr}
I_{next}

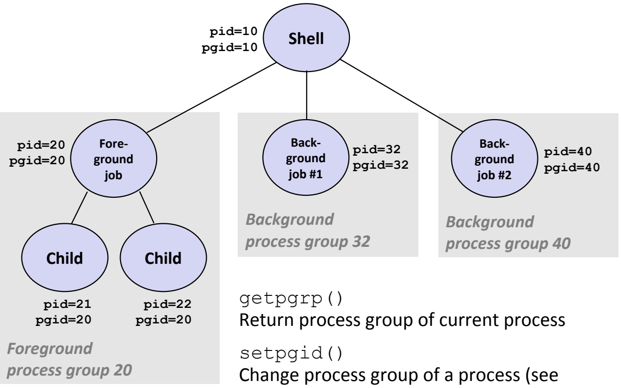
Signal Concepts: Pending and Blocked Signals

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

- 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 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` (or just `kill`) Program

- kill program sends arbitrary signal to a process or process group

- Examples
  - `kill –9 24818`
    Send SIGKILL to process 24818
  - `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>
```

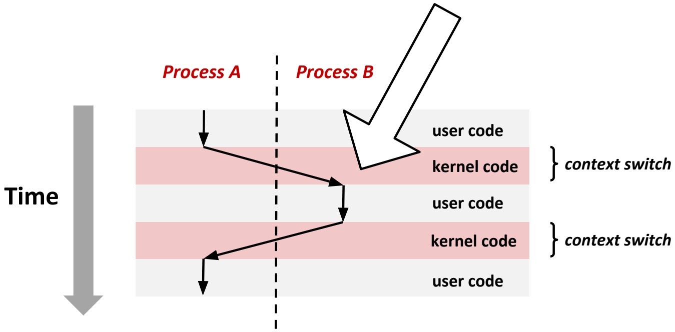
Sending Signals with `kill` System Call

```
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++) {
        pid_t 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);
    }
}
```

forks.c

Receiving Signals

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



Receiving Signals

- **Suppose kernel is returning from an exception handler and is ready to pass control to process p**
- **Kernel computes pnb = pending & ~blocked**
  - The set of pending nonblocked signals for process p
- **If (pnb == 0)**
  - Pass control to next instruction in the logical flow for p
- **Else**
  - Choose least nonzero bit k in pnb and force process p to receive signal k
  - The receipt of the signal triggers some action by p
  - Repeat for all nonzero k in pnb
  - Pass control to next instruction in logical flow for p

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

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:
  - `SIG_IGN`: ignore signals of type signum
  - `SIG_DFL`: revert to the default action on receipt of signals of type signum
  - Otherwise, handler is the address of a user-level signal handler
    - Called when process receives signal of type signum
    - Referred to as “installing” the handler
    - Executing handler is called “catching” or “handling” the signal
    - 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

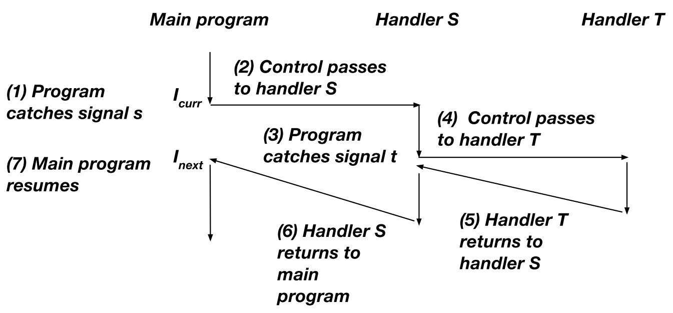
Signal Handling Example

```
void sigint_handler(int sig) /* SIGINT handler */
{
    printf("So you think you can stop the bomb with ctrl-c, do you?\n");
    sleep(2);
    printf("Well...");
    fflush(stdout);
    sleep(1);
    printf("OK. :-)\n");
    exit(0);
}

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;
}
```

sigint.c

Nested Signal Handlers

- Handlers can be interrupted by other handlers



Main program

Handler S

Handler T

(1) Program catches signal s

I_{curr}

(2) Control passes to handler S

(3) Program catches signal t

(4) Control passes to handler T

(5) Handler T returns to handler S

(6) Handler S returns to main program

(7) Main program resumes

I_{next}

Blocking and Unblocking Signals

- Implicit blocking mechanism
  - Kernel blocks any pending signals of type currently being handled.
  - E.g., A SIGINT handler can’t be interrupted by another SIGINT (because only one signal of a given type is allowed)
- Explicit blocking and unblocking mechanism
  - `sigprocmask` function
- Supporting functions
  - `sigemptyset` – Create empty set
  - `sigfillset` – Add every signal number to set
  - `sigaddset` – Add signal number to set
  - `sigdelset` – Delete signal number from set

```
 sigset_t mask, prev_mask;

Sigemptyset(&mask);         //create empty blocking mask
Sigaddset(&mask, SIGINT); //add SIGINT to the mask

/* Block SIGINT and save previous blocked set */
Sigprocmask(SIG_BLOCK, &mask, &prev_mask);

    /* Code region that will not be interrupted by SIGINT */

/* Restore previous blocked set, unblocking SIGINT */
Sigprocmask(SIG_SETMASK, &prev_mask, NULL);
```

Safe Signal Handling

- Handlers are tricky because they are concurrent with main program and share the same global data structures.
  - Shared data structures can become corrupted.
  - Misusing by assuming that signals are queued.
- Read about signals on your Linux system:

```
man 7 signal
```

- Some functions do not work well with signals (like `printf`)
- Signal handling is not portable between systems
- Newer version of signal handlers is `sigaction` (see the book for more details)

In-Correct Signal Handling

```
int ccount = 0;
void child_handler(int sig) {
    int olderrno = errno;
    pid_t pid;
    if ((pid = wait(NULL)) < 0)
        Sio_error("wait error");
    ccount--;
    Sio_puts("Handler reaped child ");
    Sio_putl((long)pid);
    Sio_puts(" \n");
    sleep(1);
    errno = olderrno;
}

void fork14() {
    pid_t pid[N];
    int i;
    ccount = N;
    Signal(SIGCHLD, child_handler);

    for (i = 0; i < N; i++) {
        if ((pid[i] = Fork()) == 0) {
            Sleep(1);
            exit(0);  /* Child exits */
        }
    }
    while (ccount > 0) /* Parent spins */
        ;
}
```

- **Pending signals are not queued**
  - For each signal type, one bit indicates whether or not signal is pending…
  - …thus at most one pending signal of any particular type.
- You can't use signals to count events, such as children terminating.

```
> ./forks 14
Handler reaped child 23240
Handler reaped child 23241
```

Correct Signal Handling

- Must wait for all terminated child processes
  - Put `wait` in a loop to reap all terminated children

```
void child_handler2(int sig)
{
    int olderrno = errno;
    pid_t pid;
    while ((pid = wait(NULL)) > 0) {
        ccount--;
        Sio_puts("Handler reaped child ");
        Sio_putl((long)pid);
        Sio_puts(" \n");
    }
    if (errno != ECHILD)
        Sio_error("wait error");
    errno = olderrno;
}
```

```
> ./forks 15
Handler reaped child 23246
Handler reaped child 23247
Handler reaped child 23248
Handler reaped child 23249
Handler reaped child 23250
```