Signals

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Multitasking (1)

- **Programmer's model of multitasking**
  - **fork()** spawns new process
    - Called once, returns twice
  - **exit()** terminates own process
    - Called once, never returns
    - Puts it into "zombie" status
  - **wait()** and **waitpid()** wait for and reap terminated children
  - **execve()** runs new program in existing process
    - Called once, (normally) never returns

Multitasking (2)

- **Programming challenge**
  - Understanding the nonstandard semantics of the functions.
  - Avoiding improper use of system resources.
    - "Fork bombs"
    - Zombie processes not reaped by parents, etc.

Shell

- **Definition**
  - An application program that runs programs on behalf of the user
    - sh: Original Unix Bourne Shell
    - csh: BSD Unix C Shell
    - tcsh: Enhanced C Shell
    - bash: Bourne-Again Shell

Execution is a sequence of read/evaluate steps

```
int main()
{
    char cmdline[MAXLINE];

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

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

Ctrl+D

Simple Shell Example (1)


```
void eval(char *cmdline) {
    char *argv[MAXARGS]; /* argv for execve() */
    int bg;              /* should the job run in bg or fg? */
    pid_t pid;           /* process id */

    bg = parseline(cmdline, argv);
    if (!builtin_command(argv)) {
        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);
            }
        }
        if (!bg) {   /* parent waits for fg job to terminate */
           int status;
            if (waitpid(pid, &status, 0) < 0)
                unix_error("waitfg: waitpid error");
        }
        else         /* otherwise, don't wait for bg job */
            printf("%d %s", pid, cmdline);
    }
}
```

Simple Shell Example (2)

- **Problem with Simple Shell 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 (typically) will not terminate.
    - Creates a memory leak that will eventually crash the kernel when it runs out of memory.

- **Solution**
  - Reaping background jobs requires a mechanism called a signal.

Signals

- **Definition**
  - A signal is a small message that notifies a process that an event of some type has occurred in the system.
    - Kernel abstraction for exceptions and interrupts.
    - Sent from kernel (sometimes at the request of another process) to a process.
    - Different signals are identified by small integer ID's.
    - The only information in a signal is its ID and the fact that it arrived.

ID	Name	Default Action	Corresponding Event
2	SIGINT	Terminate	Interrupt from keyboard (ctrl-c)
9	SIGKILL	Terminate	Kill program (cannot override or ignore)
11	SIGSEGV	Terminate & Dump	Segmentation violation
14	SIGALRM	Terminate	Timer signal
17	SIGCHLD	Ignore	Child stopped or terminated

Signal Concepts (1)

- **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:
    - Generated internally:
      - Divide-by-zero (**SIGFPE**)
      - Termination of a child process (**SIGCHLD**), …
    - Generated externally:
      - **kill** system call by another process to request signal to the destination process.

Signal Concepts (2)

- **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.
  - Three possible ways to react:
    - Ignore the signal (do nothing)
    - Terminate the process
    - Catch the signal by executing a user-level function called a signal handler.
      - Similar to a hardware exception handler being called in response to an asynchronous interrupt.

Signal Concepts (3)

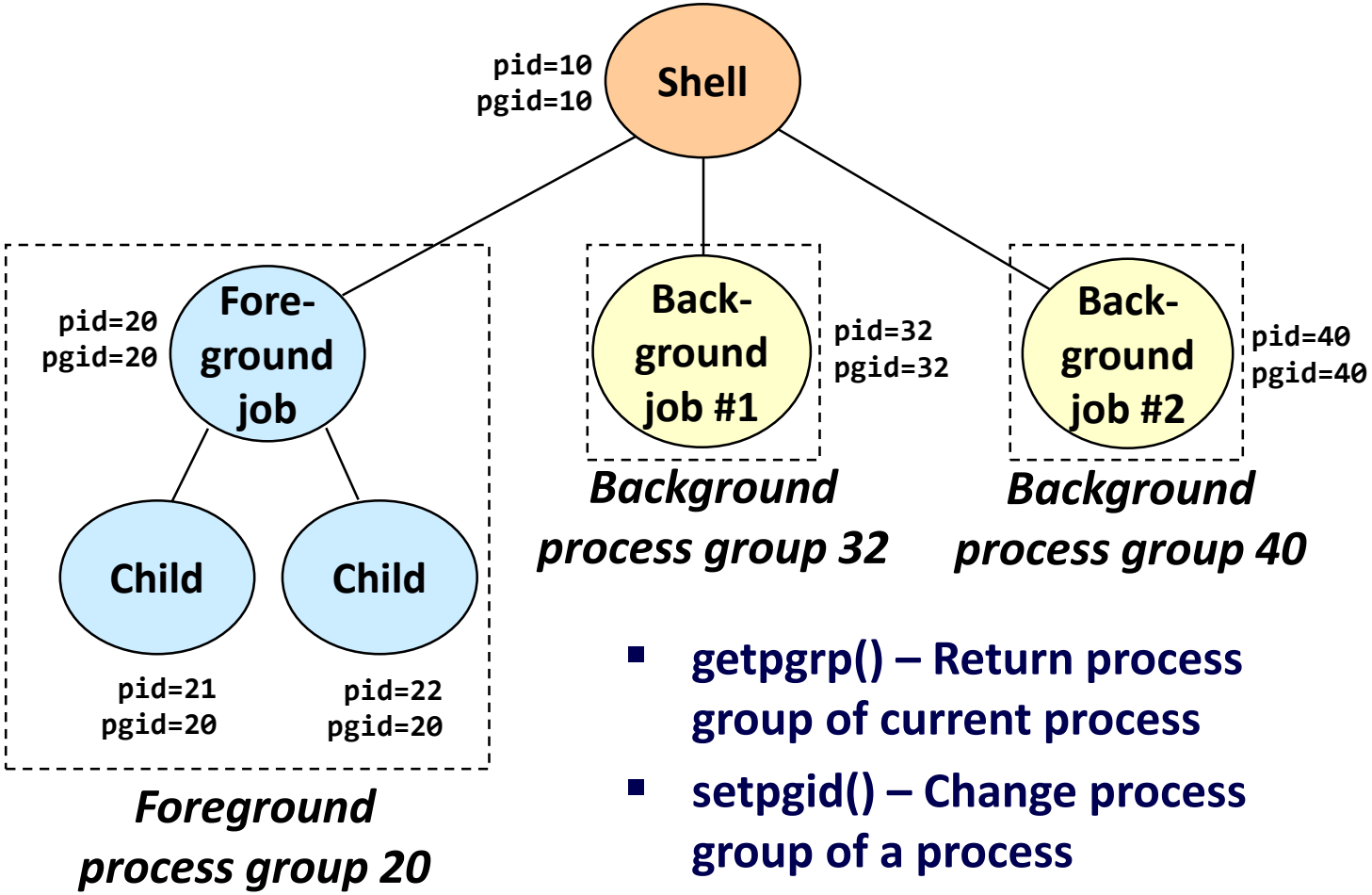
- **Signal semantics**
  - A signal is pending if it has been sent but not yet received.
    - There can be at most one pending signal of any particular type.
    - Signals are not queued!
  - A process can block the receipt of certain signals.
    - Blocked signals can be delivered, but will not be received until the signal is unblocked.
    - There is one signal that can not be blocked by the process. (**SIGKILL**)
  - A pending signal is received at most once.
    - Kernel uses a bit vector for indicating pending signals.

Signal Concepts (4)

- **Implementation**
  - 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** whenever a signal of type k is delivered.
      - Kernel clears bit k in **pending** whenever a signal of type k is received.
    - **blocked** – represents the set of blocked signals
      - Can be set and cleared by the application using the **sigprocmask** function.

Process Groups

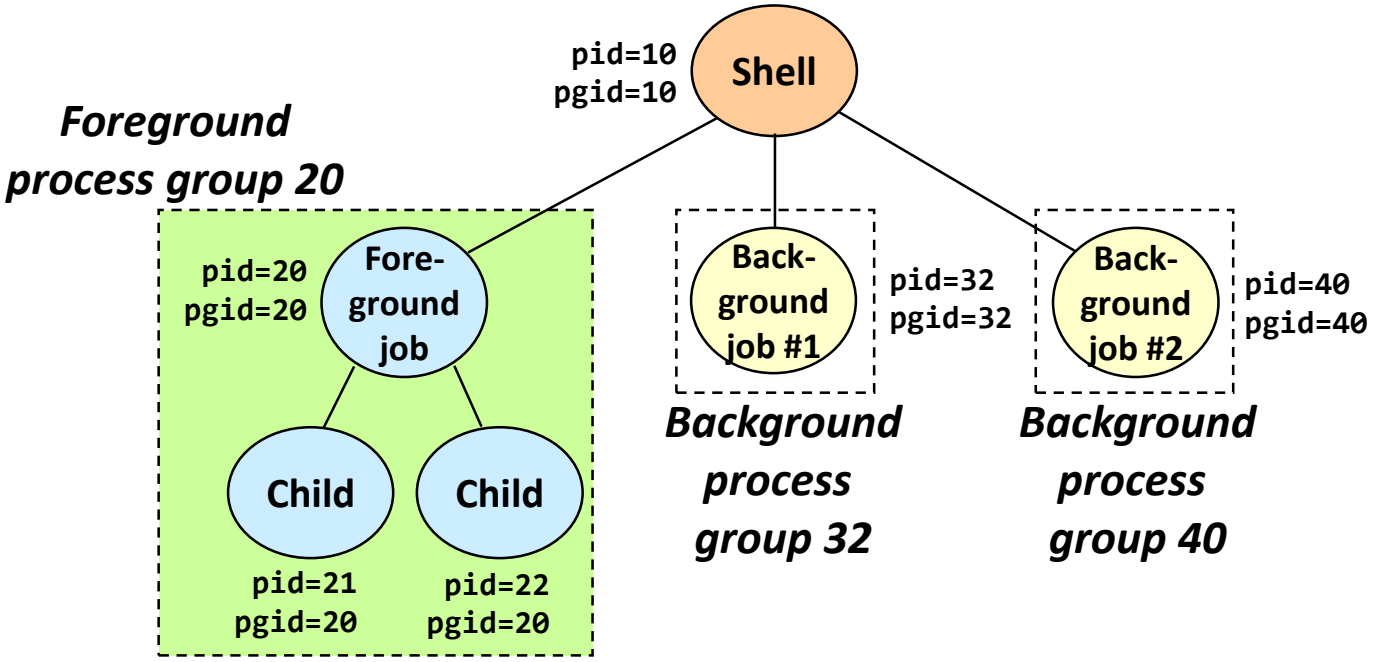
- Every process belongs to exactly one process group.



- getpgrp() – Return process group of current process
- setpgid() – Change process group of a process

Sending Signals (1)

- **Sending signals from the keyboard**
  - Typing **ctrl-c** (**ctrl-z**) sends a **SIGINT** (**SIGTSTP**) to every job in the foreground process group.
    - **SIGINT**: default action is to terminate each process.
    - **SIGTSTP**: default action is to stop (suspend) each process.



Sending Signals (2)

- **int kill(pid_t pid, int sig)**
  - Can be used to send any signal to any process group or process.
    - **pid** > 0, signal **sig** is sent to **pid**.
    - **pid** == 0, **sig** is sent to every process in the process group of the current process.
    - **pid** == -1, **sig** is sent to every process except for process 1.
    - **pid** < -1, **sig** is sent to every process in the process group -**pid**.
    - **sig** == 0, no signal is sent, but error checking is performed.
- **/bin/kill program sends arbitrary signal to a process or process group.**

```
$ kill 10231        // SIGTERM : default signal
$ kill -9 10231     // SIGKILL
```

Sending Signals (3)


```
void fork12() {
    pid_t pid[N];
    int i, child_status;
    for (i = 0; i < N; i++)
         if ((pid[i] = fork()) == 0)
             while(1); /* Child infinite loop */

    /* Parent terminates the child processes */
    for (i = 0; i < N; i++) {
         printf("Killing process %d\n", pid[i]);
         kill(pid[i], SIGINT);
    }

    /* Parent reaps terminated children */
    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);
    }
}
```

Receiving Signals (1)

- **Handling signals**
  - Suppose kernel is returning from 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) {
    - 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 the logical flow for p.

Receiving Signals (2)

- **Default actions**
  - Each signal type has a predefined default action, which is one of:
    - The process terminates.
    - The process terminates and dumps core.
    - The process stops until restarted by a **SIGCONT** signal.
    - The process ignores the signal.

Installing Signal Handlers

- **sighandler_t signal (int sig, sighandler_t handler)**
  - **typedef void (*sighandler_t)(int);**
  - The signal function modifies the default action associated with the receipt of signal **`sig`**.
- **Different values for handler:**
  - SIG_IGN: ignore signals of type sig.
  - SIG_DFL: revert to the default action.
  - Otherwise, handler is the address of a signal handler.
    - Called when process receives signal of type **sig**.
    - Referred to as "installing" the signal 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.

Handling Signals (1)

- **Things to remember**
  - Pending signals are not queued.
    - For each signal type, just have single bit indicating whether or not signal is pending.
    - Even if multiple processes have sent this signal.
  - A newly arrived signal is blocked while the handler of the signal is running.
  - Sometimes system calls such as **read()** are not restarted automatically after they are interrupted by the delivery of a signal.
    - They return prematurely to the calling application with an error condition. **(errno == EINTR)**

Handling Signals (2)

- What is the problem of the following code?

```
int ccount = 0;

void handler (int sig) {
   pid_t pid = wait(NULL);
   ccount--;
   printf ("Received signal %d from pid %d\n", sig, pid);
}

void fork14() {
   pid_t pid[N];
   int i;
   ccount = N;
   signal (SIGCHLD, handler);
   for (i = 0; i < N; i++)
      if ((pid[i] = fork()) == 0)
         /* child */
         exit(0);
   while (ccount > 0)
      sleep (5);
}
```

Handling Signals (3)

- **Dealing with nonqueueing signals.**

```
int ccount = 0;
void handler2 (int sig) {
   int child_status;
   pid_t pid;
   while ((pid = wait(&child_status)) > 0) {
       ccount--;
       printf ("Received signal %d from pid %d\n", sig, pid);
   }
}
void fork15() {
   pid_t pid[N];
   int i;
   ccount = N;
   signal (SIGCHLD, handler2);
   for (i = 0; i < N; i++)
      if ((pid[i] = fork()) == 0)
         /* child */
         exit(0);
   while (ccount > 0)
      sleep (5);
}
```

Handling Signals (4)

- **React to externally generated events**
  - Example: CTRL-C (SIGINT)

```
#include <stdlib.h>
#include <stdio.h>
#include <signal.h>
#include <unistd.h>

void handler(int sig) {
  printf("You think hitting ctrl-c will stop the bomb?\n");
  sleep(2);
  printf("Well...");
  fflush(stdout);
  sleep(1);
  printf("OK\n");
  exit(0);
}

int main() {
  signal(SIGINT, handler); /* installs ctrl-c handler */
  while(1);
  return 0;
}
```

Handling Signals (5)

- **React to internally generated events**
  - Example: **alarm(int t)** sends **SIGALRM** after t seconds.

```
#include <stdio.h>
#include <signal.h>
#include <stdlib.h>
#include <unistd.h>

int beeps = 0;
void handler(int sig) {
  printf("BEEP\n");
  fflush (stdout);
  if (++beeps < 5) alarm(1);
  else {
     printf("BOOM!\n");
     exit(0);
  }
}
int main() {
  signal(SIGALRM, handler);
  alarm(1);         // send SIGALRM in 1 second
  while(1);
  return 0;
}
```

```
linux> a.out
BEEP
BEEP
BEEP
BEEP
BEEP
BOOM!
linux>
```

Exercise

- A program that receives signals and performs a specific action
  - Print pid
  - When receiving specific signal
    - SIGINT (2)
      - *Handling Signals (4)*
    - SIGALRM (14)
      - Print "5", "4", "3", "2", "1"
      - per 1 second
    - SIGUSR1 (30)
      - Execute 'ls' program
- You use 'kill' command
  - ex) kill -14 *pid*