SSE2033

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Signals

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Multitasking

- 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

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);
    }
}
```

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.

Signal

- 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.

Table 9-1. The First 31 Signals in Linux/i386

#	Signal Name	Default Action	Comment	POSIX
1	SIGHUP	Abort	Hangup of controlling terminal or process	Yes
2	SIGINT	Abort	Interrupt from keyboard	Yes
3	SIGQUIT	Dump	Quit from keyboard	Yes
4	SIGILL	Dump	Illegal instruction	Yes
5	SIGTRAP	Dump	Breakpoint for debugging	No
6	SIGABRT	Dump	Abnormal termination	Yes
6	SIGIOT	Dump	Equivalent to SIGABRT	No
7	SIGBUS	Abort	Bus error	No
8	SIGFPE	Dump	Floating point exception	Yes
9	SIGKILL	Abort	Forced process termination	Yes
10	SIGUSR1	Abort	Available to processes	Yes
11	SIGSEGV	Dump	Invalid memory reference	Yes
12	SIGUSR2	Abort	Available to processes	Yes
13	SIGPIPE	Abort	Write to pipe with no readers	Yes
14	SIGALRM	Abort	Real timer clock	Yes
15	SIGTERM	Abort	Process termination	Yes
16	SIGSTKFLT	Abort	Coprocessor stack error	No
17	SIGCHLD	Ignore	Child process stopped or terminated	Yes
18	SIGCONT	Continue	Resume execution, if stopped	Yes
19	SIGSTOP	Stop	Stop process execution	Yes
20	SIGTSTP	Stop	Stop process issued from tty	Yes
21	SIGTTIN	Stop	Background process requires input	Yes
22	SIGTTOU	Stop	Background process requires output	Yes
23	SIGURG	Ignore	Urgent condition on socket	No
24	SIGXCPU	Abort	CPU time limit exceeded	No
25	SIGXFSZ	Abort	File size limit exceeded	No
26	SIGVTALRM	Abort	Virtual timer clock	No
27	SIGPROF	Abort	Profile timer clock	No
28	SIGWINCH	Ignore	Window resizing	No
29	SIGIO	Abort	I/O now possible	No
29	SIGPOLL	Abort	Equivalent to SIGIO	No
30	SIGPWR	Abort	Power supply failure	No
31	SIGUNUSED	Abort	Not used	No

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:
    - Explicitly ignore the signal
    - Execute the default action
    - Catch the signal by invoking signal-handler function
      - Akin to a hardware exception handler being called in response to an asynchronous interrupt.

Signal Concepts (3)

- Default actions
  - Abort
    - The process is destroyed
  - Dump
    - The process is destroyed & core dump
  - Ignore
    - The signal is ignored
  - Stop
    - The process is stopped
  - Continue
    - If the process is stopped, it is put into running state

Signal Concepts (4)

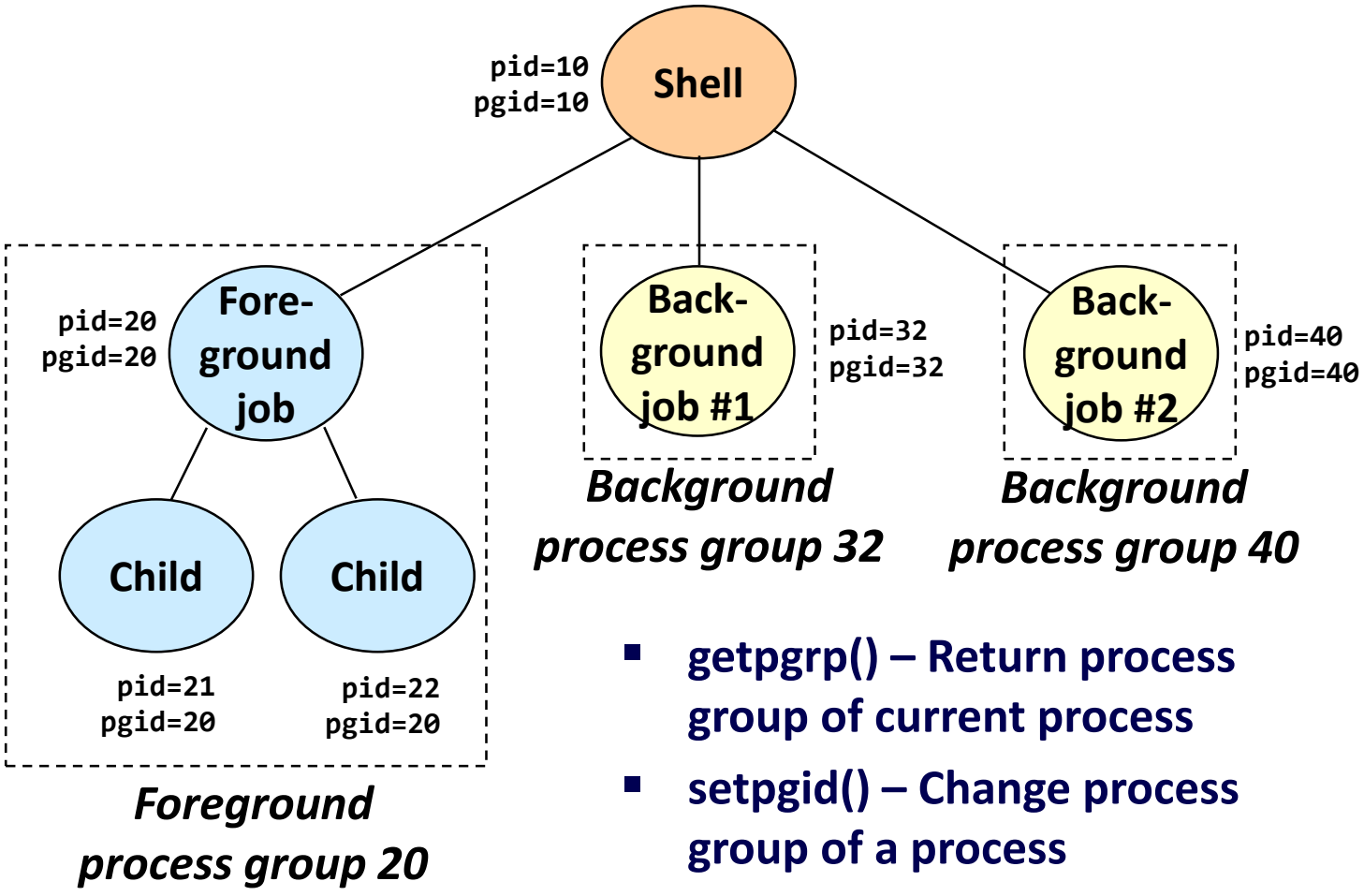
- Signal semantics
  - A signal is pending if it has been sent but not yet received.
    - There can be at most one pending signal of any particular type.
    - Signals are not queued!
  - A process can block the receipt of certain signals.
    - Blocked signals can be delivered, but will not be received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

Signal Concepts (5)

- 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

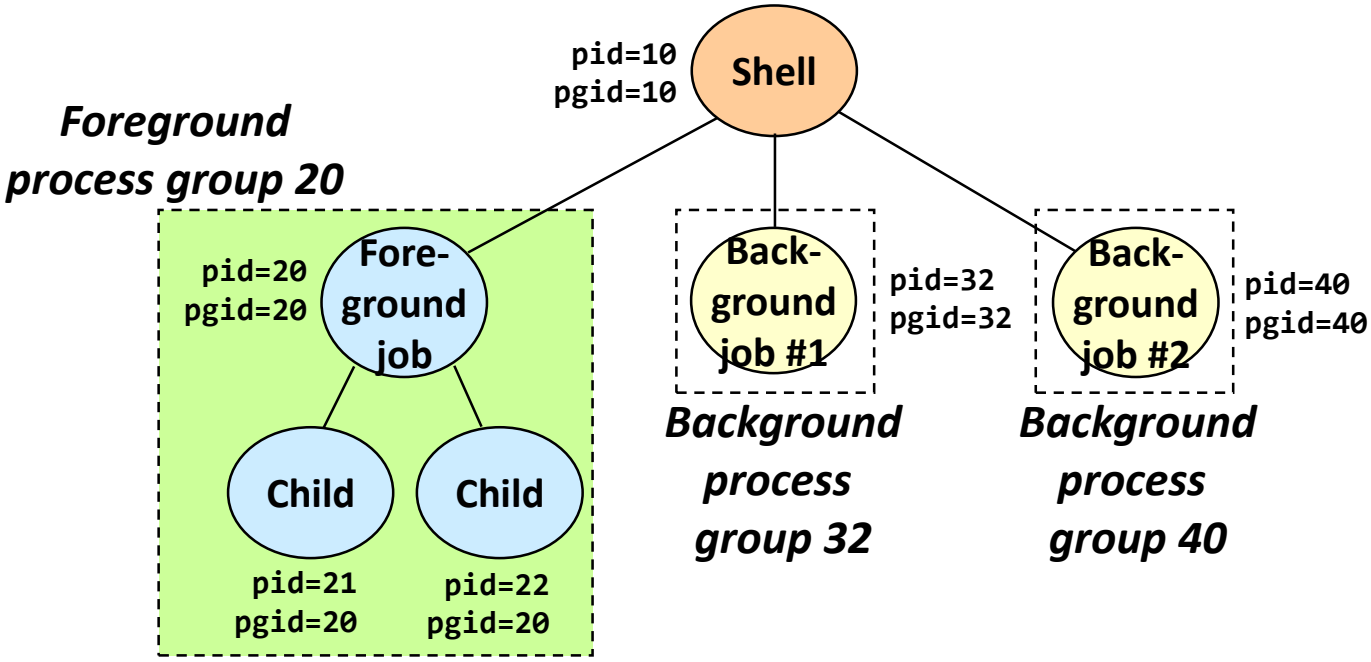
- Every process belongs to exactly one process group.



- **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 output of the following program?

```
pid_t pid;
int counter = 2;

void handler1(int sig) {
    counter = counter - 1;
    printf("%d", counter);
    fflush(stdout);
    exit(0);
}
int main() {
    signal(SIGUSR1, handler1);
    printf("%d", counter);
    fflush(stdout);

    if((pid = fork()) == 0) while(1);
    kill(pid, SIGUSR1);
    waitpid(-1, NULL, 0);
    counter = counter + 1;
    printf("%d", counter);
    exit(0);
}
```

Handling Signals (3)

- 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);
}
```

Exercise #1

- Deal with non-queueing signals

```
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);
}
```

Exercise #2

- React to internally generated events

- Make alarm for every 1 second
  - Print “BEEP” for each second
  - Tip : alarm(int t) send SIGALRM after t seconds

Exercise #3

- React to externally generated events

- Make zombie process
  - When the process get ctrl+c signal from keyboard, it just prints “beep” to the monitor 5 times with 1-second interval
  - Print “I’m Alive!” to the monitor after 5-times beep