CS 33

Signals Part 2

Digression: Core Dumps

- Core dumps
  - files (called “core”) that hold the contents of a process’s address space after termination by a signal
  - they’re large and rarely used, so they’re often disabled by default
  - use the ulimit command in bash to enable them

```
ulimit -c unlimited
```

  - use gdb to examine the process (post-mortem debugging)

```
gdb sig core
```

sigaction

```
int sigaction(int sig, const struct sigaction *new,
              struct sigaction *old);
struct sigaction {
    void (*sa_handler)(int);
    void (*sa_sigaction)(int, siginfo_t *, void *);
    sigset_t sa_mask;
    int sa_flags;
};

int main() {
    struct sigaction act; void myhandler(int);
    sigemptyset(&act.sa_mask); // zeroes the mask
    act.sa_flags = 0;
    act.sa_handler = myhandler;
    sigaction(SIGINT, &act, NULL);
    …
}
```

Example

```
int main() {
  void handler(int);
  struct sigaction act;
  act.sa_handler = handler;
  sigemptyset(&act.sa_mask);
  act.sa_flags = 0;
  sigaction(SIGINT, &act, 0);

  while(1)
    ;
  return 1;
}

void handler(int signo) {
  printf("I received signal %d. "
     "Whoopee!!\n", signo);
}
```

Quiz 1

```
int main() {
  void handler(int);
  struct sigaction act;
  act.sa_handler = hand
  sigemptyset(&act.sa_m
  act.sa_flags = 0;
  sigaction(SIGINT, &ac

  while(1)
    ;
  return 1;
}

void handler(int signo) {
  printf("I received signal %d. "
     "Whoopee!!\n", signo);
}
```

You run the example program, then quickly type ctrl-C. What is the most likely explanation if the program then terminates?

a) **this "can't happen"; thus there's a problem with the system**
b) **you're really quick or the system is really slow (or both)**
c) **what we've told you so far isn't quite correct**

Waiting for a Signal …

```
signal(SIGALRM, RespondToSignal);

…

struct timeval waitperiod = {0, 1000};
      /* seconds, microseconds */
struct timeval interval = {0, 0};
struct itimerval timerval;
timerval.it_value = waitperiod;
timerval.it_interval = interval;

setitimer(ITIMER_REAL, &timerval, 0);
      /* SIGALRM sent in ~one millisecond */
pause();  /* wait for it */
printf("success!\n");
```

Quiz 2

This program is guaranteed to print "success!".

a) no

b) yes

```
signal(SIGALRM, RespondToSignal);

…

struct timeval waitperiod = {0, 1000};
      /* seconds, microseconds */
struct timeval interval = {0, 0};
struct itimerval timerval;
timerval.it_value = waitperiod;
timerval.it_interval = interval;

setitimer(ITIMER_REAL, &timerval, 0);
      /* SIGALRM sent in ~one millisecond */
pause();  /* wait for it */
printf("success!\n");
```

Masking Signals

```
setitimer(ITIMER_REAL, &timerval, 0);
      /* SIGALRM sent in ~one millisecond */
```

No signals here, please!

```
pause();  /* wait for it */
```

Masking Signals

mask SIGALRM

```
setitimer(ITIMER_REAL, &timerval, 0);
      /* SIGALRM sent in ~one millisecond */
```

No signals here

unmask and wait for SIGALRM

Doing It Safely

```
sigset_t set, oldset;
sigemptyset(&set);
sigaddset(&set, SIGALRM);
sigprocmask(SIG_BLOCK, &set, &oldset);
      /* SIGALRM now masked */
…
setitimer(ITIMER_REAL, &timerval, 0);
      /* SIGALRM sent in ~one millisecond */

sigsuspend(&oldset);    /* unmask sig and wait */
/* SIGALRM masked again */

sigprocmask(SIG_SETMASK, &oldset, (sigset_t *)0);
      /* SIGALRM unmasked */
printf("success!\n");
```

Signal Sets

- **To clear a set:**

```
int sigemptyset(sigset_t *set);
```

- **To add or remove a signal from the set:**

```
int sigaddset(sigset_t *set, int signo);
int sigdelset(sigset_t *set, int signo);
```

- **Example: to refer to both SIGHUP and SIGINT:**

```
sigset_t set;

sigemptyset(&set);
sigaddset(&set, SIGHUP);
sigaddset(&set, SIGINT);
```

Masking (Blocking) Signals

```
#include <signal.h>
int sigprocmask(int how, const sigset_t *set,
      sigset_t *old);
```

- used to examine or change the signal mask of the calling process
  - *how* is one of three commands:
    - SIG_BLOCK
      - the new signal mask is the union of the current signal mask and set
    - SIG_UNBLOCK
      - the new signal mask is the intersection of the current signal mask and the complement of set
    - SIG_SETMASK
      - the new signal mask is set

Signal Handlers and Masking

- What if a signal occurs while a previous instance is being handled?
  - inconvenient …
- Signals are masked while being handled
  - may mask other signals as well:

```
struct sigaction act; void myhandler(int);
sigemptyset(&act.sa_mask); // zeroes the mask
sigaddset(&act.sa_mask, SIGQUIT);
   // also mask SIGQUIT
act.sa_flags = 0;
act.sa_handler = myhandler;
sigaction(SIGINT, &act, NULL);
```


Timed Out!

```
int TimedInput( ) {
    signal(SIGALRM, timeout);
    …
    alarm(30);     /* send SIGALRM in 30 seconds */
    GetInput();    /* possible long wait for input */
    alarm(0);      /* cancel SIGALRM request */
    HandleInput();
    return(0);
nogood:
    return(1);
}

void timeout( ) {
    goto nogood;   /* not legal but straightforward */
}
```

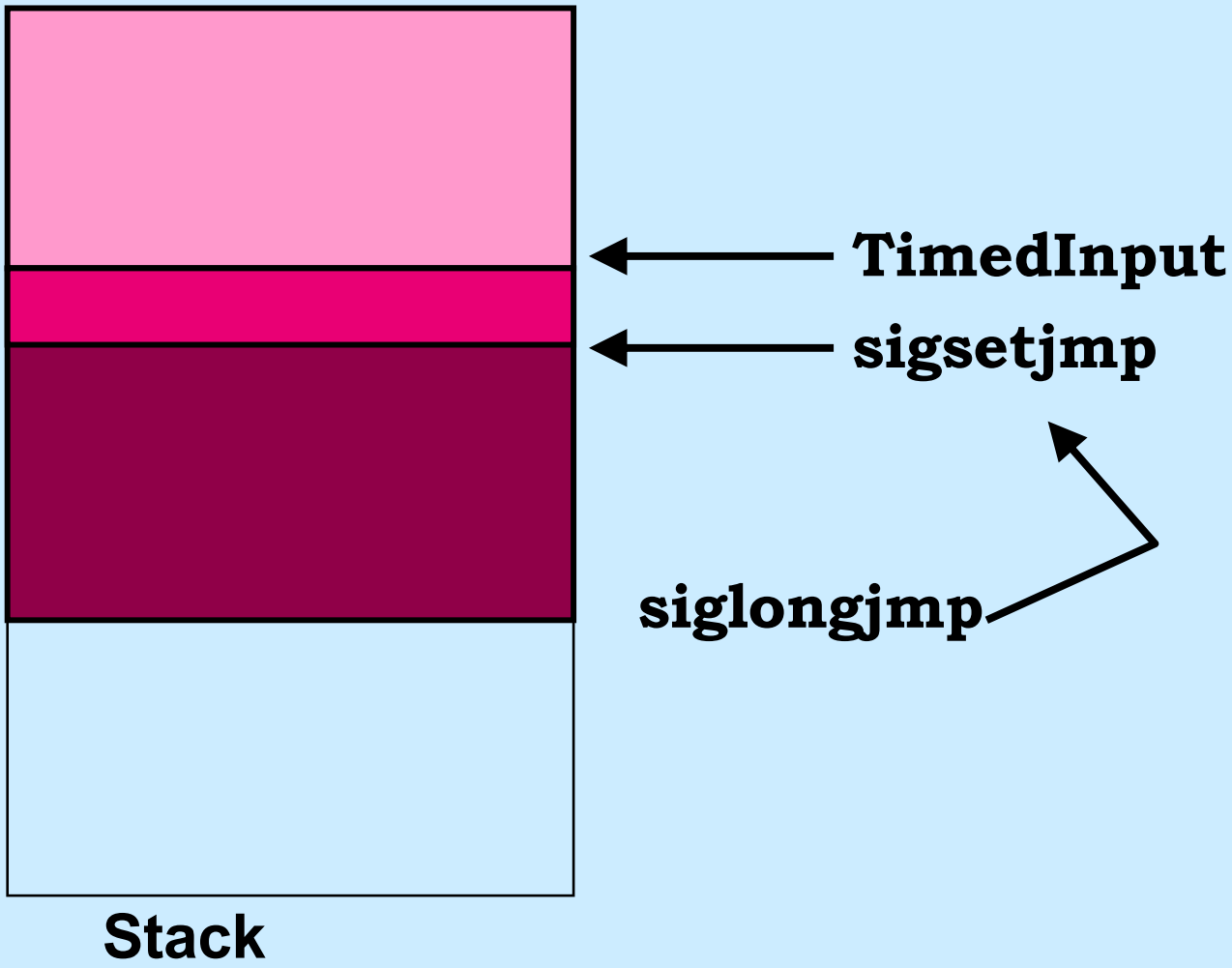
Doing It Legally (but Weirdly)

```
sigjmp_buf context;

int TimedInput( ) {
    signal(SIGALRM, timeout);
    if (sigsetjmp(context, 1) == 0) {
        alarm(30);  // cause SIGALRM in 30 seconds
        GetInput(); // possible long wait for input
        alarm(0);   // cancel SIGALRM request
        HandleInput();
        return 0;
    } else
        return 1;
}

void timeout() {
    siglongjmp(context, 1);     /* legal but weird */
}
```

sigsetjmp/siglongjmp



Job Control

```
$ who
```
- foreground job

```
$ multiprocessProgram
```
- foreground job

```
^Z
stopped
$ bg
[1] multiprocessProgram &
```
- multiprocessProgram becomes background job 1

```
$ longRunningProgram &
[2]
$ fg %1
multiprocessProgram
```
- multiprocessProgram is now the foreground job

```
^C
$
```

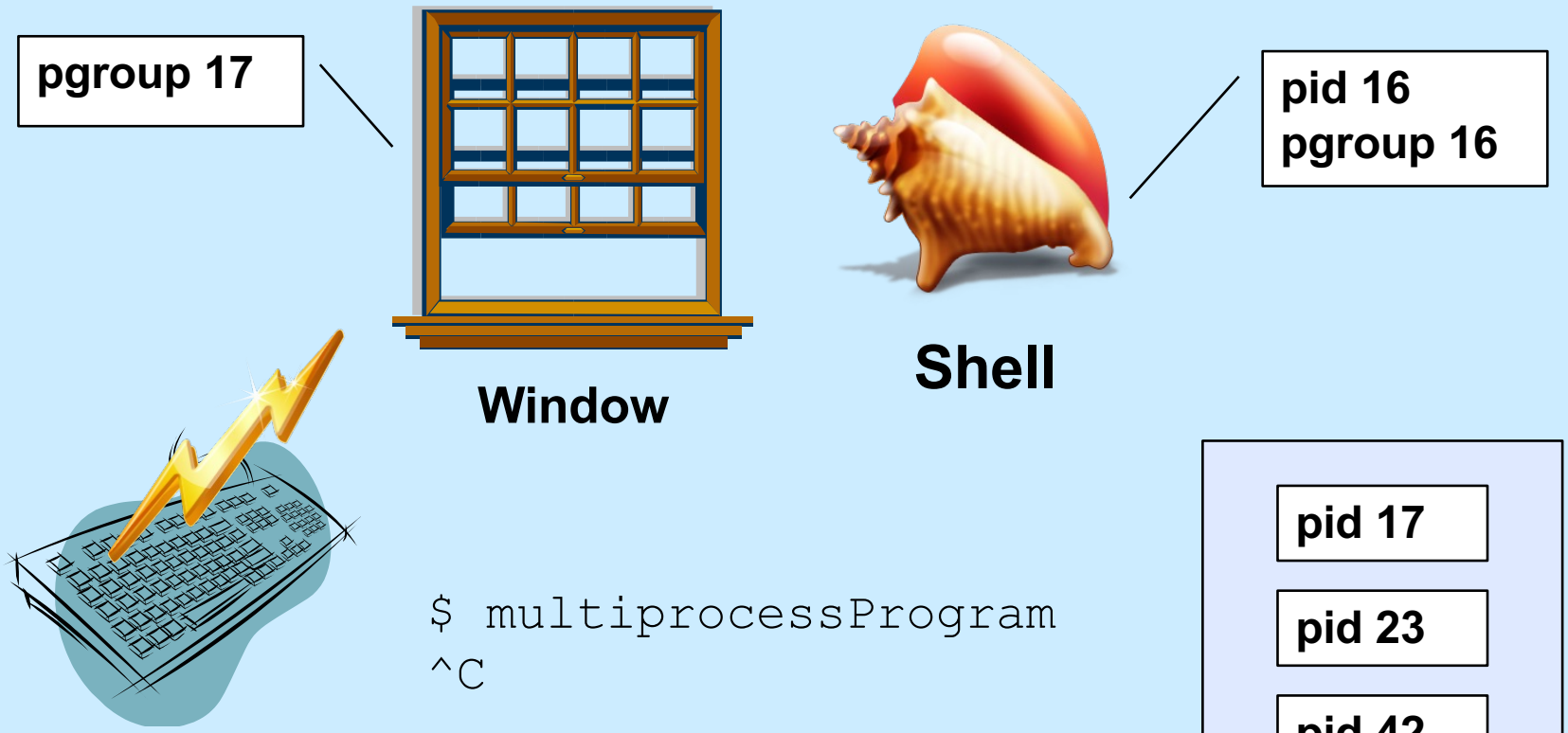
Process Groups

- Set of processes sharing the window/keyboard
  - sometimes called a *job*
- Foreground process group/job
  - currently associated with window/keyboard
  - receives keyboard-generated signals
- Background process group/job
  - not currently associated with window/keyboard
  - doesn't currently receive keyboard-generated signals

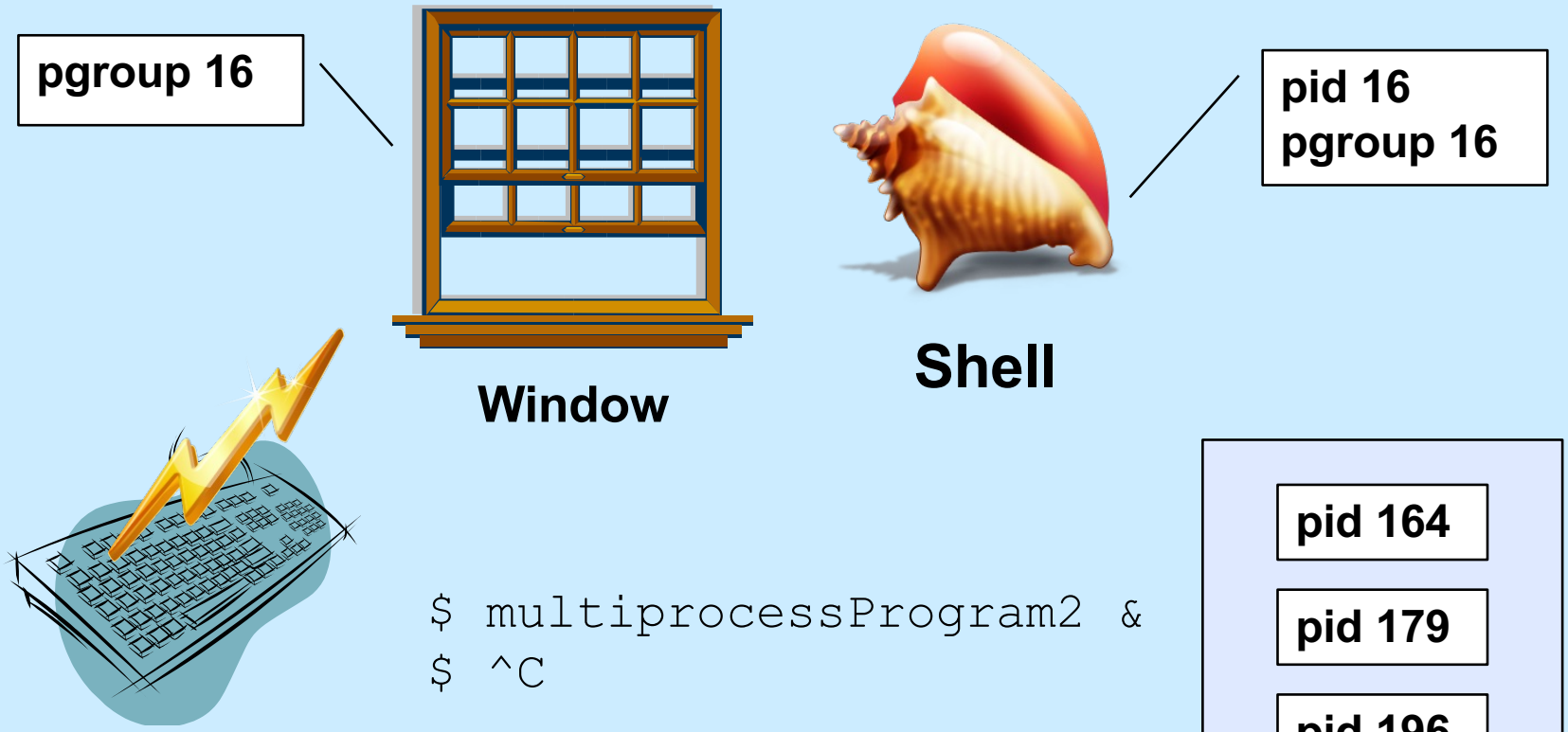
Keyboard-Generated Signals

- You type ctrl-C
- How does the system know which process(es) to send the signal to?

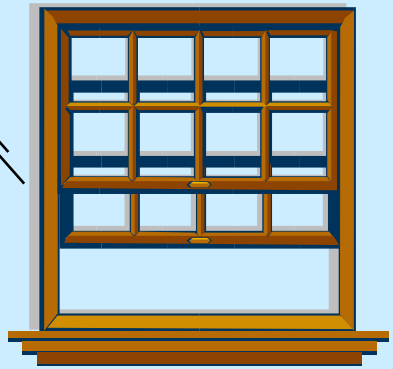
Foreground Job



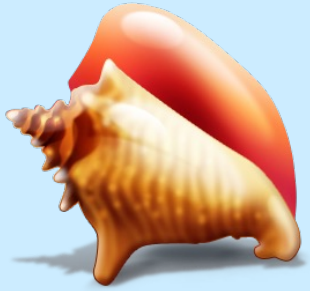
Background Job



Stopping a Foreground Job

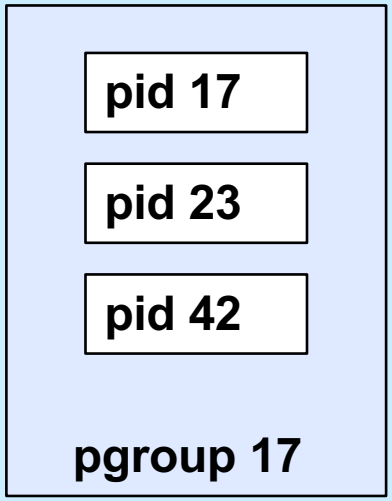


Window

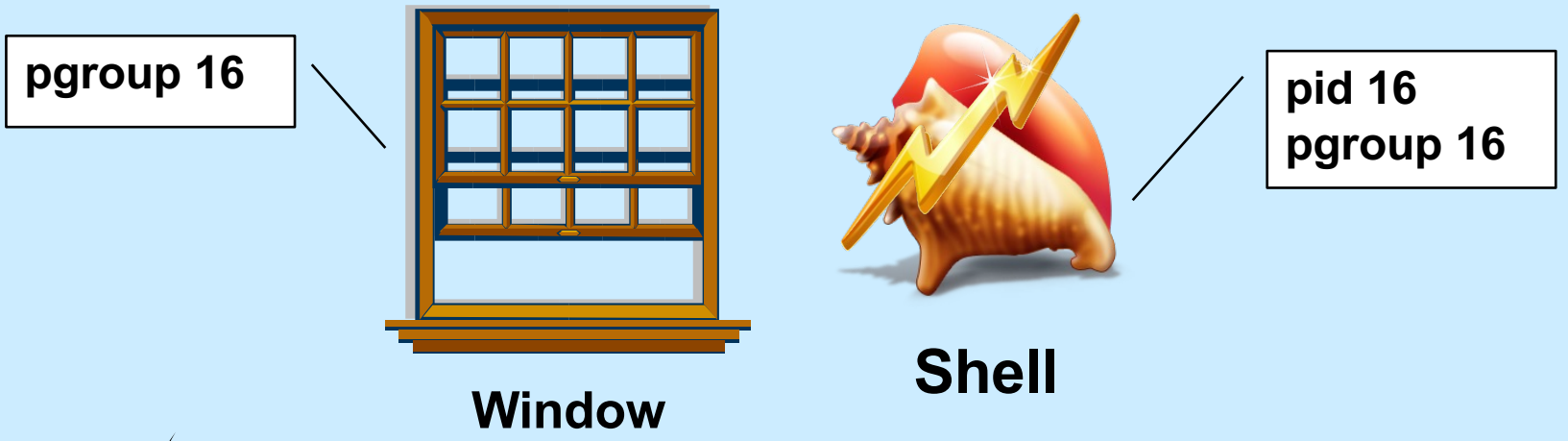


Shell

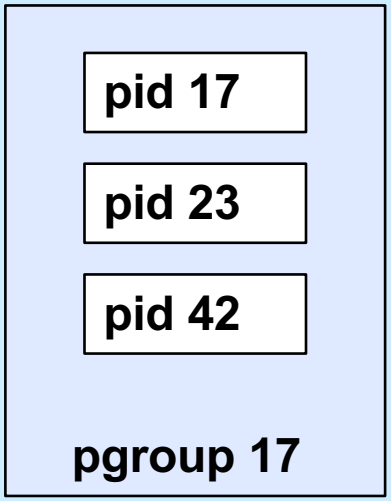
```
$ multiprocessProgram
^Z
[2] stopped
$
```



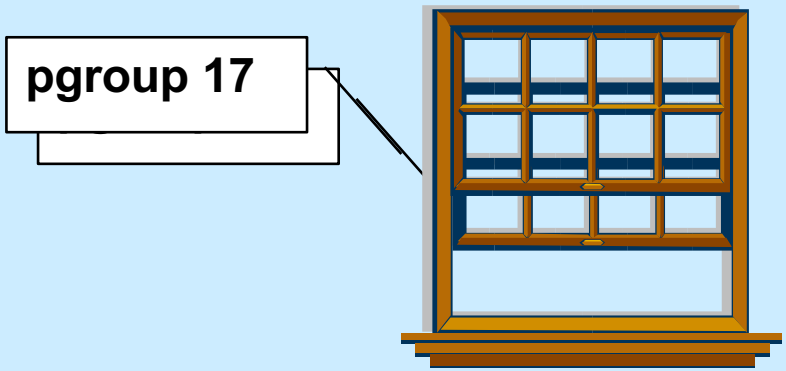
Backgrounding a Stopped Job



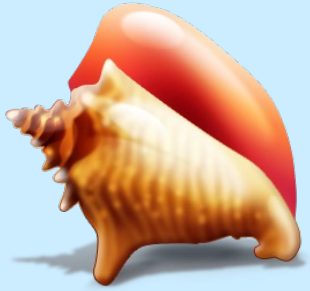
```
$ multiprocessProgram
^Z
[2] stopped
$ bg
$
```



Foregrounding a Job



Window



Shell

pid 16
pgroup 16

```
$ multiprocessProgram
^Z
[2] stopped
$ bg
$ fg %2
```

pid 17

pid 23

pid 42

pgroup 17

Quiz 3

```
$ long_running_prog1 &
$ long_running_prog2
^Z
[2] stopped
$ ^C
```

Which process group receives the SIGINT signal?

a) **the one containing long_running_prog1**
b) **the one containing long_running_prog2**
c) **the one containing the shell**

Creating a Process Group

```
if (fork() == 0) {
  // child
  setpgid(0, 0);
     /* puts current process into a
        new process group whose ID is
        the process's pid.
        Children of this process will be in
        this process's process group.
     */
  ...
  execv(...);
}
// parent
```

Setting the Foreground Process Group

```
tcsetpgrp(fd, pgid);
  // sets the process group of the
  // terminal (window) referenced by
  // file descriptor fd to be pgid
```

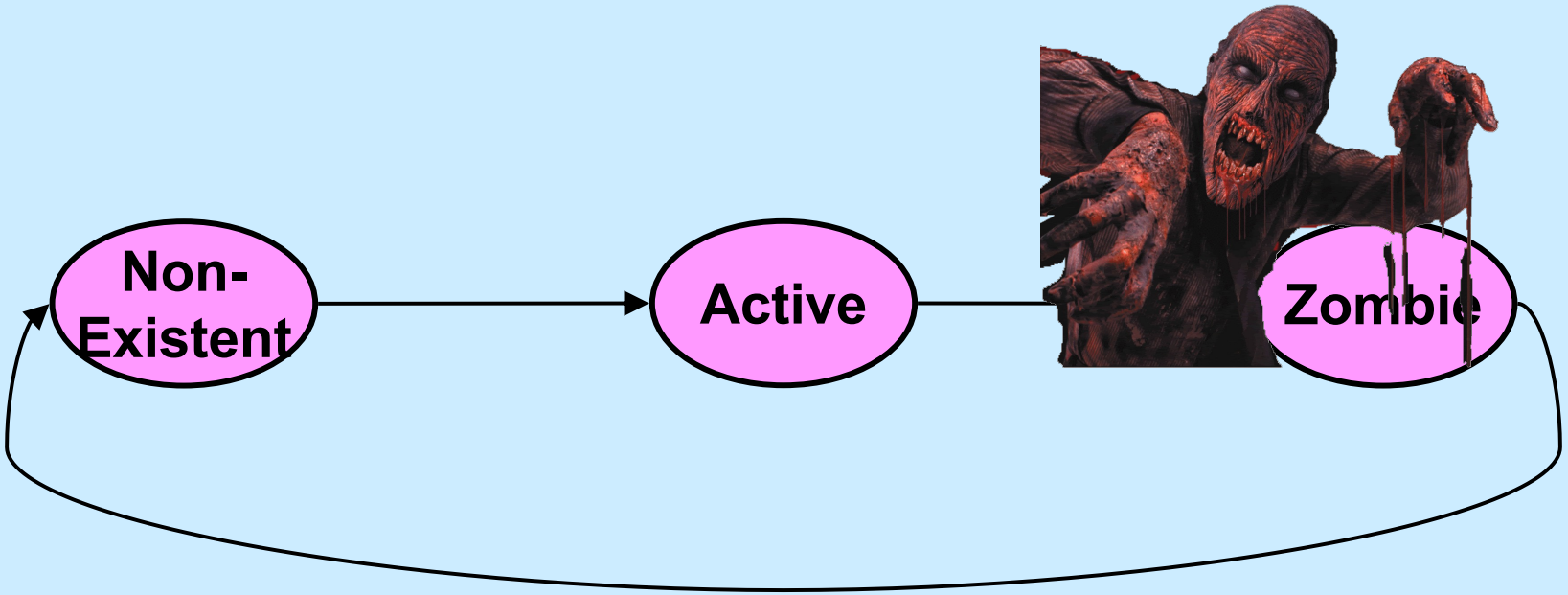
Background Input and Output

- Background process reads from keyboard
  - the keyboard really should be reserved for foreground process
  - background process gets SIGTTIN
    - » suspends it by default
- Background process writes to display
  - display also used by foreground process
  - could be willing to share
  - background process gets SIGTTOU
    - » suspends it (by default)
    - » but reasonable to ignore it

Kill: Details

- `int kill(pid_t pid, int sig)`
  - if *pid* > 0, signal *sig* sent to process *pid*
  - if *pid* == 0, signal *sig* sent to all processes in the caller's process group
  - if *pid* == −1, signal *sig* sent to all processes in the system for which sender has permission to do so
  - if *pid* < −1, signal *sig* is sent to all processes in process group −*pid*

Process Life Cycle



Reaping: Zombie Elimination

- **Shell must call `waitpid` on each child**
  - **easy for a foreground child**
  - **what about background?**

```
pid_t waitpid(pid_t pid, int *status, int options);
```

  - ***pid* values:**

< −1	**any child process whose process group is |pid|**
−1	**any child process**
0	**any child process whose process group is that of caller**
> 0	**child process whose ID is equal to pid**

  - `wait(&status)` **is equivalent to** `waitpid(-1, &status, 0)`

(continued)

```
pid_t waitpid(pid_t pid, int *status, int options);
```

- ***options*** **are some combination of the following**
  - » **WNOHANG**
    - **return immediately if no child has exited (returns 0)**
  - » **WUNTRACED**
    - **also return if a child has been stopped (suspended)**
  - » **WCONTINUED**
    - **also return if a child has been continued (resumed)**

When to Call `waitpid`

- Shell reports status only when it is about to display its prompt
  - thus sufficient to check on background jobs just before displaying prompt

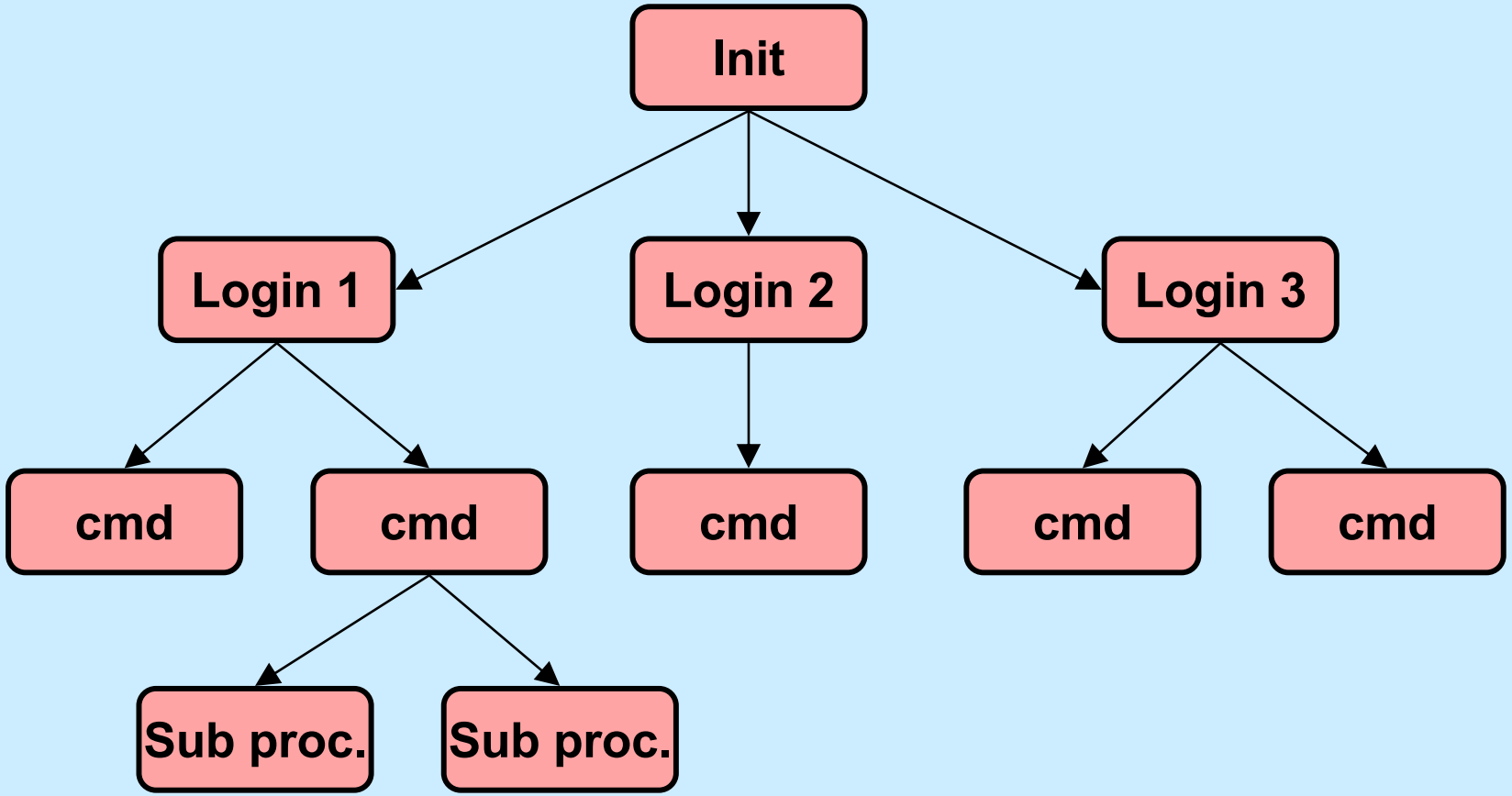
`waitpid` status

- WIFEXITED(*status): 1 if the process terminated normally and 0 otherwise
- WEXITSTATUS(*status): argument to exit
- WIFSIGNALED(*status): 1 if the process was terminated by a signal and 0 otherwise
- WTERMSIG(*status): the signal which terminated the process if it terminated by a signal
- WIFSTOPPED(*status): 1 if the process was stopped by a signal
- WSTOPSIG(*status): the signal which stopped the process if it was stopped by a signal
- WIFCONTINUED(*status): 1 if the process was resumed by SIGCONT and 0 otherwise

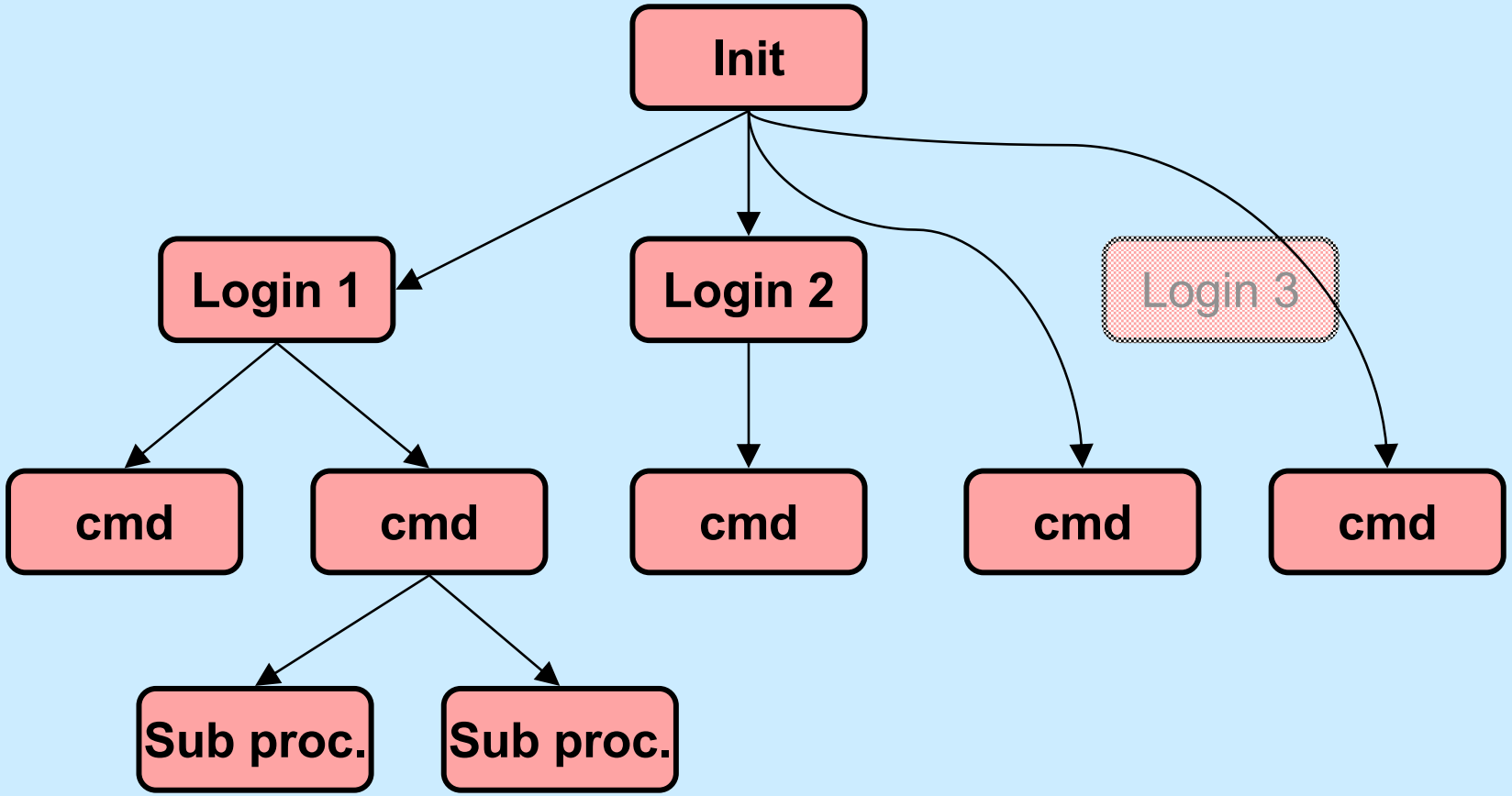
Example (in Shell)

```
int wret, wstatus;
while ((wret = waitpid(-1, &wstatus, WNOHANG|WUNTRACED)) > 0){
  // examine all children who've terminated or stopped
  if (WIFEXITED(wstatus)) {
    // terminated normally
    ...
  }
  if (WIFSIGNALED(wstatus)) {
    // terminated by a signal
    ...
  }
  if (WIFSTOPPED(wstatus)) {
    // stopped
    ...
  }
}
```

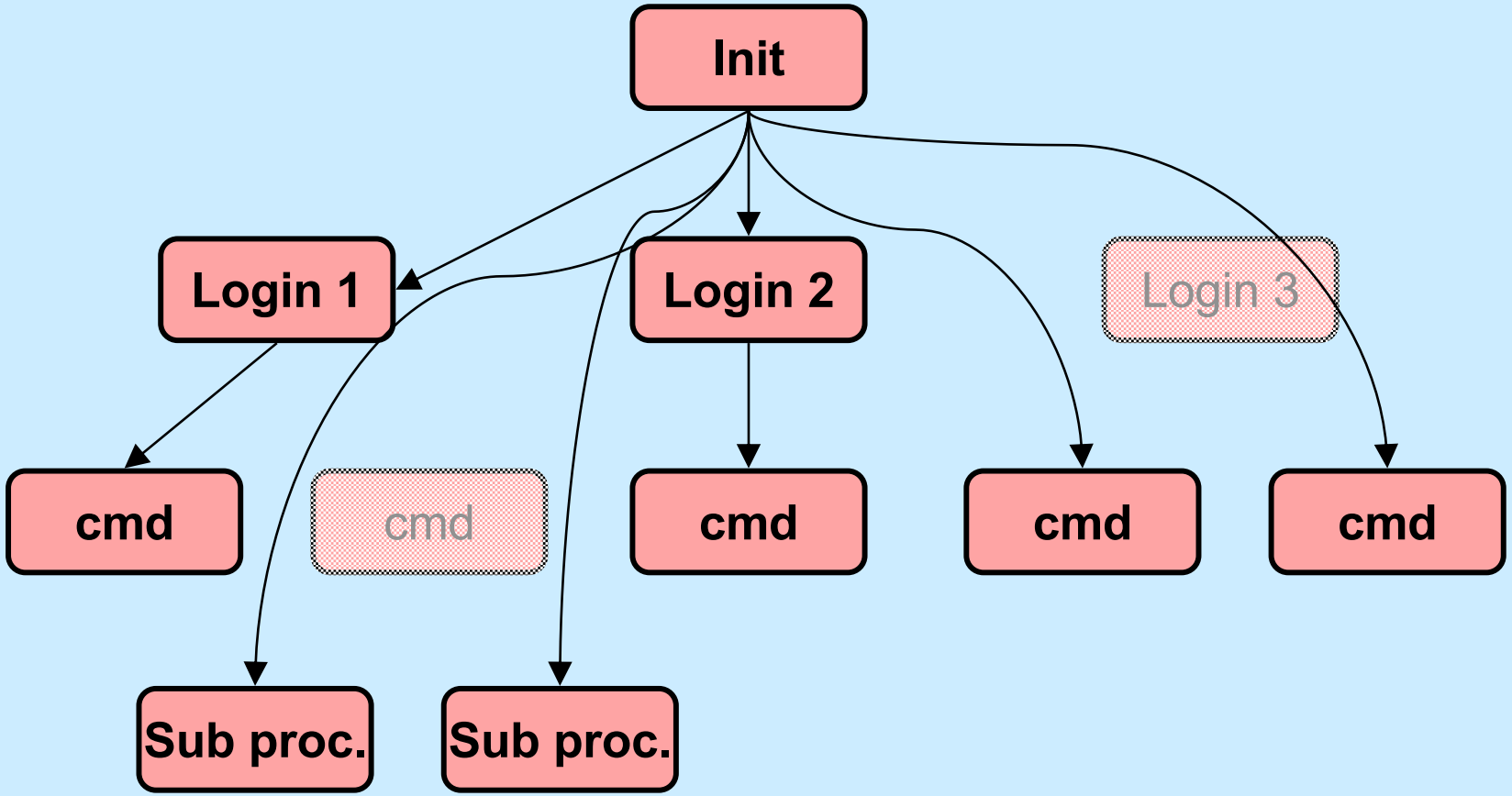
Process Relationships (1)



Process Relationships (2)



Process Relationships (3)



Signals, Fork, and Exec

```
// set up signal handlers ...
if (fork() == 0) {
   // what happens if child gets signal?
   ...
   signal(SIGINT, SIG_IGN);
   signal(SIGFPE, handler);
   signal(SIGQUIT, SIG_DFL);
   execv("new prog", argv, NULL);
   // what happens if SIGINT, SIGFPE,
   // or SIGQUIT occur?
}
```

Signals and System Calls

- What happens if a signal occurs while a process is doing a system call?
  - handler not invoked until just before system call returns to user
    - » system call might terminate early because of signal
  - system call completes
  - signal handler is invoked
  - user code resumed as if the system call has just returned

Signals and Lengthy System Calls

- Some system calls take a long time
  - large I/O transfer
    - » multi-gigabyte read or write request probably done as a sequence of smaller pieces
  - a long wait is required
    - » a read from the keyboard requires waiting for someone to type something
- If signal arrives in the midst of lengthy system call, handler invoked:
  - after current piece is completed
  - after cancelling wait

Interrupted System Calls

- What if a signal is handled before the system call completes?
  - invoke handler, then return from system call prematurely
    - if one or more pieces were completed, return total number of bytes transferred
    - otherwise return “interrupted” error

Interrupted System Calls: Non-Lengthy Case

```
while(read(fd, buffer, buf_size) == -1) {
  if (errno == EINTR) {
    /* interrupted system call — try again */
    continue;
  }
  /* the error is more serious */
  perror("big trouble");
  exit(1);
}
```


Quiz 2

```
int ret;
char buf[1024*1024*1024];

fillbuf(buf);

ret = write(1, buf, 1024*1024*1024);
```

- **The value of ret is:**
  - **a) any integer in the range [-1, 1024*1024*1024]**
  - **b) either -1 or 1024*1024*1024**
  - **c) either -1, 0, or 1024*1024*1024**

Interrupted System Calls: Lengthy Case

```
char buf[BSIZE];
fillbuf(buf);
long remaining = BSIZE;
char *bptr = buf;
while (1){
  long num_xfrd = write(fd,
       bptr, remaining);
  if (num_xfrd == -1) {
    if (errno == EINTR) {
      // interrupted early
      continue;
    }
    perror("big trouble");
    exit(1);
  }
  if (num_xfrd < remaining) {
    /* interrupted after the
       first step */
    remaining -= num_xfrd;
    bptr += num_xfrd;
    continue;
  }
  // success!
  break;
}
```

Asynchronous Signals (1)

```
main( ) {
   void handler(int);
   signal(SIGINT, handler);

   ...   /* long-running buggy code */

}

void handler(int sig) {
   ...   /* clean up */
   exit(1);
}
```


Asynchronous Signals (2)

```
computation_state_t  state;

main( ) {
  void handler(int);

  signal(SIGINT, handler);

  long_running_procedure( );
}
```

```
long_running_procedure( ) {
  while (a_long_time) {
    update_state(&state);
    compute_more( );
  }
}

void handler(int sig) {
  display(&state);
}
```

Asynchronous Signals (3)

```
main( ) {
  void handler(int);

  signal(SIGINT, handler);

  ...  /* complicated program */

  myputs("important message\n");

  ...  /* more program */

}
```

```
void handler(int sig) {

  ...  /* deal with signal */

  myputs("equally important "
      "message\n");
}
```

Asynchronous Signals (4)

```
char buf[BSIZE];
int pos;
void myputs(char *str) {
  int len = strlen(str);
  for (int i=0; i<len; i++, pos++) {
    buf[pos] = str[i];
    if ((buf[pos] == '\n') || (pos == BSIZE-1)) {
      write(1, buf, pos+1);
      pos = -1;
    }
  }
}
```

Async-Signal Safety

- **Which library functions are safe to use within signal handlers?**

- abort
- accept
- access
- aio_error
- aio_return
- aio_suspend
- alarm
- bind
- cfgetispeed
- cfgetospeed
- cfsetispeed
- cfsetospeed
- chdir
- chmod
- chown
- clock_gettime
- close
- connect
- creat
- dup
- dup2
- execle
- execve
- _exit
- fchmod
- fchown
- fcntl
- fdatasync
- fork
- fpathconf
- fstat
- fsync
- ftruncate
- getegid
- geteuid
- getgid
- getgroups
- getpeername
- getpgrp
- getpid
- getppid
- getsockname
- getsockopt
- getuid
- kill
- link
- listen
- lseek
- lstat
- mkdir
- mkfifo
- open
- pathconf
- pause
- pipe
- poll
- posix_trace_event
- pselect
- raise
- read
- readlink
- recv
- recvfrom
- recvmsg
- rename
- rmdir
- select
- sem_post
- send
- sendmsg
- sendto
- setgid
- setpgid
- setsid
- setsockopt
- setuid
- shutdown
- sigaction
- sigaddset
- sigdelset
- sigemptyset
- sigfillset
- sigismember
- signal
- sigpause
- sigpending
- sigprocmask
- sigqueue
- sigsuspend
- sleep
- sockatmark
- socket
- socketpair
- stat
- symlink
- sysconf
- tcdrain
- tcflow
- tcflush
- tcgetattr
- tcgetpgrp
- tcsendbreak
- tcsetattr
- tcsetpgrp
- time
- timer_getoverrun
- timer_gettime
- timer_settime
- times
- umask
- uname
- unlink
- utime
- wait
- waitpid
- write

Quiz 3

Printf is not listed as being async-signal safe. Can it be implemented so that it is?

a) yes, but it would be so complicated, it's not done
b) yes, it can be easily made async-signal safe
c) no, it's inherently not async-signal safe