CS 33

Signals Part 2

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

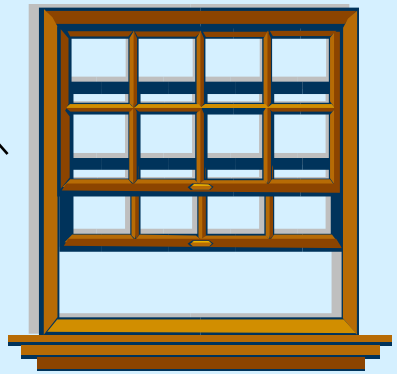
- Set of processes sharing the window/ keyboard
  - sometimes called a *job*
- Foreground process group/job
  - currently associated with window/keyboard
  - receives keyboard-generated signals
- Background process group/job
  - not currently associated with window/keyboard
  - doesn't currently receive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

Keyboard-Generated Signals

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

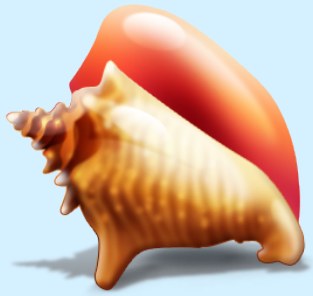
Foreground Job

Background Job



pgroup 16

Window



pid 16
pgroup 16

Shell

```
$ multiprocessProgram2 &
$
```

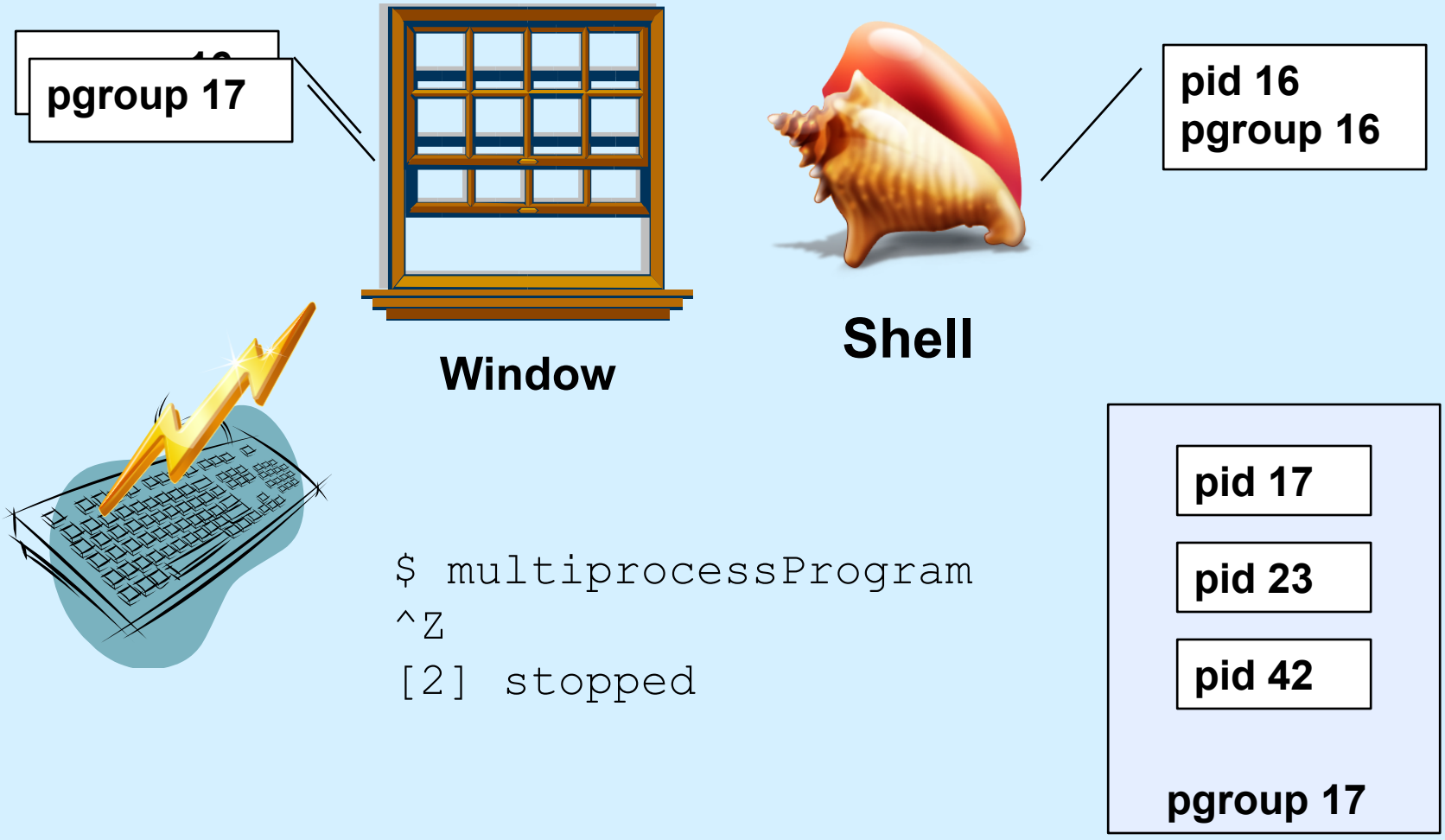
pid 164

pid 179

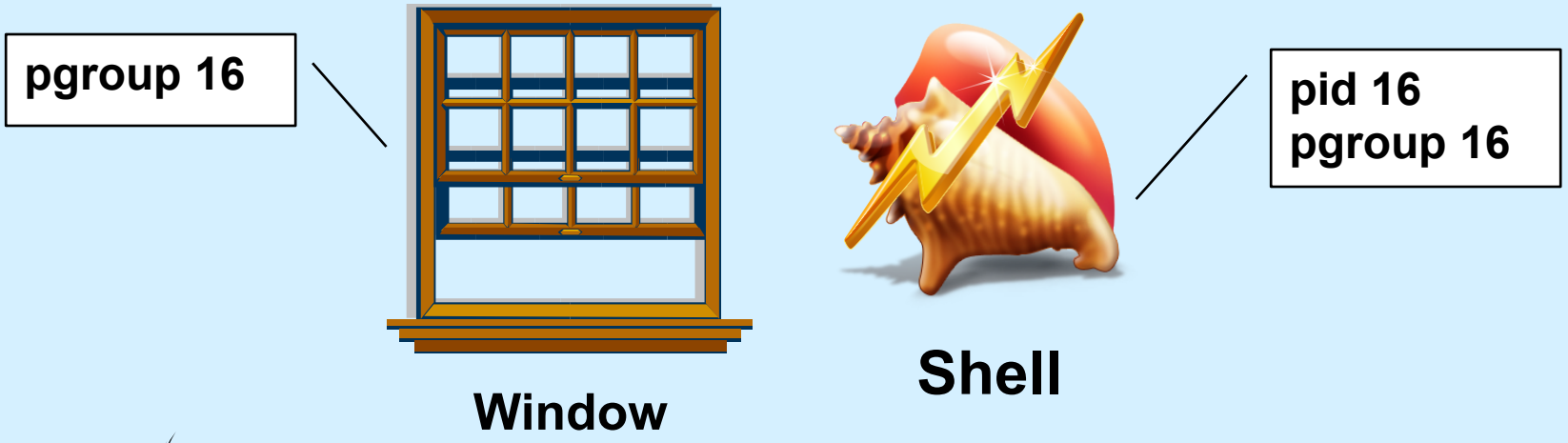
pid 196

pgroup 164

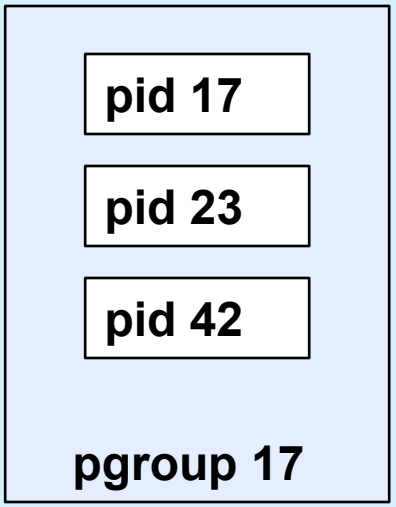
Stopping a Foreground Job



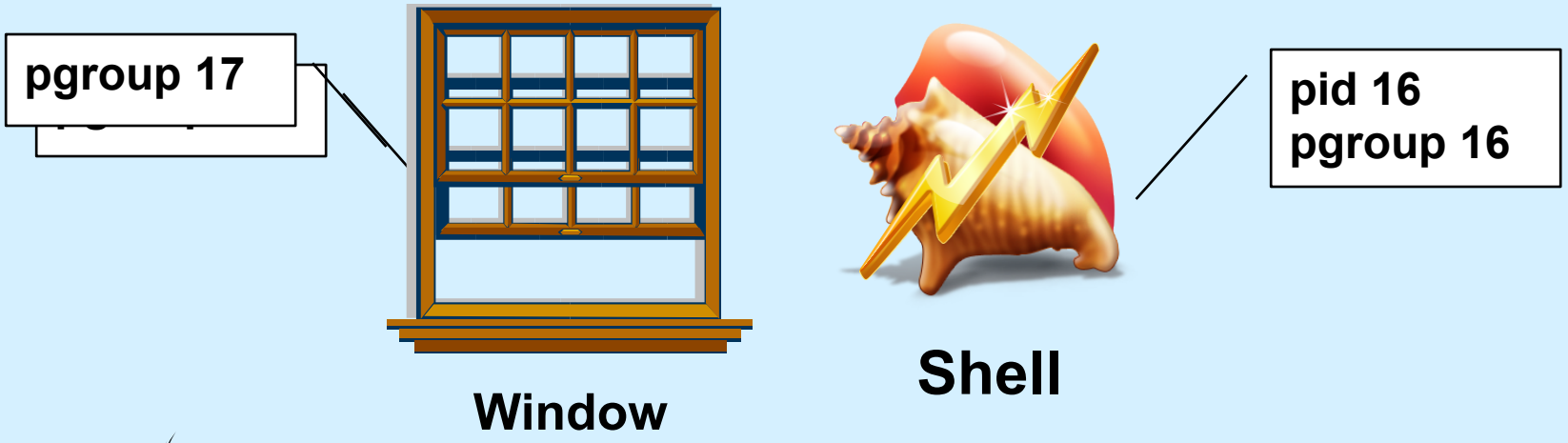
Backgrounding a Stopped Job



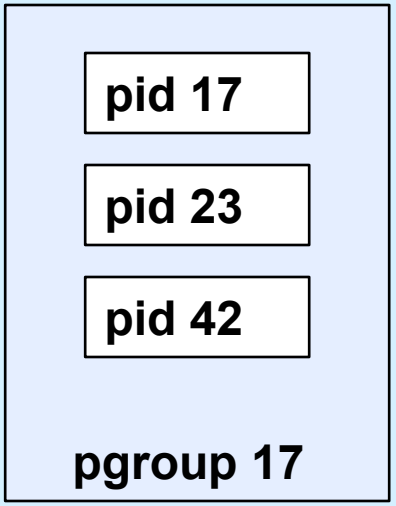
```
$ multiprocessProgram
^Z
[2] stopped
$ bg
$
```



Foregrounding a Job



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



Quiz 1

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

Which process group receives the SIGINT signal?

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

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
```

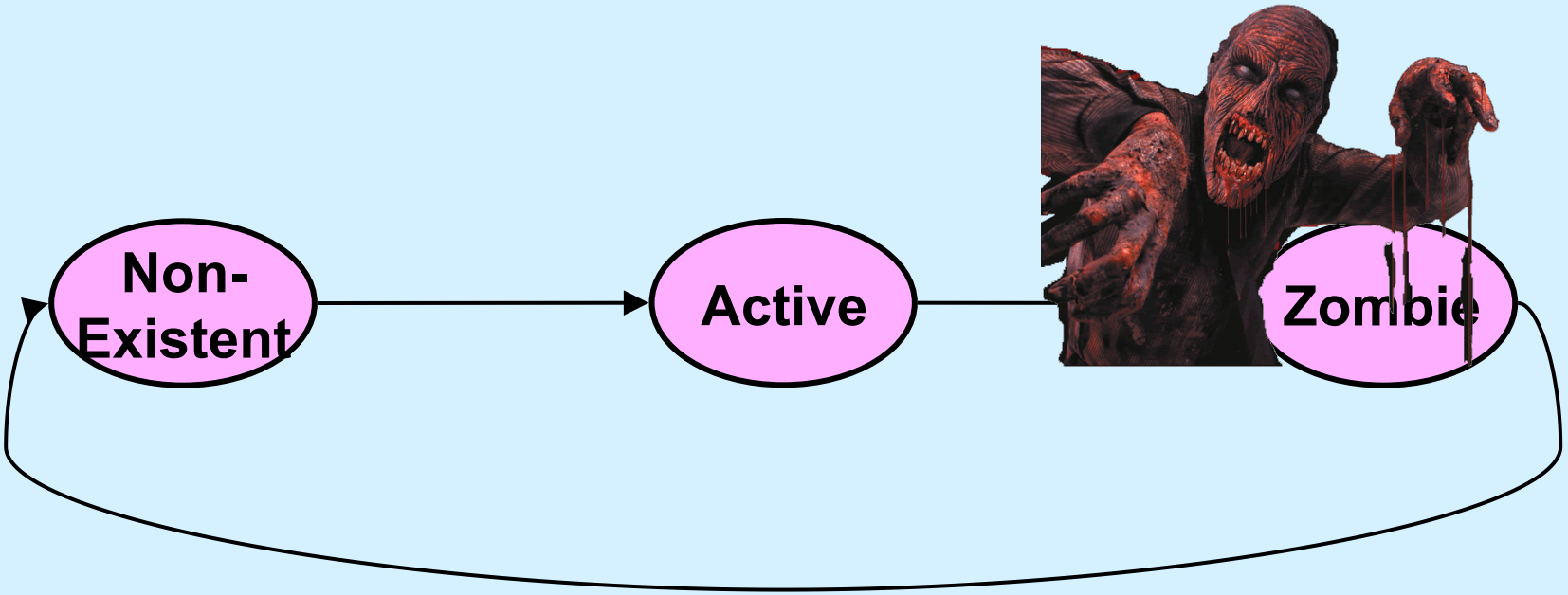

Background Input and Output

- 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 foreground processes**
  - **what about background?**

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

  - ***pid* options:**
    - **< −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** 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 stopped (been 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

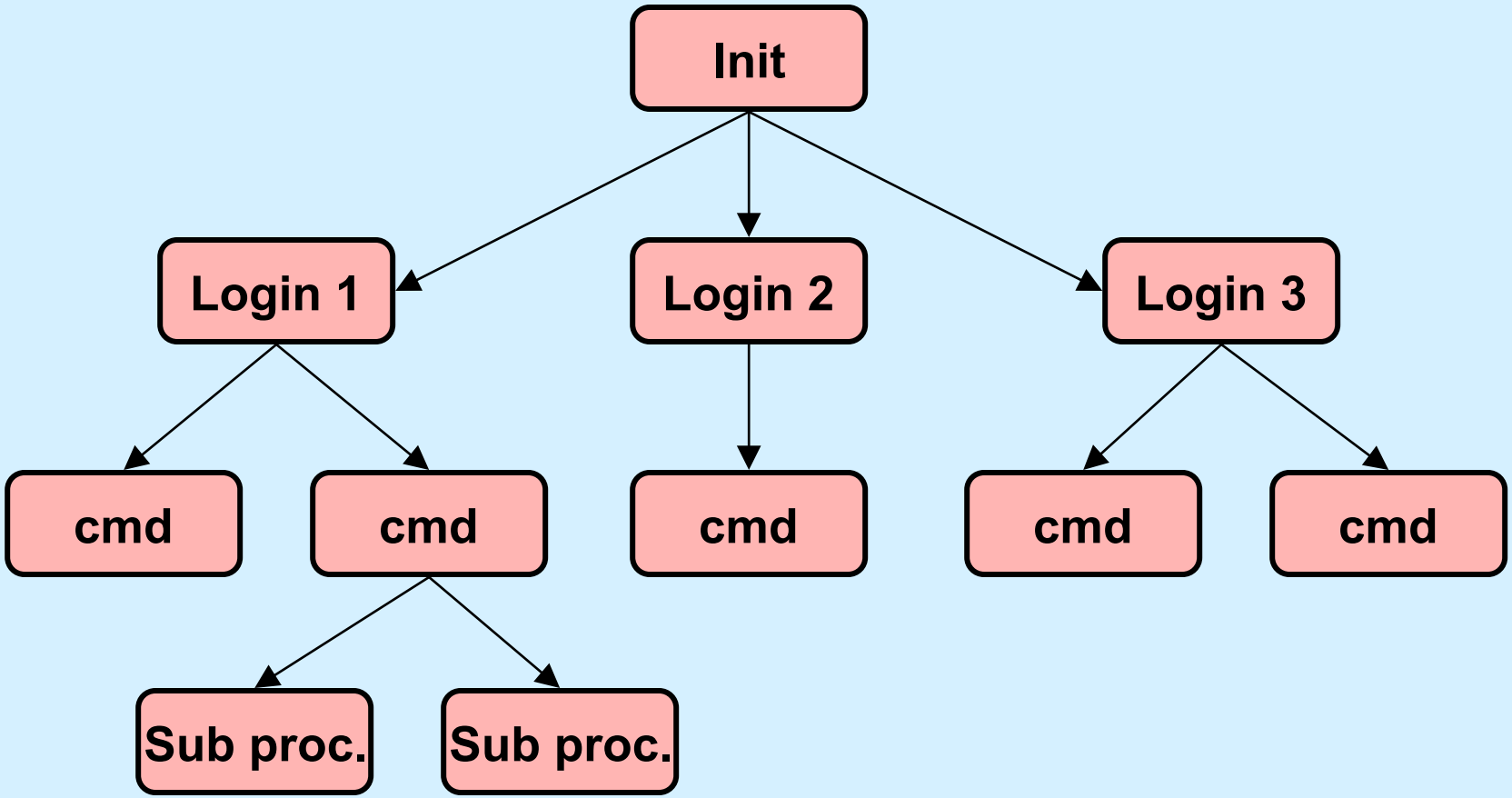
`waitpid` status

- 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

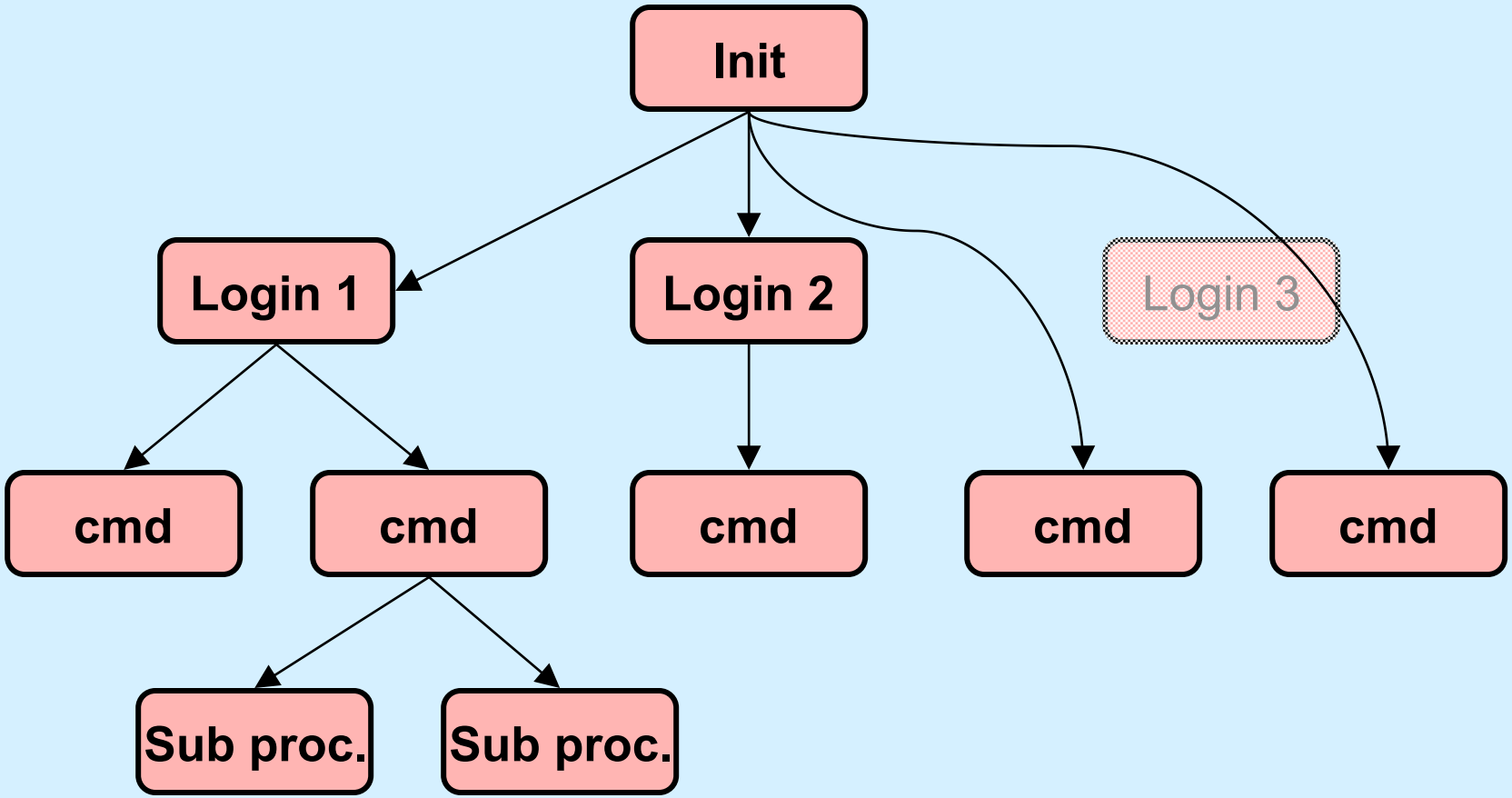
Example (in Shell)

```
int wret, status;
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
    ...
  }
}
```

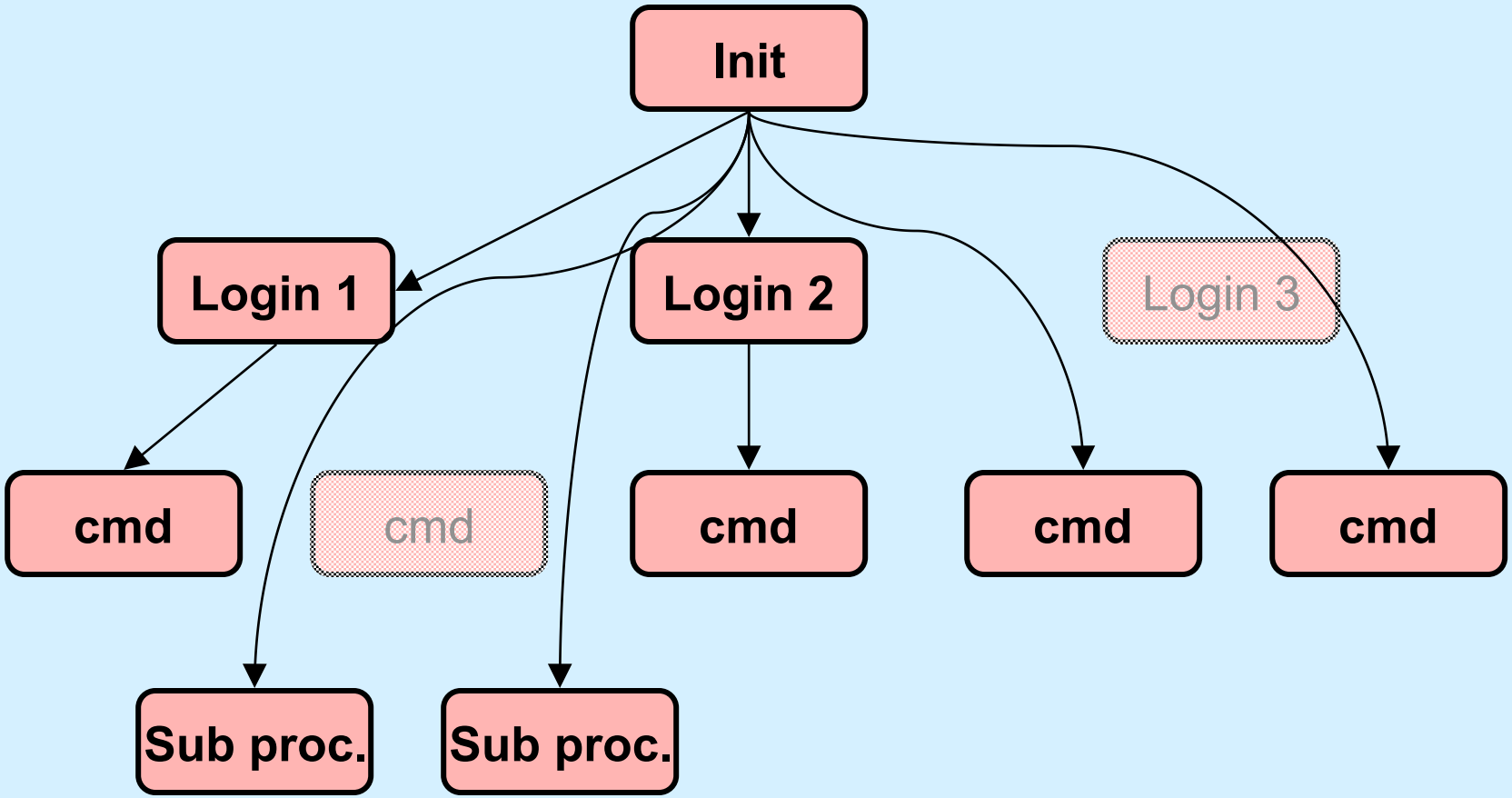

Process Relationships (1)



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?
}
```

Dealing with Failure

- ***fork***, ***execv***, ***wait***, ***kill*** **directly invoke the operating system**
- **Sometimes the OS says no**
  - **usually because you did something wrong**
  - **sometimes because the system has run out of resources**
  - **system calls return −1 to indicate a problem**

Reporting Failure

- **Integer error code placed in global variable *errno***

```
int errno;
```

  - **"man 3 errno" lists all possible error codes and meanings**
  - **to print out meaning of most recent error**

```
perror("message");
```

Fork

```
int main( ) {
  pid_t pid;
  while(1) {
    if ((pid = fork()) == -1) {
      perror("fork");
      exit(1);
    }
    ...
  }
}
```


Exec

```
int main( ) {
  if (fork() == 0) {
      char *argv[] = {"garbage", 0};
      execv("/garbage", argv);
      /* if we get here, there was an
         error! */
      perror("execv: garbage");
      exit(1);
  }
}
```

Signals and Blocking System Calls

- What if a signal is generated while a process is blocked in a system call?

  1) deal with it when the system call completes

  2) interrupt the system call, deal with signal, resume system call

  or

  3) interrupt system call, deal with signal, return from system call with indication that something happened

Interrupted System Calls

```
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);
}
```

Timed Out, Revisited

```
void timeout(int sig) {}

int main() {
  struct sigaction act;
  sigemptyset(&act.sa_mask);
  act.sa_flags = 0;
  act.sa_handler = timeout;
  sigaction(SIGALRM, &act,
    NULL);

  alarm(10);
  char password[128];
  if (read(2, password,
        128)) == -1) {
    if (errno == EINTR) {
      fprintf(stderr,
        "Timed out\n");
      return 1;
    }
    perror("read");
    exit(1);
  }
  alarm(0);
  UsePassword(password);

  return 0;
}
```

Quiz 2

```
int ret;
char buf[128] = fillbuf();

ret = write(1, buf, 128);
```

- **The value of ret is:**
  a) **either -1 or 128**
  b) **either -1, 0, or 128**
  c) **any integer in the range [-1, 128]**

Interrupted While Underway

```
remaining = total_count;
bptr = buf;
for ( ; ; ) {
  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) {
   ...   /* die gracefully */
   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 */

  myput("important message\n");

  ... /* more program */

}
```

```
void handler(int sig) {

  ... /* deal with signal */

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

Asynchronous Signals (4)

```
char buf[BSIZE];
int pos;
void myput(char *str) {
  int i;
  int len = strlen(str);
  for (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 routines 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 required to be async-signal safe. Can it be implemented so that it is?

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