CS 33

Signals Part 2

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 */
}
```

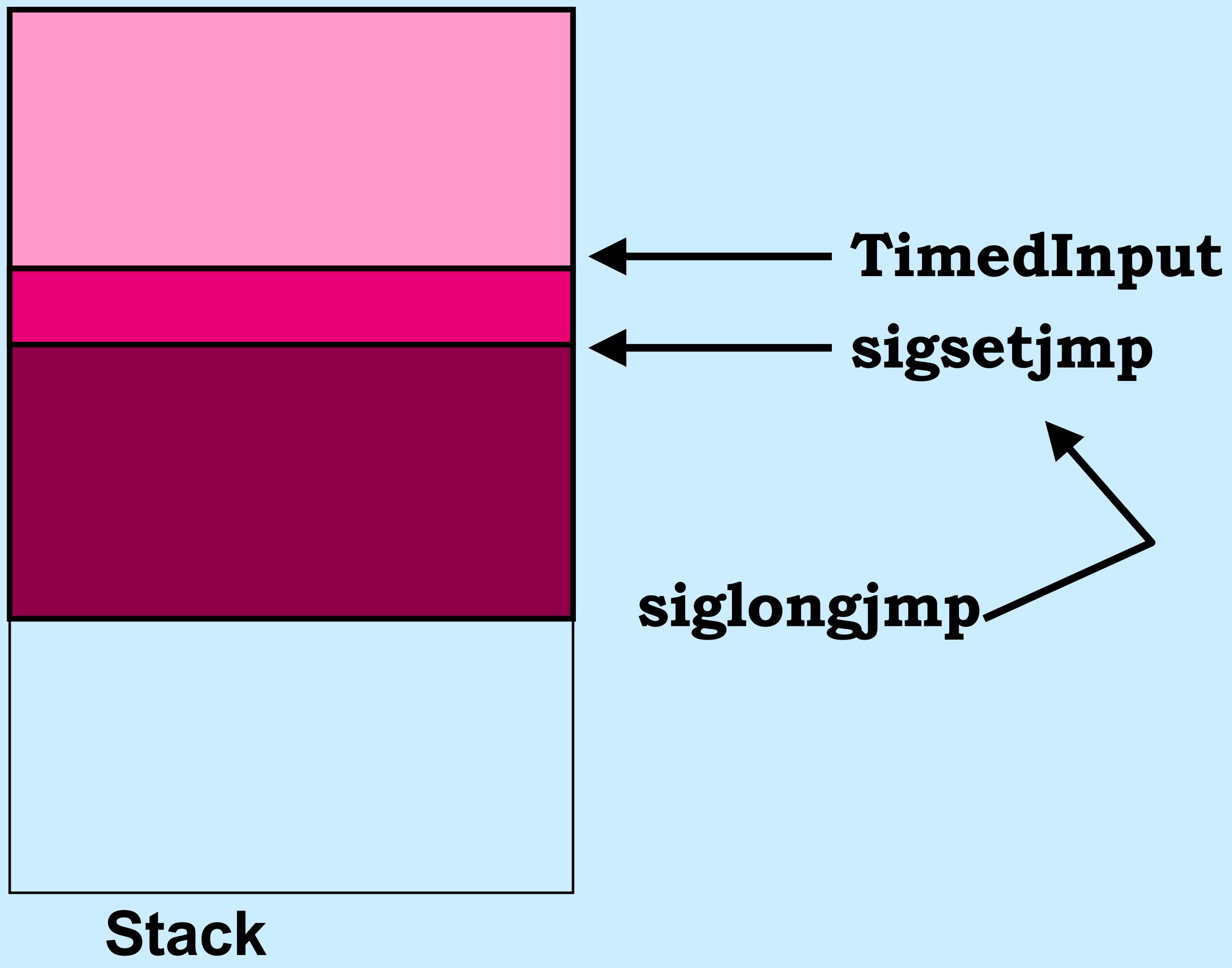
Doing It Legally (but Weirdly)

```
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



Exceptions

- **Other languages support exception handling**

```
try {
  something_a_bit_risky();
} catch(ArithmeticException e) {
  deal_with_it(e);
}
```

- **Can we do something like this in C?**

Exception Handling in C

```
void Exception(int sig) {
  THROW(sig)
}

int computation(int a) {
  return a/(a-a);
}
```

```
int main() {
  signal(SIGFPE, Exception);
  signal(SIGSEGV, Exception);
  TRY {
    computation(1);
  } CATCH(SIGFPE) {
    fprintf(stderr,
      "SIGFPE\n");
  } CATCH(SIGSEGV) {
    fprintf(stderr,
      "SIGSEGV\n");
  } END

  return 0;
}
```

Exception Handling in C

```
#define TRY \
 { \
   int excp; \
   if ((excp = \
     sigsetjmp(ctx, 1)) == 0)

#define CATCH(a_excp) \
   else if (excp == a_excp)

#define END }

#define THROW(excp) \
  siglongjmp(ctx, excp);
```

Exception Handling in C

```
sigjmp_buf ctx;                          void exception(int sig) {
                                   THROW   siglongjmp(ctx, sig);
                                         }
int main() {
 ...
 {
   int excp;
   if ((excp = sigsetjmp(ctx, 1)) == 0) { TRY
     computation(1);
   } else if (excp == SIGFPE) {  CATCH
     fprintf(stderr, "SIGFPE\n");
   } else if (excp == SIGSEGV) { CATCH
     fprintf(stderr, "SIGFPE\n");
   }
 }                                END
 return 0;
}
```

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

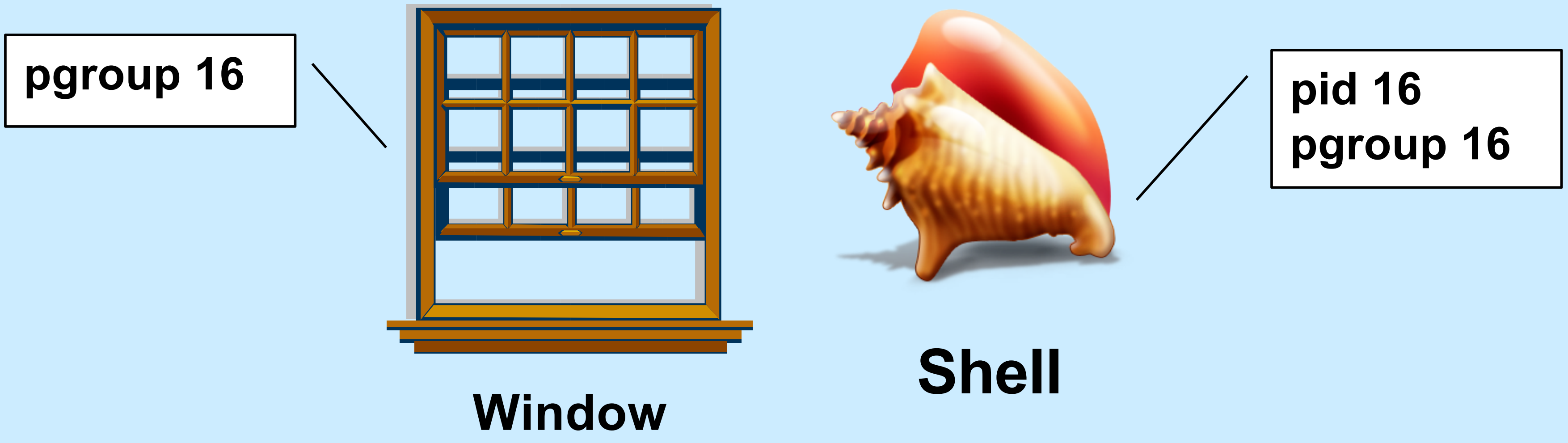
```
^C
$
```

Process Groups

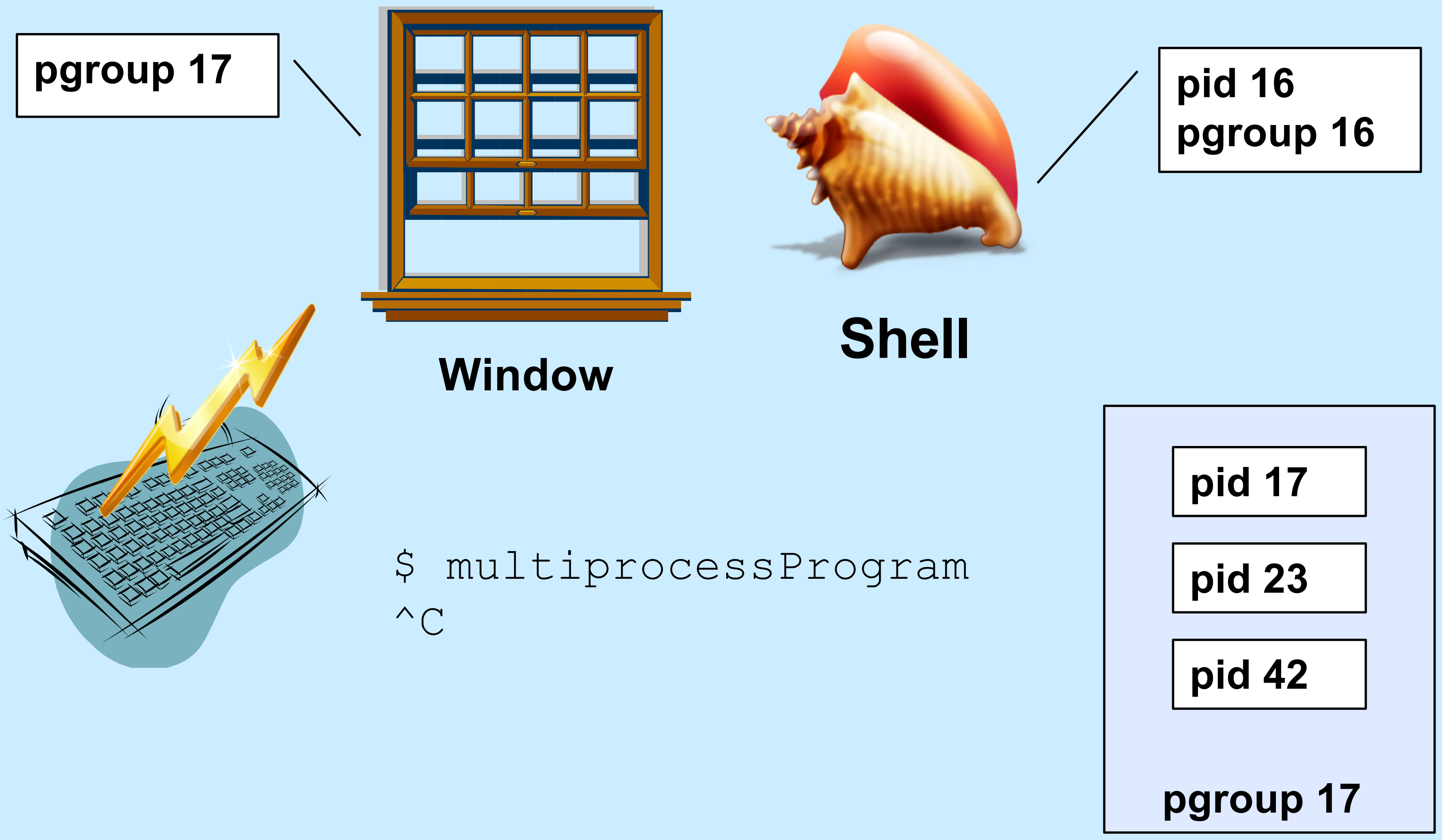
- Set of processes sharing the window/keyboard
  - sometimes called a *job*
- Foreground process group/job
  - currently associated with window/keyboard
  - receives keyboard-generated signals
- Background process group/job
  - not currently associated with window/keyboard
  - doesn’t currently receive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

Keyboard-Generated Signals

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

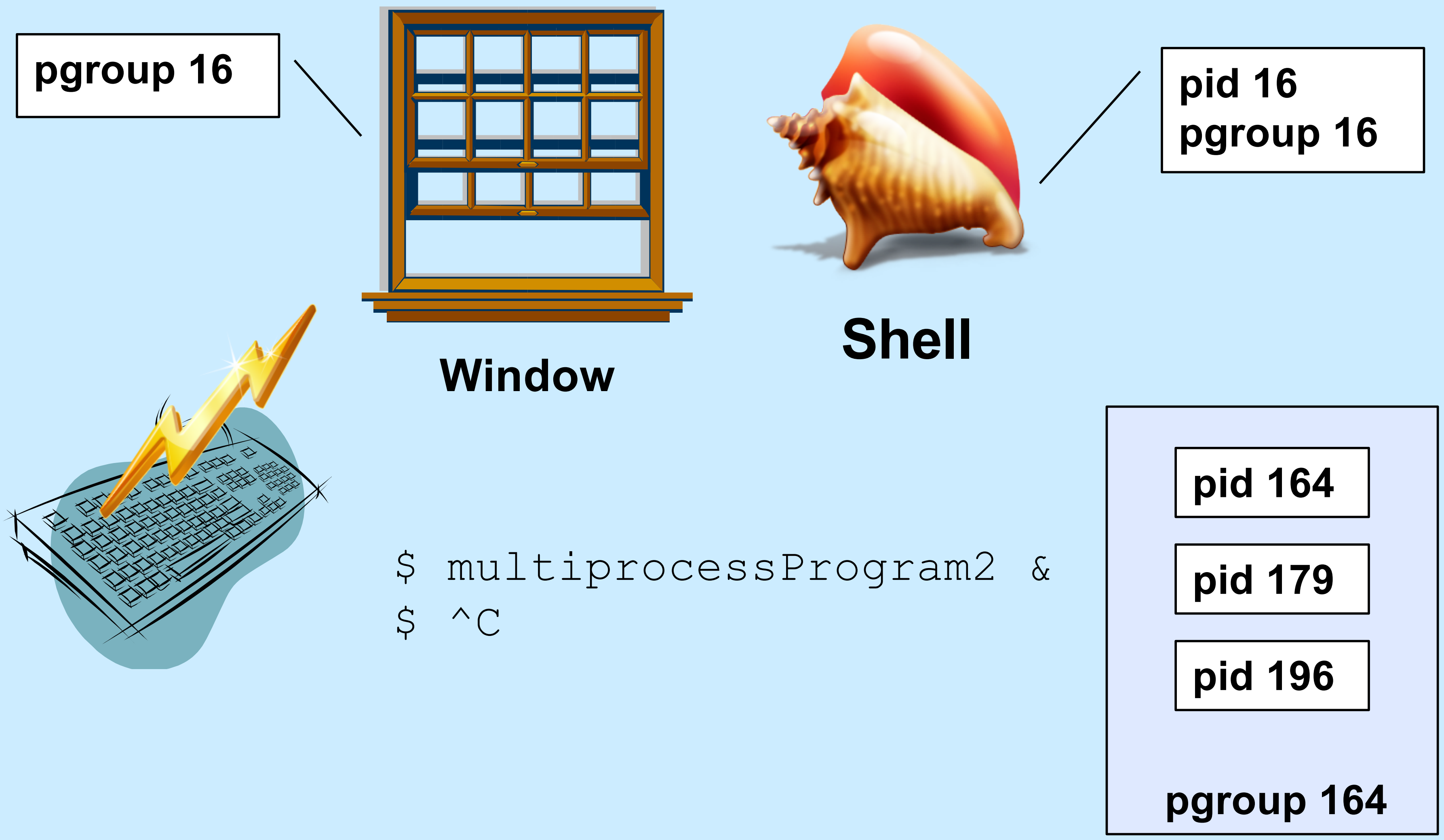


Foreground Job



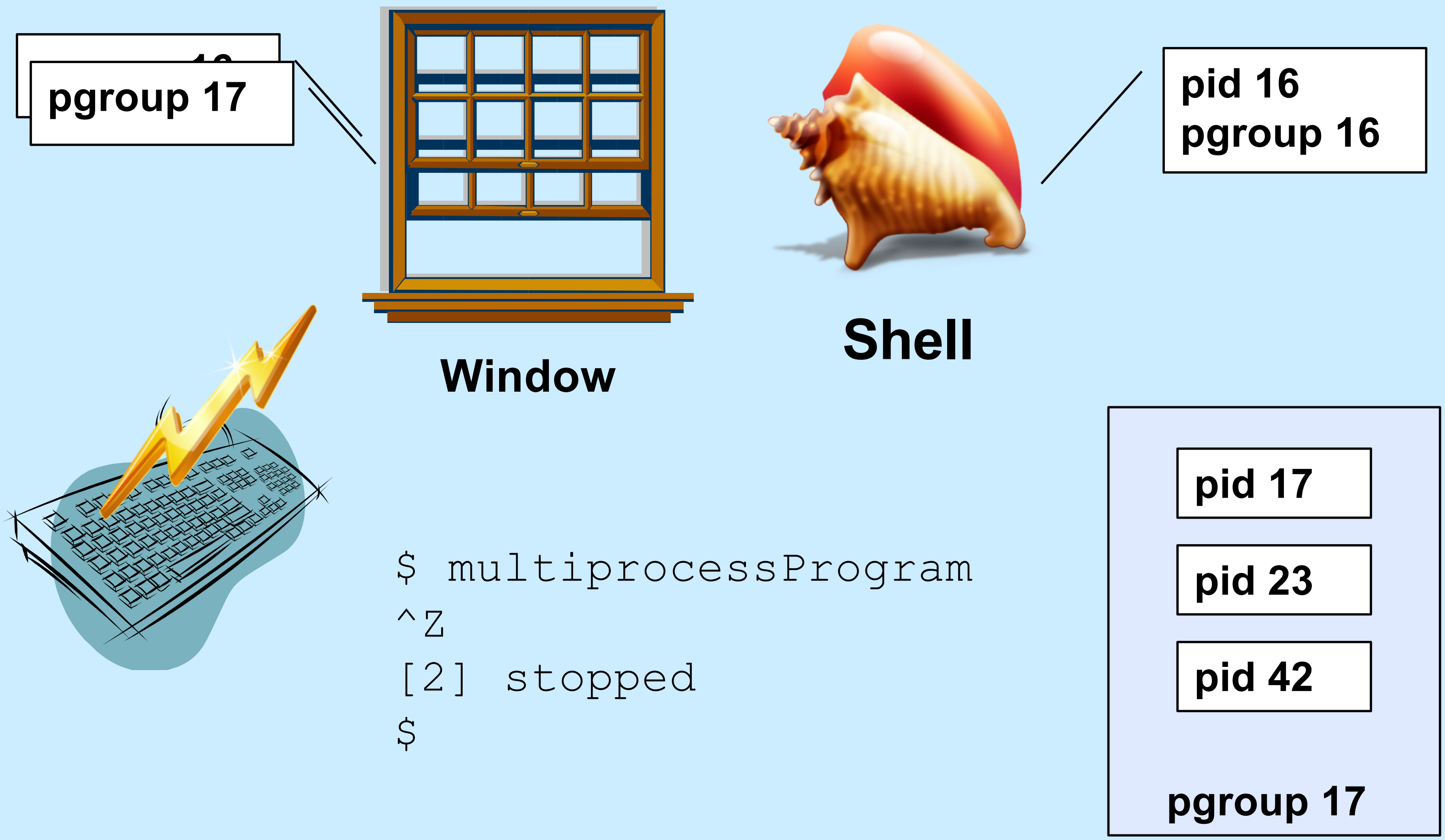
```
$ multiprocessProgram
^C
```

Background Job



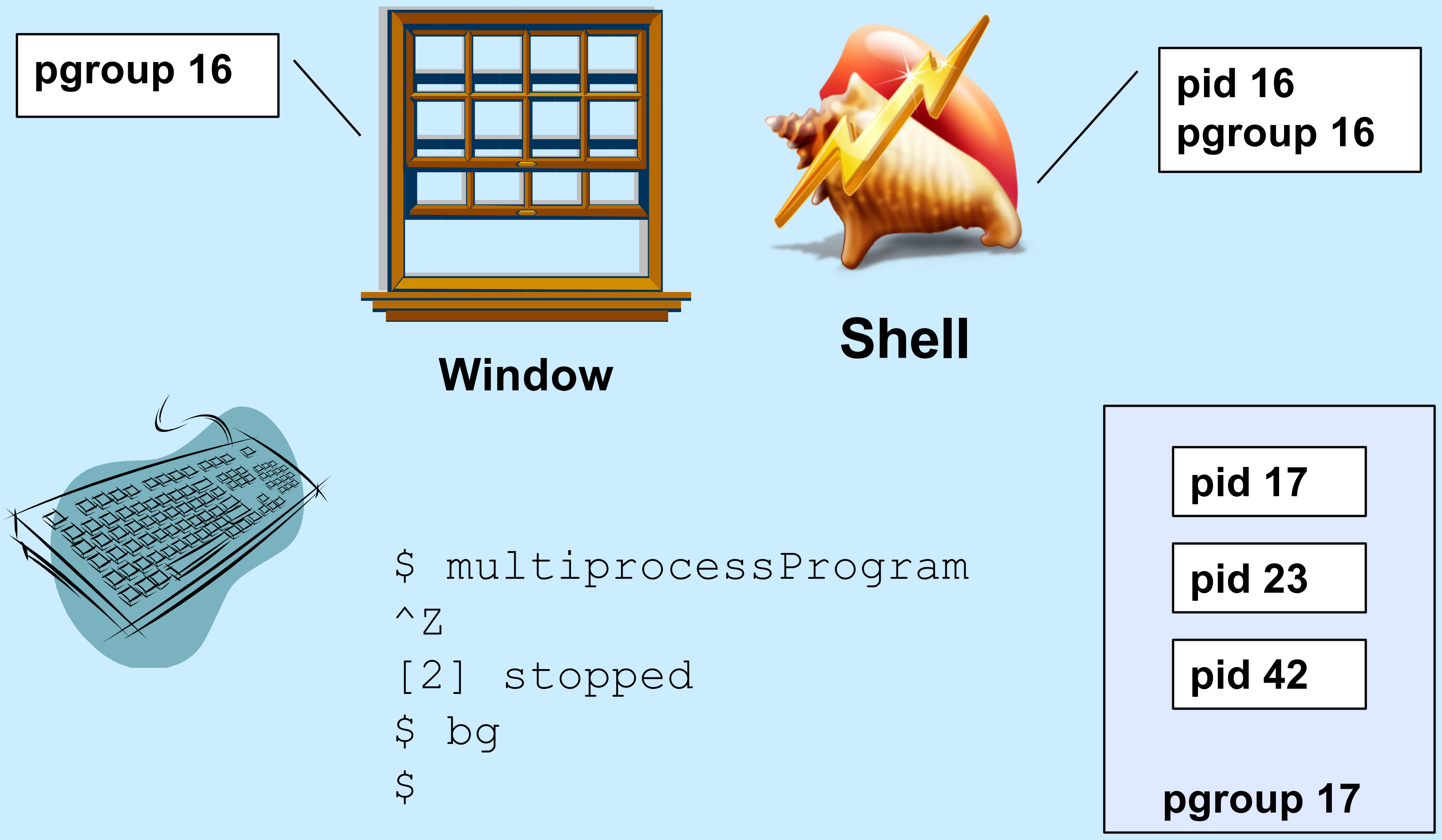
```
$ multiprocessProgram2 &
$ ^C
```

Stopping a Foreground Job



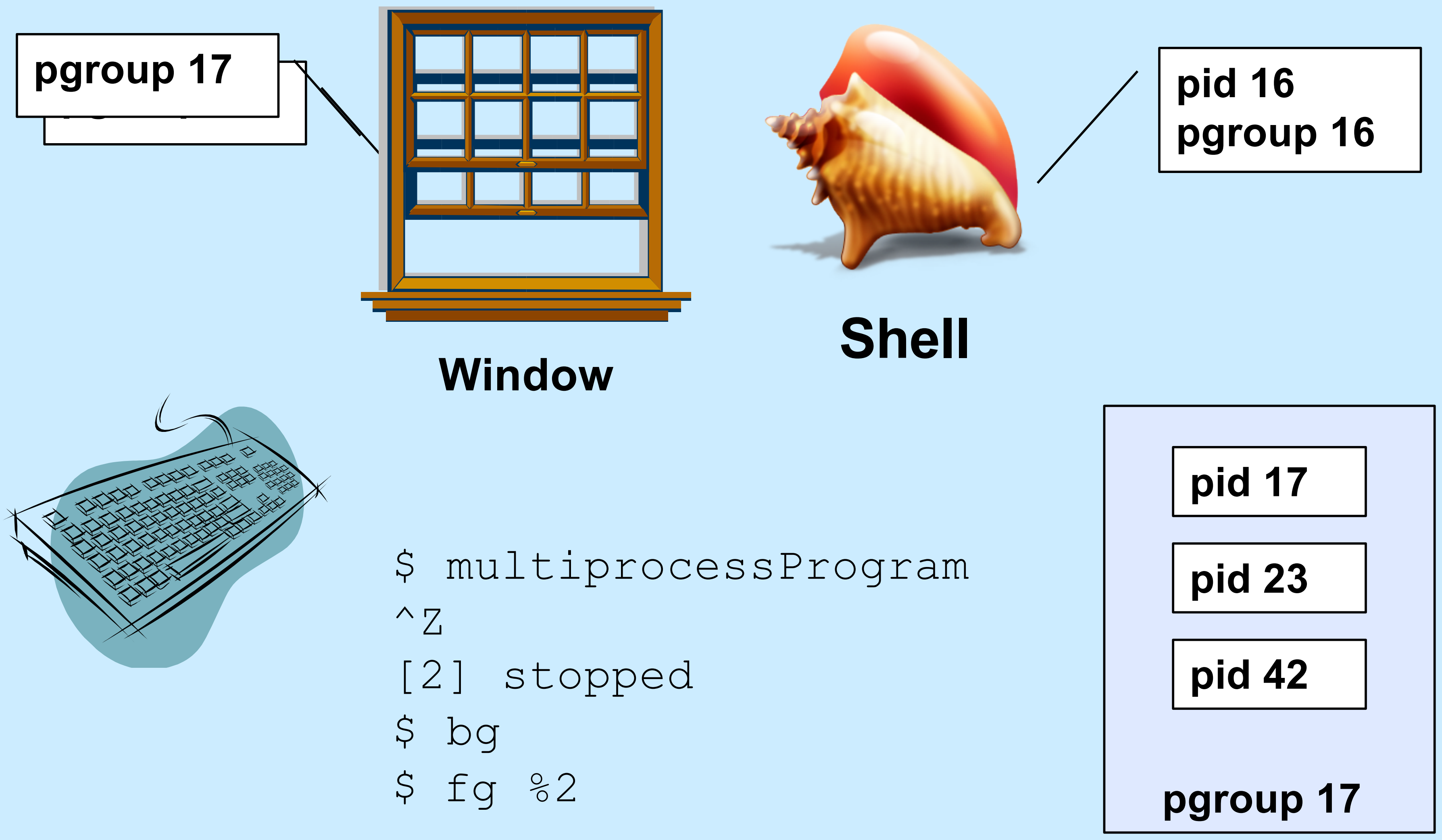
```
$ multiprocessProgram
^Z
[2] stopped
$
```

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
```

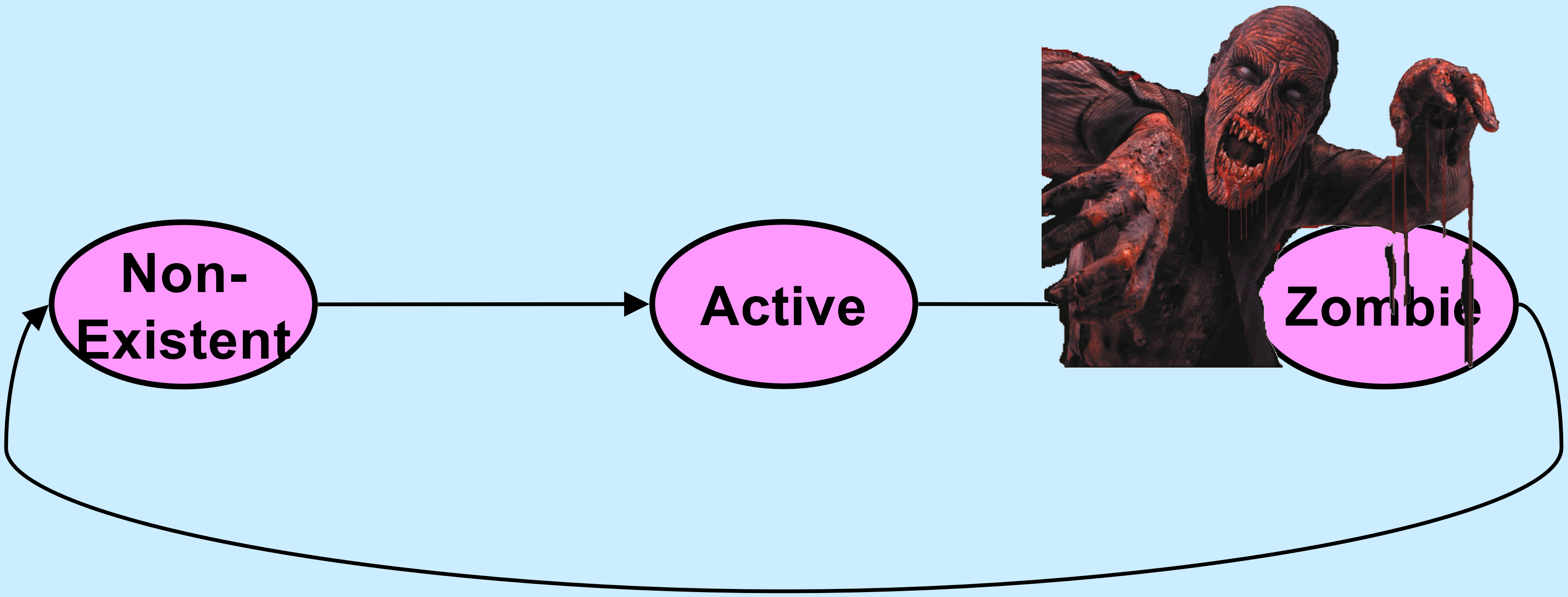
Background Input and Output

- **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* 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	**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

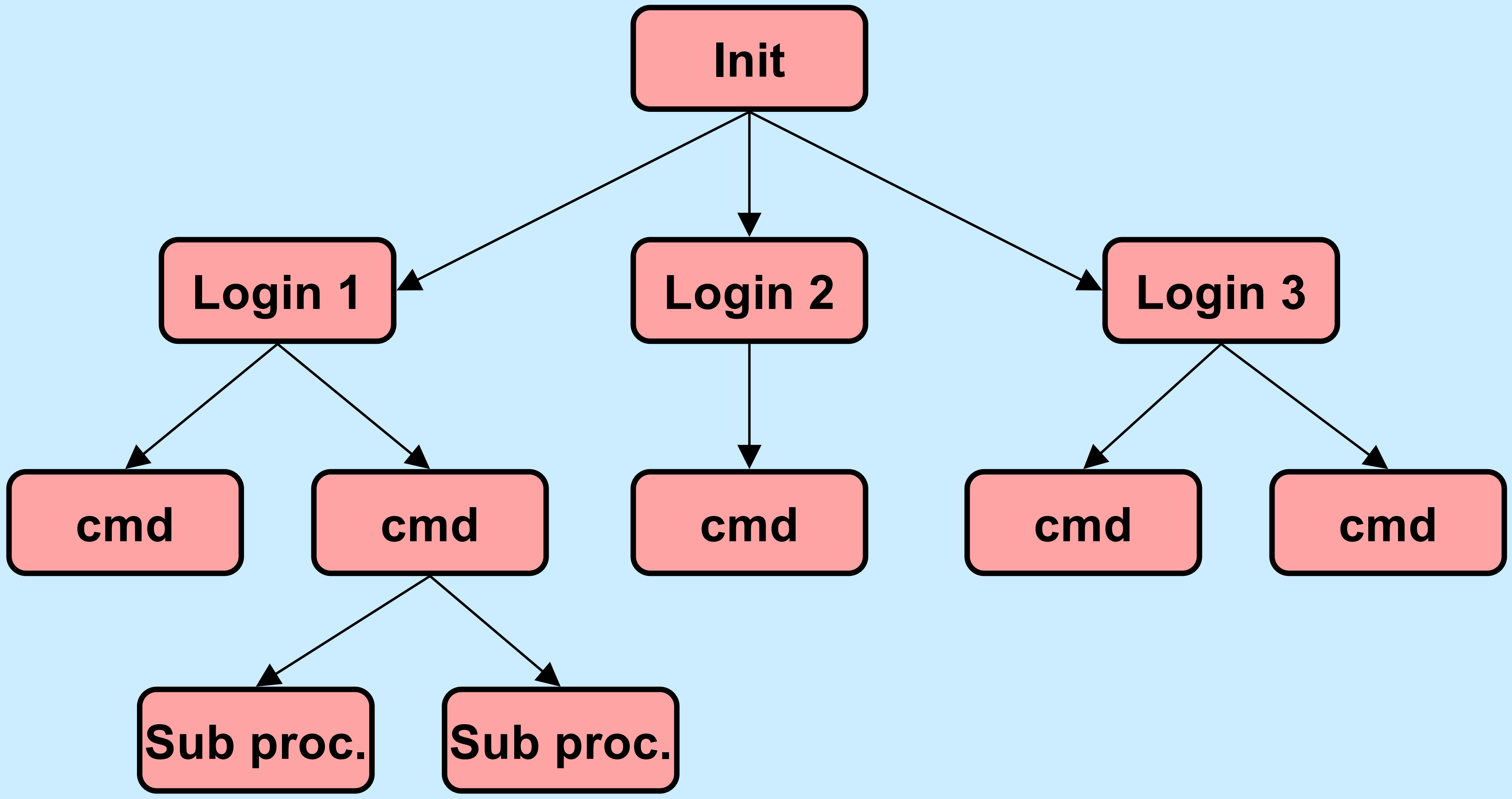
`waitpid` status

- 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

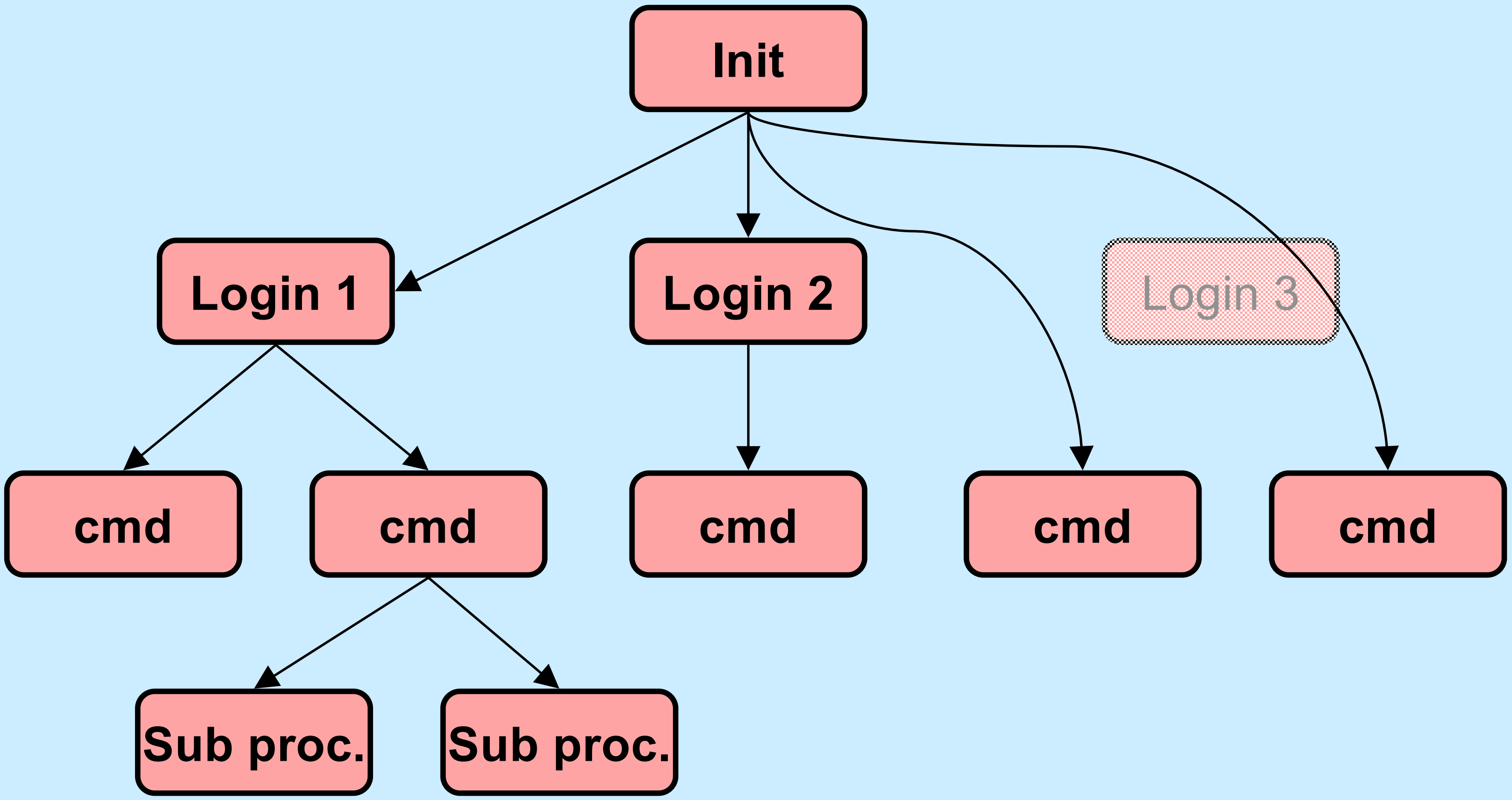
Example (in Shell)

```
int wret, 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
    ...
  }
}
```

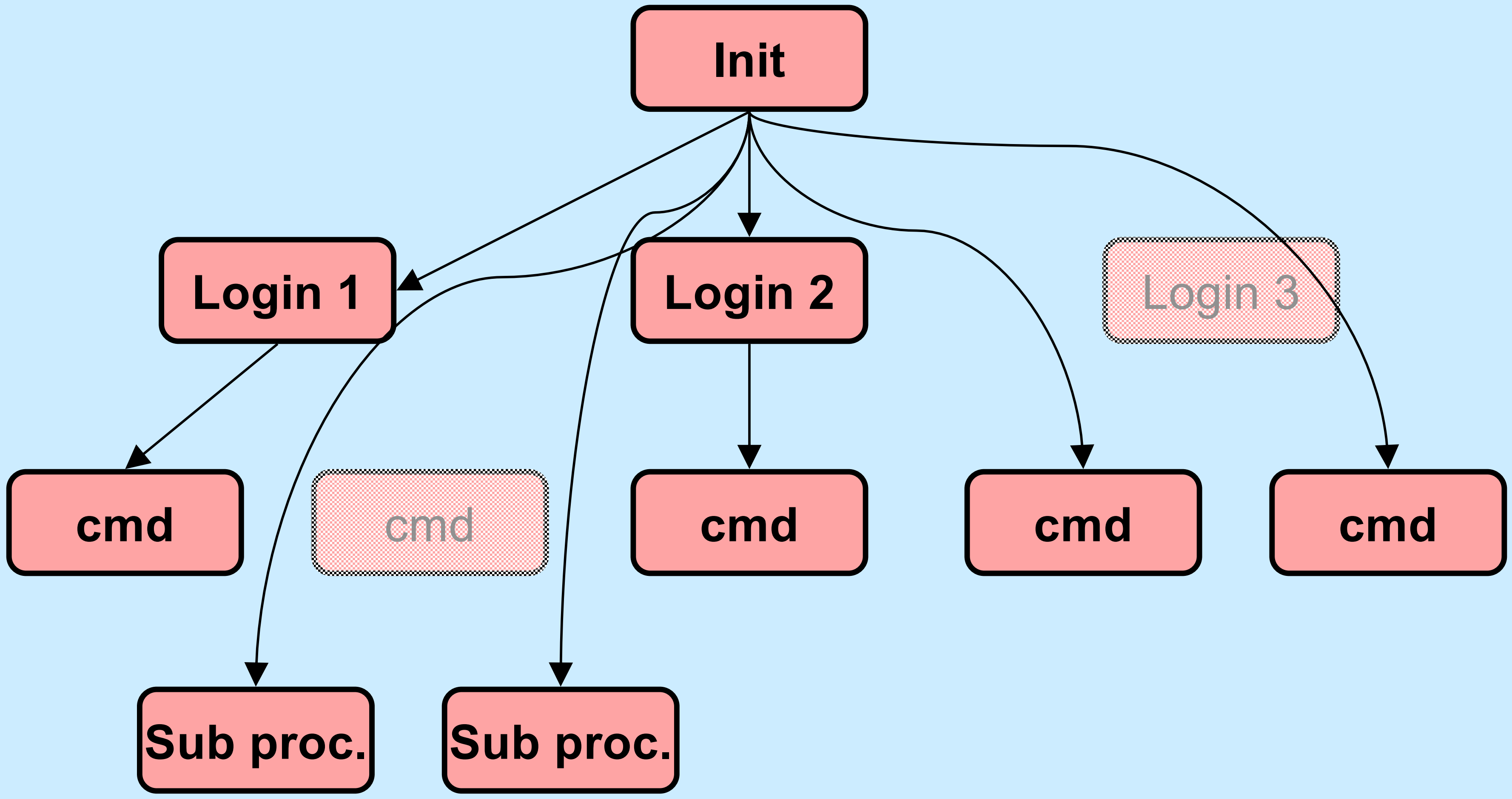
Process Relationships (1)



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?
  - deal with it at some safe point in the system-call code
  - usually just before the return to user mode
    - » system call completes
    - » signal handler is invoked
    - » user code resumed at return from system call

Signals and Lengthy System Calls

- Some system calls take a long time
  - large I/O transfer
    - » multi-megabyte 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?

~~1) invoke handler, then resume system call~~

   - ~~not clear if system call should be resumed~~

or

2) 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[128];

fillbuf(buf);

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 System Calls: Lengthy Case

```
char buf[BSIZE];
fillbuf(buf);
long remaining = BSIZE;
char *bptr = buf;
for ( ; ; ) {
  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 */

  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 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 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