Processes, wait(), signal() and more!

Computer Operating Systems, Fall 2023

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Administrivia

- Proj0 (penn-shredder) Due 09/13 @ 11:59 pm
  - This includes git & docker setup instructions. Do this part ASAP, it can take a while to debug issues with setup
  - **This assignment is done on your own**
- Check-in Quiz 0 Due before this lecture
  - Still open, to account for students joining the course a bit late
  - Don't expect this to be true with future quizzes
- Check-in Quiz 1 Due in ~1 week

Administrivia

- Optional Recitations!
  - We are going to try having optional recitations
  - First one is today after lecture from 3:30 to 4:30
  - On zoom and Moore 100C
  - This one is about C refresher including valgrind & GDB
  - Materials will be shared afterwards
  - Will it always be this time slot? idk, TBD
  - Will we have one every week? Probably not, TBD

Discuss

- Any questions, comments or concerns from last lecture or the check-in Quiz?

Discuss

- In each of these, how often is ":) \n" printed? Assume functions don't fail

```c
int main(int argc, char* argv[]) {
  char* envp[] = { NULL };

  pid_t pid = fork();
  if (pid == 0) {
    // we are the child
    char* argv[] = {"/bin/echo",
                    "hello",
                    NULL};
    execve(argv[0], argv, envp);
  }

   printf(":) \n");

  return EXIT_SUCCESS;
}
```

```c
int main(int argc, char* argv[]) {
  char* envp[] = { NULL };

  pid_t pid = fork();
  if (pid == 0) {
    // we are the child
    return EXIT_SUCCESS;
  }

   printf(":) \n");

  return EXIT_SUCCESS;
}
```

Lecture Outline

- **`wait()`, blocking, Zombies & PCB**
- `kill()`, `signal()`, `alarm()`
- Process Groups
- Process Lifetime

From last time:

```c
int main(int argc, char* argv[]) {
  char* envp[] = { NULL };
  // fork a process to exec clang
  pid_t clang_pid = fork();
  if (clang_pid == 0) {
    // we are the child
    char* clang_argv[] = {"/bin/clang", "-o",
              "hello","hello_world.c", NULL};
    execve(clang_argv[0], clang_argv, envp);
    exit(EXIT_FAILURE);
  }

  // fork to run the compiled program
  pid_t hello_pid = fork();
  if (hello_pid == 0) {
    // the process created by fork
    char* hello_argv[] = {"./hello", NULL};
    execve(hello_argv[0], hello_argv, envp);
    exit(EXIT_FAILURE);
  }
  return EXIT_SUCCESS;
}
```

broken_autograder.c

This code is broken. It compiles, but it doesn't ALWAYS do what we want. Why?

- Clang is a C compiler
- Assume it compiles
- Assume I gave the correct args to exec

"waiting" for updates on a Process

- `pid_t wait(int *wstatus);`

Usual change in status is to "terminated"

  - Calling process waits for any child process to change status
    - Also cleans up the child process if it was a zombie/terminated
  - Gets the exit status of child process through output parameter **`wstatus`**
  - Returns process ID of child who was waited for or `-1` on error

Execution Blocking

- When a process calls **`wait()`** and there is a process to wait on, the calling process **blocks**

- If a process **blocks** or is **blocking** it is not scheduled for execution.
  - It is not run until some condition "unblocks" it
  - For **`wait()`**, it unblocks once there is a status update in a child

Fixed code from last lecture

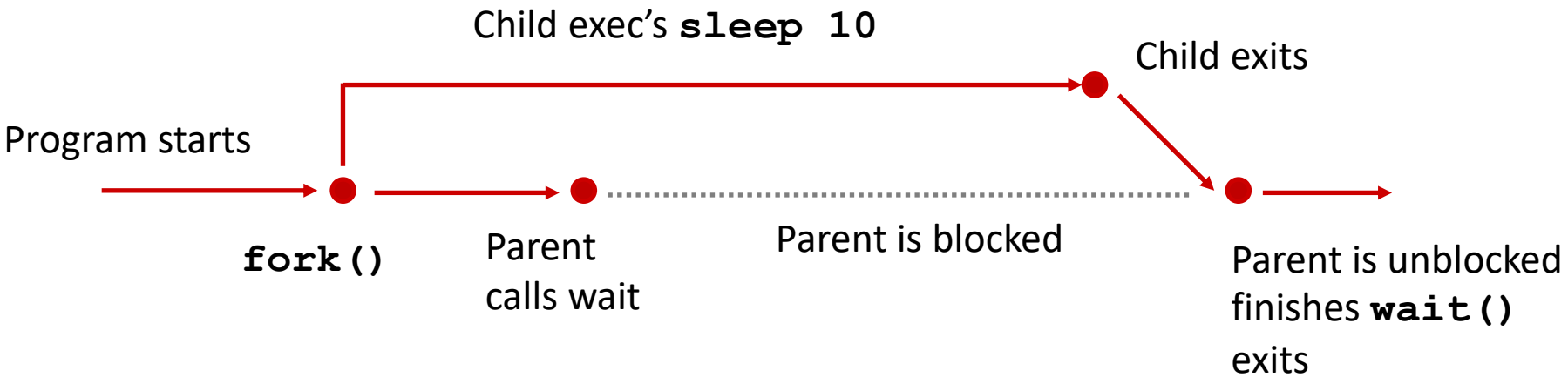
```c
int main(int argc, char* argv[]) {
  char* envp[] = { NULL };
  // fork a process to exec clang
  pid_t clang_pid = fork();
  if (clang_pid == 0) {
    // we are the child
    char* clang_argv[] = {"/bin/clang", "-o",
              "hello","hello_world.c", NULL};
    execve(clang_argv[0], clang_argv, envp);
    exit(EXIT_FAILURE);
  }
  wait(); // should error check, not enough slide space :(
  // fork to run the compiled program
  pid_t hello_pid = fork();
  if (hello_pid == 0) {
    // the process created by fork
    char* hello_argv[] = {"./hello", NULL};
    execve(hello_argv[0], hello_argv, envp);
    exit(EXIT_FAILURE);
  }
  return EXIT_SUCCESS;
}
```

autograder.c

Demo: `wait_example`

- See `wait_example.c`
  - Brief demo to see how a process blocks when it calls wait()
  - Makes use of **`fork()`**, **`execve()`**, and **`wait()`**

- Execution timeline:



discuss

- Can child finish before parent calls wait?

What if the child finishes first?

- In the timeline I drew, the parent called wait before the child executed.
  - In the program, it is extremely likely this happens if the child is calling **`sleep 10`**
  - What happens if the child finishes before the parent calls wait? Will the parent not see the child finish?

Process Tables & Process Control Blocks

- The operating system maintains a table of all processes that aren't "completely done"

- Each process in this table has a **p**rocess **c**ontrol **b**lock (**PCB**) to hold information about it.
- A PCB can contain:
  - Process ID
  - Parent Process ID
  - Child process IDs
  - Process Group ID
  - Status (e.g. running/zombie/etc)
  - Other things (file descriptors, register values, etc)

Zombie Process

- Answer: processes that are terminated become “zombies”
  - Zombie processes deallocate their address space, don’t run anymore
  - still “exists”, has a PCB still, so that a parent can check its status one final time
  - If the parent call’s wait(), the zombie becomes “reaped” all information related to it has been freed (No more PCB entry)

Diagram: wait_example.c

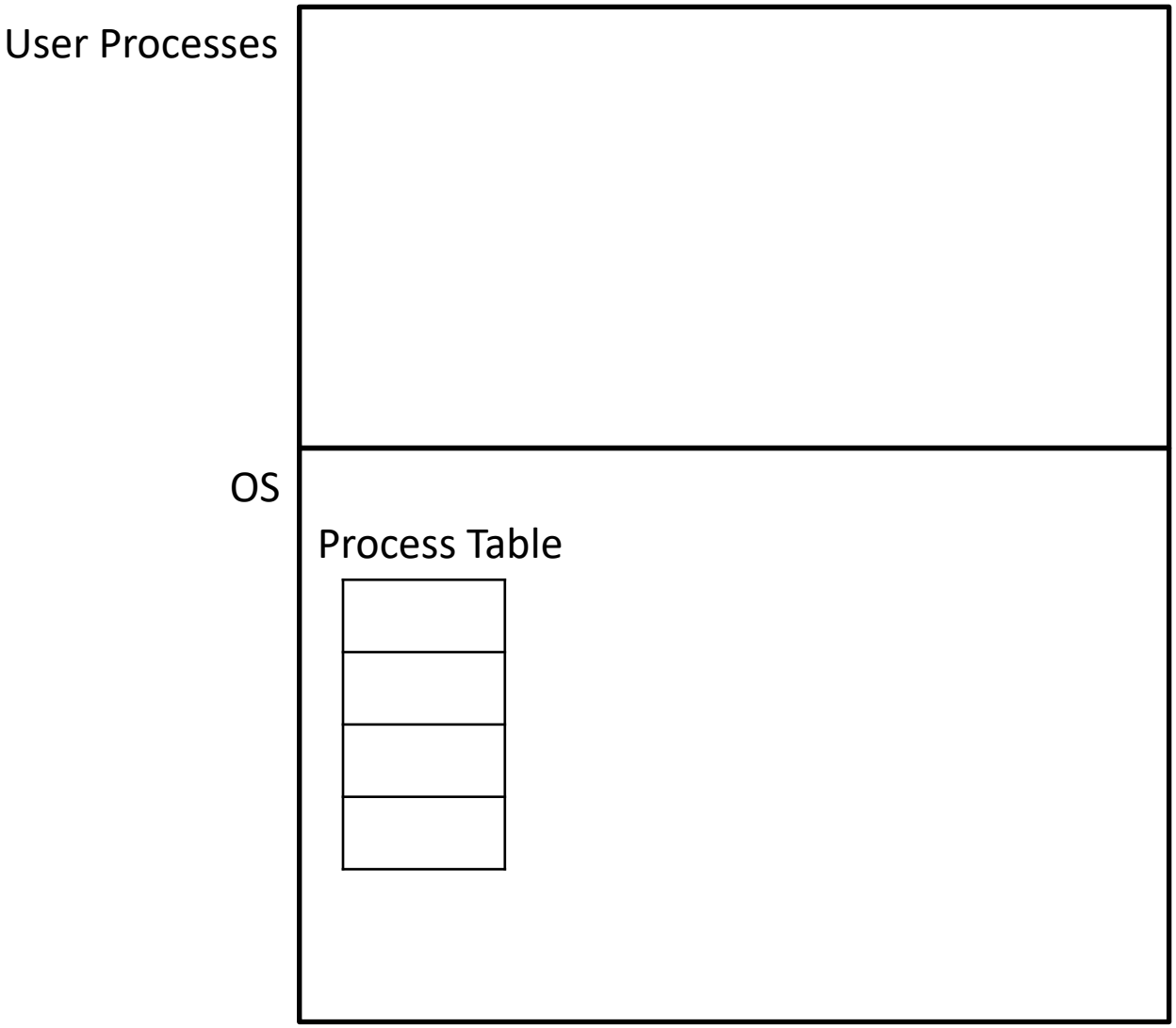


Diagram: wait_example.c

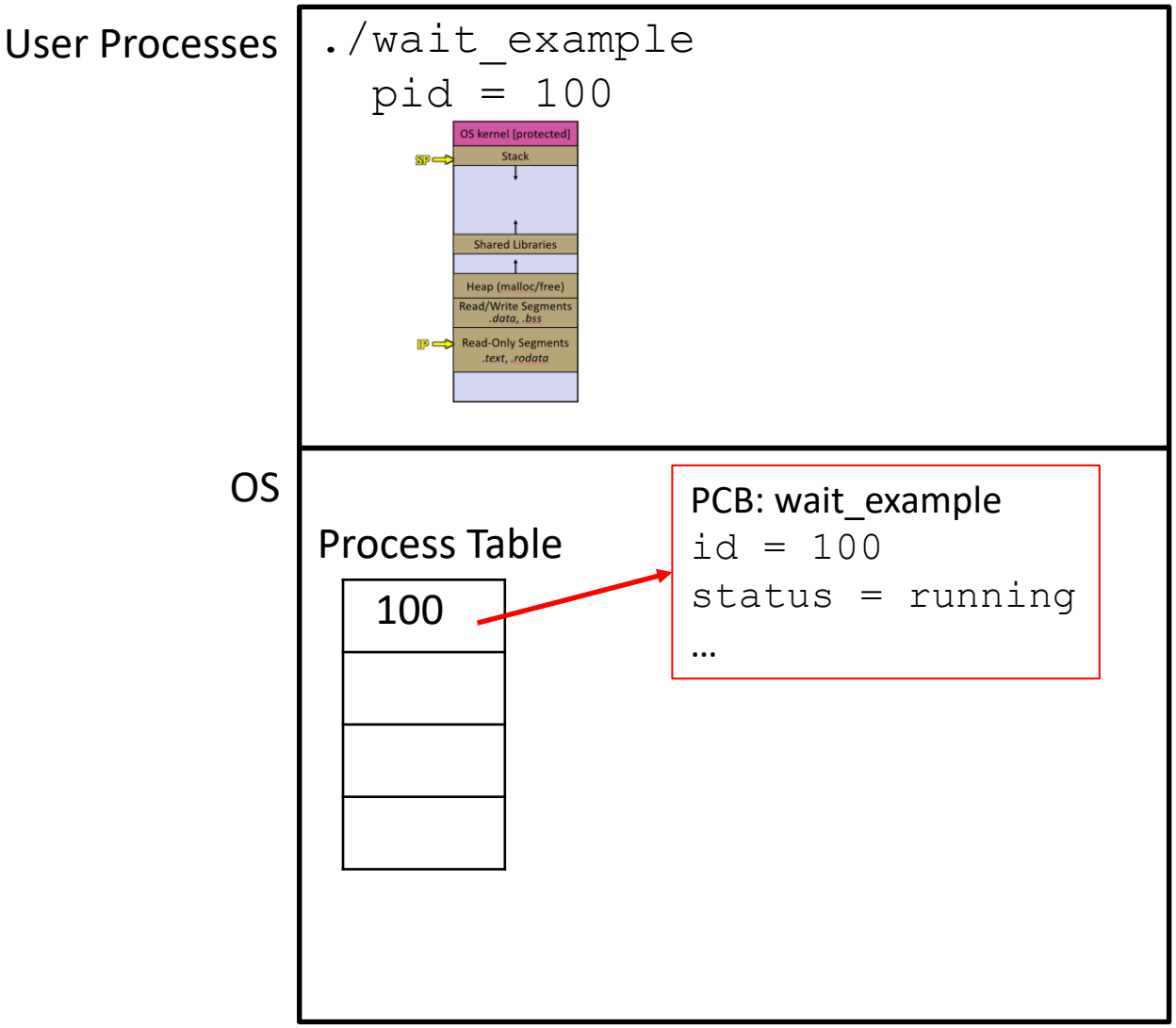


Diagram: wait_example.c

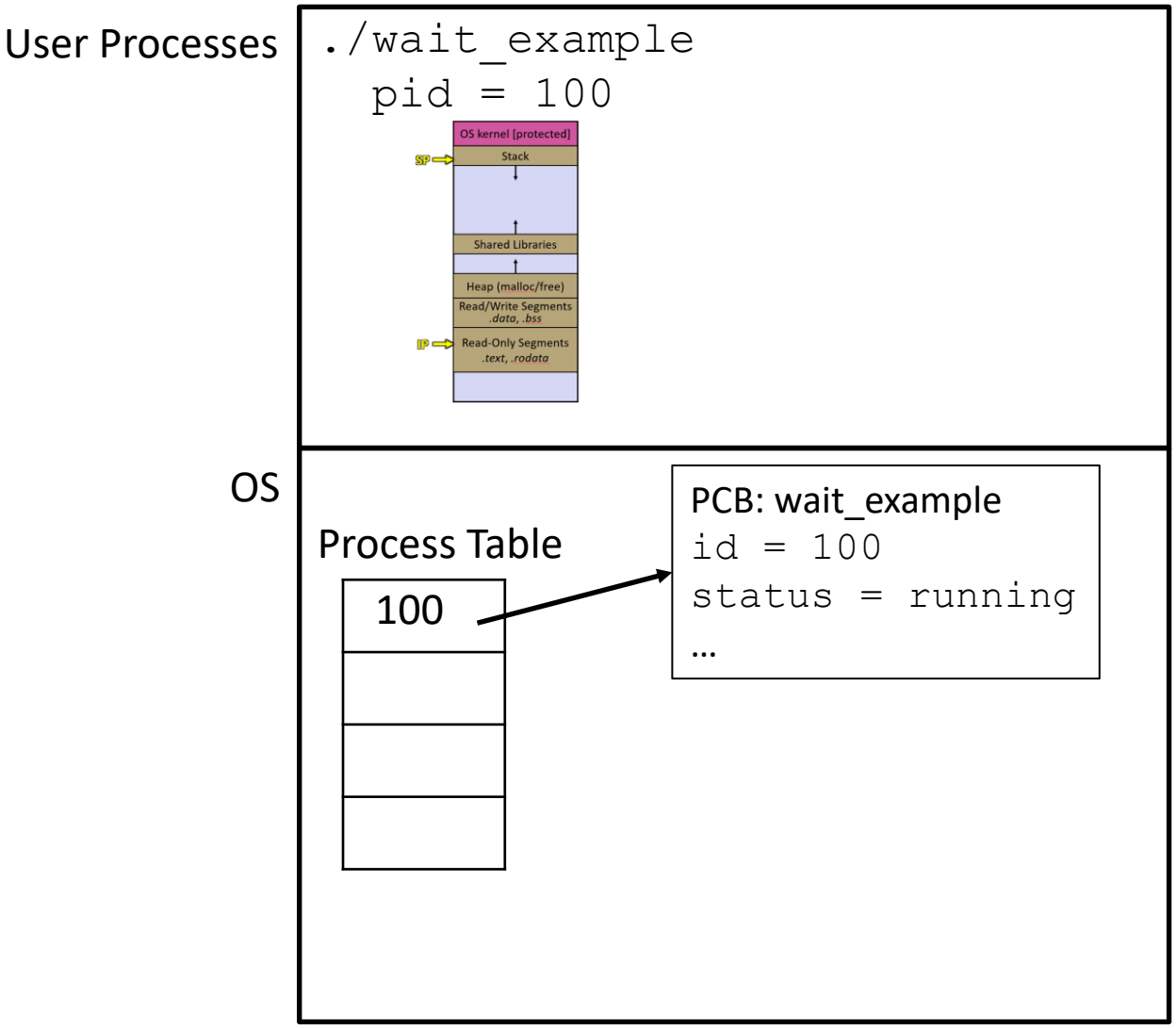


Diagram: wait_example.c

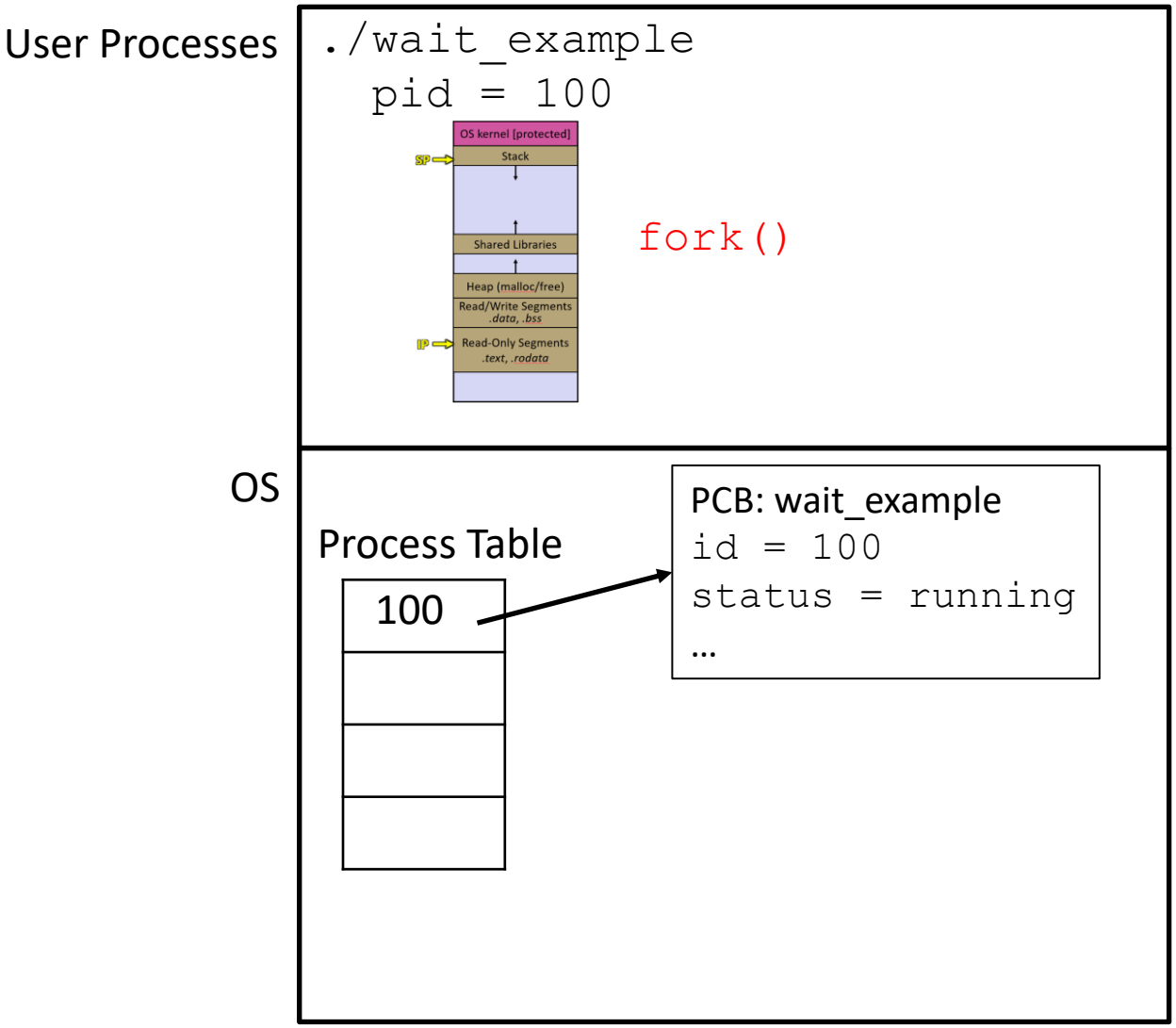


Diagram: wait_example.c

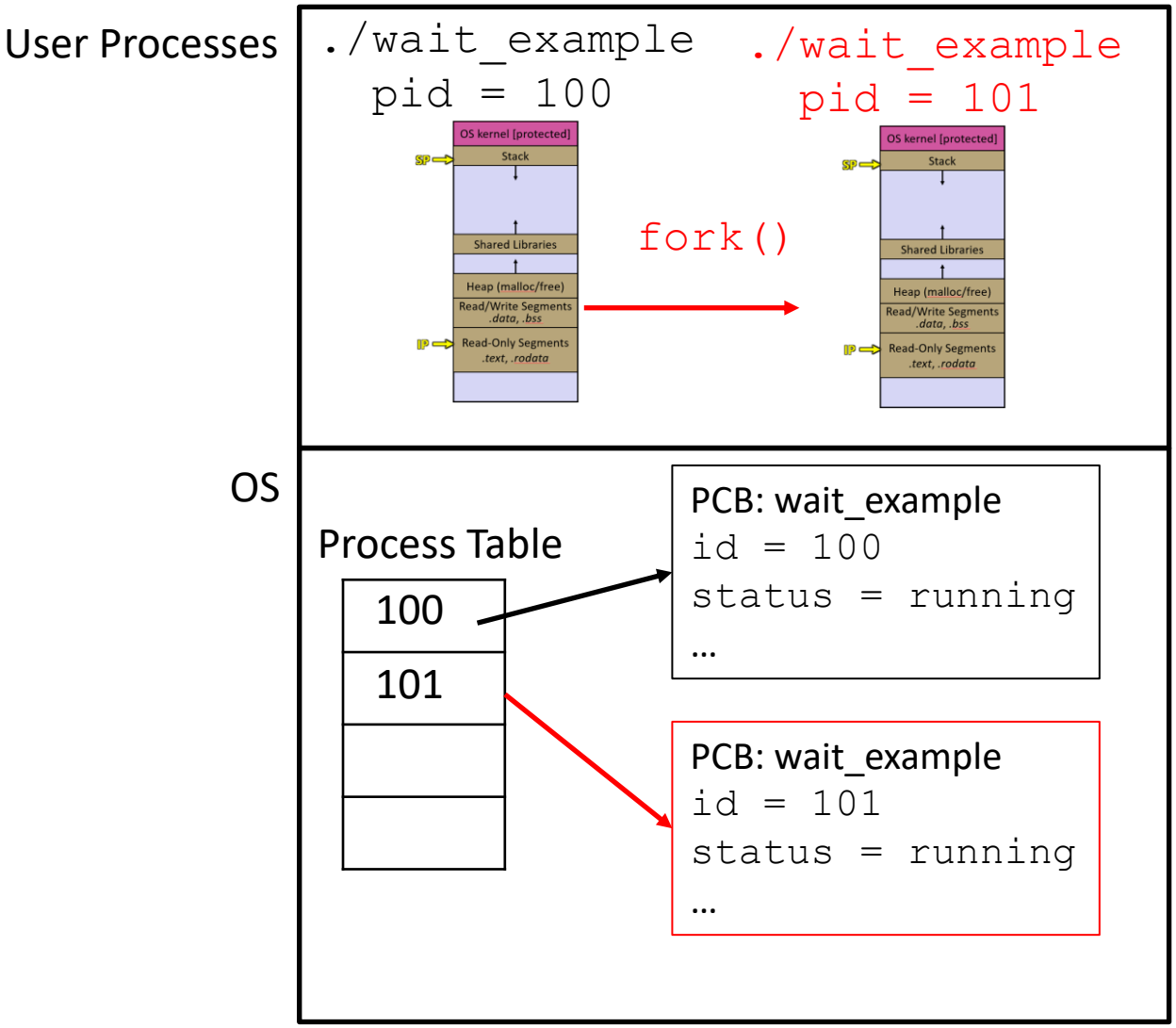


Diagram: wait_example.c

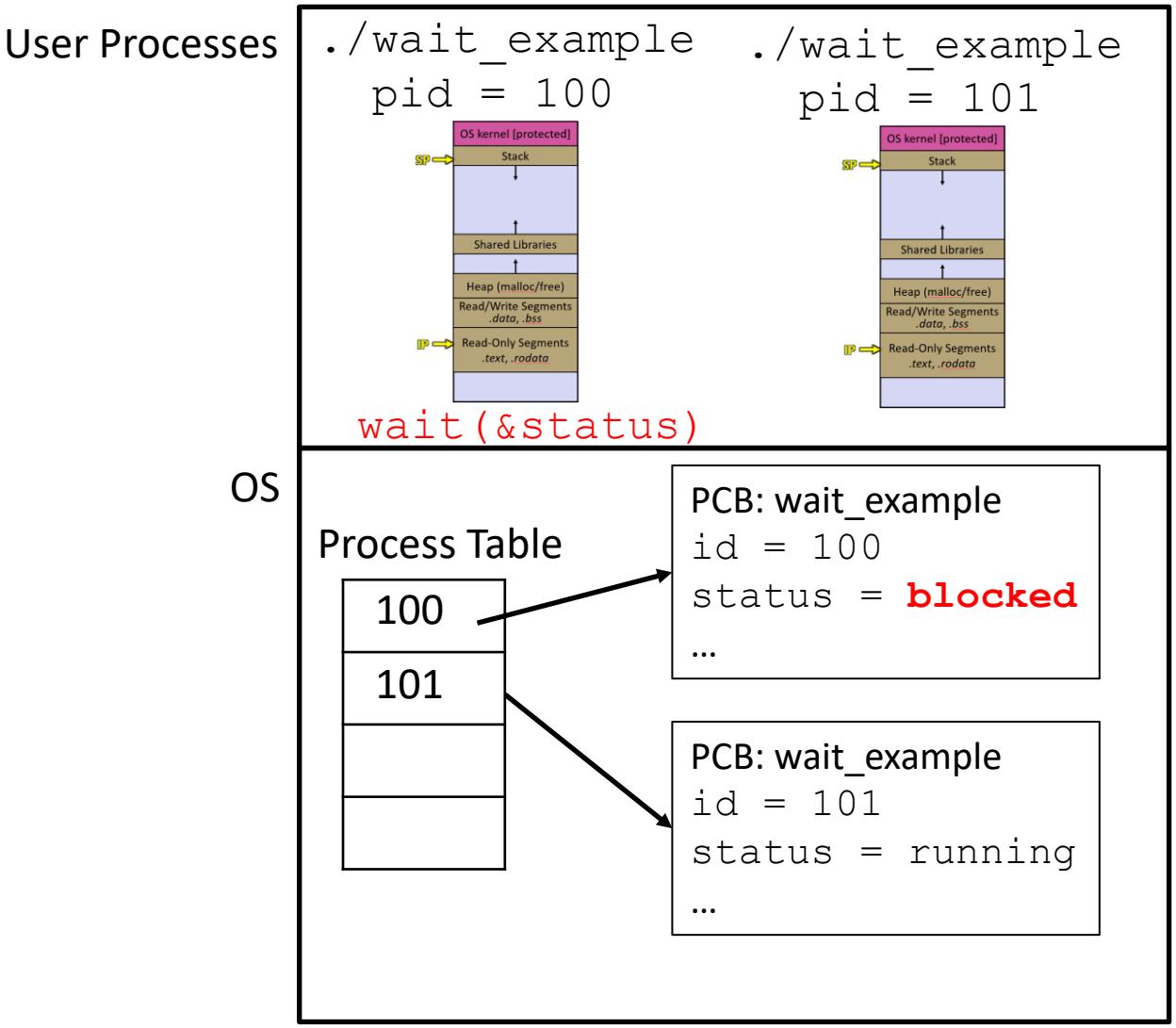


Diagram: wait_example.c

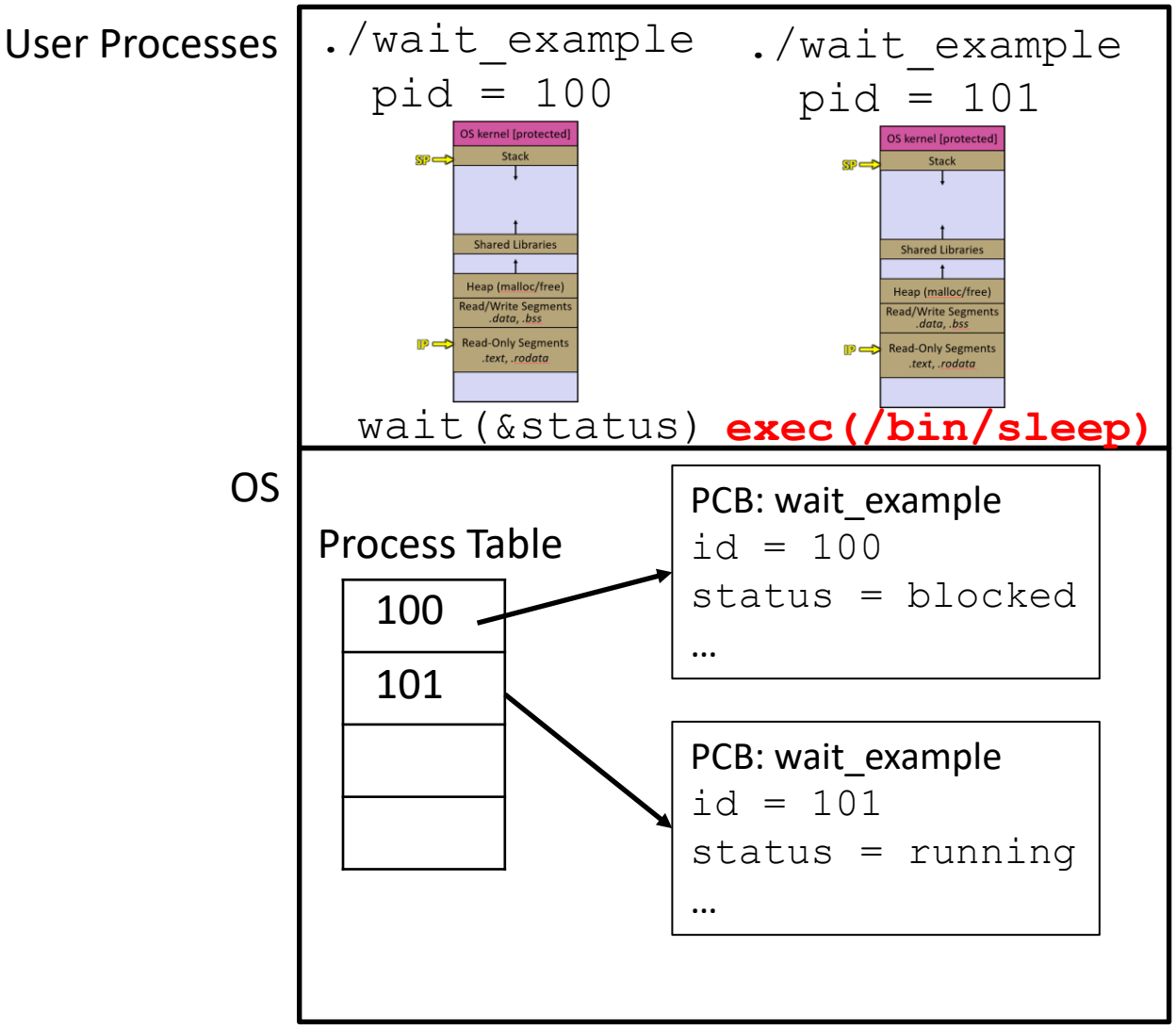


Diagram: wait_example.c

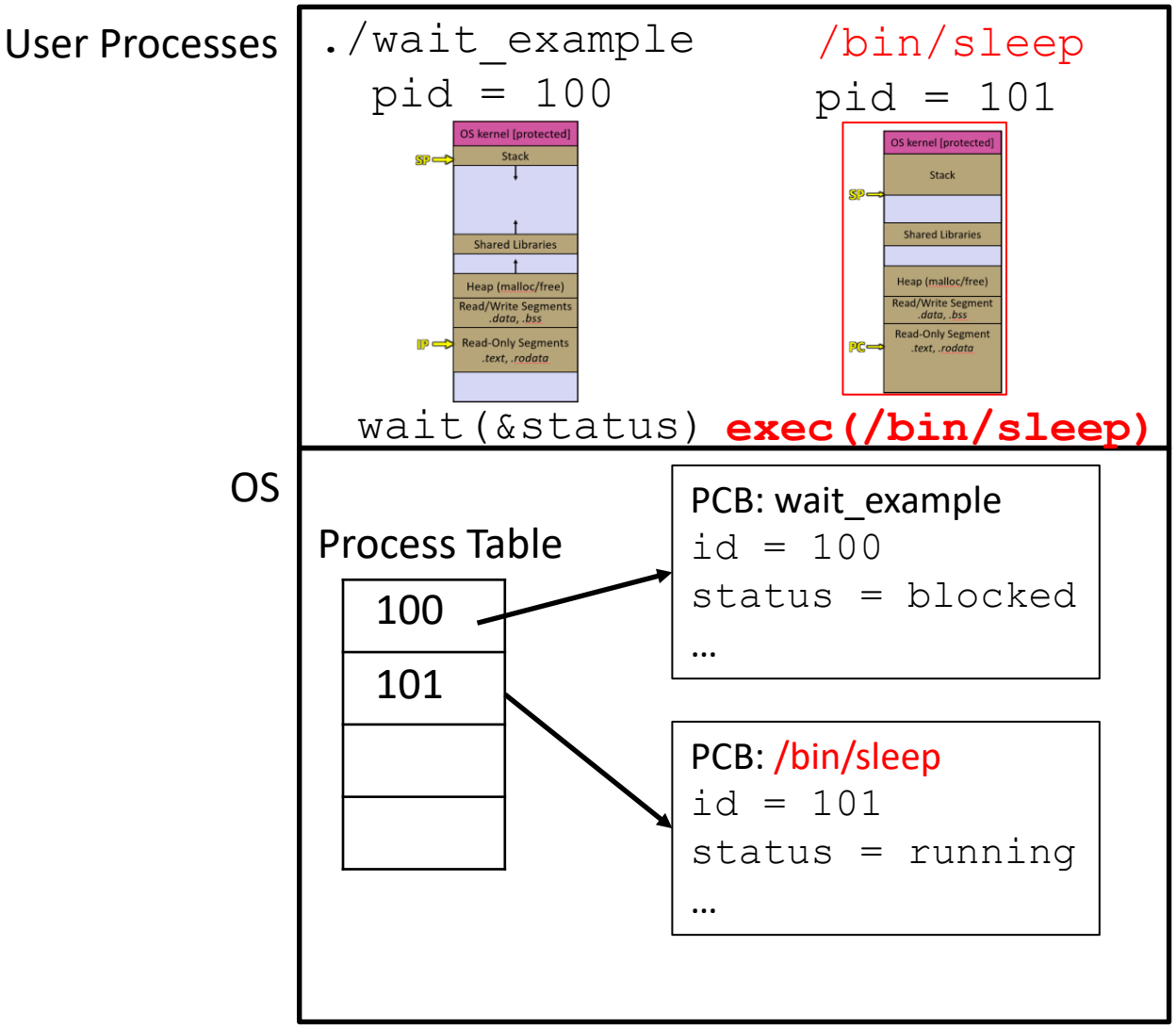


Diagram: wait_example.c

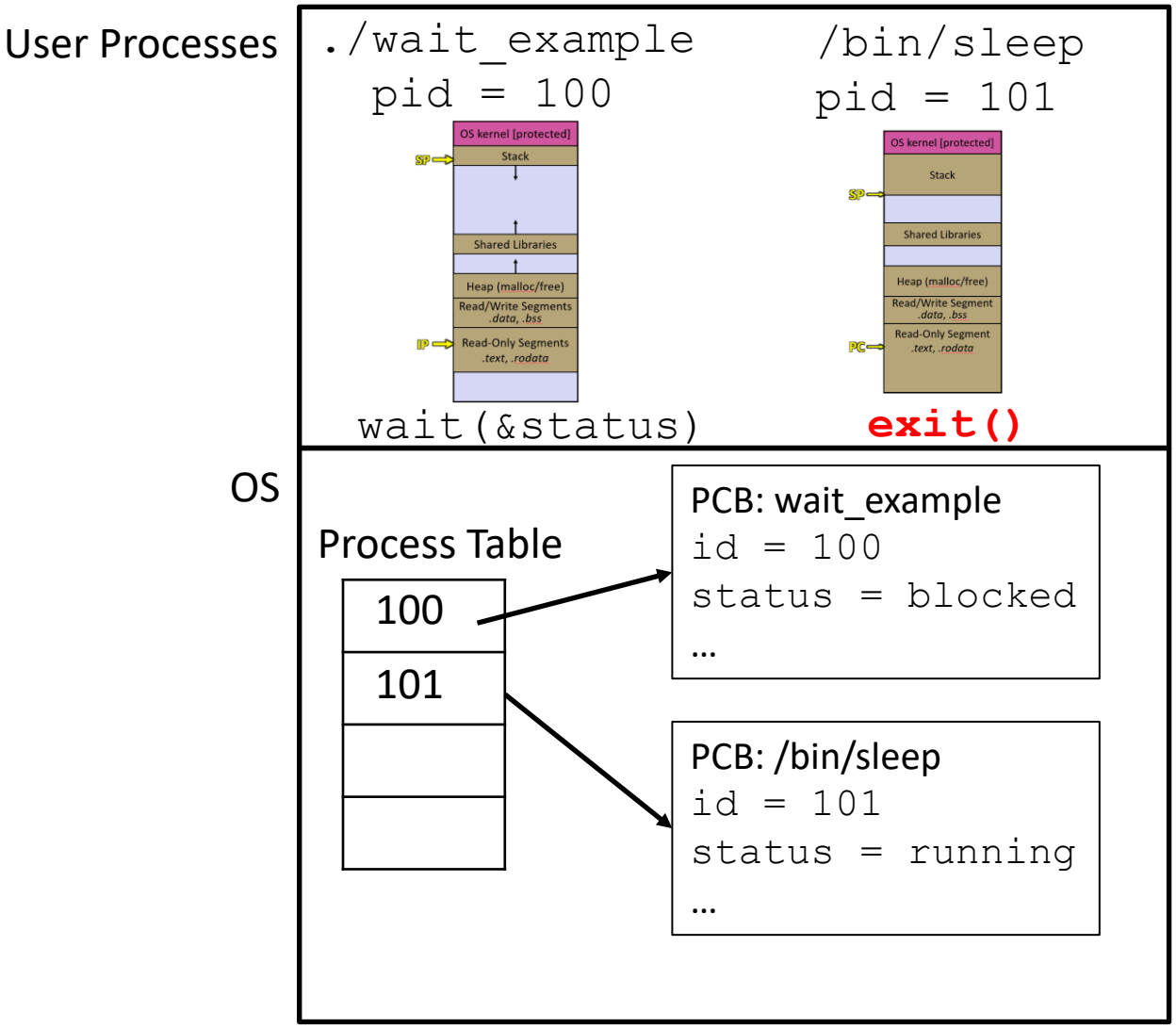


Diagram: wait_example.c

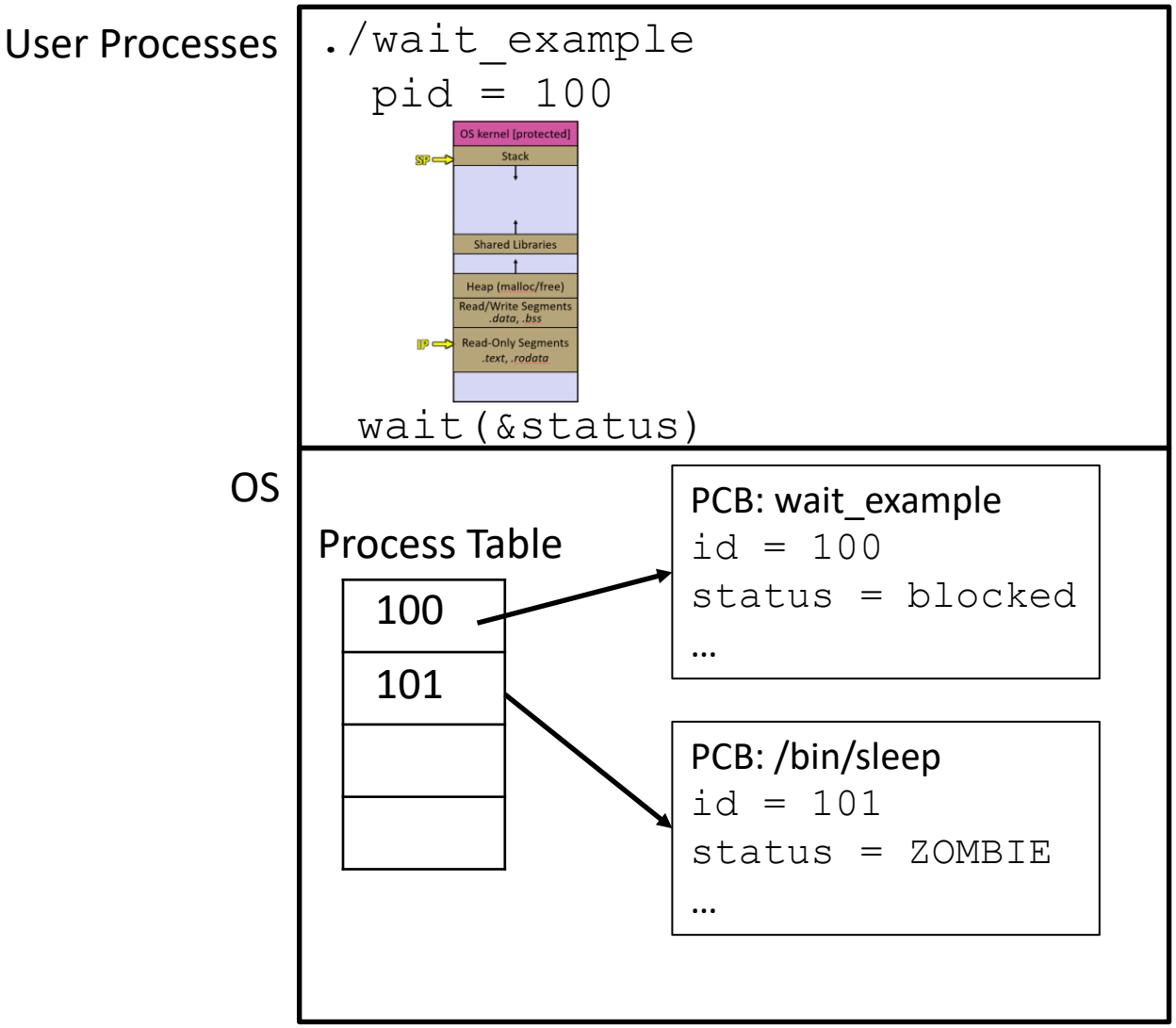


Diagram: wait_example.c

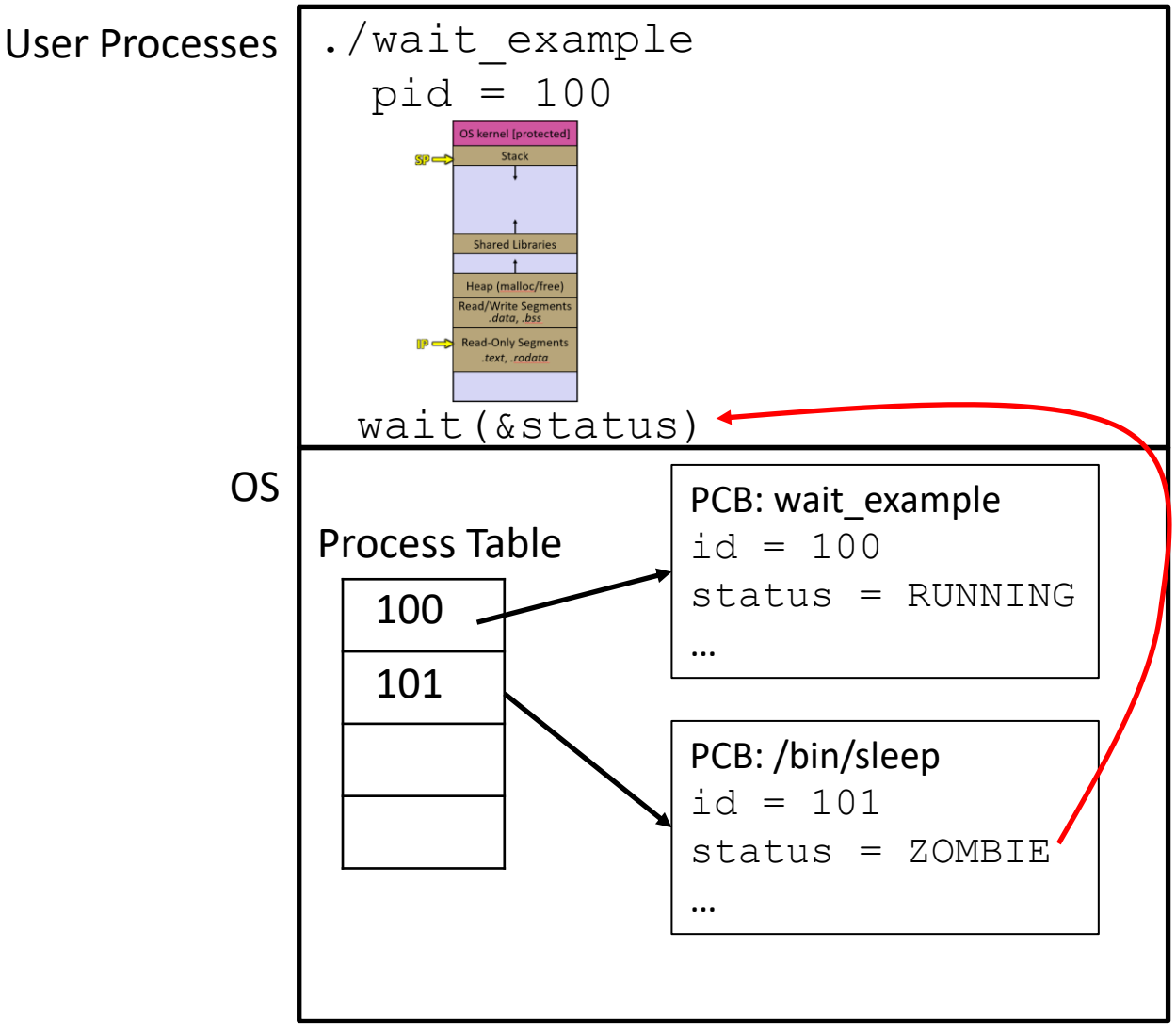


Diagram: wait_example.c

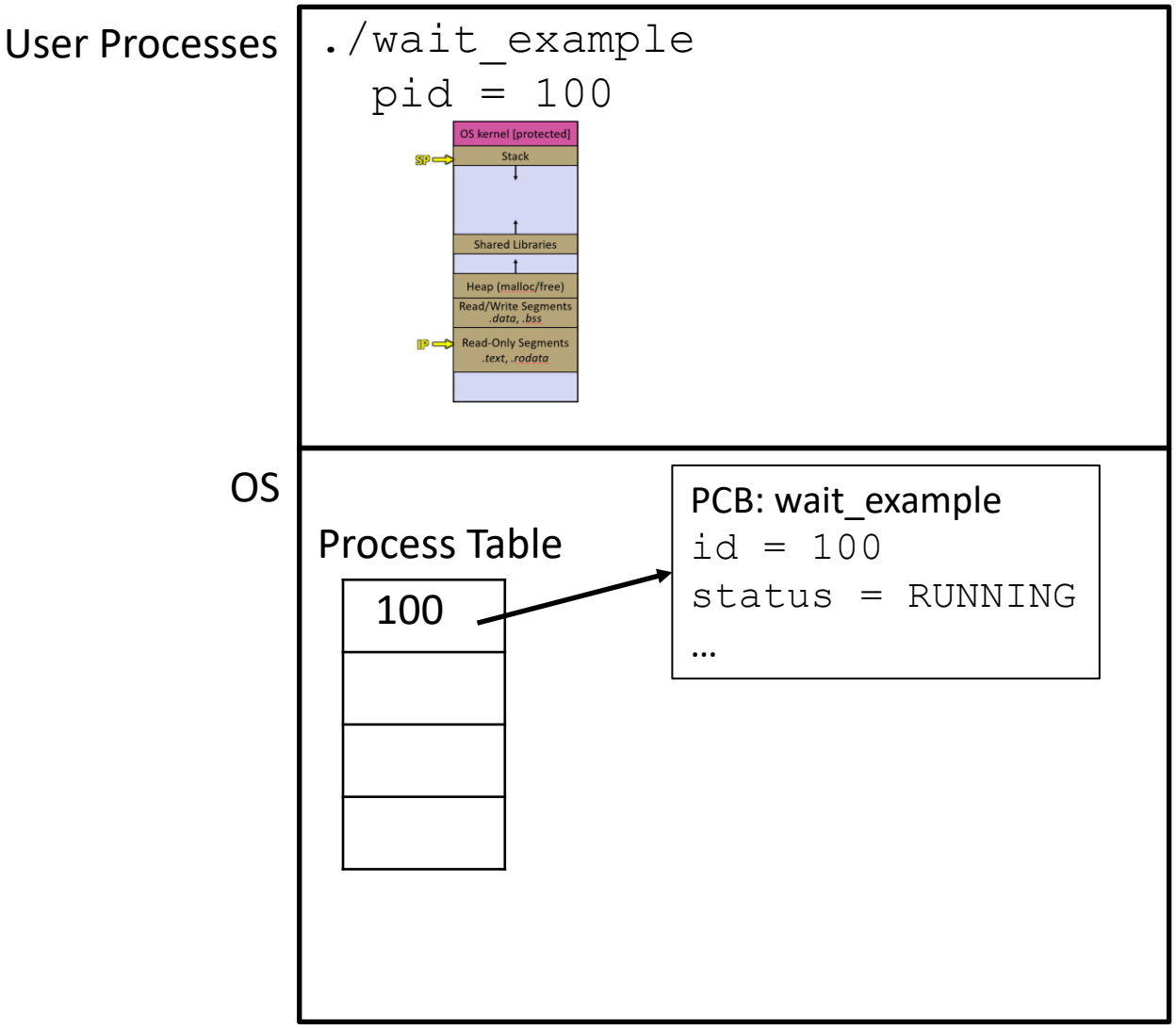


Diagram: wait_example.c

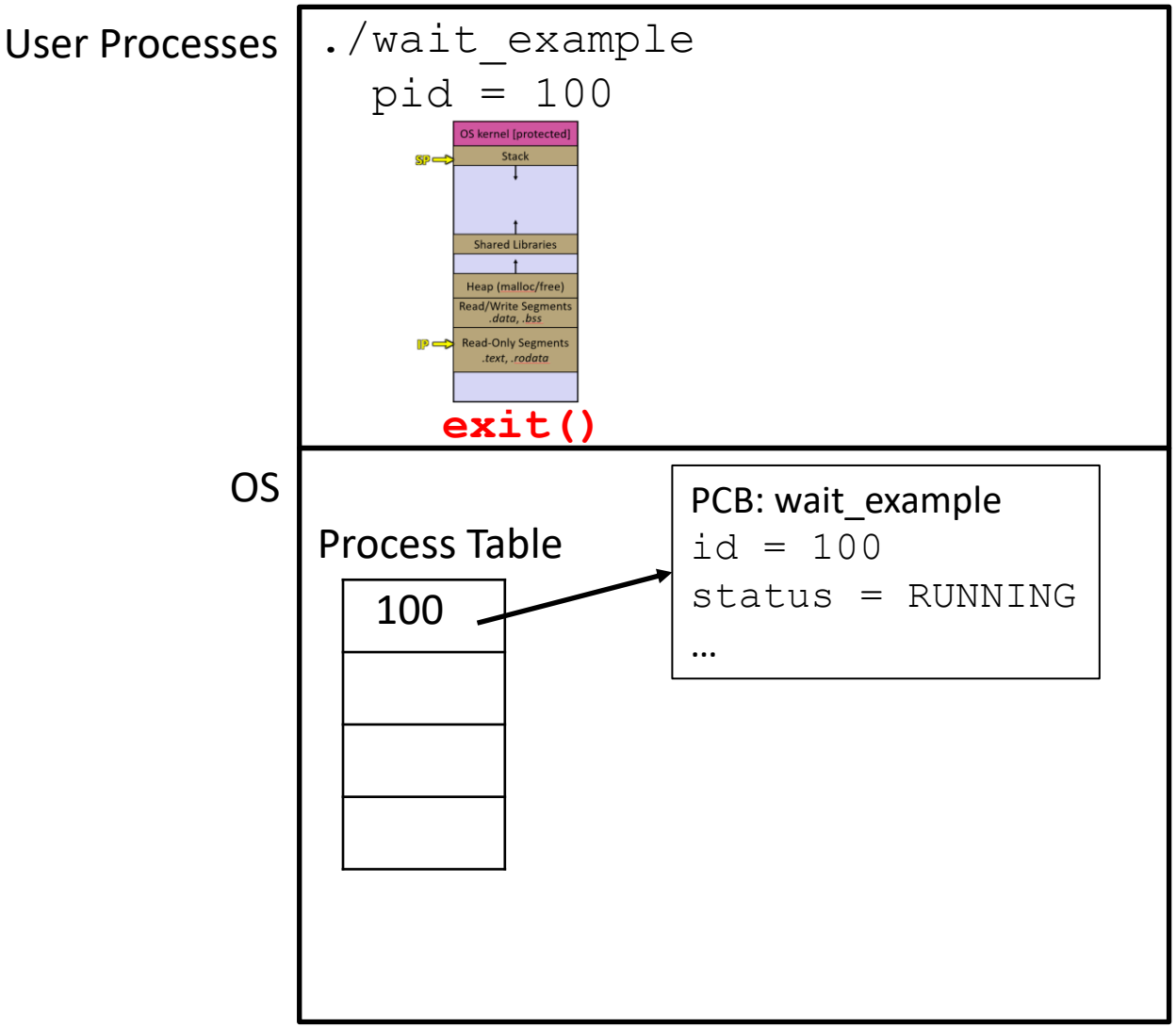
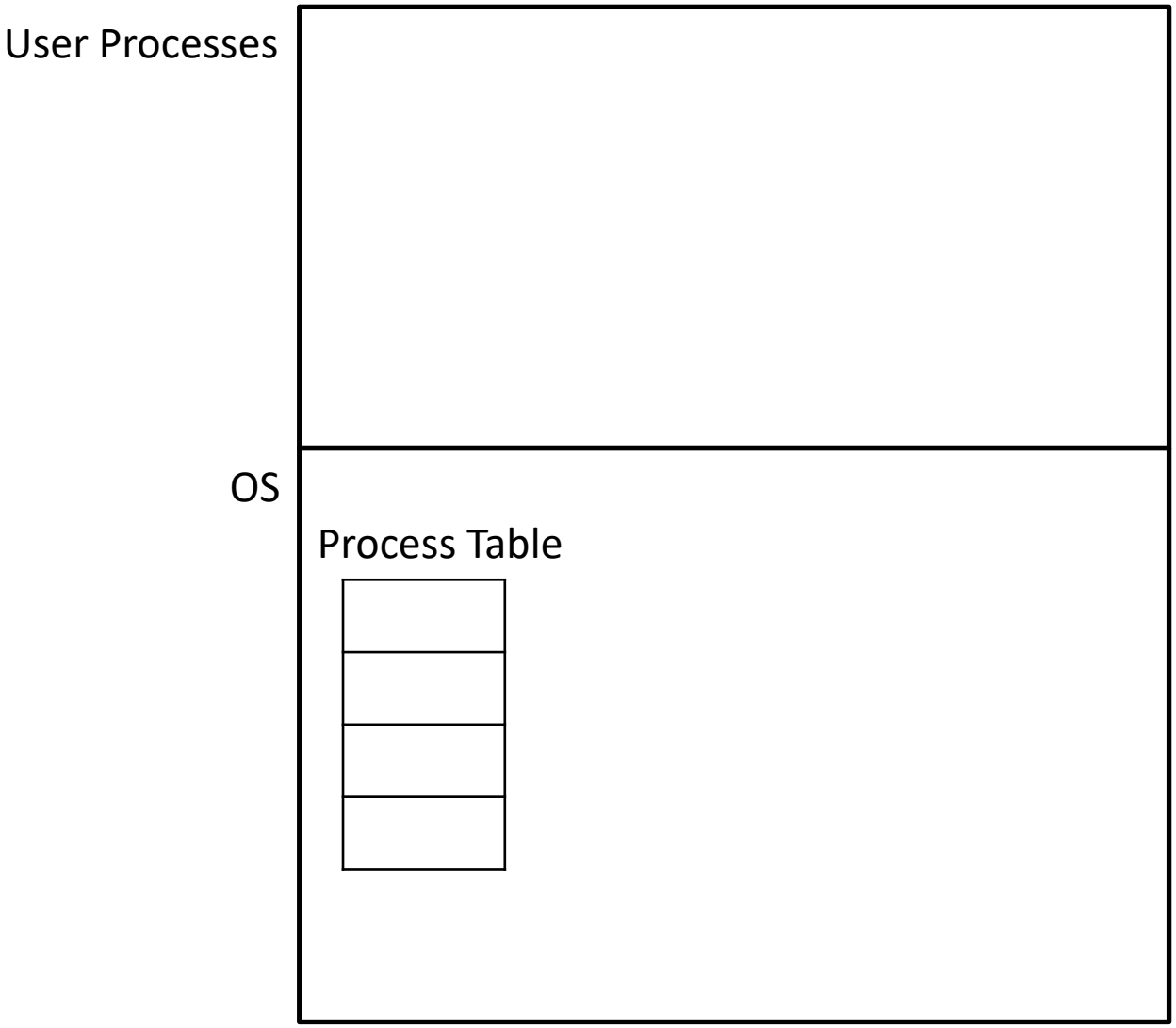


Diagram: wait_example.c



`./wait_example`
Is reaped by its parent. In our example, that is the terminal shell

Demo: `state_example`

- See `state_example.c`
  - Brief code demo to see the various states of a process
    - Running
    - Zombie
    - Terminated
  - Makes use of `sleep()`, `waitpid()` and `exit()`!
  - Aside: `sleep()` takes in an integer number of seconds and blocks till those seconds have passed

More: `waitpid()`

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

- Calling process waits for a child process (specified by **`pid`**) to exit
  - Also cleans up the child process
- Gets the exit status of child process through output parameter **`wstatus`**
- **`options`** are optional, pass in `0` for default options in *most* cases
- Returns process ID of child who was waited for or `-1` on error

wait() status

- **`status`** output from **`wait()`** can be passed to a macro to see what changed
- **`WIFEXITED()`** true iff the child exited nomrally
- **`WIFSIGNALED()`** true iff the child was signaled to exit
- **`WIFSTOPPED()`** true iff the child stopped
- **`WIFCONTINUED()`** true iff child continued

- See example in `state_check.c`

Lecture Outline

- `wait()`, blocking, Zombies & PCB
- **`kill()`, `signal()`, `alarm()`**
- Process Groups
- Process Lifetime

Signals

- A Process can be interrupted with various types of signals
  - This interruption can occur in the middle of most code
- Each signal type has a different meaning, number associated with it, and a way it is handled

- Examples:
  - `SIGCHLD` → Default: ignore
  - `SIGINT`
  - `SIGKILL` → Default: terminate the process
  - `SIGALRM`
  - `SIGSEGV` → Default: terminate & core dump

signal()

- You can change how a certain signal is handled
- ```
  sighandler_t signal(int signum,
                      sighandler_t handler);
  ```
- Uses the **sighandler_t** type: a function pointer
  - ```
    typedef void (*sighandler_t)(int);
    ```
- Returns previous handler for that signal
  - **SIG_ERR** when there is an error
- Pass in **SIG_IGN** to ignore the signal
- Pass in **SIG_DFL** for default behaviour
- Some signals like **SIG_KILL** and **SIG_STOP** can't be handled differently

Signal handlers

- ```
  typedef void (*sighandler_t)(int);
  ```
- A function that takes in as parameter, the signal number that raised this handler. Return type is void
- Is **automatically** called when your process is interrupted by a signal
- Can manipulate global state
- If you change signal behaviour within the handler, it will be undone when you return
- Signal handlers set by a process will be retained in any children that are created
  ```

Demo ctrlc.c

- See `ctrlc.c`
  - Brief code demo to see how to use a signal handler
  - Blocks the ctrl + c signal: SIGINT
  - Note: will have to terminate the process with the `kill` command in the terminal, use `ps -u` to fine the process id

discuss

```c
// assume this works
void list_push(list* this, float to_push) {
  Node* node = malloc(sizeof(Node));
  if (node == NULL) exit(EXIT_FAILURE);
  node->value = to_push;
  node->next = NULL;
  list->tail->next = node;
  list->tail = node;
}

void handler(int signo) {
  list_push(list, NaN);
}

int main(int argc, char* argv[]) {
  signal(SIGINT, handler);
  float f;
  while(list_size(list) < 20) {
    read_float(stdin, &f);
    list_push(list, f);
  }
  // omitted: do stuff with list
}
```

This code is broken. It compiles, but it doesn't ***always*** do what we want. Why?

- Assume we have implemented a linked list, and it works
- Assume **`list`** is an initialized global linked list

alarm()

- `unsigned int alarm(unsigned int seconds);`

- Delivers the **SIGALRM** signal to the calling process after the specified number of seconds

- Default **SIGALRM** behaviour: terminate the process

- How to cancel alarms?
  - I leave this as an exercise for you: try reading the man pages

- HINT FOR EXTRA CREDIT: what happens if the child process calls alarm? … and default handles it?

discuss

- Finish this program
- After 15 seconds, print a message and then exit
- Can't use the **`sleep()`** function, must use **`alarm()`**

```c
int main(int argc, char* argv[]) {

  alarm(15U);

  return EXIT_SUCCESS;
}
```

- Currently: program calls alarm then immediately exits

Demo no_sleep.c

- See `no_sleep.c`
  - "Sleeps" for 10 seconds without sleeping, using alarm
  - Brief code demo to see how to use a signal handler & alarm
  - Signal handler manipulates global state

kill()

- Can send specific signals to a specific process manually
- ```
  int kill(pid_t pid, int sig);
  ```
- pid: specifies the process
- sig: specifies the signal

- Example: `kill(child, SIGKILL);`
  ```

Non blocking wait w/ `waitpid()`

- ```
  pid_t waitpid(pid_t pid, int *wstatus,
                int options);
  ```
  - Can pass in WNOHANG for **`options`** to make **`waitpid()`** not block or "hang".
  - Returns process ID of child who was waited for or **`-1`** on error or 0 if there are no updates in children processes and WNOHANG was passed in
  ```

Demo impatient.c

- See `impatient.c`
  - Parent forks a child, checks if it finishes every second for 5 seconds, if child doesn't finish send SIGKILL

  - LOOKS SIMILAR TO WHAT YOU ARE DIONG IN penn-shredder. DO NOT COPY THIS
    - **`waitpid()`** IS NOT ALLOWED
    - USING **`sleep()`** AND **`alarm()`** TOGETHER CAN CAUSE ISSUES

SIGCHLD handler

- Whenever a child process updates, a **`SIGCHLD`** signal is received, and by default ignored.

- You can write a signal handler for **`SIGCHLD`**, and use that to help handle children update statuses: allowing the parent process to do other things instead of calling **`wait()`** or **`waitpid()`**

- Relevant for proj1: **`penn-shell`**

Lecture Outline

- `wait()`, blocking, Zombies & PCB
- `kill()`, `signal()`, `alarm()`
- **Process Groups**
- Process Lifetime

Process Groups

- Processes are associated together into Process Groups.
  - A process always is in a process group
- Allows for convenient process & signal management:
  - If ctrl + c (SIGINT) is sent to a process via the keyboard, it is also sent to all processes within its group
- When we create a process with fork(), the child belongs to the same process group as the parent
- Relevant for proj1: **`penn-shell`**

Process Group ID

- The process group ID is equal to a process ID
  - The process ID of the first process to exist in the group
  - If a process group "leader" terminates, can it's process ID be reused by another process? Even if the old group is still going?
  - Answer: no, that process ID will be reserved until the group is done

- ```
  int setpgid(pid_t pid, pid_t pgid);
  ```
- Sets page group id of the specified process to the new value
  - Only works if pgid specifies an existing process group
  - Or if pgid == pid, thus creating a new process group of that id
  ```

Process Groups: utility

- Can pass in **`-PGID`** (negative PGID) to **`kill()`** and **`waitpid()`**
- Doing so for **`kill()`** will send the signal to all processes in the group
- Doing so for **`waitpid()`** will wait for any process in the group
- You may find this useful for proj1: **`penn-shell`**

Lecture Outline

- `wait()`, blocking, Zombies & PCB
- `kill()`, `signal()`, `alarm()`
- Asynch `wait`
- Process Groups
- **Process Lifetime**

Process State Lifetime