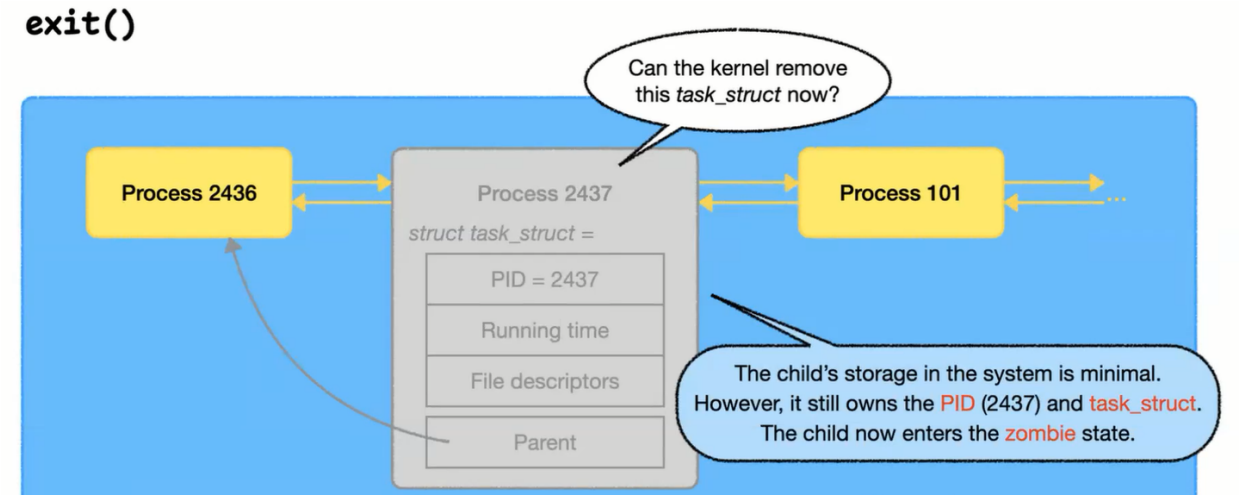
Operating Systems: Lecture 6

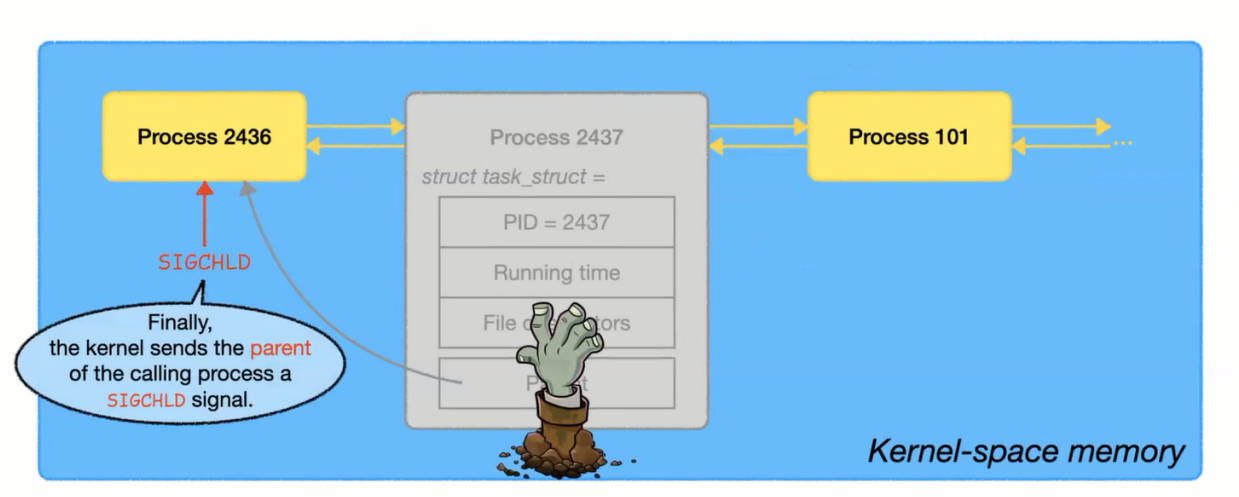
Zombies

• after `exit()`

After `exit()` called, the kernel removes everything about the process, including the codes and files opened and other data. However, we shouldn't remove the task_struct, as the PID, status and exitcode are still needed by the parent process.



A `SIGCHLD` signal is sent to the parent process.

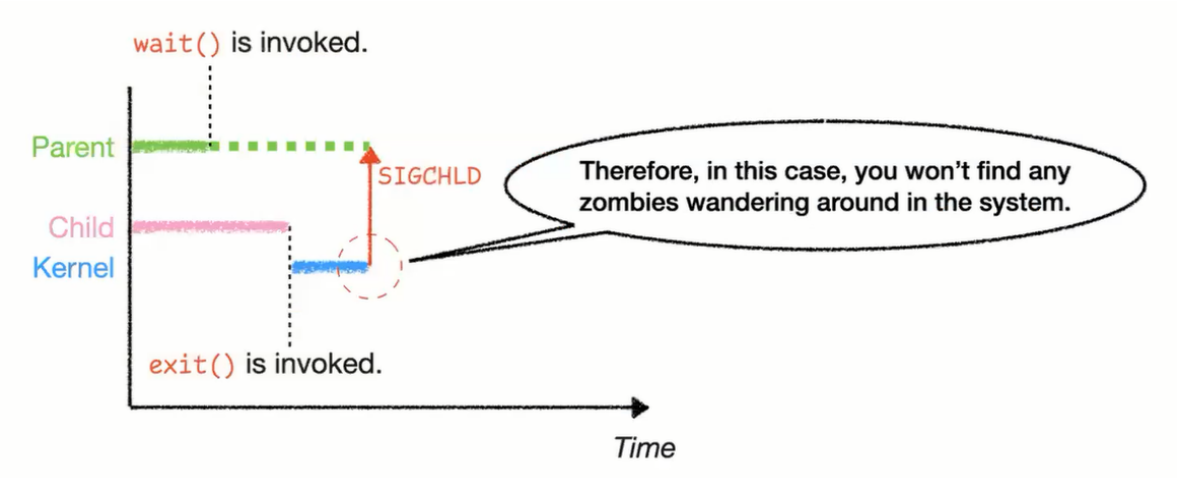


The `SIGCHLD` signal will be processed by the parent process, but it depends on the timing of `wait()`.

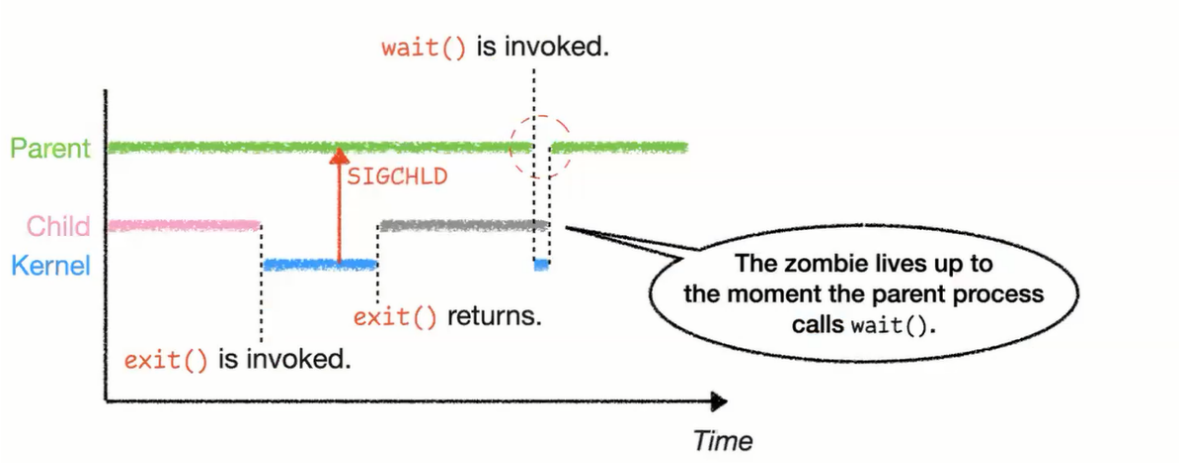
The `wait()` sets up a signal handler, which gets the exit code from the child and removes the *task_struct*.

There are two seranios:

1. `wait()` called before `SIGCHLD`



2. `wait()` called after `SIGCHLD`



- Zombie

`wait()` and `waitpid()` are to reap zombie children.

You should never leave any zombies in the system.

Linux will label zombie processes as "<defunct>".

```c
int main() {
  pid_t pid;
  if ((pid = fork()) ≠ 0) {
    printf("Look at Process %d...", pid);
    getchar();  // Press ENTER to continue
    wait(NULL);
    printf("Look again!");
    getchar();  // Press ENTER to continue
  }
}
```

zombie.c

```
Look at Process 20808...
Look again!
```

```
  PID TTY      STAT   TIME COMMAND
19973 ?        SN     0:00 sshd: yt2475@pts/9
19974 pts/9    SNs    0:00 -bash
20807 pts/9    SN+    0:00 ./zombie
20808 pts/9    ZN+    0:00 [zombie] <defunct>
20839 ?        SN     0:00 sshd: yt2475@pts/7
20840 pts/7    SNs    0:00 -bash
20973 pts/7    RN+    0:00 ps x
49141 ?        SNsl  86:01 emacs --daemon
```

```
[yt2475@linserv1 ~]$ ps x
  PID TTY      STAT   TIME COMMAND
19973 ?        SN     0:00 sshd: yt2475@pts/9
19974 pts/9    SNs    0:00 -bash
20807 pts/9    SN+    0:00 ./zombie
20839 ?        SN     0:00 sshd: yt2475@pts/7
20840 pts/7    SNs    0:00 -bash
21012 pts/7    RN+    0:00 ps x
49141 ?        SNsl  86:01 emacs --daemon
```

> “
>
> `wait()` eliminated the zombie (defunct) from the system. The PID is removed from the processes.

• Calling `wait()` is important

Why should we **remove all the zombies** from the system?

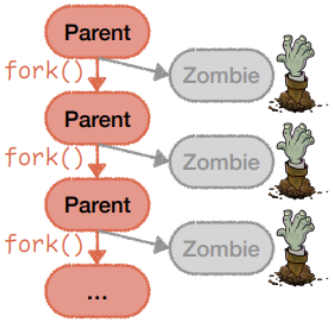
- We have already removed all the user-space memory and other kernel data. What it remains is just a PID and a node in the data struct. It takes only a tiny amount of memory.
- What could be the issue?
  - It takes a PID
- There's a maximum number of PID ($64k \approx 2^{16}$)

It's all about system resource management.

- A zombie takes up a PID.
- What would happen if we never clean up the zombies?

(Don't) try this…

```
int main() {
  while (fork());
}
```
bomb.c




```
$ cat /proc/sys/kernel/pid_max
65536
$ ./bomb
_
```

```
$ ls
No process left.
$ poweroff
No process left.
$ _
```

- The code above calls `fork()` infinitely, so it will continous create zombies and leave them in the system. The only active process running is the parent process.
- It will take up the maximum amount of PID
  - In this case it's 65536
- Then, you can't run any other process. You can't even turn off the computer, since you need `poweroff` to turn it off in Linux.

• Summary

It's important to know the internal workings of system calls.

Some system calls may produce surprising results.

Understanding those system calls helps you understand the process control in the operating system.

At least, you don't have to guess what would happen after invoking a system call.

Signals

Signals are software interrupts

It's a form of **inter-process communication** (IPC).

A process can send a **signal** to another process.

When a signal arrives, the OS interrupts the target process's normal control flow and executes the signal handler.

- In our previous example, the receiver is the parent process.
- After it receives the signal, its normal execution is interrupted, and the signal handler is invoked.

Example:

- What happens when you press *Ctrl-C* ?
  - It sends a `SIGINT` signal to the current process.
  - The default signal handler of `SIGINT` is to **terminate** the process.
  - The process can override this behavior by providing a signal handler.

- What about *Ctrl-Z* ?
  - It sends a `SIGTSTP` signal to stop the current process
  - Stop is different from terminating. It can be resumed by the signal `SIGCONT`

```
8
^Z
[1]+  Stopped                 ./loop
[yt2475@linserv1 proc]$ ps
  PID TTY          TIME CMD
19974 pts/9    00:00:00 bash
22156 pts/9    00:00:00 loop
22178 pts/9    00:00:00 ps
[yt2475@linserv1 proc]$ jobs
[1]+  Stopped                 ./loop
[yt2475@linserv1 proc]$ fg 1
./loop
```

How are signals generated?

From the user space…

- Using **keyboard**: Ctrl-C sends `SIGINT`, Ctrl-Z sends `SIGTSTP` (terminal stop), Ctrl-\ sends `SIGQUIT`.
- Using **commands**: `kill`, `top` …
- Using the `kill()` system call.

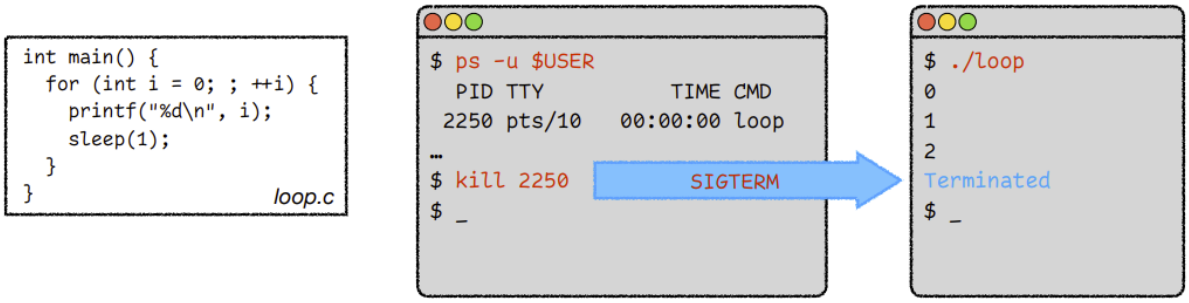
From the kernel or hardware…

- `SIGCHLD` (child stopped or terminated) comes from the kernel.
- `SIGFPE` (floating point exception, e.g., division by zero) comes from the CPU.
- `SIGSEGV` (invalid memory reference, a.k.a. segmentation fault) comes from the CPU to the kernel and then to the process.

Sending signals using the `kill` command

The `kill` command sends `SIGTERM` to the target process by default.

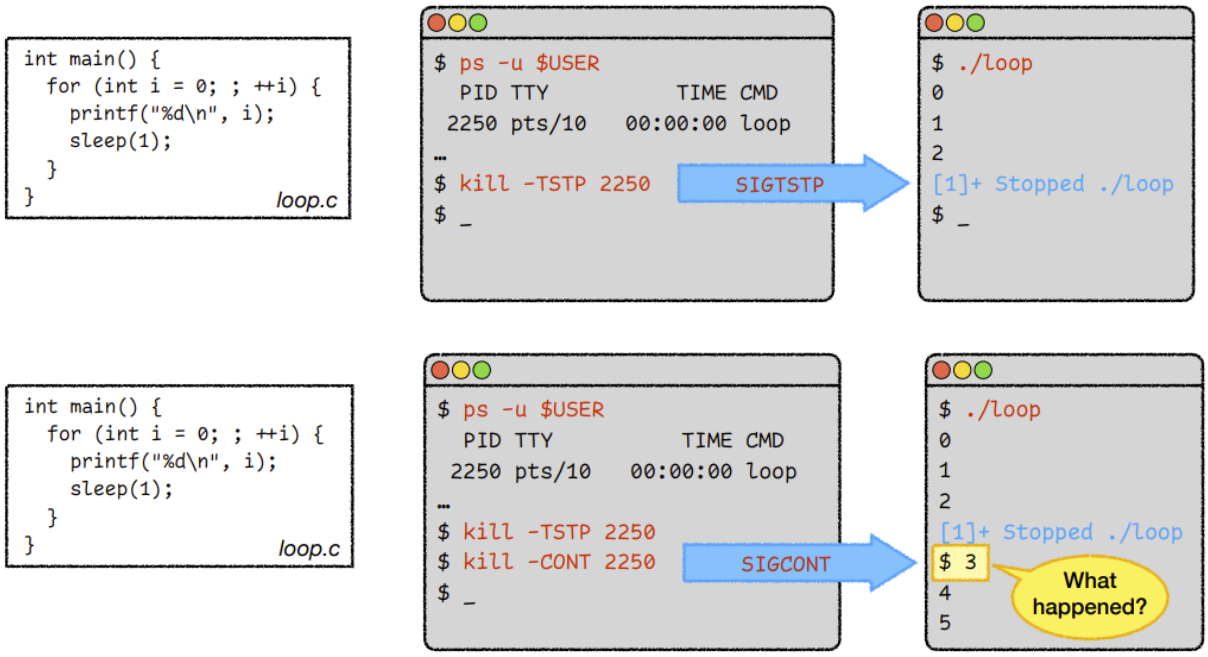
The default signal handler of `SIGTERM` is to terminate the process



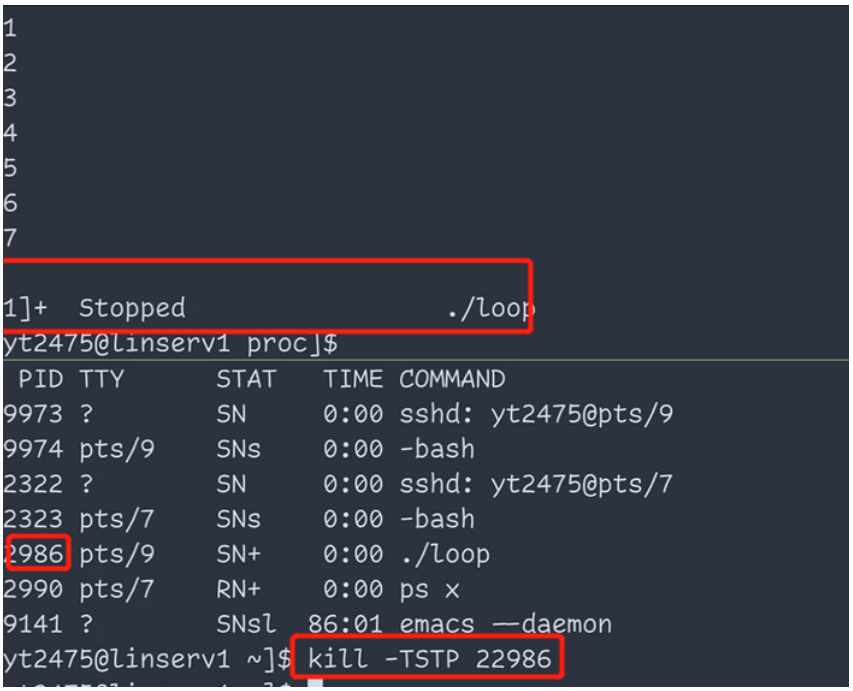
```
33
34
35
36
37
38
39
40
Terminated
[yt2475@linserv1 proc]$
  PID TTY      STAT   TIME COMMAND
19973 ?        SN     0:00 sshd: yt2475@pts/9
19974 pts/9    SNs    0:00 -bash
22300 pts/9    SN+    0:00 ./loop
22322 ?        SN     0:00 sshd: yt2475@pts/7
22323 pts/7    SNs    0:00 -bash
22460 pts/7    RN+    0:00 ps x
49141 ?        SNsl  86:01 emacs --daemon
[yt2475@linserv1 ~]$ kill 22300
[yt2475@linserv1 ~]$
```

Actually, the `kill` command can send any signal.

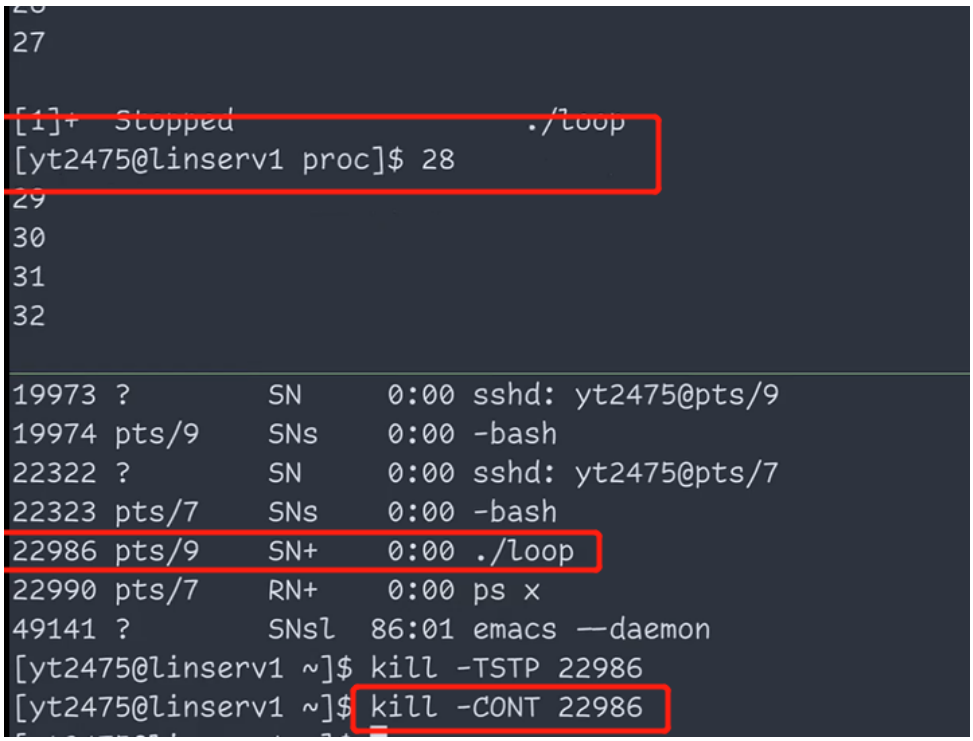
Let's try `SIGTSTP` and `SIGCONT`.



- use `-TSTP` to send `SIGTSTP`
  - the same as *Ctrl-Z*



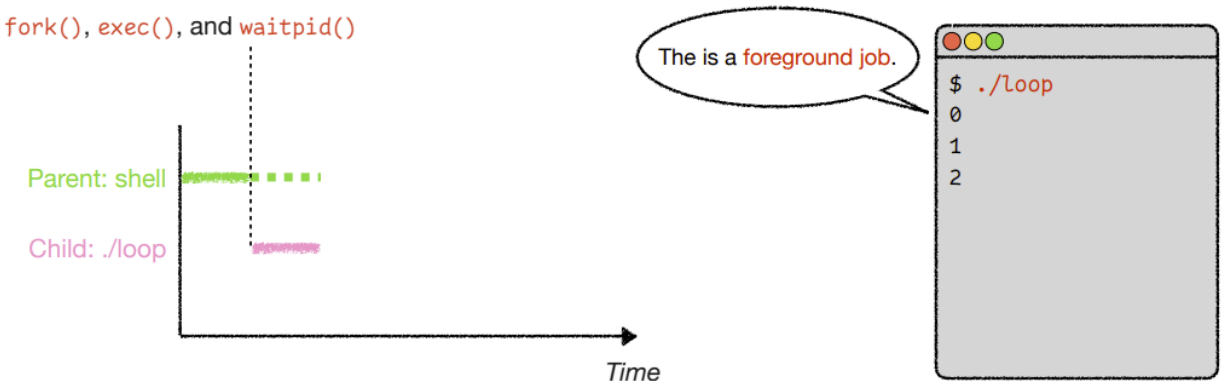
- Use `-CONT` to send `SIGCONT`

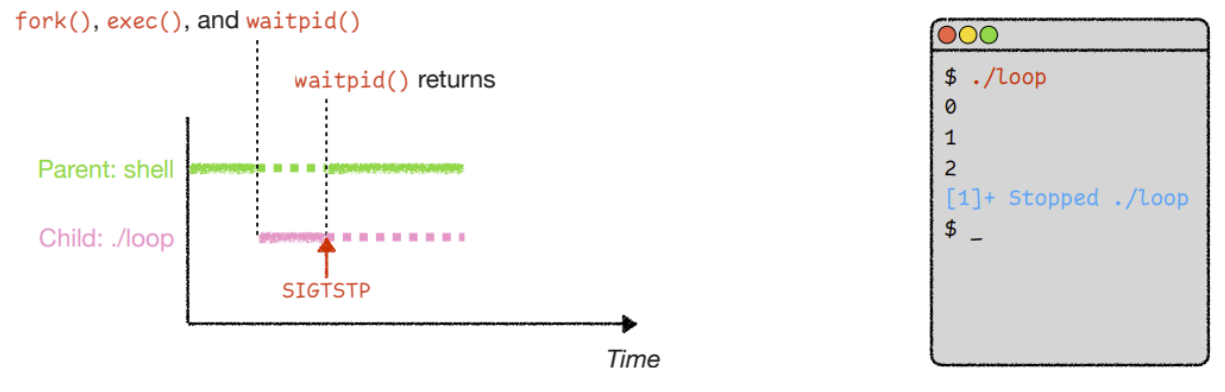


- The `kill` command is actually a command to send signal. Although it by default kills a process, the true purpose of the command is to send signals
- However, after the process is resumed by `SIGCONT`, it can't be stopped by *Ctrl-C*!
    - Why?

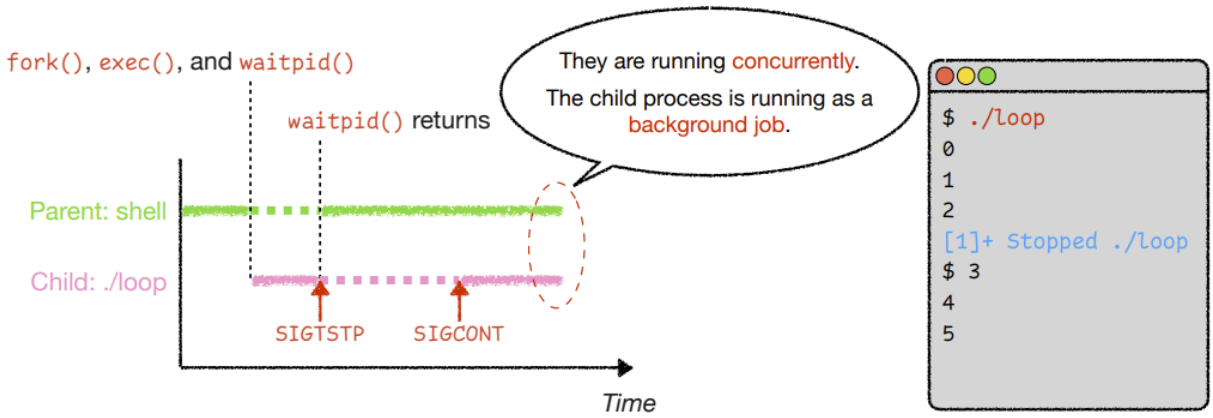
```
103
104
^C
[yt2475@linserv1 proc]$ 105
106
107
^C
[yt2475@linserv1 proc]$ 108
109
```

- **Foreground and background jobs**



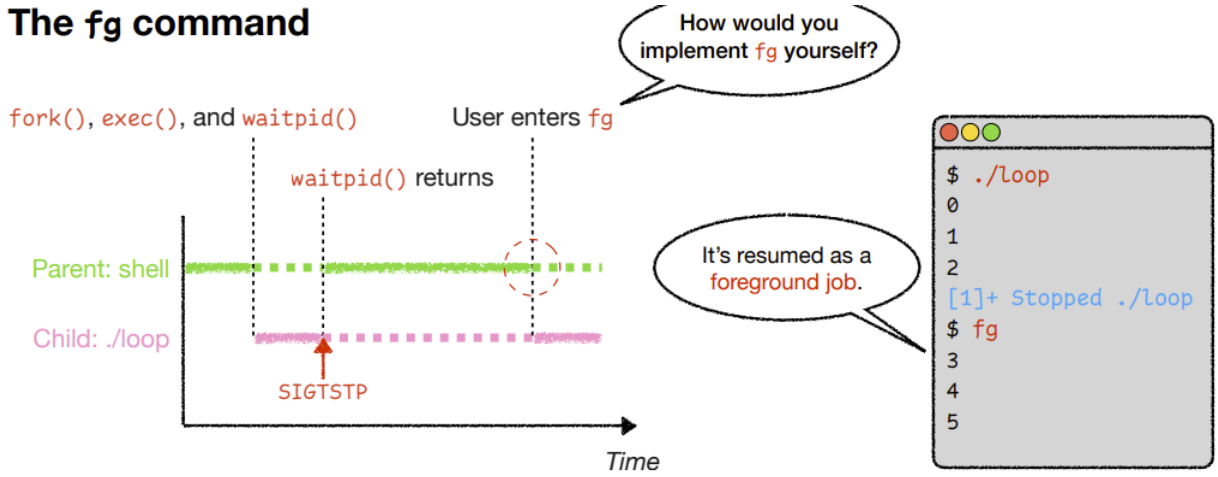


- Here, the shell calls `wait()`, and it will be blocked until the loop (child process) terminates or stops
- As long as the forground program is still running, the shell will block itself. It won't take any command until the child stops or terminates



- Here, we send a `SIGCONT` to the process from another window, and it continues running
- However, the shell **has no idea** that the process has continued running. So the shell is not blocking itself anymore.
  - As a result, **Both** the shell and the process are running at the same time.
- Note the shell runs as the foreground job, and the child process runs as the background job.
  - When you press Ctrl-C or other keys in shell, the signal is only sent to the shell, not the child process
  - Only shell has access to your keyboard input
  - This is not a good thing
  - Therefore, we should use the `fg` command to resume a job.

The `fg` command



- After you used the `fg` command, the shell knows that you want to resume that process.
  - **The shell** will send a `SIGCONT` to the process
  - it'll block itself to wait for this process
- The difference is that `fg` is initiated by the **Shell**
  - So the shell knows you want to continue this process. It'll send a `SIGCONT` and wait
  - If you send `SIGCONT` from another process instead of the shell, it has no idea that you have resumed the process. So it has no idea that it needs to wait.

- To stop the loop process before, you can type `fg` in shell.
  - The shell will regain control of the child process.
  - Now you can use *Ctrl-C* to stop the process

The `kill()` system call

Just like the `kill` command, the `kill()` syscall sends a signal to a process.

```
int kill(pid_t pid, int sig);
```

The `raise()` library function sends a signal to yourself.

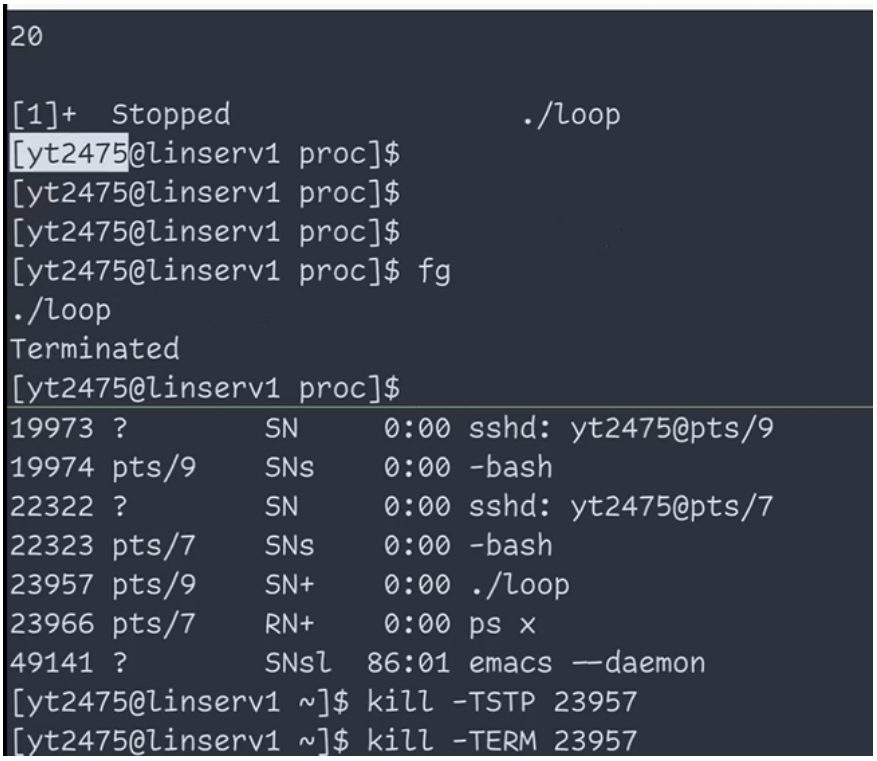
```
int raise(int sig);
```

How would you implement `raise()`?

- To implement `raise()`, you can just use `getPID()` and `kill()`

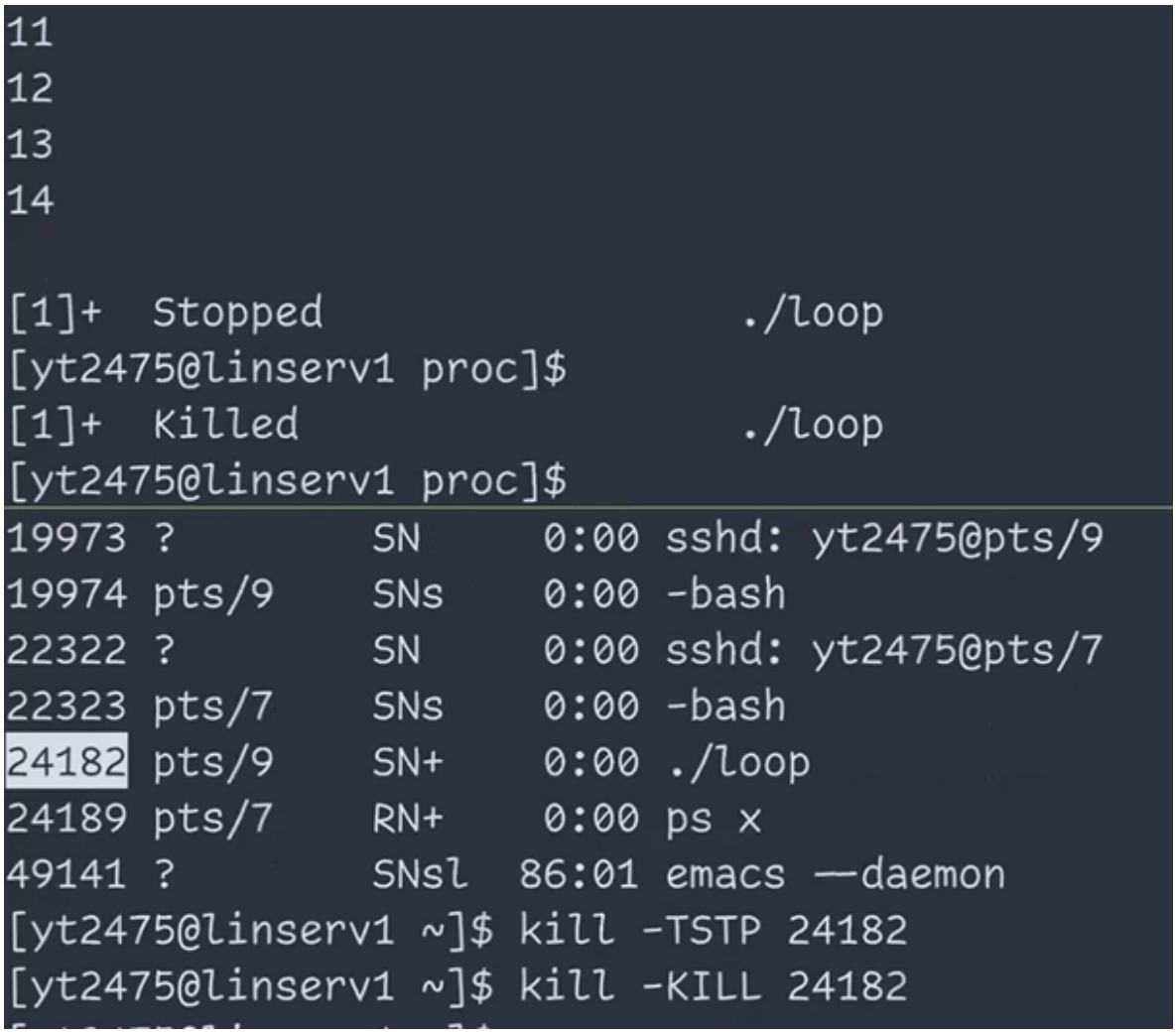
`SIGTSTP` and then `SIGTERM`

- What would happen if we stop a process and then terminate it?



- What we did is that we sent a `SIGTSTP` to the process to stop it.
- Then we send a `SIGTERM` to it when it's stopped, trying to terminate that process
  - Because the process was stopped, it conldn't handle the `SIGTERM`.

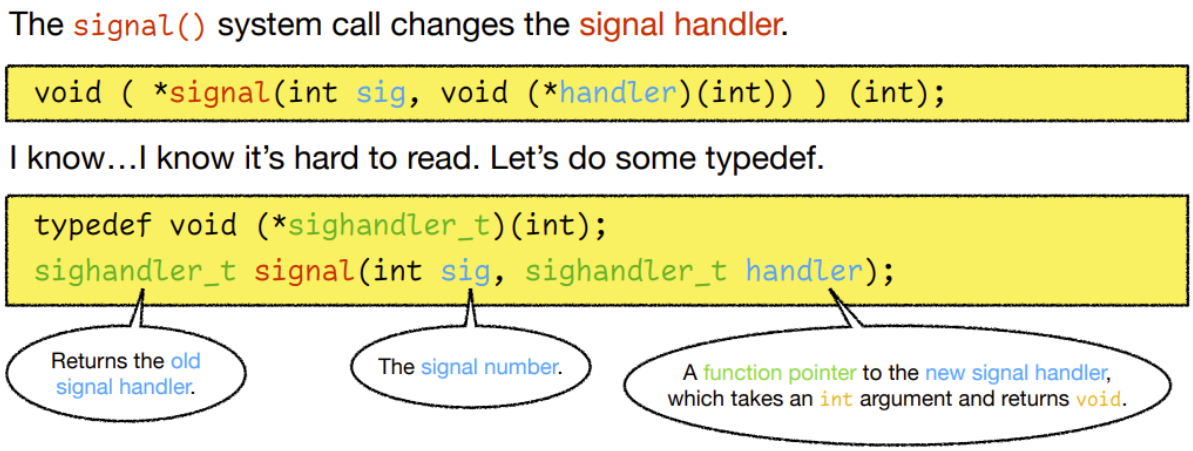
    - So it seems like nothing happens.
    - The `SIGTERM` is a pending signal. It will be handled whenever the process is resumed
- When we use `fg`, the process is continued
- Right after it's continued, the `SIGTERM` is handled, and the process is terminated
- However, we can also send a `SIGKILL` to kill the process immediatly



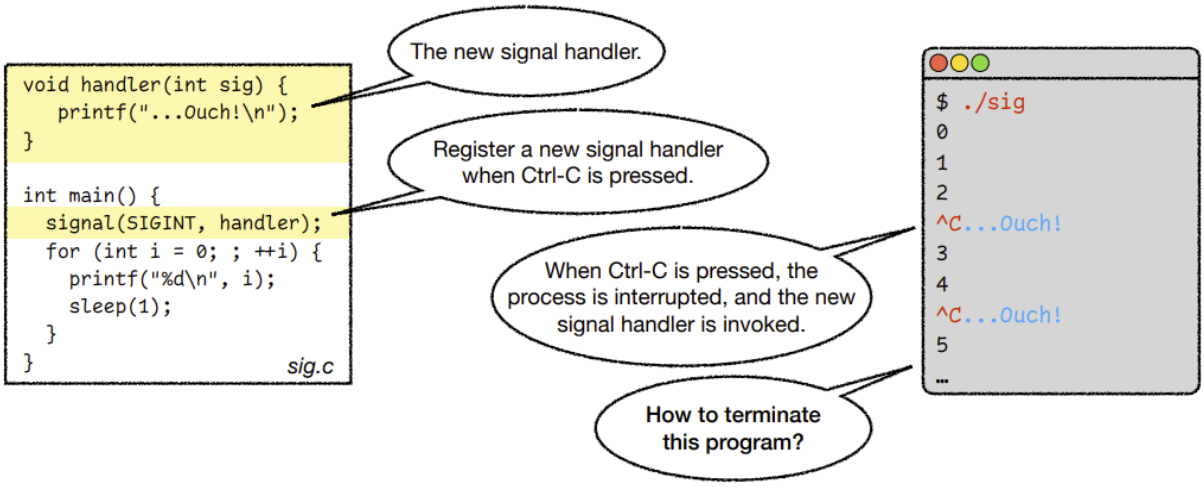
- **Some standard signals (man 7 signal)**

Signal	Default handler	Default handler
`SIGINT`	Interrupt from keyboard (Ctrl-C).	Terminate the process.
`SIGTERM`	Termination (the default signal sent by the *kill* command).	Terminate the process.
`SIGKILL`	Kill, no matter what.	Terminate the process (cannot be overridden).
`SIGTSTP`	Stop typed at terminal (Ctrl-Z).	Stop the process.
`SIGCONT`	Continue if stopped.	Continue the process.
`SIGCHLD`	Child stopped or terminated.	Ignore the signal.
`SIGFPE`	Floating point exception.	Terminate the process and dump core.
`SIGSEGV`	Invalid memory reference (segmentation fault).	Terminate the process and dump core.

- **Changing signal handlers**



  - **Example: change the behavior of Ctrl-C**




```c
#include <signal.h>
#include <stdio.h>
#include <unistd.h>

void handler (int sig) {
  printf(" ... Ouch!\n");
}

int main() {
  signal(SIGINT, handler);
  int i;
  for (i=0; ;++i) {
    printf("%d\n", i);
    sleep(1);
  }
}
```

```
26
27
^C...Ouch!
28
29
^C^C...Ouch!
30
^C...Ouch!
31
```

```
53
...Ouch!
54
55
56
...Ouch!
57
58

19973 ?        SN     0:00 sshd: yt2475@pts/9
19974 pts/9    SNs    0:00 -bash
22322 ?        SN     0:00 sshd: yt2475@pts/7
22323 pts/7    SNs    0:00 -bash
25043 pts/9    SN+    0:00 ./sig
25081 pts/7    RN+    0:00 ps x
49141 ?        SNsl  86:01 emacs —daemon
[yt2475@linserv1 ~]$ kill -INT 25043
[yt2475@linserv1 ~]$ kill -INT 25043
[yt2475@linserv1 ~]$
```

- We changed the default signal handler for the signal `SIGINT`, so when we press Ctrl-C or use `kill` to send the signal, it'll only print Ouch, but the process won't be stopped
- Now, we can still use `SIGTSTP` to stop the process and use `SIGTERM` to terminate the process. However, we can also overwrite these two handlers.
- The only signal we can't overwrite is `SIGKILL`. If we overwrite every other signal handlers, we could only use `SIGKILL` to kill the process

> “
>
> There are also some signal reserved for user to define, like `SIGUSR1`, `SIGUSR2`.
>
> But there's a fixed amount of signals

Waiting for a signal

The `pause()` system call puts the process to block (sleep) until the delivery of…

- a signal handled by the process, or
- a signal terminating the process.

```c
void handler(int sig) {
}

int main() {
  signal(SIGINT, handler);
  printf("Press Ctrl-C to continue...\n");
  pause();
  printf("...Adiós!\n");
}
```

pause.c

```
$ ./pause
Press Ctrl-C to continue...
^C...Adiós!
$ _
```

Timer

The `alarm()` system call sets up a one-time asynchronous timer for the process.

- A *SIGALRM* signal will be sent to the process at the timeout.
- The default *SIGALRM* handler terminates the process, but you can override it.

The `setitimer()` system call sets up an interval timer.

Can you implement `sleep()` ?

Summary

Signal is a kind of software interrupt.

It has many quirky behaviors.

`kill()` is not intended to kill anybody, but to **send signals**.

When in doubt, refer to the man pages.

Midterm Exam

Announcement

Mid-term exam

Due to scheduling difficulties, our mid-term exam will be held online via Brightspace Quizzes.

Time & venue: Thursday, March 9, 12:30 p.m.—1:45 p.m. @ anywhere.

You must connect to the Zoom session and turn on your webcam for the entire duration of the exam.

As a result, our mid-term exam will be open-book.

Our final exam will still be in-person and closed-book (with one “cheat sheet”).

You can refer to…

- Slides.
- Textbooks.
- Docker & CIMS servers (*e.g.*, read man pages, use `gcc` to try out programs).
- Online websites (you can search existing information, but you are not allowed to ask questions and seek answers).

However, keep in mind that by doing these things, you will likely waste a lot of time with little gain.

You must not communicate with any other people or AI-based assistants.