CS 332/532 Systems Programming

Lecture 23

Signals

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Agenda

- Signals

Signals

- Signals are software interrupts that provide a mechanism to deal with asynchronous events (e.g., a user pressing Control-C to interrupt a program that the shell is currently executing).
- A signal is a notification to a process that an event has occurred that requires the attention of the process (this typically interrupts the normal flow of execution of the interrupted process).
- Signals can also be used as a synchronization technique or even as a simple form of interprocess communication.
- Signals could be generated by hardware interrupts, the program itself, other programs, the OS kernel, or by the user.

- All these signals have a unique symbolic name and starts with SIG. The standard signals (also called POSIX reliable signals) are defined in the header file *<signal.h>*.
- Here are some examples:
- `SIGINT:` Interrupt a process from keyboard (e.g., pressing Control-C). The process is terminated.
- `SIGQUIT:` Interrupt a process to quit from keyboard (e.g., pressing Control-/). The process is terminated and a core file is generated.
- `SIGTSTP:` Interrupt a process to stop from keyboard (e.g., pressing Control-Z). The process is stopped from executing.
- `SIGUSR1` and `SIGUSR2`: These are user-defined signals, for use in application programs.

- ***NOTE***: Please see Section 10.2 and Figure 10.1 in the textbook for a complete list of UNIX System signals. You can also find more details using *man 7 signal* on any CS UNIX system (*man signal* on Mac).
- After a signal is generated, it is delivered to a process to perform some action in response to this signal.
- Since signals are asynchronous events, a process has to decide ahead of time how to respond when the particular signal is delivered.
- There are three different options possible when a signal is delivered to a process:

- <u>Perform the default action</u>. Most signals have a default action associated with them, if the process does not change the default behavior then the default action specific to that particular signal will occur.
  - The predefined default signal is specified as `SIG_DFL`.
- <u>Ignore the signal.</u> If a signal is ignored, then the default action is performed.
  - The predefined ignore signal handler is specified as `SIG_IGN`.
- <u>Catch and Handle the signal</u>. It is also possible to override the default action and invoke a specific user-defined task when a signal is received.
  - This is usually performed by invoking a signal handler using *`signal()`* or *`sigaction()`* system calls.
- However, the signals `SIGKILL` and `SIGSTOP` cannot be caught, blocked, or ignored.

signal()

- signal - ANSI C signal handling
-
  ```
  typedef void (*sighandler_t)(int);
  ```

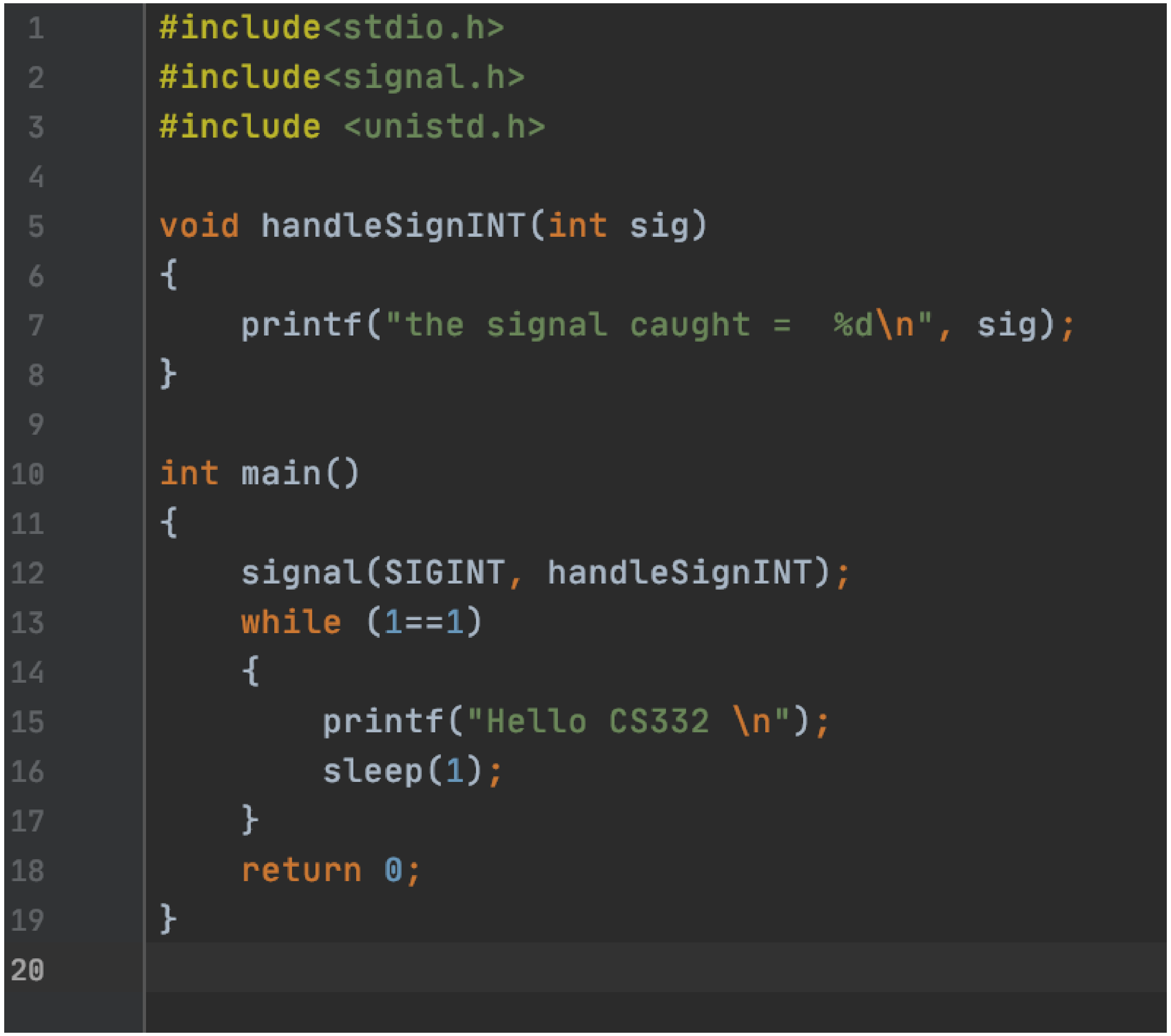
-
  ```
  sighandler_t signal(int signum, sighandler_t handler);
  ```

- **signal**() sets the disposition of the signal *signum* to *handler*, which is either **SIG_IGN**, **SIG_DFL**, or the address of a programmer-defined function (a "signal handler").

Sending Signals Using The Keyboard

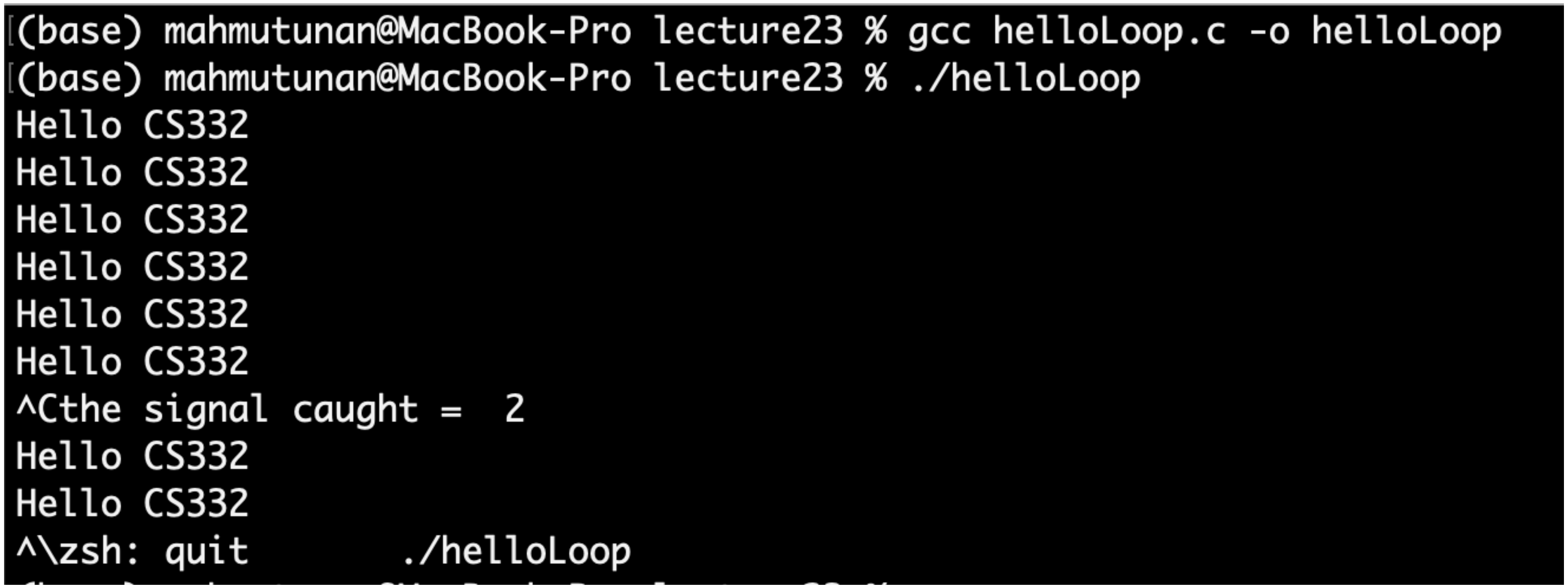
- Ctrl-C to send an INT signal (SIGINT) to the running process.
  - This signal causes the process to immediately terminate.
- Ctrl-Z to send a TSTP signal (SIGTSTP) to the running process.
  - This signal causes the process to suspend execution.
- Ctrl-\ to send a ABRT signal (SIGABRT) to the running process.
  - This signal causes the process to immediately terminate.
  - Ctrl-\ doing the same as Ctrl-C but it gives us some better flexibility.

infinite loop



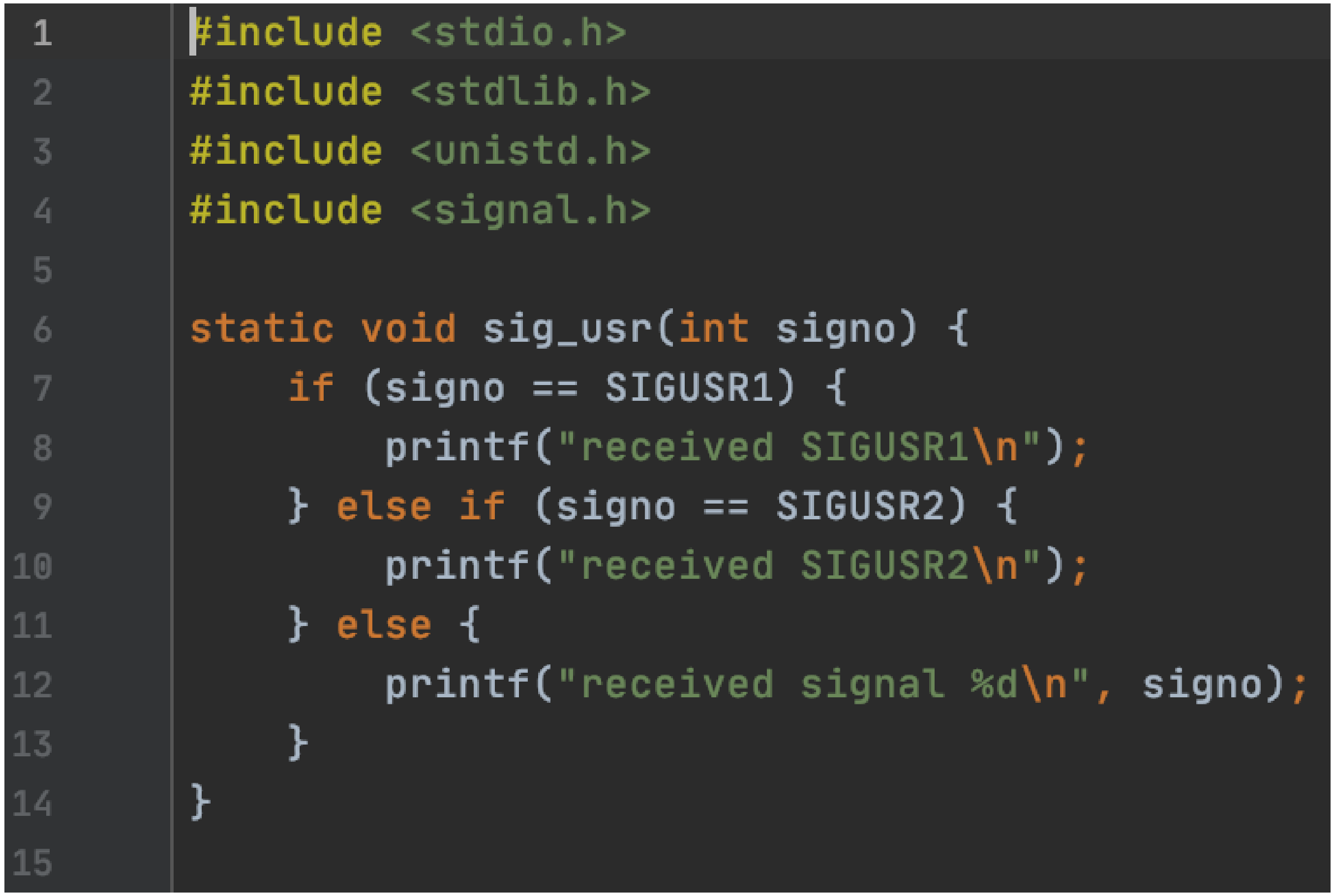
```c
#include<stdio.h>
#include<signal.h>
#include <unistd.h>

void handleSignINT(int sig)
{
    printf("the signal caught =  %d\n", sig);
}

int main()
{
    signal(SIGINT, handleSignINT);
    while (1==1)
    {
        printf("Hello CS332 \n");
        sleep(1);
    }
    return 0;
}

```

compile & run



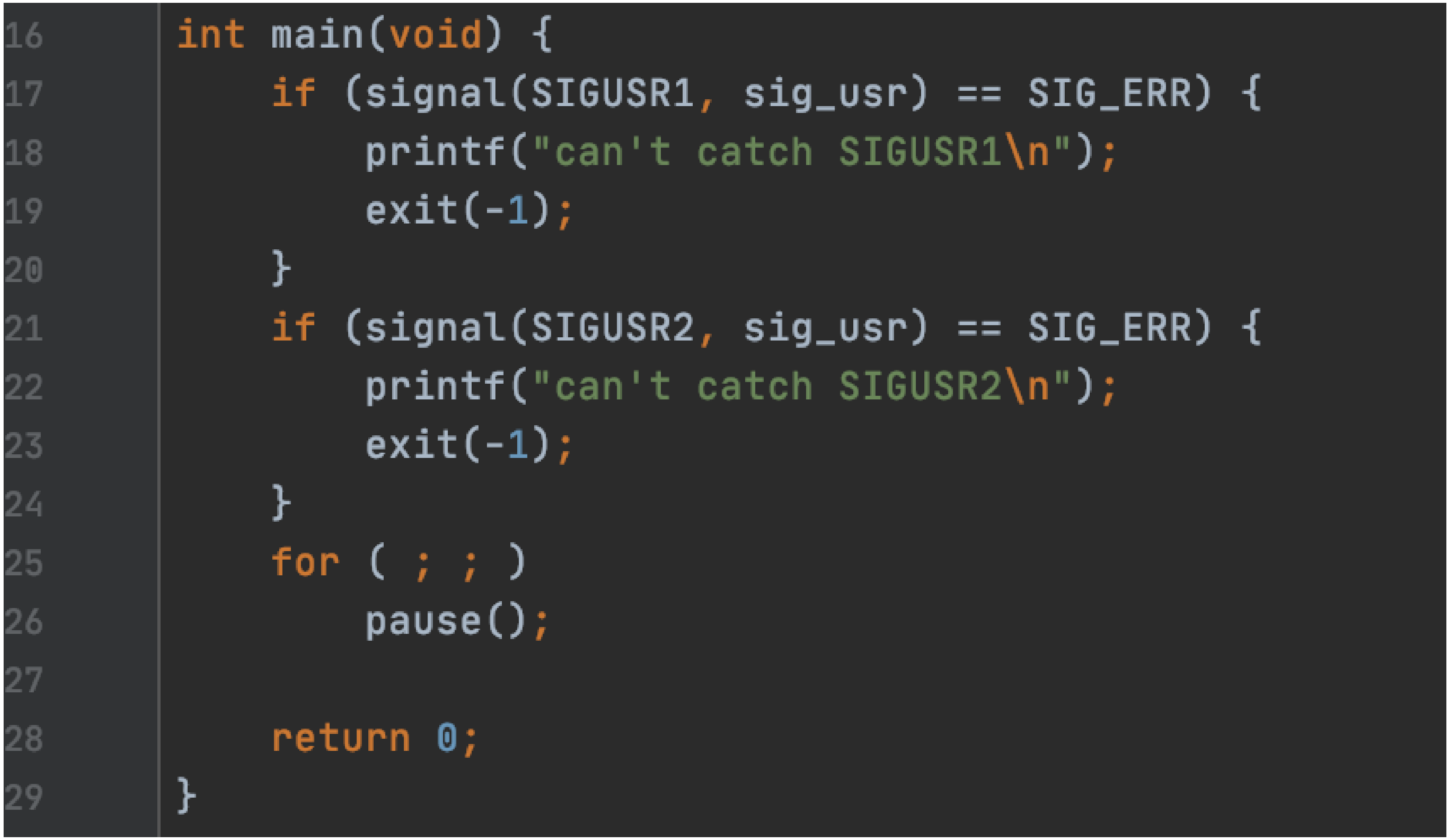
```
(base) mahmutunan@MacBook-Pro lecture23 % gcc helloLoop.c -o helloLoop
(base) mahmutunan@MacBook-Pro lecture23 % ./helloLoop
Hello CS332
Hello CS332
Hello CS332
Hello CS332
Hello CS332
Hello CS332
^Cthe signal caught =  2
Hello CS332
Hello CS332
^\zsh: quit       ./helloLoop
```

- Now, let’s write a program to handle a simple signal that catches either of the two user-defined signals and prints the signal number (see Figure 10.2 in the textbook).
- 1. Create a user-defined function (signal handler) that will be invoked when a signal is received:

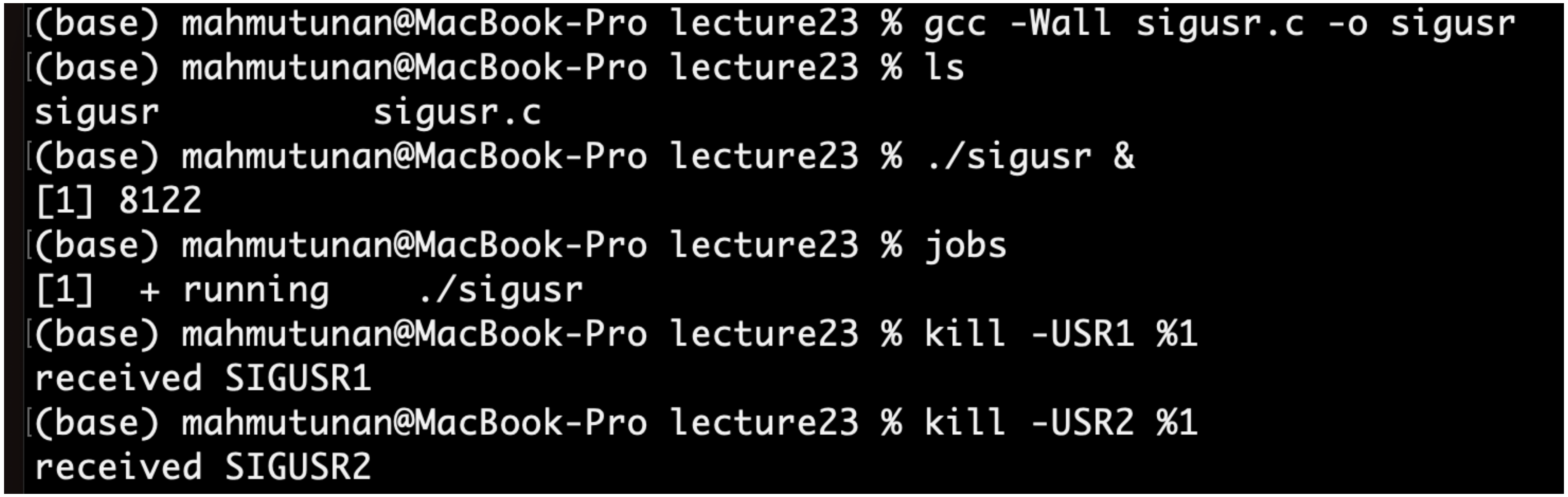


```c
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include <signal.h>

static void sig_usr(int signo) {
    if (signo == SIGUSR1) {
        printf("received SIGUSR1\n");
    } else if (signo == SIGUSR2) {
        printf("received SIGUSR2\n");
    } else {
        printf("received signal %d\n", signo);
    }
}

```

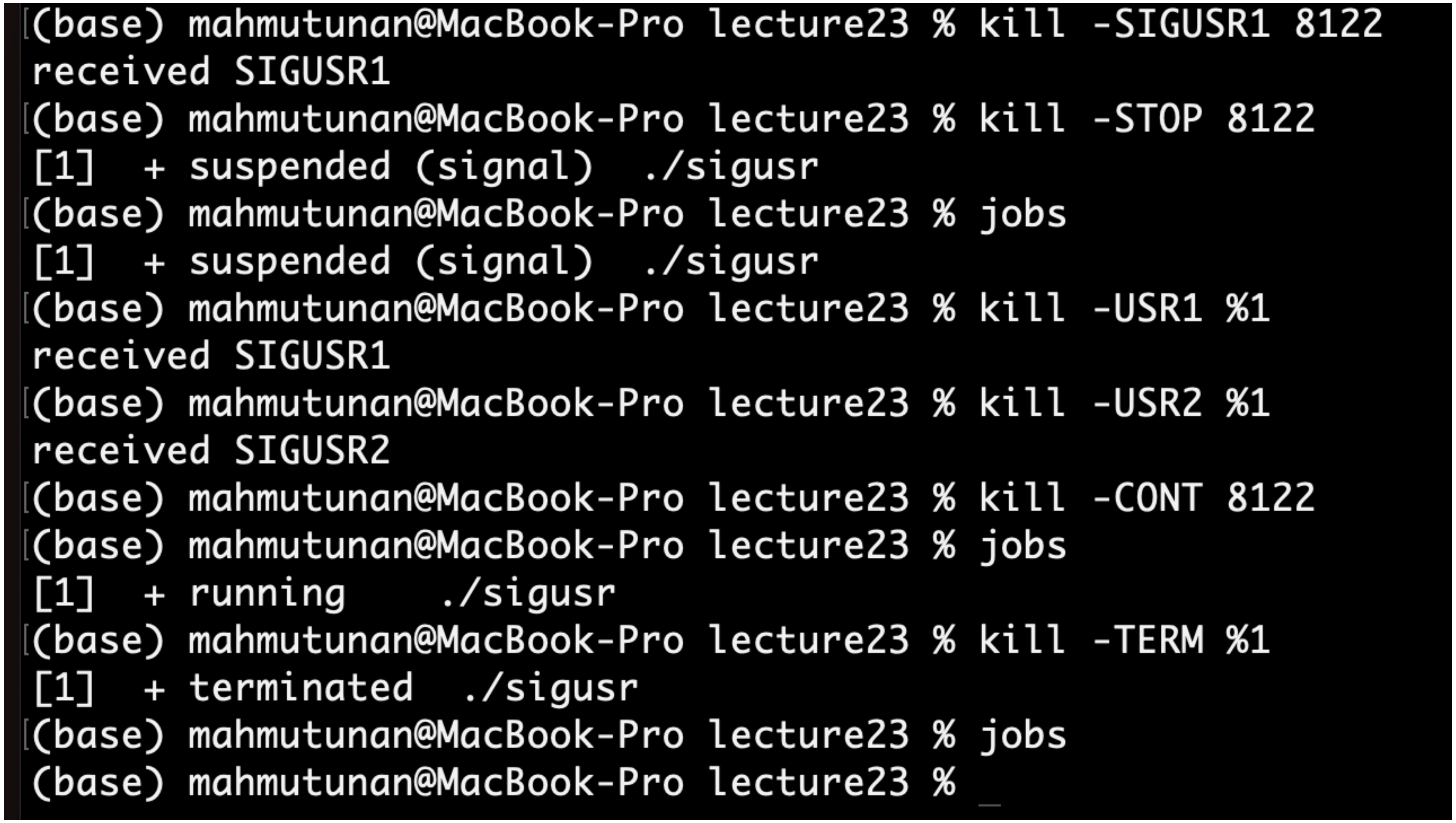
- 2. Now let’s call above user-defined signal.



```c
int main(void) {
    if (signal(SIGUSR1, sig_usr) == SIG_ERR) {
        printf("can't catch SIGUSR1\n");
        exit(-1);
    }
    if (signal(SIGUSR2, sig_usr) == SIG_ERR) {
        printf("can't catch SIGUSR2\n");
        exit(-1);
    }
    for ( ; ; )
        pause();

    return 0;
}
```



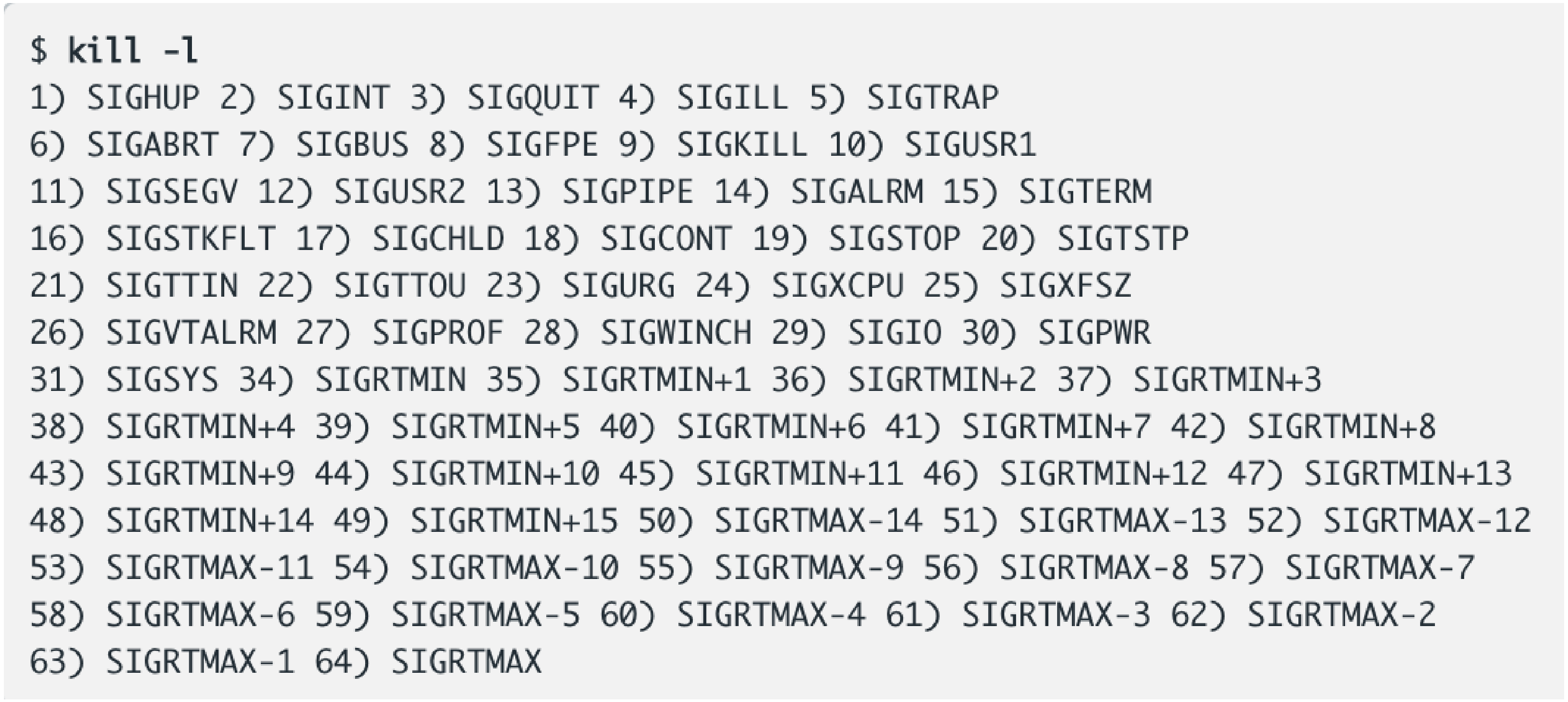
```
(base) mahmutunan@MacBook-Pro lecture23 % gcc -Wall sigusr.c -o sigusr
(base) mahmutunan@MacBook-Pro lecture23 % ls
sigusr          sigusr.c
(base) mahmutunan@MacBook-Pro lecture23 % ./sigusr &
[1] 8122
(base) mahmutunan@MacBook-Pro lecture23 % jobs
[1]  + running    ./sigusr
(base) mahmutunan@MacBook-Pro lecture23 % kill -USR1 %1
received SIGUSR1
(base) mahmutunan@MacBook-Pro lecture23 % kill -USR2 %1
received SIGUSR2
```



```
(base) mahmutunan@MacBook-Pro lecture23 % kill -SIGUSR1 8122
received SIGUSR1
(base) mahmutunan@MacBook-Pro lecture23 % kill -STOP 8122
[1]  + suspended (signal)  ./sigusr
(base) mahmutunan@MacBook-Pro lecture23 % jobs
[1]  + suspended (signal)  ./sigusr
(base) mahmutunan@MacBook-Pro lecture23 % kill -USR1 %1
received SIGUSR1
(base) mahmutunan@MacBook-Pro lecture23 % kill -USR2 %1
received SIGUSR2
(base) mahmutunan@MacBook-Pro lecture23 % kill -CONT 8122
(base) mahmutunan@MacBook-Pro lecture23 % jobs
[1]  + running    ./sigusr
(base) mahmutunan@MacBook-Pro lecture23 % kill -TERM %1
[1]  + terminated  ./sigusr
(base) mahmutunan@MacBook-Pro lecture23 % jobs
(base) mahmutunan@MacBook-Pro lecture23 % _
```

- In the example we used the *kill* command that we used in the previous lecture to generate the signal.
- While we used the kill command in the previous lecture to terminate a process using the TERM signal (the default signal if no signal is specified), the kill command could be used to generate any other signal that is supported by the kernel.

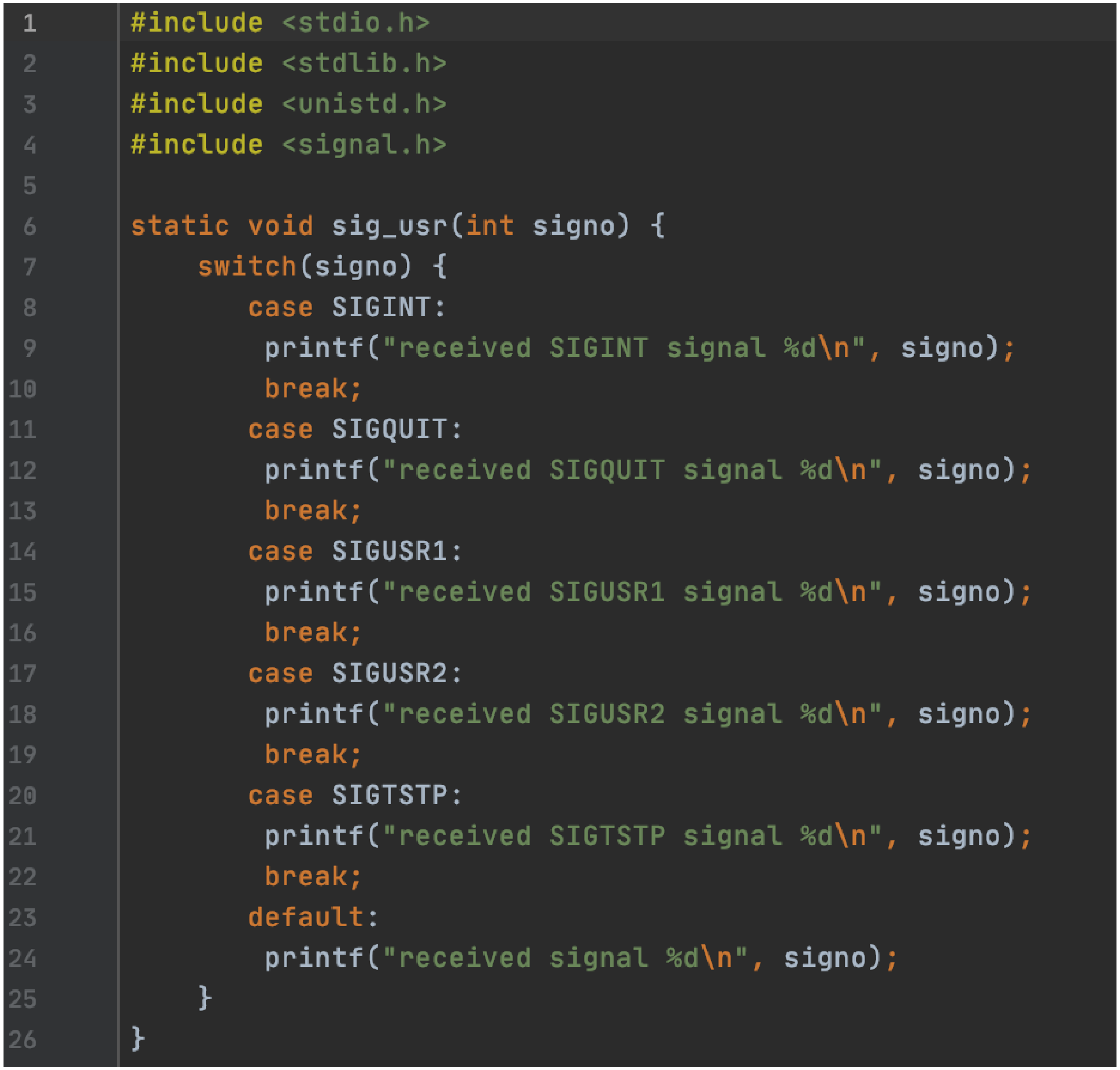
- You can list all signals that can be generated using *kill -l*. For example, on the CS Linux systems you see the following output:



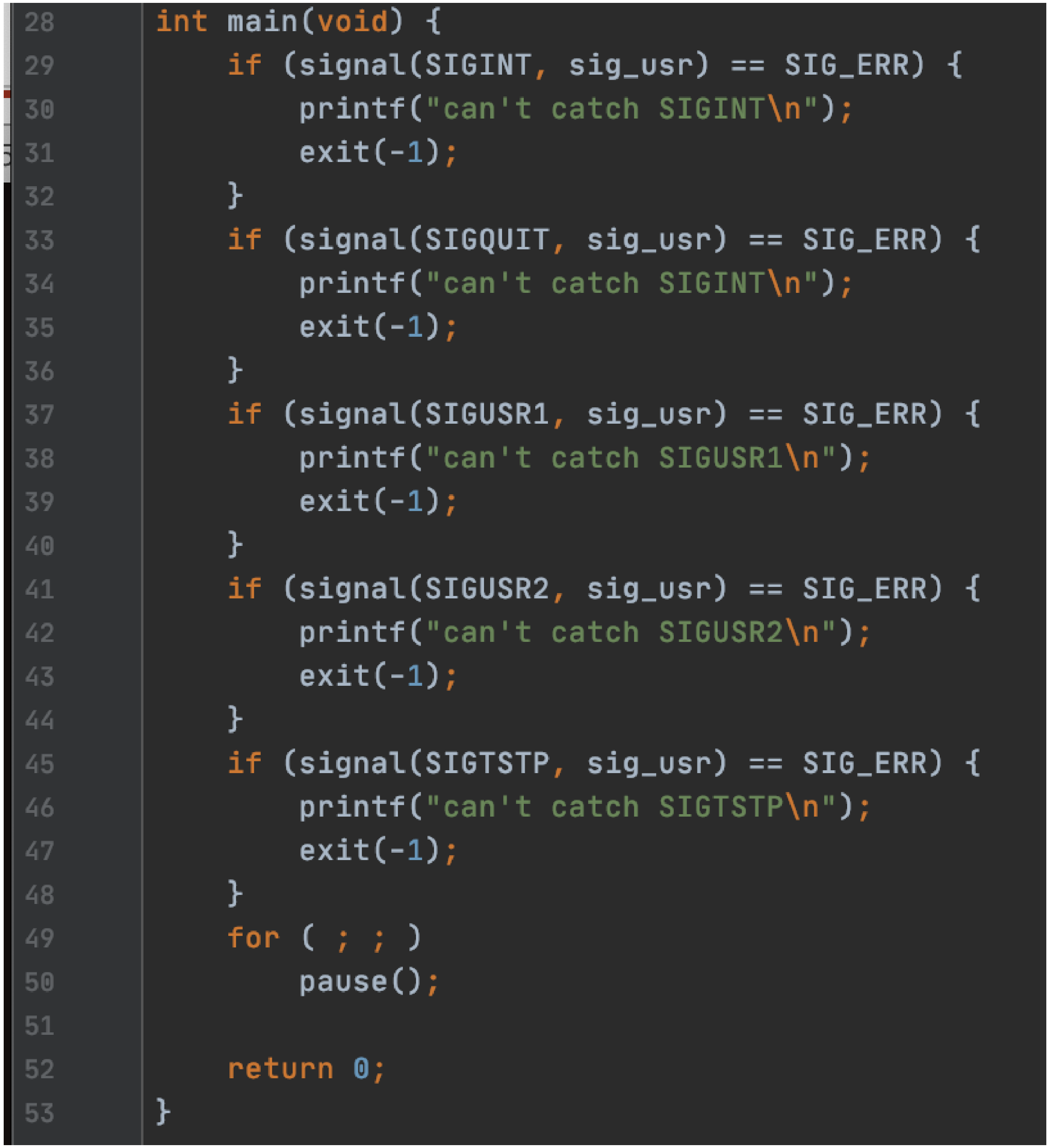
```
$ kill -l
1) SIGHUP 2) SIGINT 3) SIGQUIT 4) SIGILL 5) SIGTRAP
6) SIGABRT 7) SIGBUS 8) SIGFPE 9) SIGKILL 10) SIGUSR1
11) SIGSEGV 12) SIGUSR2 13) SIGPIPE 14) SIGALRM 15) SIGTERM
16) SIGSTKFLT 17) SIGCHLD 18) SIGCONT 19) SIGSTOP 20) SIGTSTP
21) SIGTTIN 22) SIGTTOU 23) SIGURG 24) SIGXCPU 25) SIGXFSZ
26) SIGVTALRM 27) SIGPROF 28) SIGWINCH 29) SIGIO 30) SIGPWR
31) SIGSYS 34) SIGRTMIN 35) SIGRTMIN+1 36) SIGRTMIN+2 37) SIGRTMIN+3
38) SIGRTMIN+4 39) SIGRTMIN+5 40) SIGRTMIN+6 41) SIGRTMIN+7 42) SIGRTMIN+8
43) SIGRTMIN+9 44) SIGRTMIN+10 45) SIGRTMIN+11 46) SIGRTMIN+12 47) SIGRTMIN+13
48) SIGRTMIN+14 49) SIGRTMIN+15 50) SIGRTMAX-14 51) SIGRTMAX-13 52) SIGRTMAX-12
53) SIGRTMAX-11 54) SIGRTMAX-10 55) SIGRTMAX-9 56) SIGRTMAX-8 57) SIGRTMAX-7
58) SIGRTMAX-6 59) SIGRTMAX-5 60) SIGRTMAX-4 61) SIGRTMAX-3 62) SIGRTMAX-2
63) SIGRTMAX-1 64) SIGRTMAX
```

Exercise 2

- We will now extend the exercise 1 to handle other signal generated from keyboard such as Control-C (SIGINT), Control-Z (SIGTSTP), and Control-\ (SIGQUIT). In this example we will use a single signal handler to handle all these signals using a switch statement (instead of separate signal handlers).

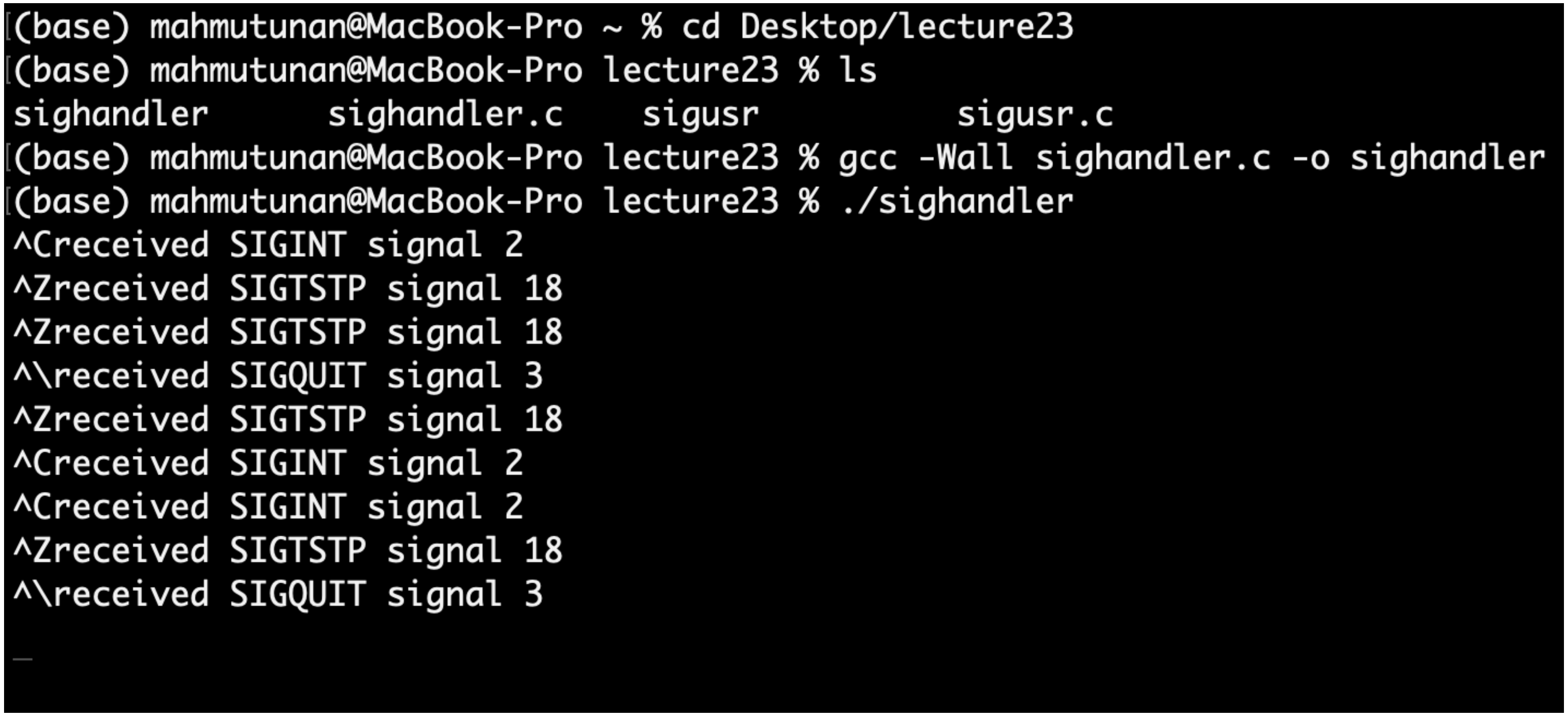


```c
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include <signal.h>

static void sig_usr(int signo) {
    switch(signo) {
       case SIGINT:
        printf("received SIGINT signal %d\n", signo);
        break;
       case SIGQUIT:
        printf("received SIGQUIT signal %d\n", signo);
        break;
       case SIGUSR1:
        printf("received SIGUSR1 signal %d\n", signo);
        break;
       case SIGUSR2:
        printf("received SIGUSR2 signal %d\n", signo);
        break;
       case SIGTSTP:
        printf("received SIGTSTP signal %d\n", signo);
        break;
       default:
        printf("received signal %d\n", signo);
    }
}
```



```c
int main(void) {
    if (signal(SIGINT, sig_usr) == SIG_ERR) {
        printf("can't catch SIGINT\n");
        exit(-1);
    }
    if (signal(SIGQUIT, sig_usr) == SIG_ERR) {
        printf("can't catch SIGINT\n");
        exit(-1);
    }
    if (signal(SIGUSR1, sig_usr) == SIG_ERR) {
        printf("can't catch SIGUSR1\n");
        exit(-1);
    }
    if (signal(SIGUSR2, sig_usr) == SIG_ERR) {
        printf("can't catch SIGUSR2\n");
        exit(-1);
    }
    if (signal(SIGTSTP, sig_usr) == SIG_ERR) {
        printf("can't catch SIGTSTP\n");
        exit(-1);
    }
    for ( ; ; )
        pause();

    return 0;
}
```

compile & run



```
(base) mahmutunan@MacBook-Pro ~ % cd Desktop/lecture23
(base) mahmutunan@MacBook-Pro lecture23 % ls
sighandler      sighandler.c    sigusr          sigusr.c
(base) mahmutunan@MacBook-Pro lecture23 % gcc -Wall sighandler.c -o sighandler
(base) mahmutunan@MacBook-Pro lecture23 % ./sighandler
^Creceived SIGINT signal 2
^Zreceived SIGTSTP signal 18
^Zreceived SIGTSTP signal 18
^\received SIGQUIT signal 3
^Zreceived SIGTSTP signal 18
^Creceived SIGINT signal 2
^Creceived SIGINT signal 2
^Zreceived SIGTSTP signal 18
^\received SIGQUIT signal 3

_
```

infinite loop

- Notice that we have replaced the default signal handlers to kill this job from the keyboard and the program is in an infinite loop with pause. As a result we cannot terminate this program from the keyboard. We have to login to the specific machine this process is running and kill this process using either *kill* or *top* commands. You can follow the examples from the first part and kill this process.