

UNIX Signals

Bach 7.2

Operating Systems Course
The Hebrew University
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Reminder: Kernel Mode

- When the CPU is in *kernel mode*, it is assumed to be executing *trusted* software, and thus it can execute any instructions and reference any memory addresses.
- The *kernel* is the core of the operating system and it has complete control over everything that occurs in the system.
- The kernel is *trusted* software, all other programs are considered *untrusted* software.
- A *system call* is a request to the kernel in a Unix-like operating system by an *active process* for a service performed by the kernel.

Some Definitions

- A **process** is an executing instance of a program. An **active process** is a process that is currently advancing in the CPU (while other processes are waiting in memory for their turns to use the CPU).
- The execution of a process can be interrupted by an **interrupt**.
- An **interrupt** is a **notification to the operating system** that an event has occurred, which results in changes in the sequence of instructions that is executed by the CPU.

Types of Interrupts

- **Hardware interrupts** (also called **external/asynchronous interrupts**), are ones in which the notification originates from a hardware device such as a keyboard, mouse or system clock.
- **Software interrupts** include **exceptions** and **traps**
 - **Exceptions**: triggered by an action of the process without its knowledge (division by zero, access to paged memory, etc.)
 - **Traps**: triggered by the process using system calls
- Usually, no interrupt should be ignored by the OS.

Interrupts:

The basic mechanism

1. The CPU receives the interrupt,
2. Control is transferred to the OS,
3. Current state is saved,
4. The request is serviced,
5. Previous state is restored,
6. Control is returned.

Signals

- Signals are **notifications sent to a process** in order to notify it of various "important" events.
- Signals cause the process to **stop whatever it is doing** at the moment, and force the process to **handle them immediately**.
- The process may configure how it handles a signal.
 - (Except for some signals that it cannot configure)
- **Signals** are different from **interrupts**:
 - Signals are generated by the **OS**, and received and handled by a **process**.
 - Interrupts are generated by the **hardware**, and received and handled by the **OS**.
- Signals and interrupts are both **asynchronous**
- Signals in unix have names and numbers.
 - Use 'man kill' to see the types of signals

Triggers for Signals

Some examples for signal triggers:

- Asynchronous input from the user such as ^C (SIGINT), or typing 'kill pid' at the shell
- The system or another process, for instance if an alarm set by the process has timed out (SIGALRM)
- An exception in hardware caused by the process, such as Illegal memory access (SIGSEGV)
 - The exception causes a hardware interrupt,
 - The hardware interrupt is received by the OS
 - The signal is generated by the OS and 'sent' to the process
- A debugger wishing to suspend or resume the process

Sending Signals Using the Keyboard

The most common way of sending signals to processes is using the keyboard:

- **Ctrl-C**: Causes the system to send an `INT` signal (`SIGINT`) to the running process.
- **Ctrl-Z**: causes the system to send a `TSTP` signal (`SIGTSTP`) to the running process.
- **Ctrl-**:causes the system to send a `ABRT` signal (`SIGABRT`) to the running process.

Sending Signals from the Command Line

- The `kill` command sends a signal to a process.

```
kill [options] pid
```

-l lists all the signals you can send

-signal defines the signal to send

- the default is to send a `TERM` signal to the process.

- The `fg` command resumes execution of a process (that was suspended with **Ctrl-Z**), by sending it a `CONT` signal.

Handling Signals

- The kernel handles signals in the context of the process that receives them, so **a process must run to handle signals.**
- There are three types of handling for signals:
 - The process **exits**. (default for some signals)
 - The process **ignores**. (default for some other signals)
 - The process executes a **signal handler**:

```
oldfun = signal(signum, newfun) ;
```

Signal Handlers – Example

(Note: “signal” is deprecated!)

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

void catch_int(int sig_num) {
    signal(SIGINT, catch_int); //install again!
    printf("Don't do that\n");
    fflush(stdout);
}

int main(int argc, char* argv[]) {
    signal(SIGINT, catch_int);
    for ( ;; )
        pause();//wait until receives a signal.
}
```

Handling Signals (cont.)

- There are some signals that the process cannot catch.
 - For example: `KILL` and `STOP`.
- If you install no signal handlers of your own, the runtime environment sets up a set of **default signal handlers**.
 - For example:
 - The default signal handler for `TERM` calls `exit()`.
 - The default handler for `ABRT` is to dump the process's memory image into a file, and then `exit`.

Pre-defined Signal Handlers

- There are two pre-defined signal handler functions that we can use:, instead of writing our own.
 - **SIG_IGN**: Causes the process to ignore the specified signal.
 - `signal(SIGINT, SIG_IGN);`
 - **SIG_DFL**: Causes the system to set the default signal handler for the given signal.
 - `signal(SIGTSTP, SIG_DFL);`

Intermediate Summary

- Each signal may have a **signal handler**, which is a function that gets called when the process receives that signal.
- If a signal is sent to the process, the next time the process runs, the operating system causes the process to **run the signal handler**, no matter what it was doing before.
- When that signal handler function returns, the process **continues execution** from wherever it happened to be before the signal was received.

Avoiding Signal Races – Masking Signals

- Because signals are handled **asynchronously**, race conditions can occur:
 - A signal may be received and handled in the middle of an operation that should not be interrupted;
 - A second signal may occur before the current signal handler finished.
 - The second signal may be of a different type or of the same type as the first one.
- Therefore we need to **block signals** from being processed when they are harmful.
 - The blocked signal will be processed after the block is removed.
 - Some signals cannot be blocked.

Sigprocmask

Allows to specify a set of signals to block, and/or get the list of signals that were previously blocked.

```
int sigprocmask(int how, const sigset_t *set,
                sigset_t *oldset)
```

1. `int how`:

- Add (SIG_BLOCK)
- Delete (SIG_UNBLOCK)
- Set (SIG_SETMASK).

2. `const sigset_t *set`:

- The set of signals.

3. `sigset_t *oldse`:

- If not NULL, the previous mask will be returned.

```
sigset_t set;

sigemptyset(&set);
sigaddset(&set, SIGINT);
sigaddset(&set, SIGTERM);
sigprocmask(SIG_SETMASK, &set, NULL);
//blocked signals: SIGINT and SIGTERM

sigemptyset(&set);
sigaddset(&set, SIGINT);
sigaddset(&set, SIGALRM);
sigprocmask(SIG_BLOCK, &set, NULL);
//blocked signals: SIGINT, SIGTERM, SIGALRM

sigemptyset(&set);
sigaddset(&set, SIGTERM);
sigaddset(&set, SIGUSR1);
sigprocmask(SIG_UNBLOCK, &set, NULL);
//blocked signals: SIGINT and SIGALRM
```

Handling Signals

- So far we saw two system calls:
 - `signal`
 - Installs a signal for a single use,
 - Must reinstall each time we get a signal!
 - **Deprecated!**
 - `sigprocmask`
 - Defines which signals to block,
 - Must be called in each signal handler to block and release signals.

Sigaction

```
int sigaction(int sig,  
              struct sigaction *new_act,  
              struct sigaction *old_act);
```

- Allows the calling process to examine and/or specify the **action** to be associated with a specific signal.
 - **action** = signal handler+signal mask+flags

Sigaction cont.

- The signal mask is calculated and installed **only for the duration of the signal handler.**
- By default, the signal “sig” is also blocked when the signal occurs.
- Once an action is installed for a specific signal using `sigaction`, **it remains installed** until another action is explicitly requested.

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

void termination_handler(int signum) {
    exit(7);
}

int main (void) {
    struct sigaction new_action,old_action;
    new_action.sa_handler =
        termination_handler;
    sigemptyset(&new_action.sa_mask);
    sigaddset(&new_action.sa_mask, SIGTERM);
    new_action.sa_flags = 0;
    sigaction(SIGINT, NULL, &old_action);
    if (old_action.sa_handler != SIG_IGN) {
        sigaction(SIGINT,&new_action,NULL);
    }
    sleep(10);
    return 0;
}
```

Signals: Summary

- Signals are **notifications** sent to a process
- The OS causes the process to handle a signal **immediately** the next time it runs.
- There are **default signal handlers** for processes.
- These handlers can be changed using `signal` or `sigaction`.
- To avoid race conditions, one usually needs to block signals some of the time using `sigprocmask` and/or `sigaction`.