CSCB09 Software Tools and Systems Programming
Inter-Process Communication – Signals

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Today's class

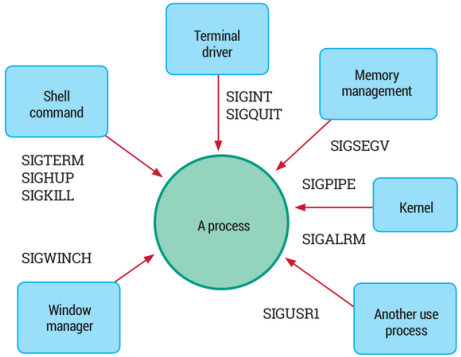
Today we will discuss the following topics:

- Signals
- Signals Handling
- Examples

Signals

Signals

- are used to notify a program of a given "event"
- standardized messages sent to a running program to trigger specific behavior, such as quitting or error handling
- a limited form of inter-process communication (IPC)
- asynchronous notification sent to a process or thread within a process to notify of an event
- Common uses of signals are to interrupt, suspend, terminate or kill a process.



- Unexpected/unpredictable asynchronous events
  - floating point error
  - segmentation fault
  - control-C (termination request)
  - control-Z (suspend request)
- Events are called interrupts
- When the OS kernel recognizes an event, it sends a signal to the process.
- Normal processes may send signals.

What are signals for?

- Synchronization between processes (e.g. parent and forked children)
- OS communicates hardware events to a process
- Signals are generated by
  - machine interrupts
  - the program itself, other programs or the user.

Signals Table

`man 7 signal` $\rightsquigarrow$ description of signals with default actions

Signal	Default Action	Comment
`SIGINT`	Terminate	Interrupt from keyboard
`SIGSEGV`	Terminate/Dump core	Invalid memory reference
`SIGKILL`	Terminate (cannot ignore)	Kill
`SIGCHLD`	Ignore	Child stopped or terminated
`SIGSTOP`	Stop (cannot ignore)	Stop process
`SIGCONT`		Continue if stopped

```
...
       Signal      Standard   Action   Comment

       SIGABRT      P1990      Core    Abort signal from abort(3)
       SIGALRM      P1990      Term    Timer signal from alarm(2)
       SIGBUS       P2001      Core    Bus error (bad memory access)
       SIGCHLD      P1990      Ign     Child stopped or terminated
       SIGCLD         -        Ign     A synonym for SIGCHLD
       SIGCONT      P1990      Cont    Continue if stopped
       SIGEMT         -        Term    Emulator trap
       SIGFPE       P1990      Core    Floating-point exception
       SIGHUP       P1990      Term    Hangup detected on controlling terminal
                                       or death of controlling process
       SIGILL       P1990      Core    Illegal Instruction
       SIGINFO        -                A synonym for SIGPWR
       SIGINT       P1990      Term    Interrupt from keyboard
       SIGIO          -        Term    I/O now possible (4.2BSD)
       SIGIOT         -        Core    IOT trap. A synonym for SIGABRT
       SIGKILL      P1990      Term    Kill signal
       SIGLOST        -        Term    File lock lost (unused)
       SIGPIPE      P1990      Term    Broken pipe: write to pipe with no
                                       readers; see pipe(7)
       SIGPOLL      P2001      Term    Pollable event (Sys V);
                                       synonym for SIGIO
       SIGPROF      P2001      Term    Profiling timer expired
       SIGPWR         -        Term    Power failure (System V)
       SIGQUIT      P1990      Core    Quit from keyboard
       SIGSEGV      P1990      Core    Invalid memory reference
       SIGSTKFLT      -        Term    Stack fault on coprocessor (unused)
       SIGSTOP      P1990      Stop    Stop process

       SIGTSTP      P1990      Stop    Stop typed at terminal
       SIGSYS       P2001      Core    Bad system call (SVr4);
                                       see also seccomp(2)
       SIGTERM      P1990      Term    Termination signal
       SIGTRAP      P2001      Core    Trace/breakpoint trap
       SIGTTIN      P1990      Stop    Terminal input for background process
       SIGTTOU      P1990      Stop    Terminal output for background process
       SIGUNUSED      -        Core    Synonymous with SIGSYS
       SIGURG       P2001      Ign     Urgent condition on socket (4.2BSD)
       SIGUSR1      P1990      Term    User-defined signal 1
       SIGUSR2      P1990      Term    User-defined signal 2
       SIGVTALRM    P2001      Term    Virtual alarm clock (4.2BSD)
       SIGXCPU      P2001      Core    CPU time limit exceeded (4.2BSD);
                                       see setrlimit(2)
       SIGXFSZ      P2001      Core    File size limit exceeded (4.2BSD);
                                       see setrlimit(2)
       SIGWINCH       -        Ign     Window resize signal (4.3BSD, Sun)

       The signals SIGKILL and SIGSTOP cannot be caught, blocked, or ignored.
...
```

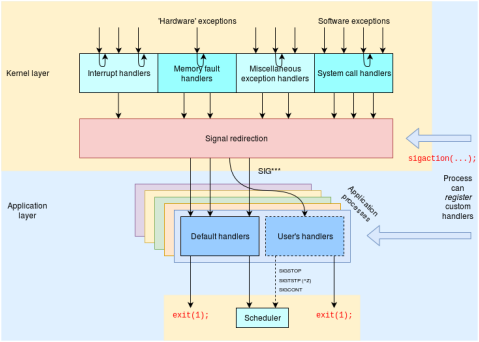
SIGINT	2	Interrupt a process (used by **Ctrl-C**)
SIGHUP	1	Hang up or shut down and restart process
SIGKILL	9	Kill the process (cannot be ignored or caught elsewhere)
SIGTERM	15	Terminate signal, (can be ignored or caught)
SIGTSTP	20	Stop the terminal (used by **Ctrl-z**)
SIGSTOP	19	Stop execution (cannot be caught or ignored)

- There are 31 standard signals, numbered 1-31.
  Each signal is named as "SIG" followed by a suffix.
- Starting from version 2.2, the Linux kernel supports 33 different real-time signals.
  These have numbers 32-64 but one should instead use SIGRTMIN+n notation.
- Linux implementation of signals is fully POSIX compliant.
- Just as hardware subsystems can interrupt the processor, signals interrupt process execution. They are therefore seen as *software interrupts*.
- Some signals are mapped to specific key inputs:
  SIGINT for ctrl+c, SIGSTOP for ctrl+z, SIGQUIT for ctrl+\.

- When a signal is sent, the operating system interrupts the target process' normal flow of execution to deliver the signal.
- If the process has previously registered a *signal handler*, that routine is executed. Otherwise, the default signal handler is executed.
- Signals are similar to *interrupts*, the difference being that interrupts are mediated by the CPU and handled by the kernel while signals are mediated by the kernel (possibly via system calls) and handled by individual processes.
- The kernel may pass an interrupt as a signal to the process that caused it (typical examples are `SIGSEGV`, `SIGBUS`, `SIGILL` and `SIGFPE`).

OS Structures for Signals

- For each process, the OS maintains 2 integers with the bits corresponding to a signal numbers.
- The two integers keep track of: pending signals and blocked signals
- With 32 bit integers, up to 32 different signals can be represented.



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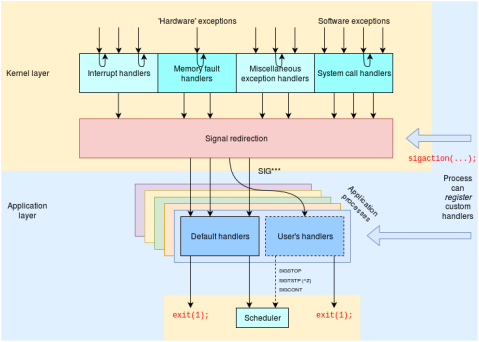

Example: `SIGINT` (= 2) signal is blocked and no other signals are pending

Pending Signals

31	30	29	28	. . .	3	2	1	0
0	0	0	0	. . .	0	0	0	0

Blocked Signals

31	30	29	28	. . .	3	2	1	0
0	0	0	0	. . .	0	1	0	0

- A signal is sent to a process setting the corresponding bit in the pending signals integer for the process.
- Each time the OS selects a process to be run on a processor, the pending and blocked integers are checked.
  - If no signals are pending, the process is restarted normally and continues executing at its next instruction.
  - If $\exists$ pendings signals:
    1. "blocked" $\rightarrow$ restart normally, but with the signals still marked as pending
    2. "pending" and *not* blocked $\rightarrow$ OS executes the process' routines to handle the signals

Sending a signal

- From the command line use
  `kill [-signal] pid [pid] ...`
- If no signal is specified, kill sends the `TERM` signal to the process.
- `signal` can be specified by the number or name of the signal.
- Examples:
  `kill -QUIT 8883`
  `kill -STOP 78911`
  `kill -9 76433` – (9 == KILL)
- Try `kill -l` to see the supported signals

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Programatically

- A signal can be generated by calling `raise()` or `kill()` system calls
- `raise()` sends a signal to the current process
- `kill()` sends a signal to a specific process

Signalling between processes

- One process can send a signal to another process using the "misleadingly" named function call: `kill(int pid, int sig);`
- This call sends the signal `sig` to the process `pid`
- Signalling between processes can be used for many purposes:
  - kill errant processes
  - temporarily suspend execution of a process
  - make a process aware of the passage of time
  - synchronize the actions of processes.

Default Actions

SIGINT	2	Interrupt a process (used by Ctrl-C)
SIGHUP	1	Hang up or shut down and restart process
SIGKILL	9	Kill the process (cannot be ignored or caught elsewhere)
SIGTERM	15	Terminate signal, (can be ignored or caught)
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Each signal has a default actions:

- Terminate
- Stop
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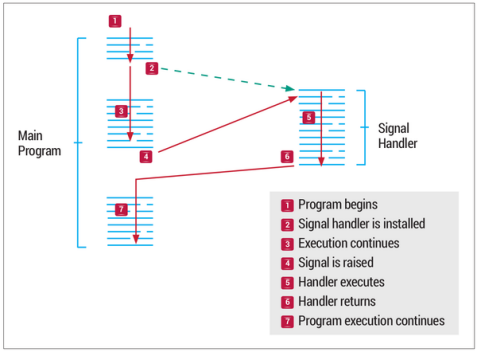
- The default action can be changed by installing a *signal handler* using the `sigaction()` function.
  The exceptions are `SIGKILL` and `SIGSTOP`.
- Note: You don't explicitly call the signal handler – OS will transfer control to this function when signal occurs.

Signals Handlers

- `void handler (int signum) { ... }`
- Defines action(s) to be taken when receiving a particular signal.
- Called with the number of the signal that triggered it as an argument

Signals Handlers

- `void handler (int signum) { ... }`
- Defines action(s) to be taken when receiving a particular signal.
- Called with the number of the signal that triggered it as an argument
- signal handling is vulnerable to *race conditions*.
  As signals are asynchronous, another signal (even of the same type) can be delivered to the process during execution of the signal handling routine.



- Install a signal handler, `act`, for the signal `sig`

```
int sigaction(int sig,
              const struct sigaction *act,
              struct sigaction *oldact);
```

- Struct defined in `<signal.h>` to pass in for `act`

```
struct sigaction {
  /* SIG_DFL, SIG_IGN, or pointer to function */
  void (*sa_handler)(int);
  sigset_t sa_mask; /* Signals to block during handler */
  int sa_flags; /* flags and options */
};
```

- You may come across various extensions, including another field in the `sigaction` struct for a function to catch signals.

Groups of Signals

- Signal masks are used to store the set of signals that are currently blocked.
- Operations on sets of signals:

```
int sigemptyset(sigset_t *set);
int sigfillset(sigset_t *set);
int sigaddset(sigset_t *set, int signo);
int sigdelset(sigset_t *set, int signo);
int sigismember(const sigset_t *set, int
    signo);
```

```
/* define a new mask set */
sigset_t mask_set;
/* first clear the set (i.e. make it
    contain no signal numbers) */
sigemptyset(&mask_set);
/* lets add the TSTP and INT signals to
    our mask set */
sigaddset(&mask_set, SIGTSTP);
sigaddset(&mask_set, SIGINT);
/* and just for fun, lets remove the TSTP
    signal from the set. */
sigdelset(&mask_set, SIGTSTP);
/* finally, lets check if the INT signal
    is defined in our set */
if (sigismember(&mask_set, SIGINT)
    printf("signal␣INT␣is␣in␣our␣set\n");
else
    printf("signal␣INT␣is␣not␣in␣our␣set␣-
        ␣how␣strange...\n");
/* finally, lets make the set contain ALL
    signals available on our system */
sigfillset(&mask_set)
```

Blocking Signals

- Signals can arrive at any time.
- To temporarily prevent a signal from being delivered we **block** it.
- The signal is held until the process unblocks the signal.
- When a process **ignores** a signal, it is thrown away.

```
int sigprocmask(int how, const sigset_t *set, sigset_t *oset);
```

- `how` indicates how the signal will be modified
  - `SIG_BLOCK`: add to those currently blocked
  - `SIG_UNBLOCK`: delete from those currently blocked
  - `SIG_SETMASK`: set the collection of signals being blocked
- `set` points to the set of signals to be used for modifying the mask
- `oset` on return holds the set of signals that were blocked before the call.

Timer Signals

- Three interval timers are maintained for each process:
  - `SIGALRM` (real-time alarm, like a stopwatch)
  - `SIGVTALRM` (virtual-time alarm, measuring CPU time)
  - `SIGPROF` (used for profilers)
- Useful functions to set and get timer info:
  - `sleep()` – cause calling process to suspend.
  - `usleep()` – like sleep() but at a finer granularity.
  - `alarm()` – sets SIGALRM
  - `pause()` – suspend until next signal arrives
  - `setitimer()`, `getitimer()`
- `sleep()` and `usleep()` are interruptible by other signals.

Signals Handling

Function	Description
`raise`	artificially sends a signal to the calling process
`kill`	artificially sends a signal to a specified process
`signal`	sets the action taken when the program receives a specific signal

Examples

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

static void catch_function(int signo) {
    puts("Interactive attention signal caught.");
}

int main(void) {
    // Set above function as signal handler for the SIGINT signal:
    if (signal(SIGINT, catch_function) == SIG_ERR) {
        fputs("An error occurred while setting a signal handler.\n", stderr);
        return EXIT_FAILURE;
    }
    puts("Raising the interactive attention signal.");
    if (raise(SIGINT) != 0) {
        fputs("Error raising the signal.\n", stderr);
        return EXIT_FAILURE;
    }

    puts("Exiting.");
    return EXIT_SUCCESS;
    // exiting after raising signal
}
```

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

/* signal handling function */
void quit(int code) {
  fprintf(stderr, "\nInterrupt (code=%d,)\n", code);
//  exit(1);
}

int main() {
  int i = 0;
  struct sigaction newact;

  /* fill in newact */
  newact.sa_handler = quit;
  newact.sa_flags = 0;

  if (sigaction(SIGINT, &newact, NULL) == -1) exit(1);

  /* compute for a while */
  for(;;)
  if ((i++ % 50000000) == 0) fprintf(stderr,".");
}
```

```c
// C program to implement sighup(), sigint()
// and sigquit() signal functions
#include <signal.h>
#include <stdio.h>
#include <stdlib.h>
#include <sys/types.h>
#include <unistd.h>

// function declaration
void sighup();
void sigint();
void sigquit();

// driver code
void main()
{
  int pid;

  /* get child process */
  if ((pid = fork()) < 0) {
    perror("fork");
    exit(1);
  }
  if (pid == 0) { /* child */
    signal(SIGHUP, sighup);
    signal(SIGINT, sigint);
    signal(SIGQUIT, sigquit);
    for (;;)
      ; /* loop for ever */
  }

  else /* parent */
  { /* pid hold id of child */
    printf("\nPARENT: sending SIGHUP\n\n");
    kill(pid, SIGHUP);

    sleep(3); /* pause for 3 secs */
    printf("\nPARENT: sending SIGINT\n\n");
    kill(pid, SIGINT);

    sleep(3); /* pause for 3 secs */
    printf("\nPARENT: sending SIGQUIT\n\n");
    kill(pid, SIGQUIT);
    sleep(3);
  }
}
```

```c
// sighup() function definition
void sighup()
{
  signal(SIGHUP, sighup); /* reset signal */
  printf("CHILD: I have received a SIGHUP\n");
}

// sigint() function definition
void sigint()
{
  signal(SIGINT, sigint); /* reset signal */
  printf("CHILD: I have received a SIGINT\n");
}

// sigquit() function definition
void sigquit()
{
  printf("My Parent has Killed me!!!\n");
  exit(0);
}
```

Further Resources

- https://man7.org/linux/man-pages/man2/signal.2.html
- https://man7.org/linux/man-pages/man7/signal.7.html