Signals

CS 217

Outline

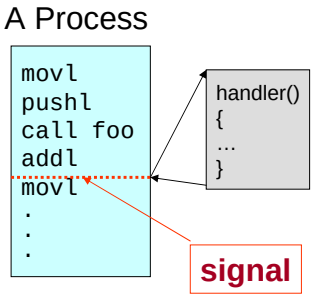
- What are signals?
- Sending signals
- Catching signals, processing signals, and resuming after signals
- Race conditions and masking signals
- Alarms

What Are Signals?

- Event notifications that can be sent to a running program (a “process”) at *any* time

What Are Signals?

- Signals are notifications sent to a process
  - ^C, ^Z, Alarm, . . .
- Each signal may have a signal handler
  - When a signal is sent to a process, the OS *stops* the process *immediately*
  - Handler executes and finishes
  - Resume the process
- Signals are not interrupts
  - Interrupts are sent to OS by HW
  - Signals are sent to processes by OS
- Each UNIX signal has an integer number and a symbolic name
  - Defined in <signal.h>



Some Predefined Signals

(/usr/include/bits/signum.h included by signal.h)

```
#define SIGHUP          1       /* Hangup (POSIX).  */
#define SIGINT          2       /* Interrupt (ANSI).  */
#define SIGQUIT         3       /* Quit (POSIX).  */
#define SIGILL          4       /* Illegal instruction (ANSI).  */
#define SIGTRAP         5       /* Trace trap (POSIX).  */
#define SIGABRT         6       /* Abort (ANSI).  */
#define SIGFPE          8       /* Floating-point exception (ANSI).  */
#define SIGKILL         9       /* Kill, unblockable (POSIX).  */
#define SIGUSR1         10      /* User-defined signal 1 (POSIX).  */
#define SIGSEGV         11      /* Segmentation violation (ANSI).  */
#define SIGUSR2         12      /* User-defined signal 2 (POSIX).  */
#define SIGPIPE         13      /* Broken pipe (POSIX).  */
#define SIGALRM         14      /* Alarm clock (POSIX).  */
#define SIGTERM         15      /* Termination (ANSI).  */
#define SIGCHLD         17      /* Child status has changed (POSIX).  */
#define SIGCONT         18      /* Continue (POSIX).  */
#define SIGSTOP         19      /* Stop, unblockable (POSIX).  */
#define SIGTSTP         20      /* Keyboard stop (POSIX).  */
#define SIGTTIN         21      /* Background read from tty (POSIX).  */
#define SIGTTOU         22      /* Background write to tty (POSIX).  */
#define SIGPROF         27      /* Profiling alarm clock (4.2 BSD).  */
```


Predefined and Defined Signals

- Find out the predefined signals

```
% kill –l
% HUP INT QUIT ILL TRAP ABRT BUS FPE KILL USR1 SEGV
  USR2 PIPE ALRM TERM STKFLT CHLD CONT STOP TSTP
  TTIN TTOU URG XCPU XFSZ VTALRM PROF WINCH POLL PWR
  SYS RTMIN RTMIN+1 RTMIN+2 RTMIN+3 RTMAX-3 RTMAX-2
  RTMAX-1 RTMAX
```

- Applications can define their own signals
  - An application can define signals with unused values

Catchable and Non-Catchable Signals

- Non-catchable signals
  - KILL
    - Terminate the process immediately
    - Catchable termination signal is TERM
  - STOP
    - Suspend the process immediately
    - Catchable suspension signal is TSTP
    - Can resume the process with signal CONT
- Catchable signals
  - All other predefined signals
  - All user-defined signals

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Sending Signals from Keyboard

- Steps
  - Pressing keys generates interrupts to OS
  - OS interprets a key sequence and sends a signal to the running process
- Examples
  - Ctrl-C causes the OS to send an INT signal to the running process.
    - By default, this causes the process to immediately terminate.
  - Ctrl-Z causes the OS to send a TSTP signal to the running process.
    - By default, this causes the process to suspend execution.
  - Ctrl-\ causes the OS to send a ABRT signal to the running process.
    - By default, this causes the process to immediately terminate.
- Question
  - Why do we have both Ctrl-C and Ctrl-\?

Sending Signals From The Shell

- **`kill -<signal> <PID>`**
  - If no signal name or number is specified, the default is to send an SIGTERM signal to the process,
  - Signal SIGKILL or 9 is special; it cannot be caught
  - Example: send the INT signal to process with PID 1234:
    `kill -INT 1234`
    - The same affect as pressing Ctrl-C if process 1234 is running.
- **`fg`**
  - The command is "foreground"
  - On UNIX shells, this command will send a **CONT** signal
  - Resume execution of the process (that was suspended with Ctrl-Z or a command "**bg**")
  - See man pages for **fg** and **bg**

Sending Signals from a Program

- The kill command is implemented by a system call

```
#include <sys/types.h>
#include <signal.h>
int kill(pid_t pid, int sig);
```

- Example: send a signal to itself

```
if (kill(getpid(), SIGABRT))
   exit(0);
```

  - The equivalent in ANSI C is:

```
int raise(int sig);

if (raise(SIGABRT) > 0)
      exit(1);
```


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Installing A Signal Handler

- Predefined signal handlers
  - **SIG_DFL:** default handler
  - **SIG_IGN:** Ignore the signal
- To install a handler, use

```
#include <signal.h>

typedef void (*sighandler_t)(int);
sighandler_t signal(int sig, sighandler_t handler);
```

  - Handler **handler** will be invoked, when signal **sig** occurs
  - Return the old handler on success; **SIG_ERR** on error
  - On most non-Linux UNIX systems, after the handler executes, the OS resets the handler to **SIG_DFL**
- Example

```
#include <signal.h>
...
if (signal(SIGINT, SIG_IGN) == SIG_ERR)
    exit(1);
```


Example: Catch INT Signal

```
#include <stdio.h>
#include <signal.h>    /* signal interface */

void handler(int sig_num) {
   if (signal(SIGINT, handler) == SIG_ERR)
      ...;
   printf("Don't do that.\n");
   fflush(stdout);
}

main(void) {
   if (signal(SIGINT, handler) == SIG_ERR)
      exit(1);
   for ( ;; )
      pause();
}
```


Example: Cleanup on Termination

```
#include <signal.h>

char *tmpfile = “temp.xxx”;
void cleanup(int sig) {
   unlink(tmpfile);
   exit(1);
}
void main(void) {
   int fd;
   if (signal(SIGINT, cleanup) == SIG_ERR)
      fprintf(stderr, “cannot setup signal\n”);
   fd = open(tmpfile, O_CREAT, 0666);
      ...
   close(fd);
}
```


Example: Resuming after signal (try 1)

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

int i;
int *p;

void handler(int sig_num) {
    printf("Don't do that. p=%x\n", p);
    p = &i;
    sleep(2);
}

main(void) {
    p = NULL;
    if (signal(SIGSEGV, handler) == SIG_ERR)
        exit(-1);

    *p = 1;
    printf("after resuming\n");
}
```

Example: Resuming after signal (try 2)

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

int i;
int *p;

static jmp_buf env;

void handler(int sig_num) {
    printf("Don't do that. p=%x\n", p);
    p = &i;
    sleep(2);
    longjmp(env, sig_num);
}

main(void) {
    p = NULL;
    int ret;

    if (signal(SIGSEGV, handler) == SIG_ERR)
        exit(-1);

    ret = setjmp(env);

    *p = 1;
    printf("after resuming\n");
}
```


Non-local goto statements

```
#include <setjmp.h>

int setjmp(jmp_buf env);
    /* save the stack environment */
void longjmp(jmp_buf env, int val);
    /* jump to the saved environment */
int sigsetjmp(sigjmp_buf env, int savemask);
    /* setjmp plus saving signals */
void siglongjmp(sigjmp_buf env, int val);
    /* restore what sigsetjmp saved */
```


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What is a “race condition”?

“Monthly salary signal”

```
void add_salary_to_savings(int sig) {
    int tmp;
    tmp = savingsBalance;
    tmp += monthlySalary;
    savingsBalance = tmp;
}
```

What is a “race condition”?

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    int tmp;
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}
```

```
void add_salary_to_savings(int sig) {
    int tmp;
    tmp = savingsBalance;
    tmp += monthlySalary;
    savingsBalance = tmp;
}
```

- You just lost a month’s worth of salary

Masking Signals

- Why masking out signals?
  - An application wants to ignore certain signals
  - Avoid race conditions when another signal happens in the middle of the signal handler’s execution
- Two ways to mask signals
  - Affect all signal handlers
    `sigprocmask()`
  - Affect a specific handler
    `sigaction()`

Mask Signals for All Handlers

- Each Unix process has a signal mask in the kernel
  - OS use this mask to decide which signals to deliver
  - **`sigprocmask()`** takes a user-defined mask install it in the kernel, with some limitations
- Use sigprocmask()

```
#include <signal.h>
int sigprocmask(
   int how, /* SIG_BLOCK, SIG_UNBLOCK, SIG_SETMASK
  */
   const sigset_t *set,     /* set of signals */
   sigset_t *oldset         /* set of old signals */
);
```

  - `SIG_BLOCK:` Add **`set`** to the current mask
  - `SIG_UNBLOCK:` Remove **`set`** from the current mask
  - `SIG_SETMASK:` Install **`set`** as the signal mask

Example: Masking SIGINT Signal

```
#include <signal.h>
#define MYSIG   40

void handler(int sig) {
   sigset_t mask_set, old_set;
   sigfillset(&mask_set);   /* fill all signals */
   sigprocmask(SIG_SETMASK, &mask_set, &old_set);
   ...
}

main(void) {
   signal(MYSIG, handler);
   ...
}
```

- Anything wrong with this example?

Install Handler and Mask Together

- Use **`sigaction()`** with a data structure

```
struct sigaction {
   void (*sa_handler)(int);
   void (*sa_sigaction)(int, siginfo_t *, void *);
   sigset_t sa_mask;
   int sa_flags;
   void (*sa_restorer)(void);
}
```

  - Use either sa_handler or sa_sigaction, but not both
  - Do not use sa_restorer (obsolete)

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


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Coarse-Grained Alarm

- Sends an SIGALRM signal after n seconds

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

  - This call may be different on other UNIX systems

- Example

```
#include <signal.h>    /* signal names and API */
void catch_alarm(int sig) {
   if (signal(SIGALRM, catch_alarm) == SIG_ERR)
      ...;
   ...
   alarm(10);
}
main(void) {
   if (signal(SIGALRM, catch_alarm) == SIG_ERR)
      ...;
   alarm(10);

   ...;
}
```

Fine-Grained Alarm

- Send an SIGALRM signal after a fine-grained timer expires

```
#include <sys/time.h>
int setitimer(
  int which,      /* ITIMER_REAL, ITIMER_VIRTUAL, ITIMER_PROF */
  const struct itimerval *value,
  struct itimerval *ovalue
  );
```

- Example

```
struct itimerval timer;

timer.it_interval.tv_sec = 0;
timer.it_interval.tv_usec = 10000; /* reload alarm 10ms */
timer.it_value.tv_sec = 0;
timer.it_value.tv_usec = 10000;    /* 10ms */
if (setitimer(ITIMER_PROF, &timer, NULL) == ...)
   ...;
```

- On Linux, the minimal effective granularity is **10ms**.

Summary

- Signals
  - An asynchronous event mechanism, but not the only one
  - Use sigaction() to avoid race conditions
  - Signal handlers should be simple and short
  - Most predefined signals are catchable, but be careful with the “fault” signals (such as SIGSEGV).
- Alarms or timers
  - Use one timer at a time
  - Linux imposes 10ms as the minimal granularity