Signals
Goals of this Lecture

Help you learn about:

- Sending signals
- Handling signals
- … and thereby …
- How the OS exposes the occurrence of some exceptions to application processes
- How application processes can control their behavior in response to those exceptions
Agenda

Unix Process Control
  Signals
  Sending Signals
  Handling Signals
  Alarms
Unix Process Control

- **Non-Existing Process**
  - `command` → Running Foreground Process
  - `command &` → Running Background Process
  - `kill -2 pid` → Stopped Background Process
  - `kill -20 pid` → Stopped Background Process

- **Running Foreground Process**
  - `Ctrl-c` → Non-Existing Process
  - `fg` → Running Background Process
  - `kill -2 pid` → Stopped Background Process

- **Running Background Process**
  - `Ctrl-z` → Stopped Background Process
  - `fg` → Running Foreground Process
  - `kill -2 pid` → Non-Existing Process

- **Stopped Background Process**
  - `fg` → Running Background Process
  - `kill -20 pid` → Stopped Background Process

[Demo]
Process Control Implementation

Exactly what happens when you:

Type Ctrl-c?
• Keystroke generates interrupt
• OS handles interrupt
• OS sends a 2/SIGINT signal

Type Ctrl-z?
• Keystroke generates interrupt
• OS handles interrupt
• OS sends a 20/SIGTSTP signal

Recall * Exceptions and Processes lecture
Exactly what happens when you:

Issue a `kill -sig pid` command?
- `kill` command executes `trap`
- OS handles trap
- OS sends a `sig` signal to the process whose id is `pid`

Issue a `fg` or `bg` command?
- `fg` or `bg` command executes `trap`
- OS handles trap
- OS sends a 18/SIGCONT `signal` (and does some other things too!)

Recall *Exceptions and Processes* lecture
Agenda

Unix Process Control

Signals

Sending Signals

Handling Signals

Alarms
Signals

**Signal**: A notification of an exception

**Typical signal sequence:**
- Process P is executing
- Exception occurs (interrupt, trap, fault, or abort)
- OS gains control of CPU
- OS wishes to inform process P that something significant happened
- OS **sends** a signal to process P
  - OS sets a bit in **pending bit vector** of process P
  - Indicates that OS is sending a signal of type X to process P
  - A signal of type X is **pending** for process P
Typical signal sequence (cont.):

- Sometime later…
- OS is ready to give CPU back to process P
- OS checks **pending** for process P, sees that signal of type X is pending
- OS forces process P to **receive** signal of type X
  - OS clears bit in process P’s **pending**
- Process P executes action for signal of type X
  - Normally process P executes **default action** for that signal
  - If **signal handler** was installed for signal of type X, then process P executes signal handler
    - Action might terminate process P; otherwise…
- Process P resumes where it left off
Examples of Signals

User types Ctrl-c
- Interrupt occurs
- OS gains control of CPU
- OS sends 2/SIGINT signal to process
- Process receives 2/SIGINT signal
- Default action for 2/SIGINT signal is “terminate”

Process makes illegal memory reference
- Segmentation fault occurs
- OS gains control of CPU
- OS sends 11/SIGSEGV signal to process
- Process receives 11/SIGSEGV signal
- Default action for 11/SIGSEGV signal is “terminate”
Agenda

Unix Process Control
Signals
**Sending Signals**
Handling Signals
Alarms
User can send three signals from keyboard:

- **Ctrl-c** ⇒ **2/SIGINT** signal
  - Default action is “terminate”
- **Ctrl-z** ⇒ **20/SIGTSTP** signal
  - Default action is “stop until next 18/SIGCONT”
- **Ctrl-\** ⇒ **3/SIGQUIT** signal
  - Default action is “terminate”
User can send any signal by executing command:

**kill command**

- **kill** *[ -sig pid]*
  - Send a signal of type *sig* to process *pid*
  - No *-sig* option specified ⇒ sends 15/SIGTERM signal
    - Default action for 15/SIGTERM is “terminate”
  - You must own process *pid* (or have admin privileges)
  - Commentary: Better command name would be *sendsig*

**Examples**

- **kill** *[ -2 1234]*
- **kill** *[ -SIGINT 1234]*
- Same as pressing Ctrl-c if process 1234 is running in foreground
Sending Signals via Function Calls

Program can send any signal by calling function:

**raise() function**

- `int raise(int iSig);`
- Commands OS to send a signal of type `iSig` to calling process
- Returns 0 to indicate success, non-0 to indicate failure

Example

- `iRet = raise(SIGINT);`
  - Send a 2/SIGINT signal to calling process
Sending Signals via Function Calls

**kill() function**

- `int kill(pid_t iPid, int iSig);`
- Sends a `iSig` signal to the process `iPid`
- Equivalent to `raise(iSig)` when `iPid` is the id of current process
- You must own process `pid` (or have admin privileges)
- Commentary: Better function name would be `sendsig()`

**Example**

- `iRet = kill(1234, SIGINT);`
  - Send a 2/SIGINT signal to process 1234
Agenda

Unix Process Control

Signals

Sending Signals

Handling Signals

Alarms
Handling Signals

Each signal type has a default action
  • For most signal types, default action is “terminate”

A program can install a signal handler
  • To change action of (almost) any signal type
Installing a Signal Handler

signal() function

- `sighandler_t signal(int iSig, sighandler_t pfHandler);`
- Install function `pfHandler` as the handler for signals of type `iSig`
- `pfHandler` is a function pointer:
  ```c
typedef void (*sighandler_t)(int);
```
- Return the old handler on success, `SIG_ERR` on error
- After call, `(*pfHandler)` is invoked whenever process receives a signal of type `iSig`
Predefined value: **SIG_DFL**

Use as argument to `signal()` to **restore default action**

```c
int main(void)
{
    ...
    signal(SIGINT, somehandler);
    ...
    signal(SIGINT, SIG_DFL);
    ...
}
```

Subsequently, process will handle 2/SIGINT signals using default action for 2/SIGINT signals ("terminate")
SIG_IGN

Predefined value: **SIG_IGN**

Use as argument to `signal()` to **ignore signals**

```c
int main(void)
{
    signal(SIGINT, SIG_IGN);
    ...
}
```

Subsequently, process will ignore 2/SIGINT signals
Uncatchable Signals

Special cases: A program cannot install a signal handler for signals of type:

• **9/SIGKILL**
  • Default action is “terminate”

• **19/SIGSTOP**
  • Default action is “stop until next 18/SIGCONT”
Signal Handling Example 1

Program testsignal.c:

```c
#define _GNU_SOURCE /* Use modern handling style */
#include <stdio.h>
#include <signal.h>

static void myHandler(int iSig)
{  printf("In myHandler with argument \%d\n", iSig);
}

int main(void)
{  signal(SIGINT, myHandler);
  printf("Entering an infinite loop\n");
  for (;;)
    ;
  return 0; /* Never get here. */
}
```

Error handling code omitted in this and all subsequent programs in this lecture
Signal Handling Example 2

Program testsignalall.c:

```c
#define _GNU_SOURCE
#include <stdio.h>
#include <signal.h>

static void myHandler(int iSig)
{
    printf("In myHandler with argument \%d\n", iSig);
}

int main(void)
{
    int i;
    /* Install myHandler as the handler for all kinds of signals. */
    for (i = 1; i < 65; i++)
    {
        signal(i, myHandler);
    }
    printf("Entering an infinite loop\n");
    for (;;)
    {
        ;
    return 0; /* Never get here. */
}
Signal Handling Example 3

Program generates lots of temporary data
- Stores the data in a temporary file
- Must delete the file before exiting

```c
... int main(void) {
    FILE *psFile;
    psFile = fopen("temp.txt", "w");
    ...
    fclose(psFile);
    remove("temp.txt");
    return 0;
}
```
Example 3 Problem

What if user types Ctrl-c?
- OS sends a 2/SIGINT signal to the process
- Default action for 2/SIGINT is “terminate”

Problem: The temporary file is not deleted
- Process terminates before `remove("temp.txt")` is executed

Challenge: Ctrl-c could happen at any time
- Which line of code will be interrupted???

Solution: Install a signal handler
- Define a “clean up” function to delete the file
- Install the function as a signal handler for 2/SIGINT
static FILE *psFile; /* Must be global. */
static void cleanup(int iSig)
{
    fclose(psFile);
    remove("temp.txt");
    exit(0);
}

int main(void)
{
    psFile = fopen("temp.txt", "w");
    signal(SIGINT, cleanup);
    cleanup(0); /* or raise(SIGINT); */
    return 0; /* Never get here. */
}
Agenda

Unix Process Control
Signals
Sending Signals
Handling Signals
Alarms
Alarms

alarm() function

- `unsigned int alarm(unsigned int uiSec);`
- Send 14/SIGALRM signal after `uiSec` seconds
- Cancel pending alarm if `uiSec` is 0
- Use **wall-clock time**
  - Time spent executing other processes counts
  - Time spent waiting for user input counts
- Return value is irrelevant for our purposes

Used to implement time-outs
Alarm Example 1

Program testalarm.c:

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

static void myHandler(int iSig)
{  printf("In myHandler with argument %d\n", iSig);
    alarm(2); /* Set another alarm */
}

int main(void)
{  signal(SIGALRM, myHandler);
    alarm(2); /* Set an alarm. */
    printf("Entering an infinite loop\n");
    for (;;)
        ;
    return 0; /* Never get here. */
}
```
# define _GNU_SOURCE
#include <stdio.h>
#include <stdlib.h>
#include <signal.h>
#include <unistd.h>

static void myHandler(int iSig)
{
    printf("\nSorry. You took too long.\n");
    exit(EXIT_FAILURE);
}

int main(void)
{
    int i;
    signal(SIGALRM, myHandler);
    printf("Enter a number: ");
    alarm(5);
    scanf("%d", &i);
    alarm(0);
    printf("You entered the number %d.\n", i);
    return 0;
}
List of the predefined signals:

```
$ 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) SIGCHLD
 17) SIGCONT   18) SIGSTOP    19) SIGTSTP    20) SIGTTIN
 21) SIGPIPE   22) SIGURG    23) SIGURG     24) SIGXCPU
 25) SIGXFSZ   26) SIGVTALRM 27) SIGPROF    28) SIGWINCH
 29) SIGIO     30) SIGPWR    31) SIGSYS     32) SIGRTMIN
 33) SIGRTMIN+134) SIGRTMIN+2 35) SIGRTMIN+3 36) SIGRTMIN+4
 37) SIGRTMIN+5 38) SIGRTMIN+6 39) SIGRTMIN+7 40) SIGRTMIN+8
 41) SIGRTMIN+9 42) SIGRTMIN+10 43) SIGRTMIN+11 44) SIGRTMIN+12
 45) SIGRTMIN+13 46) SIGRTMIN+14 47) SIGRTMIN+15 48) SIGRTMAX-14
 49) SIGRTMAX-15 50) SIGRTMAX-16 51) SIGRTMAX-17 52) SIGRTMAX-18
 53) SIGRTMAX-19 54) SIGRTMAX-20 55) SIGRTMAX-21 56) SIGRTMAX-22
 57) SIGRTMAX-23 58) SIGRTMAX-24 59) SIGRTMAX-25 60) SIGRTMAX-26
 61) SIGRTMAX-27 62) SIGRTMAX-28 63) SIGRTMAX-29 64) SIGRTMAX
```

See Bryant & O’ Hallaron book for default actions, triggering exceptions.

Application program can define signals with unused values.
Summary

Signals
• Sending signals
  • From the keyboard
  • By calling function: `raise()` or `kill()`
  • By executing command: `kill`
• Catching signals
  • `signal()` installs a signal handler
  • Most signals are catchable

Alarms
• Call `alarm()` to send 14/SIGALRM signals in wall-clock time
• Alarms can be used to implement time-outs
For more information:

Bryant & O’Hallaron, *Computer Systems: A Programmer’s Perspective*, Chapter 8
Wrapping Up the Course

Assignment 7
- Due on Dean’s Date at 5 PM
- No extensions past 11:59 PM without permission of the Dean

Office hours and exam prep sessions
- Will be announced on Piazza

Final exam
- Thursday, 5/24, 7:30 – 10:30 PM, Friend Center Room 101
- Covers everything, emphasizing material since the midterm
- Mixture of short-answer questions and writing snippets of code
- Closed book and notes, no electronic anything
- Relevant reference material will be provided

Old exams and study guide will be posted on schedule page
Course Summary

We have covered:

Programming in the large
- The C programming language
- Testing
- Building
- Debugging
- Program & programming style
- Data structures
- Modularity
- Performance
Course Summary

We have covered (cont.):

Under the hood
- Number systems
- Language levels tour
  - Assembly language
  - Machine language
  - Assemblers and linkers
- Service levels tour
  - Exceptions and processes
  - Storage management
  - Dynamic memory management
  - Process management
  - I/O management
  - Signals
The end.

```c
return EXIT_SUCCESS;
```