


Princeton University
Computer Science 217: Introduction to Programming Systems

Signals



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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

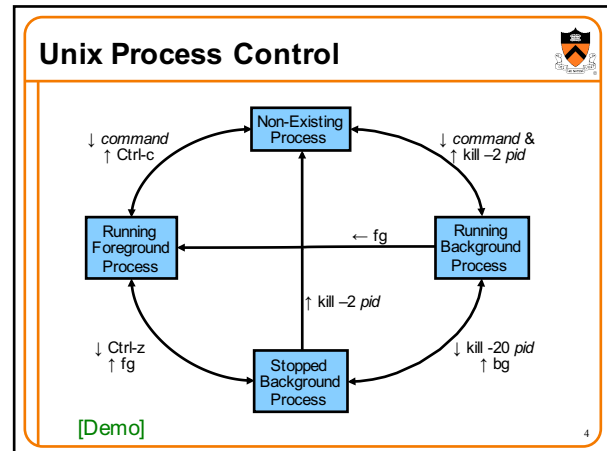
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Agenda

Unix Process Control

- Signals
- Sending Signals
- Handling Signals
- Alarms

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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

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Process Control Implementation (cont.)

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

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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

Signals


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

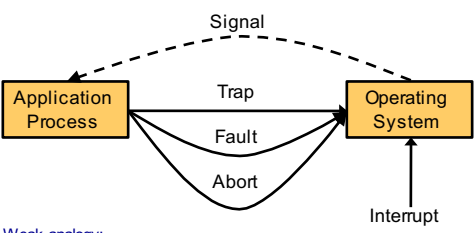
- Interrupt occurs
- OS gains control of CPU
- OS sends 2/SIGINT signal to process
- Process receives 2/SIGINT signal
- Default action for 2/SIGINT signal is "terminate"



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"

Signals as Callbacks



Weak analogy:

- Trap** (and fault and abort) is similar to **function call**
App process requests service of OS
- Signal** is similar to **function callback**
OS informs app process that something happened

Agenda

- Unix Process Control
- Signals
- Sending Signals**
- Handling Signals
- Alarms

Sending Signals via Keystrokes



User can send three signals from keyboard:

- **Ctrl-c** \Rightarrow 2/SIGINT signal
 - Default action is "terminate"
- **Ctrl-z** \Rightarrow 20/SIGTSTP signal
 - Default action is "stop until next 18/SIGCONT"
- **Ctrl-** \Rightarrow 3/SIGQUIT signal
 - Default action is "terminate"

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Sending Signals via Commands



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 \Rightarrow 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

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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

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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

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Agenda



Unix Process Control

Signals

Sending Signals

Handling Signals

Alarms

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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

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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"

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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:


```
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`

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Signal Handling Example 1

Program `testsignal.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

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Signal Handling Example 2

Program `testsignalall.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. */
}
```

Will fail: `signal(9, myHandler)`
`signal(19, myHandler)`

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Signal Handling Example 3

Program generates lots of temporary data

- Stores the data in a temporary file
- Must delete the file before exiting

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

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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

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Example 3 Solution

```

...
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. */
}

```

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SIG_DFL

Predefined value: **SIG_DFL**

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

```

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")

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SIG_IGN

Predefined value: **SIG_IGN**

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

```

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

```

Subsequently, process will ignore 2/SIGINT signals

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SIG_IGN Example

Program `testsignalignore.c`

```

#define _GNU_SOURCE
#include <stdio.h>
#include <stdlib.h>
#include <signal.h>

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

```

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Agenda

Unix Process Control

Signals

Sending Signals

Handling Signals

Alarms

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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



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Alarm Example 1

Program testalarm.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); /* Sec another alarm */
}

int main(void)
{ signal(SIGALRM, myHandler);
  alarm(2); /* Set an alarm. */
  printf("En te zing an infinite loop\n");
  for (;;)
  ;
  return 0; /* Never get here. */
}
```

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Alarm Example 2

Program testalarmtimeout.c:

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

static void myHandler(int iSig)
{ printf("Sorry 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;
}
```

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Summary

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    17) SIGCHLD
18) SIGCONT    19) SIGSTOP   20) SIGTSTP    21) SIGTIN
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
```

See Bryant & O'Hallaron book for default actions, triggering exceptions
Application program can define signals with unused values

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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

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Summary (cont.)

For more information:

Bryant & O'Hallaron, *Computer Systems: A Programmer's Perspective*, Chapter 8

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Course Summary

We have covered:

Programming in the large

- The C programming language
- Testing
- Building
- Debugging
- Program & programming style
- Data structures
- Modularity
- Performance

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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

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The Rest of the Course



Lecture on Wednesday

Assignment 7

- Due on Dean's Date at 5PM
- Cannot submit late (University regulations)
- Cannot use late pass

Office hours and exam prep sessions

- Will be announced on Piazza

Final exam

- When: Friday, 5/19, 1:30 – 4:30 PM
- Where: Friend Center 101
- Closed book, closed notes, no electronic devices

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Thank you!



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