



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

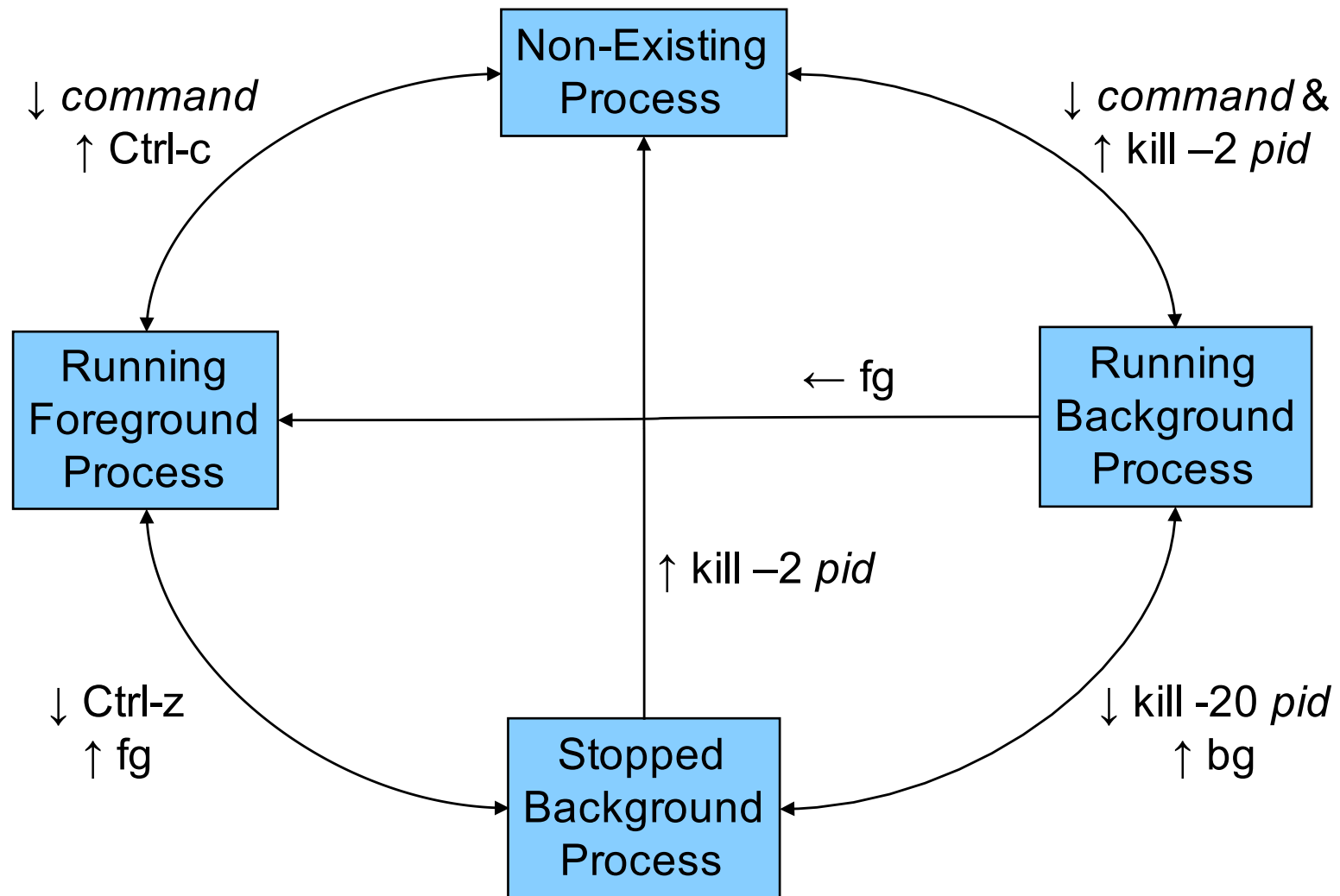
Signals

Sending Signals

Handling Signals

Alarms

Unix Process Control



[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

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

Agenda



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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

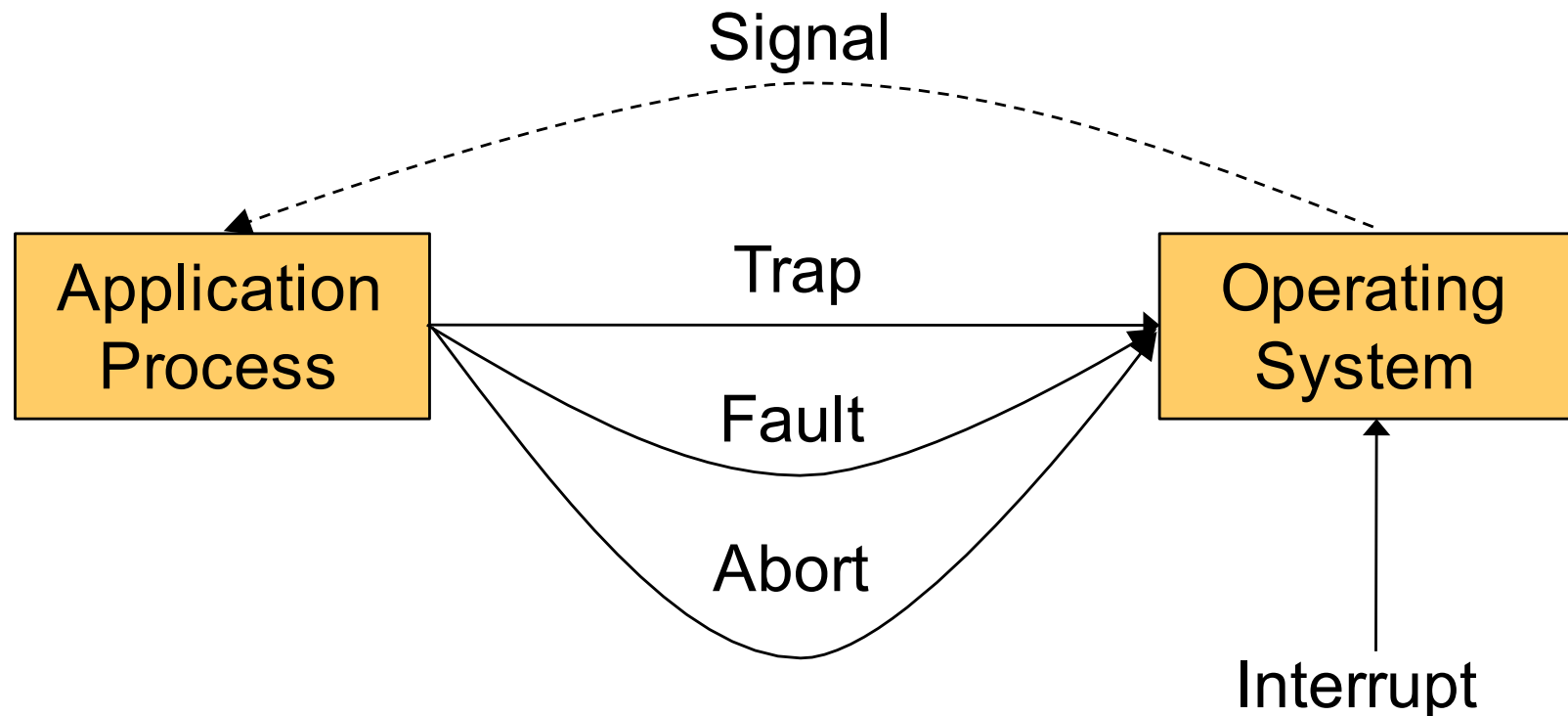
- Interrupt occurs
- OS gains control of CPU
- OS sends 2/SIGINT signal to process
- Process receives 2/SIGINT signal
- Default action for 2/SIGINT signal is “terminate”



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



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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”

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

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

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”

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`

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

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)
```

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;  
}
```

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

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. */
}
```

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”)

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

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. */
}
```

Agenda



Unix Process Control

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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:

```
#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. */
}
```

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("\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;
}
```


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) SIGTTIN
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

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

Summary (cont.)



For more information:

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

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 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



Thank you!