System Programming

Week 7: Signals

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07_signal

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introduction

This chapter covers following items

- The concept
- Use cases of signal
- The problems of earlier implementations
- The correct ways

Signal Concepts

Signal Concepts

Every signal has a name that begins with `SIG` and it is assigned with a positive number defined in `<signal.h>`

- `SIGABRT`: generated when a process calls `abort` function
- `SIGALRM`: generated when a timer set byt `alarm` function goes off
- Different versions of UNIX have different number of signals

Signal Concepts

Signal generating conditions

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4. `kill(1)` command sends signal to other process
5. Software conditions can generate signals

Signal Concepts cont'd

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1. **Ignore the signal** following two can never be ignored: `SIGKILL` and `SIGSTOP`
2. **Catch the signal** We tell the kernel to call a customized function whenever the signal occurs
   - if `SIGCHLD` signal is caught, it means child has terminated
   - signal catching function calls `waitpid` to fetch the child's process ID and termination status

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   - if `SIGCHLD` signal is caught, it means child has terminated
   - signal catching function calls `waitpid` to fetch the child's process ID and termination status
3. **Use default action** every signal has a default action
   - the default action for most signals is to terminate the process>

Signal Concepts cont'd

Name	Description	ISO C	SUS	FreeBSD 8.0	Linux 3.2.0	Mac OS X 10.6.8	Solaris 10	Default action
SIGABRT	abnormal termination (abort)	•	•	•	•	•	•	terminate+core
SIGALRM	timer expired (alarm)		•	•	•	•	•	terminate
SIGBUS	hardware fault		•	•	•	•	•	terminate+core
SIGCANCEL	threads library internal use						•	ignore
SIGCHLD	change in status of child		•	•	•	•	•	ignore
SIGCONT	continue stopped process		•	•	•	•	•	continue/ignore
SIGEMT	hardware fault			•	•	•	•	terminate+core
SIGFPE	arithmetic exception	•	•	•	•	•	•	terminate+core
SIGFREEZE	checkpoint freeze						•	ignore
SIGHUP	hangup		•	•	•	•	•	terminate
SIGILL	illegal instruction	•	•	•	•	•	•	terminate+core
SIGINFO	status request from keyboard			•		•		ignore
SIGINT	terminal interrupt character	•	•	•	•	•	•	terminate
SIGIO	asynchronous I/O			•	•	•	•	terminate/ignore
SIGIOT	hardware fault			•	•	•	•	terminate+core
SIGJVM1	Java virtual machine internal use						•	ignore
SIGJVM2	Java virtual machine internal use						•	ignore
SIGKILL	termination		•	•	•	•	•	terminate
SIGLOST	resource lost						•	terminate
SIGLWP	threads library internal use			•			•	terminate/ignore
SIGPIPE	write to pipe with no readers		•	•	•	•	•	terminate
SIGPOLL	pollable event (poll)				•		•	terminate
SIGPROF	profiling time alarm (setitimer)			•	•	•	•	terminate

Figure: UNIX System signals

`signal` Function

```
#include <signal.h>
void (*signal(int signo, void (*func)(int)))(int);
// Returns: previous disposition of signal (see following) if OK, SIG_ERR on
     error
```

- `signo` is name of the signal from the Table 10.1
- `func` is
  - `SIG_IGN` : to ignore the signal
  - `SIG_DFL` : to use the default value
  - address of a function to be called when the signal occurs—they are called *signal handler* or *signal-catching function*

Signal Exmple Code: codes/usr_sig.c I

```
1  #include <stdio.h>
2  #include <stdlib.h>
3  #include <unistd.h>
4  #include <string.h>
5  #include <signal.h> // for signalling
6  #include <errno.h>
7
8  static void sig_usr(int); /* one handler for both signals */
9
10 int
11 main(void) {
12    if (signal(SIGUSR1, sig_usr) == SIG_ERR) {
13       fprintf(stderr, "Can't catch SIGUSR1: %s", strerror(errno));
14       exit(1);
15    }
16    if (signal(SIGUSR2, sig_usr) == SIG_ERR) {
17       fprintf(stderr, "Can't catch SIGUSR2: %s", strerror(errno));
18       exit(1);
19    }
20
21    if (signal(SIGHUP, sig_usr) == SIG_ERR) {
22       fprintf(stderr, "Can't catch SIGHUP: %s", strerror(errno));
```

Signal Exmple Code: codes/usr_sig.c II

```
23          exit(1);
24       }
25
26       for ( ; ; )
27          pause();
28    }
29
30    static void
31    sig_usr(int signo) { /* argument is signal number */
32       if (signo == SIGUSR1)
33          printf("received SIGUSR1\n");
34       else if (signo == SIGUSR2)
35          printf("received SIGUSR2\n");
36       else if (signo == SIGHUP)
37          printf("received SIGHUP\n");
38       else {
39          fprintf(stderr, "received signal: %d\n", signo);
40          exit(1);
41       }
42       return;
43    }
```

Signal Exmaples

invoke the program in the background and use `kill(1)` to send signal

```
James@maker:codes$ ./usr\_sig &
[2] 4987
James@maker:codes$ kill -USR1 4987
received SIGUSR1
James@maker:codes$ kill -USR2 4987
received SIGUSR2
James@maker:codes$ kill -HUP 4987
received SIGHUP
James@maker:codes$ kill -INT 4987
[2]+ Interrupt: 2 ./usr\_sig
James@maker:codes$
```

`signal` Function

At process creation

- When a process calls `fork`, the child inherits the parents signal disposition
- Child starts off with copy of the parent's memory image
- the address of a signal-catching function has meaning in the child

The issues

Unreliable Signals

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1. signals get lost: signal occurs and the process never know about it
2. window of time—after the signal has occured, but before the call to `signal` in the signal handler—when the interrupt signal could occur another time. The second signal would cause the default action to occur (terminate the process)
3. little control over a signal: unable to turn a signal off when it didn't want the signal to occur. All it can do is to catch or ignore the signal.

Interrupted System Calls cont'd

The slow system calls are those that can block forever

- reads (for pipes, terminal devices, and network devices) that can block the caller
- writes that can block the caller forever if the data can't be accepted immediately
- open on a certain file types (terminal device) that block the caller until some condition occurs
- the `pause` and `wait` function
- certain `ioctl` operations
- some of interprocess communication function

Interrupted System Calls cont'd

The problem with interrupted system calls is that error returns must be explicit

```
again:
    if ((n = read(fd, buf, BUFFSIZE)) < 0 ) {
        if (errno == EINTR)
            goto again; /* just an interrupted system call */
        /* handle other errors */
    }
```

The solution of 4.2BSD was to introduce the automatic restaring of `ioctl`, `read`, `readv`, `write`, `writev`, `wait`, and `waitpid`

Reentrant Functions

Reentrant fuctions are guarnateed to be safe to call from within a signal hanlder. They are also called *async-signal safe*. As a general rule, when calling the reentrant functions from a signal handler, we should save and restore `errno`.

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The problem is that signal handler can't tell whether a process was in the middle of execution. *The result becomes unpredictable*

Reentrant Functions cont'd

abort	faccessat	linkat	select	socketpair
accept	fchmod	listen	sem_post	stat
access	fchmodat	lseek	send	symlink
aio_error	fchown	lstat	sendmsg	symlinkat
aio_return	fchownat	mkdir	sendto	tcdrain
aio_suspend	fcntl	mkdirat	setgid	tcflow
alarm	fdatasync	mkfifo	setpgid	tcflush
bind	fexecve	mkfifoat	setsid	tcgetattr
cfgetispeed	fork	mknod	setsockopt	tcgetpgrp
cfgetospeed	fstat	mknodat	setuid	tcsendbreak
cfsetispeed	fstatat	open	shutdown	tcsetattr
cfsetospeed	fsync	openat	sigaction	tcsetpgrp
chdir	ftruncate	pause	sigaddset	time
chmod	futimens	pipe	sigdelset	timer_getoverrun
chown	getegid	poll	sigemptyset	timer_gettime
clock_gettime	geteuid	posix_trace_event	sigfillset	timer_settime
close	getgid	pselect	sigismember	times
connect	getgroups	raise	signal	umask
creat	getpeername	read	sigpause	uname
dup	getpgrp	readlink	sigpending	unlink
dup2	getpid	readlinkat	sigprocmask	unlinkat
execl	getppid	recv	sigqueue	utime
execle	getsockname	recvfrom	sigset	utimensat
execv	getsockopt	recvmsg	sigsuspend	utimes
execve	getuid	rename	sleep	wait
_Exit	kill	renameat	sockatmark	waitpid
_exit	link	rmdir	socket	write

Figure: Reentrant functions that may be called from a signal handler

Reliable-Singnal Teminology and Semantics

- **a signal is *generated* (or sent) for a process** when the event that causes the signal occurs
  - The event can be hardware exception, software condition, a terminal-generated signal, or a call to the `kill` function
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- POSIX.1 defines a data type `sigset_t` that holds a ***signal set***

Use cases of signal

`kill` and `raise` Functions

`kill` function sends a signal to a process or a group of processes

`raise` function allows a process to send a signal to itself

```
#include <signal.h>
int kill(pid_t pid, int signo);
int raise(int signo);
// Both return: 0 if OK, 1 on error
```

`raise(signo);` == `kill(getpid(), singo);`

- `pid>0` sends signal to `pid`
- `pid==0` sends signal to all prosesses in process group ID of the sender
- `pid<0` The signal is sent to all process in process group ID of $|pid|$
- `pid==-1` send signal to all processes on the system for which the sender has permission to send the signal

`alarm` Function

`alarm` function allows us to set a time that will expire at a specified time in the future. When the timer expires, the `SIGALRM` signal is generated

```
#include <unistd.h>
unsigned int alarm(unsigned int seconds);
// Returns: 0 or number of seconds until previously set alarm
```

- only one of alarm clocks per process
- if previously registered alarm clock has not expired, the number of seconds left for that alarm clock is returned as the value of this function
- if previous alarm is not expired and *seconds* value is `0`, the previous alarm is cacled
- most processes using alarm, catches this signal

pause Function

pause function suspends the calling process until a signal is caught

```
#include <unistd.h>
int pause(void);
// Returns: 1 with errno set to EINTR
```

alarm and pause Functions Example

codes/sleep-pause.c

```
1  #include <signal.h>
2  #include <unistd.h>
3
4  static void
5  sig_alrm(int signo)
6  {
7     /* nothing to do, just return to wake up the pause */
8  }
9
10 unsigned int
11 sleep1(unsigned int seconds)
12 {
13    if (signal(SIGALRM, sig_alrm) == SIG_ERR)
14       return(seconds);
15    alarm(seconds); /* start the timer */
16    pause(); /* next caught signal wakes us up */
17    return(alarm(0)); /* turn off timer, return unslept time */
18 }
```

`alarm` and `pause` Functions Example

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1. if the caller already has an alarm set, that alarm is erased by the first call to `alarm`
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   - we have to check the return value of `alarm`, and make sure we wait only until the existing alarm expires
2. disposition for `SIGALRM` is modified
   - if others are going to use this call, make sure the function is restored after use
3. there is race condition between the first call to `alarm` and the call to `puase`
   - use `setjmp` or `sigprocmask` with `sigsuspend`

Example cont'd codes/sleep-pause2.c

to avoid race condition SVR2 used `setjmp` and `longjmp`

```
1  #include <setjmp.h>
2  #include <signal.h>
3  #include <unistd.h>
4
5  static jmp_buf env_alrm;
6
7  static void
8  sig_alrm(int signo)
9  {
10    longjmp(env_alrm, 1);
11 }
12
13 unsigned int
14 sleep2(unsigned int seconds)
15 {
16    if (signal(SIGALRM, sig_alrm) == SIG_ERR)
17       return(seconds);
18    if (setjmp(env_alrm) == 0) {
19       alarm(seconds); /* start the timer */
20       pause(); /* next caught signal wakes us up */
21    }
22    return(alarm(0)); /* turn off timer, return unslept time */
23 }
```

Example cont'd codes/tsleep.c I

There is subtle problem with sleep2 function when it interacts with other signals

In this example, we are trying to make it execute longer than 5 seconds (the argument to sleep2()

```
1  #include <setjmp.h>
2  #include <signal.h>
3  #include <unistd.h>
4  #include <stdio.h>
5  #include <stdlib.h>
6  #include <errno.h>
7
8  unsigned int sleep2(unsigned int);
9  static void  sig_int(int);
10
11 static jmp_buf env_alrm;
12
13 int
14 main(void)
15 {
16    unsigned int unslept;
17
```

Example cont'd codes/tsleep.c II

```
18      if (signal(SIGINT, sig_int) == SIG_ERR){
19         fprintf(stderr, "signal(SIGINT) error");
20         exit(1);
21      }
22      unslept = sleep2(5);
23      printf("sleep2 returned: %u\n", unslept);
24      exit(0);
25   }
26
27   static void
28   sig_int(int signo)
29   {
30      int    i, j;
31      volatile int k = 0;
32
33      /*
34       * Tune these loops to run for more than 5 seconds
35       * on whatever system this test program is run.
36       */
37      printf("\nsig_int starting\n");
38      for (i = 0; i < 900000; i++)
39         for (j = 0; j < 10000; j++)
40            k += i * j;
41      printf("sig_int finished\n");
42   }
43
```

Example cont'd codes/tsleep.c III

```
44  static void
45  sig_alrm(int signo)
46  {
47     longjmp(env_alrm, 1);
48  }
49
50  unsigned int
51  sleep2(unsigned int seconds)
52  {
53     if (signal(SIGALRM, sig_alrm) == SIG_ERR)
54        return(seconds);
55     if (setjmp(env_alrm) == 0) {
56        alarm(seconds); /* start the timer */
57        pause(); /* next caught signal wakes us up */
58     }
59     return(alarm(0)); /* turn off timer, return unslept time */
60  }
```

Example cont'd codes/tsleep.c

```
make tsleep
```

We execute the program by `./tsleep` and interrupt the sleep by typing in the interrupt character

```
James@maker:codes$ time ./tsleep
sleep2 returned: 0

real 0m5.014s
user 0m0.005s
sys 0m0.007s
```

```
James@maker:codes$ time ./tsleep
^C
sig_int starting
sleep2 returned: 0

real 0m5.008s
user 0m4.590s
sys 0m0.023s
```

we can see that the `longjmp` from the `sleep2` aborted the other signal handler, `sig_int`, even though it wasn't finished

Last Words

Last Words

- Prepare for Exam