UNIX System Programming

Signals

Overview

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1. Definition

- A signal is an *asynchronous* event which is delivered to a process.

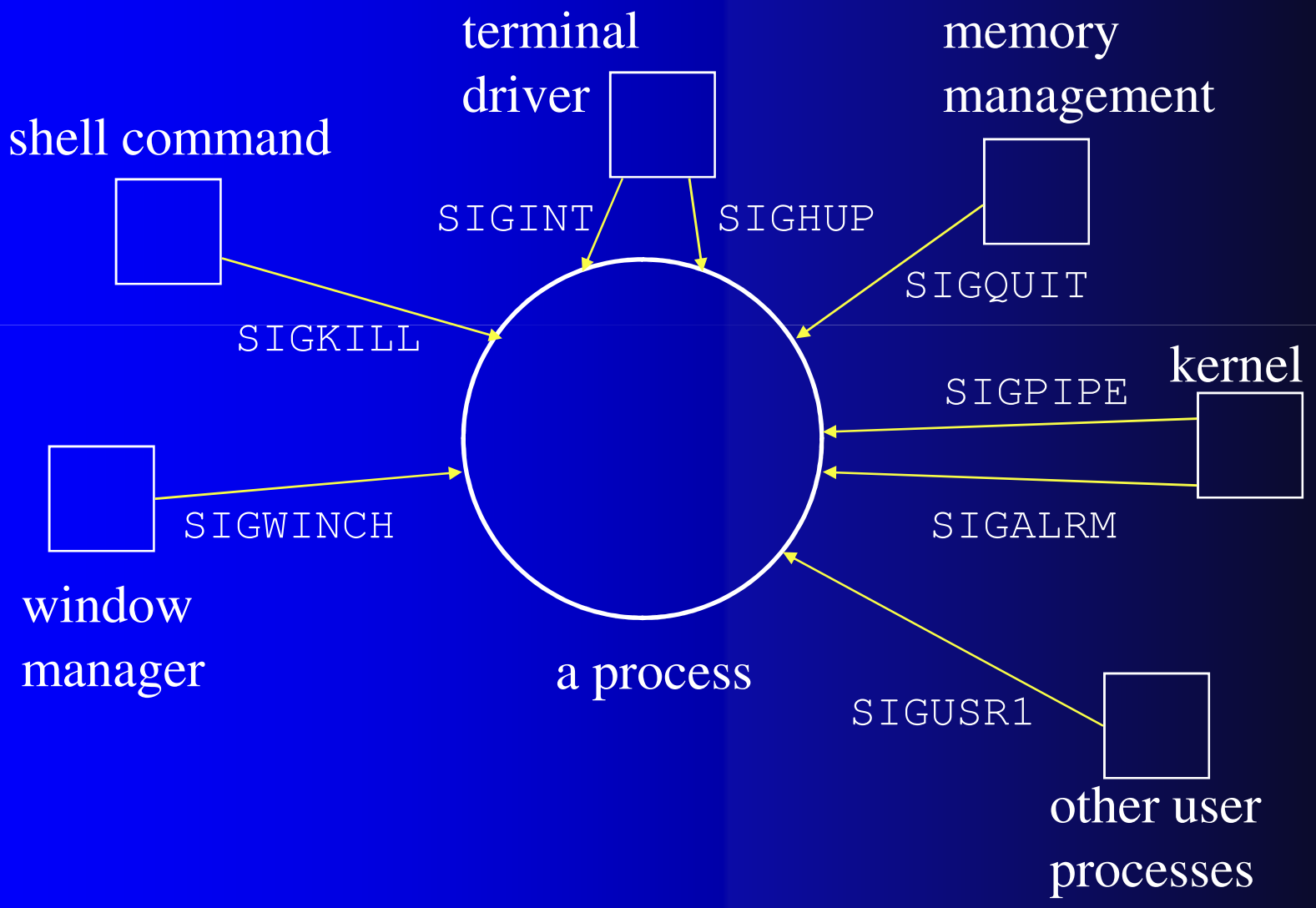
- Asynchronous means that the event can occur at any time
  - may be unrelated to the execution of the process
  - e.g. user types `ctrl-C`, or the modem hangs

2. Signal Types (31 in POSIX)

Name	*Description*	*Default Action*
`SIGINT`	Interrupt character typed	terminate process
`SIGQUIT`	Quit character typed (`^\`)	create core image
`SIGKILL`	`kill -9`	terminate process
`SIGSEGV`	Invalid memory reference	create core image
`SIGPIPE`	Write on pipe but no reader	terminate process
`SIGALRM`	`alarm()` clock 'rings'	terminate process
`SIGUSR1`	user-defined signal type	terminate process
`SIGUSR2`	user-defined signal type	terminate process

- See `man 7 signal`

Signal Sources



3. Generating a Signal

- Use the UNIX command:

```
$ kill -KILL 4481
```

  - send a `SIGKILL` signal to pid 4481
  - check
    - **`ps -l`**
  - to make sure process died

- `kill` is not a good name; `send_signal` might be better.

kill()

- Send a signal to a process (or group of processes).

- ```
  #include <signal.h>

  int kill( pid_t pid, int signo );
  ```

- Return 0 if ok, -1 on error.
  ```

Some pid Values

pid	*Meaning*
> 0	send signal to process `pid`
== 0	send signal to all processes whose process group ID equals the sender's pgid. e.g. parent kills all children

4. Responding to a Signal

- A process can:
  - ignore/discard the signal (not possible with `SIGKILL` or `SIGSTOP`)
  - execute a signal handler function, and then possibly resume execution or terminate
  - carry out the default action for that signal
- The choice is called the process' *signal disposition*

signal(): library call

- Specify a signal handler function to deal with a signal type.
- ```
  #include <signal.h>
  typedef void Sigfunc(int);   /* my defn */
  ```

  ```
  Sigfunc *signal( int signo, Sigfunc *handler );
  ```
  - signal returns a pointer to a function that returns an int (i.e. it returns a pointer to Sigfunc)
- Returns *previous* signal disposition if ok, `SIG_ERR` on error.
  ```

Actual Prototype

- The actual prototype, listed in the "man" page is a bit perplexing but is an expansion of the `Sigfunc` type:

```
void (*signal(int signo, void(*handler)(int)))(int);
```

- In Linux:

```
typedef void (*sighandler_t)(int);

sig_handler_t signal(int signo, sighandler_t handler);
```

- Signal returns a pointer to a function that returns an int

ing

The signal function itself returns a pointer to a function. The return type is the same as the function that is passed, i.e., a function that takes an int and returns a void

The *handler* function Receives a single integer Argument and returns *void*

```
#include <signal.h>

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

- signal returns a pointer to the PREVIOUS signal handler

Signal is a function that takes two arguments: *sig* and *handler*

The function to be called when the specified signal is received. It is a pointer to a function that takes a integer parameter.

The returned function takes a integer parameter.

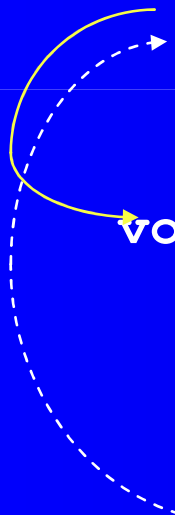
Example

```
int main()
    {
    signal( SIGINT, foo );
      :

    /* do usual things until SIGINT */
    return 0;
    }

void foo( int signo )
    {
      :          /* deal with SIGINT signal */


    return;      /* return to program */
    }
```



sig_examp.c

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

void sig_usr( int signo );     /* handles two signals */

int main()
   {
   int i = 0;
   if( signal( SIGUSR1,sig_usr ) == SIG_ERR )
       printf( "Cannot catch SIGUSR1\n" );
   if( signal( SIGUSR2,sig_usr ) == SIG_ERR )
      printf("Cannot catch SIGUSR2\n");
                    :
```

continued

```
        :
    while(1)
        {
        printf( "%2d\n", I );
        pause();
        /* pause until signal handler
         * has processed signal */
        i++;
        }
    return 0;
}
```

continued

```
void sig_usr( int signo )
/* argument is signal number */
{
  if( signo == SIGUSR1 )
        printf("Received SIGUSR1\n");
  else if( signo == SIGUSR2 )
        printf("Received SIGUSR2\n");
  else
        printf("Error: received signal
                    %d\n", signo);

  return;
}
```

Usage

```
$ sig_examp &
[1]      4720
 0
$ kill -USR1 4720
Received SIGUSR1
 1
$ kill -USR2 4720
Received SIGUSR2
 2
$ kill 4720                 /* send SIGTERM */
[1] + Terminated    sig_examp &
$
```

Special Sigfunc * Values

Value	*Meaning*
`SIG_IGN`	Ignore / discard the signal.
`SIG_DFL`	Use default action to handle signal.
`SIG_ERR`	Returned by `signal()` as an error.

Multiple Signals

- If many signals of the *same* type are waiting to be handled (e.g. two `SIGINT`s), then most UNIXs will only deliver one of them.
  - the others are thrown away

- If many signals of *different* types are waiting to be handled (e.g. a `SIGINT`, `SIGSEGV`, `SIGUSR1`), they are not delivered in any fixed order.

pause()

- Suspend the calling process until a signal is caught.
- ```
  #include <unistd.h>
  int pause(void);
  ```
- Returns -1 with `errno` assigned `EINTR`.
  (Linux assigns it `ERESTARTNOHAND`).
- `pause()` only returns after a signal handler has returned.
  ```

The Reset Problem

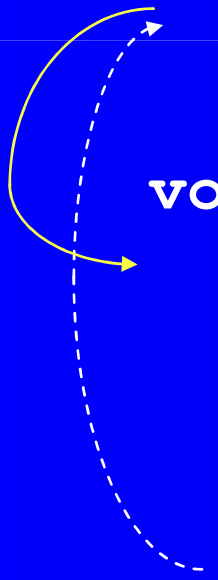
- In Linux (and many other UNIXs), the signal disposition in a process is reset to its default action immediately after the signal has been delivered.

- Must call `signal()` again to reinstall the signal handler function.

Reset Problem Example

```
int main()
    {
    signal(SIGINT, foo);
     :
    /* do usual things until SIGINT */
    }

void foo(int signo)
    {
    signal(SIGINT, foo); /* reinstall */
          :
    return;
    }
```



Reset Problem

```
    :
void ouch( int sig )
        {
        printf( "OUCH! - I got signal %d\n", sig );
        (void) signal(SIGINT, ouch);
        }
int main()
        {
        (void) signal( SIGINT,
        while(1)
                {
                printf("Hello World!\n");
                sleep(1);
                }
        }
```

To keep catching the signal with this function, must call the *signal* system call again.

Problem: from the time that the interrupt function starts to just before the signal handler is re-established the signal will not be handled.

If another SIGINT signal is received during this time, default behavior will be done, i.e., program will terminate.

Re-installation may be too slow!

- There is a (very) small time period in `foo()` when a new `SIGINT` signal will cause the default action to be carried out -- process termination.

- With `signal()` there is no answer to this problem.
  - POSIX signal functions solve it (and some other later UNIXs)

5. Common Uses of Signals

5.1. Ignore a Signal

5.2. Clean up and Terminate

5.3. Dynamic Reconfiguration

5.4. Report Status

5.5. Turn Debugging on/off

5.6. Restore Previous Handler

5.1. Ignore a Signal

```
    :
int main()
{
  signal(SIGINT, SIG_IGN);
  signal(SIGQUIT, SIG_IGN);
    :
  /* do work without interruptions */
}
```

- Cannot ignore/handle `SIGKILL` or `SIGSTOP`
- Should check for `SIG_ERR`

5.2. Clean up and Terminate

```
    :
/* global variables */
int my_children_pids;
    :
void clean_up(int signo);

int main()
{
  signal(SIGINT, clean_up);
    :
}
```

continued

```
void clean_up(int signo)
{
   unlink(“/tmp/work-file”);
   kill(my_children_pids, SIGTERM);
   wait((int *)0);
   fprintf(stderr,
        “Program terminated\n”);
   exit(1);
}
```

Problems

- If a program is run in the background then the interrupt and quit signals (`SIGINT`, `SIGQUIT`) are automatically ignored.

- Your code should not override these changes:
  - check if the signal dispositions are `SIG_IGN`

Checking the Disposition


```
    :
if( signal(SIGINT, SIG_IGN ) != SIG_IGN )
    signal(SIGINT, clean_up);
```

```
 if( signal(SIGQUIT, SIG_IGN ) != SIG_IGN )
    signal(SIGQUIT, clean_up);
    :
```

- *Note*: cannot check the signal disposition without changing it (sigaction that we will look at later , is different)

5.3. Dynamic Reconfiguration

```
  :
void read_config(int signo);

int main()
   {
   read_config(0);  /* dummy argument */

   while (1)
     /* work forever */
   }
```

continued

```
void read_config(int signo)
{
  int fd;

  signal( SIGHUP, read_config );

  fd = open("config_file", O_RDONLY);
  /* read file and set global vars */
  close(fd);

  return;
}
```

Problems

- Reset problem
- Handler interruption
  - what is the effect of a `SIGHUP` in the middle of `read_config()`'s execution?
- Can only affect global variables.

5.4. Report Status

```
   :
void print_status(int signo);
int count;   /* global */

int main()
{ signal(SIGUSR1, print_status);
    :
  for( count=0; count < BIG_NUM; count++ )
    {
     /* read block from tape */
     /* write block to disk */
    }
  ...
}
```

continued

```
void print_status(int signo)
{
   signal(SIGUSR1, print_status);
   printf("%d blocks copied\n", count);
   return;
}
```

- Reset problem
- `count` value not always defined.
- Must use global variables for status information

5.5. Turn Debugging on/off

```
   :
void toggle_debug(int signo);

int debug = 0;  /* initialize here */
```

```
int main()
{
  signal(SIGUSR2, toggle_debug);

  /* do work */
  if (debug == 1)
        printf("...");
  ...
}
```

continued

```
void toggle_debug(int signo)
{
  signal(SIGUSR2, toggle_debug);

  debug = ((debug == 1) ? 0 : 1);

  return;
}
```

5.6. Restore Previous Handler

```
    :
Sigfunc *old_hand;

/* set action for SIGTERM;
   save old handler */
old_hand = signal(SIGTERM, foobar);

/* do work */

/* restore old handler */
signal(SIGTERM, old_hand);
    :
```

6. Implementing a read() Timeout

- Put an upper limit on an operation that might block forever
  - e.g. `read()`

- 6.1. `alarm()`
  6.2. Bad `read()` Timeout
  6.3. `setjmp()` and `longjmp()`
  6.4. Better `read()` Timeout

6.1. alarm()

- Set an alarm timer that will ‘ring’ after a specified number of seconds
  - a `SIGALRM` signal is generated

- ```
  #include <unistd.h>
  long alarm(long secs);
  ```

- Returns 0 or number of seconds until previously set alarm would have ‘rung’.
  ```

Some Tricky Aspects

- A process can have at most one alarm timer running at once.
- If `alarm()` is called when there is an existing alarm set then it returns the number of seconds remaining for the old alarm, and sets the timer to the new alarm value.
  - What do we do with the "old alarm value"?
- An `alarm(0)` call causes the previous alarm to be cancelled.

6.2. Bad read() Timeout

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

#define MAXLINE  512

void sig_alrm( int signo );

int main()
    {
    int n;
    char line[MAXLINE];
          :
```

continued

```
    if( signal(SIGALRM, sig_alrm) == SIG_ERR )
            {
            printf("signal(SIGALRM) error\n");
            exit(1);
            }

    alarm(10);
    n = read( 0, line, MAXLINE );
    alarm(0);

    if( n < 0 )  /* read error */
            fprintf( stderr, "\nread error\n" );
    else
            write( 1, line, n );
    return 0;
}
```

continued

```
void sig_alrm(int signo)
/* do nothing, just handle signal */
{
  return;
}
```

Problems

- The code assumes that the `read()` call terminates with an error after being interrupted (talk about this later).

- Race Conditon: The kernel may take longer than 10 seconds to start the `read()` after the `alarm()` call.
  - the alarm may 'ring' before the `read()` starts
  - then the `read()` is not being timed; may block forever
  - Two ways two solve this:
    - **`setjmp`**
    - **`sigprocmask`** and **`sigsuspend`**

6.3. setjmp() and longjmp()

- In C we cannot use `goto` to jump to a label in another function
  - use `setjmp()` and `longjmp()` for those 'long jumps'

- Only uses which are good style:
  - error handling which requires a deeply nested function to recover to a higher level (e.g. back to `main()`)
  - coding timeouts with signals

Prototypes

- ```
  #include <setjmp.h>
  int setjmp( jmp_buf env );
  ```

- Returns 0 if called directly, non-zero if returning from a call to `longjmp()`.

- ```
  #include <setjmp.h>
  void longjmp( jmp_buf env, int val );
  ```

Behavior

- In the `setjmp()` call, `env` is initialized to information about the current state of the stack.
- The `longjmp()` call causes the stack to be reset to its `env` value.
- Execution restarts after the `setjmp()` call, but this time `setjmp()` returns `val`.

Example

```
    :
jmp_buf env;              /* global */

int main()
    {
    char line[MAX];
    int errval;

    if(( errval = setjmp(env) ) != 0 )
          printf( "error %d: restart\n", errval );

    while( fgets( line, MAX, stdin ) != NULL )
          process_line(line);
    return 0;
    }
```

continued

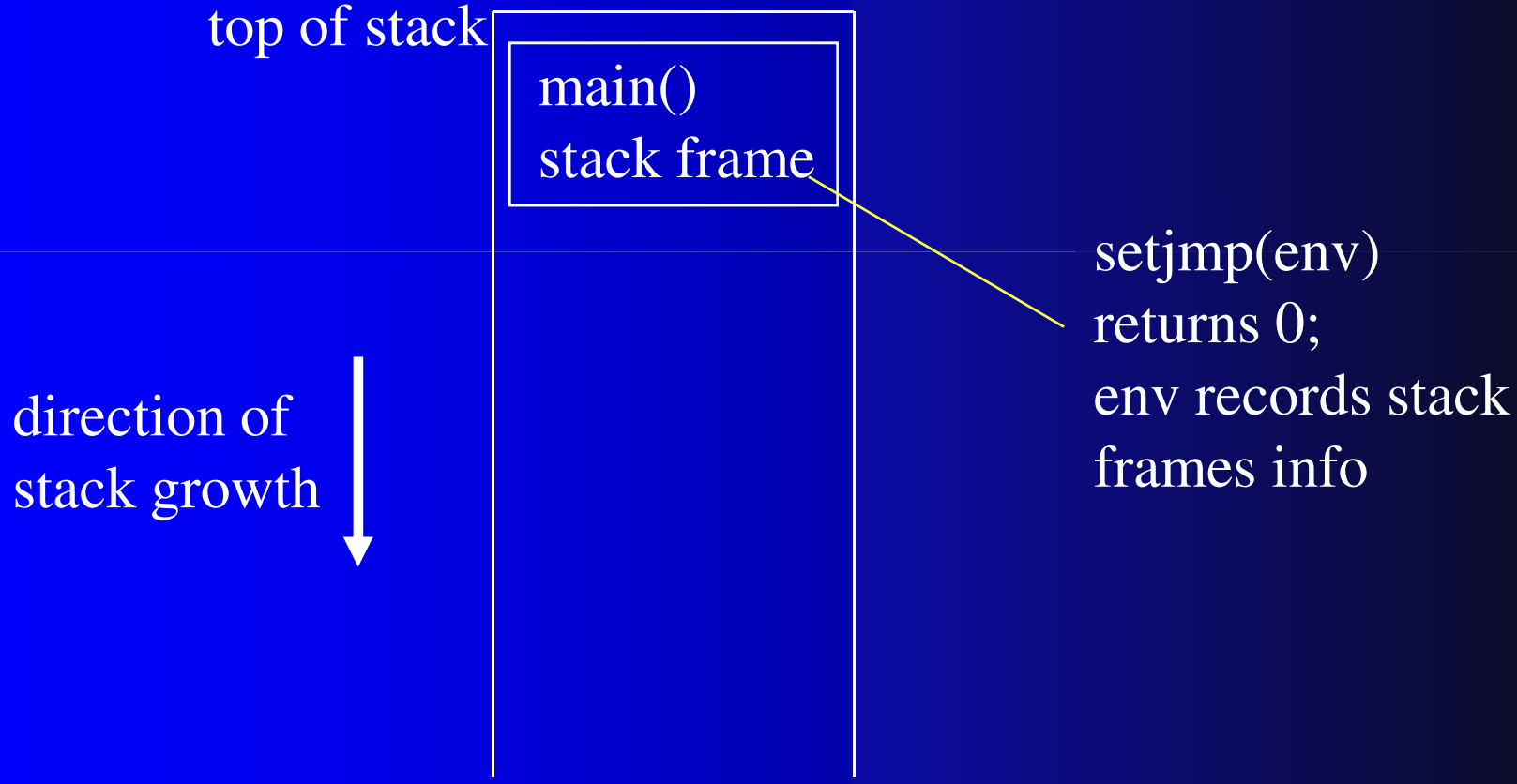
```
        :
void process_line( char * ptr )
        {
        :
        cmd_add()
        :
        }

void cmd_add()
        {
        int token;

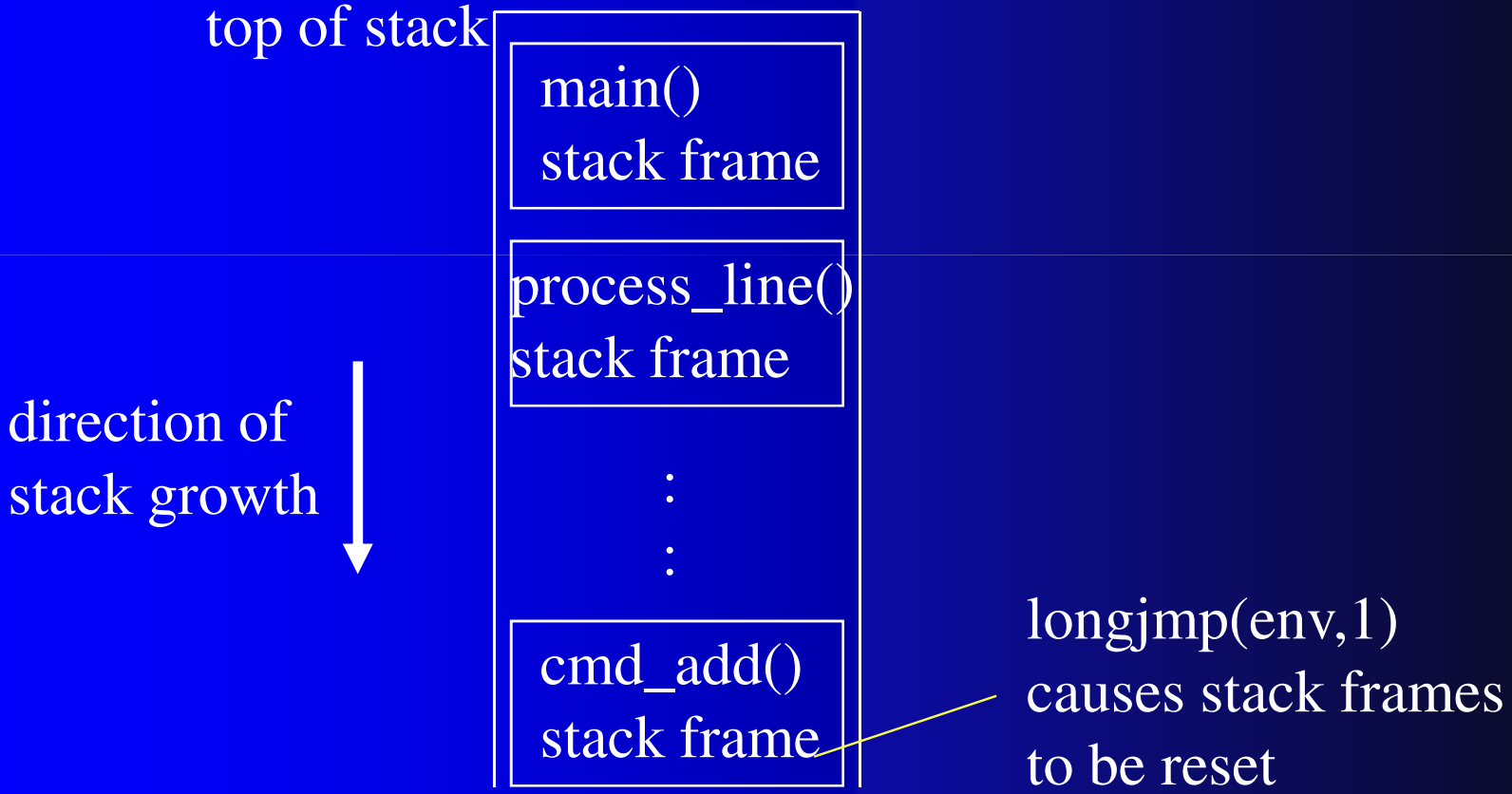
        token = get_token();
        if( token < 0 )       /* bad error */
                longjmp( env, 1 );

        /* normal processing */
        }
int get_token()
        {
        if( some error )
                longjmp( env, 2 );
        }
```

Stack Frames at setjmp()



Stack Frames at longjmp()



sleep1()

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

void sig_alrm( int signo )
    {
    return; /* return to wake up pause */
    }
unsigned int sleep1( unsigned int nsecs )
    {
    if( signal( SIGALRM, sig_alrm ) == SIG_ERR )
          return (nsecs);
    alarm( nsecs );              /* starts timer */
    pause();                     /* next caught signal wakes */
    return( alarm( 0 ) );        /* turn off timer, return unslept
                                  * time */
    }
```

sleep2()

```
static void jmp_buf env_alrm;

void sig_alrm( int signo )
    {
    longjmp( env_alrm, 1 );
    }
unsigned int sleep2( unsigned int nsecs )
    {
    if( signal( SIGALRM, sig_alrm ) == SIG_ERR )
            return (nsecs);
    if( setjmp( env_alrm) == 0 )
            {
            alarm( nsecs );      /* starts timer */
            pause();             /* next caught signal wakes */
            }
    return( alarm( 0 ) );
    }
```

continued

Sleep1 and Sleep2

- Sleep2 fixes race condition. Even if the pause is never executed.

- There is one more problem (will talk about that after “fixing the earlier read function”)

Status of Variables?

- The POSIX standard says:
  - global and static variable values will not be changed by the `longjmp()` call

- Nothing is specified about local variables, are they "rolled back" to their original values (at the setjmp call) as the stack"?
  - they may be restored to their values at the first `setjmp()`, but maybe not
    - Most implementations do not roll back their values

6.4. Better read() Timeout

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

#define MAXLINE  512
void sig_alrm( int signo );
jmp_buf env_alrm;

int main()
{ int n;
  char line[MAXLINE];
        :
```

continued

```
 if( signal(SIGALRM, sig_alrm) == SIG_ERR)
        {
        printf("signal(SIGALRM) error\n");
        exit(1);
        }

if( setjmp(env_alrm) != 0 )
        {
        fprintf(stderr, "\nread() too slow\n");
        exit(2);
        }

alarm(10);
n = read(0, line, MAXLINE);
alarm(0);
```

continued

```
    if( n < 0 )   /* read error */
          fprintf( stderr, "\nread error\n" );
    else
          write( 1, line, n );
    return 0;
}
```

continued

```
void sig_alrm(int signo)
/* interrupt the read() and jump to
   setjmp() call with value 1
*/
{
  longjmp(env_alrm, 1);
}
```

Caveat: Non-local Jumps

From the UNIX **man** pages:

WARNINGS

If longjmp() or siglongjmp() are called even though env was never primed by a call to setjmp() or sigsetjmp(), or when the last such call was in a function that has since returned, absolute chaos is guaranteed.

A Problem Remains!

- If the program has several signal handlers then:
  - execution might be inside one when an alarm 'rings'
  - the `longjmp()` call will jump to the `setjmp()` location, and abort the other signal handler -- might lose / corrupt data

7. POSIX Signal Functions

- The POSIX signal functions can control signals in more ways:
  - can *block signals* for a while, and deliver them later (good for coding critical sections)
  - can *switch off the resetting* of the signal disposition when a handler is called (no reset problem)

- The POSIX signal system, uses signal sets, to deal with pending signals that might otherwise be missed while a signal is being processed

7.1. Signal Sets

- The signal set stores collections of signal types.
- Sets are used by signal functions to define which signal types are to be processed.
- POSIX contains several functions for creating, changing and examining signal sets.

Prototypes

- `#include <signal.h>`

```
int sigemptyset( sigset_t *set );
int sigfillset( sigset_t *set );

int sigaddset( sigset_t *set, int signo );
int sigdelset( sigset_t *set, int signo );

int sigismember( const sigset_t *set,
                 int signo );
```

7.2. sigprocmask()

- A process uses a signal set to create a mask which defines the signals it is blocking from delivery. – good for critical sections where you want to block certain signals.

- ```
  #include <signal.h>
  int sigprocmask( int how,
                   const sigset_t *set,
                   sigset_t *oldset);
  ```
- **how – indicates how mask is modified**
  ```

how Meanings

- *Value* — *Meaning*

`SIG_BLOCK`	`set` signals are added to mask
`SIG_UNBLOCK`	`set` signals are removed from mask
`SIG_SETMASK`	`set` becomes new mask

A Critical Code Region

```
sigset_t newmask, oldmask;

sigemptyset( &newmask );
sigaddset( &newmask, SIGINT );

/* block SIGINT; save old mask */
sigprocmask( SIG_BLOCK, &newmask, &oldmask );

/* critical region of code */

/* reset mask which unblocks SIGINT */
sigprocmask( SIG_SETMASK, &oldmask, NULL );
```

7.3. sigaction()

- Supercedes (more powerful than) `signal()`
  - `sigaction()` can be used to code a non-resetting `signal()`

- **`#include <signal.h>`**

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

sigaction Structure

```
struct sigaction
    {
    void       (*sa_handler)( int );
                  /* action to be taken or SIG_IGN, SIG_DFL */
    sigset_t   sa_mask; /* additional signal to be blocked */
    int        sa_flags; /* modifies action of the signal */
    void       (*sa_sigaction)( int, siginfo_t *, void * );

    }
```

- sa_flags –
  - SIG_DFL reset handler to default upon return
  - SA_SIGINFO denotes extra information is passed to handler (.i.e. specifies the use of the "second" handler in the structure.

sigaction() Behavior

- A `signo` signal causes the `sa_handler` signal handler to be called.
- While `sa_handler` executes, the signals in `sa_mask` are blocked. Any more `signo` signals are also blocked.
- `sa_handler` remains installed until it is changed by another `sigaction()` call. No reset problem.

Signal Raising

```
int main()
  {
  struct sigaction act;

  act.sa_handler = ouch;

  sigemptyset( &act.sa_mask );

  act.sa_flags = 0;

                SIGINT, &act, 0

                ("Hello
        sleep(1);
        }
  }
```

```
struct sigaction
        {
        void (*) (int) sa_handler
        sigset_t sa_mask
        int sa_flags
        }
```

Set the signal handler to be the function `ouch`

We can manipulate sets of signals..

No flags are needed here. Possible flags include:
SA_NOCLDSTOP
SA_RESETHAND

This call sets the signal handler for the SIGINT (ctrl-C) signal

Signal Raising

- This function will continually capture the ctrl-C (SIGINT) signal.
- Default behavior is **not** restored after signal is caught.
- To terminate the program, must type ctrl-\, the SIGQUIT signal.

sigexPOS.c

```
/* sigexPOS.c - demonstrate sigaction() */
/* include files as before */

int main(void)
{
    /* struct to deal with action on signal set */
    static struct sigaction act;

    void catchint(int); /* user signal handler */

    /* set up action to take on receipt of SIGINT */
    act.sa_handler = catchint;
```

```
/* create full set of signals */
sigfillset(&(act.sa_mask));

/* before sigaction call, SIGINT will terminate
* process */

/* now, SIGINT will cause catchint to be executed */
sigaction( SIGINT, &act, NULL );
sigaction( SIGQUIT, &act, NULL );

printf("sleep call #1\n");
sleep(1);

/* rest of program as before */
```

Signals - Ignoring signals

- Other than SIGKILL and SIGSTOP, signals can be ignored:

- Instead of in the previous program:

```
  act.sa_handler = catchint /* or whatever */
We use:
  act.sa_handler = SIG_IGN;
The ^C key  will be ignored
```

Restoring previous action

- The third parameter to sigaction, oact, can be used:

```
/* save old action */
sigaction( SIGTERM, NULL, &oact );
```

```
/* set new action */
act.sa_handler = SIG_IGN;

sigaction( SIGTERM, &act, NULL );

/* restore old action */
sigaction( SIGTERM, &oact, NULL );
```

A Basic signal()

```
#include <signal.h>

Sigfunc *signal( int signo, Sigfunc *func )
    {
    struct sigaction act, oact;

    act.sa_handler = func;
    sigemptyset( &act.sa_mask );
    act.sa_flags = 0;

    act.sa_flags |= SA_INTERRUPT;
    if( signo != SIGALRM )
            act.sa_flags |= SA_RESTART;
            /* any system call interrupted by a signal
     * other than alarm is restarted */
    if( sigaction( signo, &act, &oact) < 0 )
            return(SIG_ERR);
    return( oact.sa_handler );
    }
```

7.4. Other POSIX Functions

- `sigpending()` examine blocked signals
- `sigsetjmp()`
  `siglongjmp()` jump functions for use in signal handlers which handle masks correctly
- `sigsuspend()` atomically reset mask and sleep

[sig]longjmp & [sig]setjmp

NOTES (longjmp, sigjmp)

POSIX does not specify whether longjmp will restore the signal context. If you want to save and restore signal masks, use siglongjmp.

NOTES (setjmp, sigjmp)

POSIX does not specify whether setjmp will save the signal context. (In SYSV it will not. In BSD4.3 it will, and there is a function _setjmp that will not.) If you want to save signal masks, use sigsetjmp.

Example

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

sigjmp_buf buf;

void handler(int sig)
        {
        siglongjmp(buf, 1);
        }

main()
{
  signal(SIGINT, handler);

  if( sigsetjmp(buf, 1) == 0 )
        printf("starting\n");
  else
        printf("restarting\n");
  …
```

```
  …
  while(1)
        {
        sleep(5);
        printf("  waiting...\n");
        }
}
```

```
> a.out
starting
  waiting...
  waiting...          <-- Control-c
restarting
  waiting...
  waiting...
  waiting...
restarting            <-- Control-c
  waiting...
restarting            <-- Control-c
  waiting...
  waiting...
```

8. Interrupted System Calls

- When a system call (e.g. `read()`) is interrupted by a signal, a signal handler is called, returns, and then what?

- On many UNIXs, *slow* system function calls do not resume. Instead they return an error and `errno` is assigned `EINTR`.
  - true of Linux, but can be altered with (Linux-specific) `siginterrupt()`

Slow System Functions

- Slow system functions carry out I/O on things that can possibly block the caller forever:
  - pipes, terminal drivers, networks
  - some IPC functions
  - `pause()`, some uses of `ioctl()`
- Can use signals on slow system functions to code up timeouts (e.g. did earlier)

Non-slow System Functions

- Most system functions are non-slow, including ones that do *disk* I/O
  - e.g. `read()` of a disk file
  - `read()` is sometimes a slow function, sometimes not
- Some UNIXs resume non-slow system functions after the handler has finished.
- Some UNIXs only call the handler after the non-slow system function call has finished.

9. System Calls inside Handlers

- If a system function is called inside a signal handler then it may interact with an interrupted call to the same function in the main code.
  - e.g. `malloc()`
- This is not a problem if the function is *reentrant*
  - a process can contain multiple calls to these functions at the same time
  - e.g. `read()`, `write()`, `fork()`, many more

Non-reentrant Functions

- A functions may be non-reentrant (only one call to it at once) for a number of reasons:
  - it uses a static data structure
  - it manipulates the heap: `malloc()`, `free()`, etc.
  - it uses the standard I/O library
    - e,g, `scanf()`, `printf()`
    - the library uses global data structures in a non-reentrant way

errno Problem

- `errno` is usually represented by a global variable.
- Its value in the program can be changed suddenly by a signal handler which produces a new system function error.