Signals and Inter-Process Communication (IPC)

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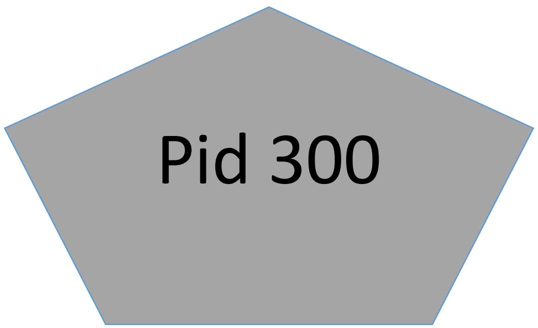
Outline

- Signals
  - Overview and APIs
  - Handlers
  - Kernel-level delivery
  - Interrupted system calls
- Interprocess Communication (IPC)
  - Pipes and FIFOs
  - System V IPC

What is a Signal?

- Like an interrupt, but for applications
  - < 64 numbers with specific meanings
  - Sending: A process can raise a signal to another process or thread
  - Sending: Kernel can send signals to processes or threads
  - Receiving: A process or thread registers a handler function
- For both IPC and delivery of hardware exceptions
  - Application-level handlers: divzero, segfaults, etc.
- No "message" beyond the signal was raised + a little metadata
  - PID of sender, faulting address, etc.

Example

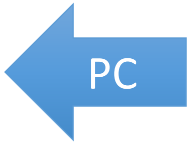



```
int main() {
   ...
   signal(SIGUSR1, &usr_handler);
   ...
}
```

Register usr_handler() to handle SIGUSR1

Example


```
int main() {
   ...
}
```




```
kill(300, SIGUSR1);
```

```
int usr_handler() { …
```

Send signal to PID 300

Basic Model

- Application registers handlers with `signal()` or `sigaction()`
- Send signals with `kill()` and friends
  - Or raised by hardware exception handlers in kernel
- Signal delivery jumps to signal handler
  - Irregular control flow, similar to an interrupt

API names are admittedly confusing

Some Signal Types

See man7 signal for the full list: (varies by sys/arch)

SIGTSTP: Stop typed at terminal (Ctrl+Z)

SIGKILL: Kill a process

SIGSEGV: Segmentation fault

SIGPIPE: Broken pipe (write with no readers)

SIGALRM: Timer

SIGUSR1: User-defined signal 1

SIGCHLD: Child stopped or terminated

SIGSTOP: Stop a process

SIGCONT: Continue if stopped

Language Exceptions

- Signals are the underlying mechanism for Exceptions and catch blocks
- JVM or other runtime system sets signal handlers
  - Signal handler causes execution to jump to the catch block

Signal Handler Control Flow

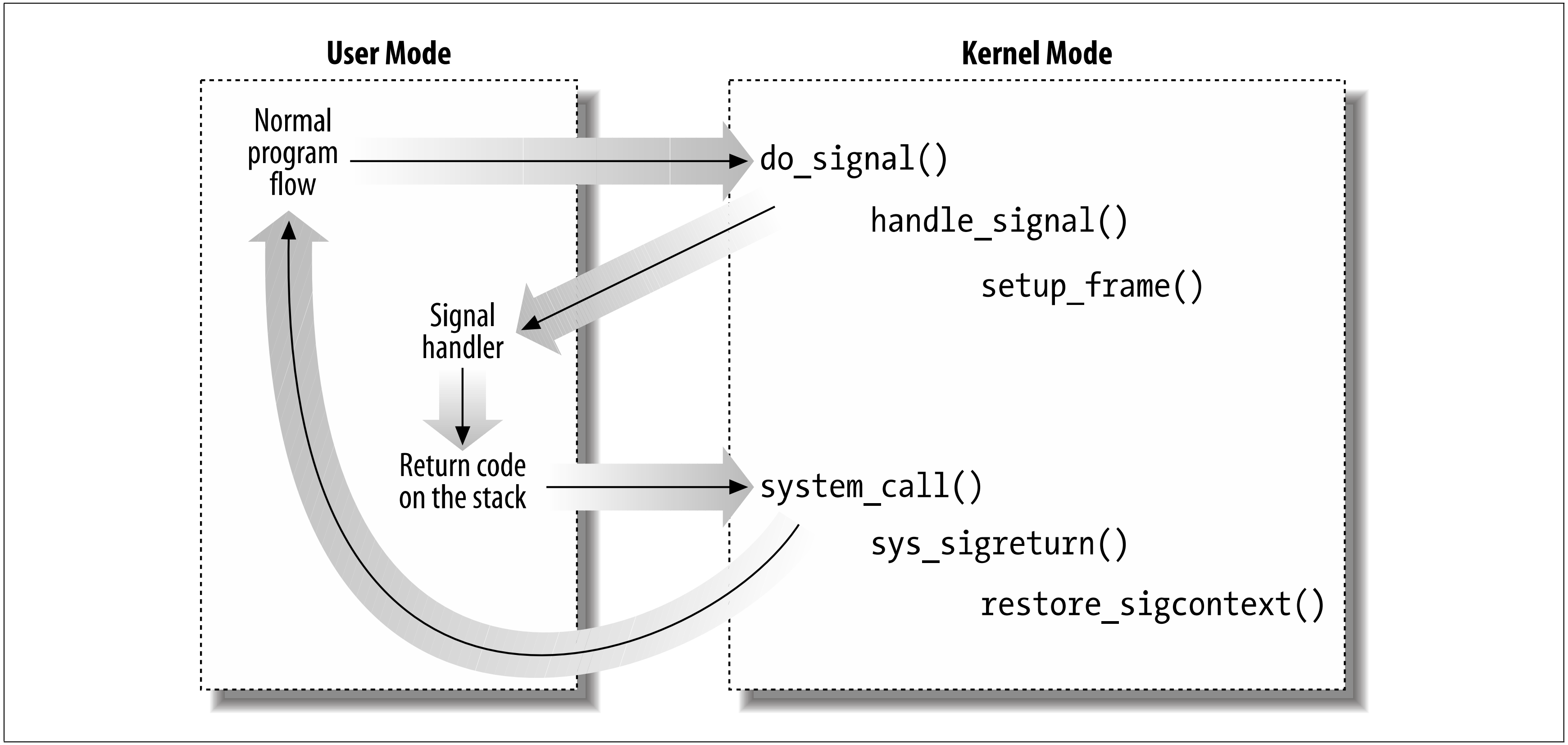


Figure 11-2. Catching a signal

Source: Understanding the Linux Kernel

Alternate Stacks

- Signal handlers can execute on a different stack than program execution.
  - Set with `sigaltstack()` system call
- Like an interrupt handler, kernel pushes register state on interrupt stack
  - Return to kernel with `sigreturn()` system call
  - App can change its own on-stack register state!

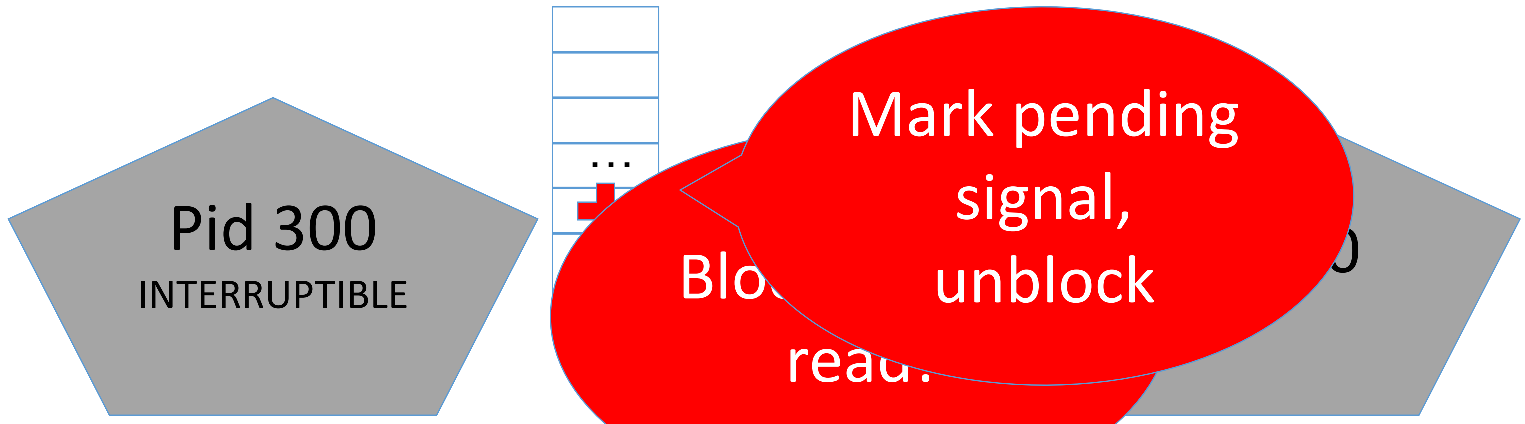
Default handlers

- Signals have default handlers:
  - Ignore, kill, suspend, continue, dump core
  - These execute inside the kernel
- Installing a handler with `signal()/sigaction()` overrides the default
- A few (SIGKILL, SIGSTOP) cannot be overridden

Signal Delivery

- Kernel is lazy!
  - Send a signal == mark a pending signal in the task
    - And make runnable if blocked with `TASK_INTERRUPTIBLE` flag
  - Check pending signals <u>on return from interrupt or syscall</u>
    - Deliver if pending

Example




```
int main() {
  read();
}
```

What happens to read?

```
SIGUSR1);
```

```
int usr_handler() { …
```

Send signal to PID 300

Interrupted System Calls

- If a system call blocks in the `TASK_INTERRUPTIBLE` state, a signal wakes it up
- Yet signals are delivered on *return* from a system call
- How is this resolved?
- The system call fails with a special error code
  - `EINTR` and friends
  - Many system calls transparently retry after `sigreturn()`
  - Some do not – check for `EINTR` in your applications!

Nested Signals

- What happens when you get a signal in the signal handler?
- And why should you care?

The Problem with Nesting

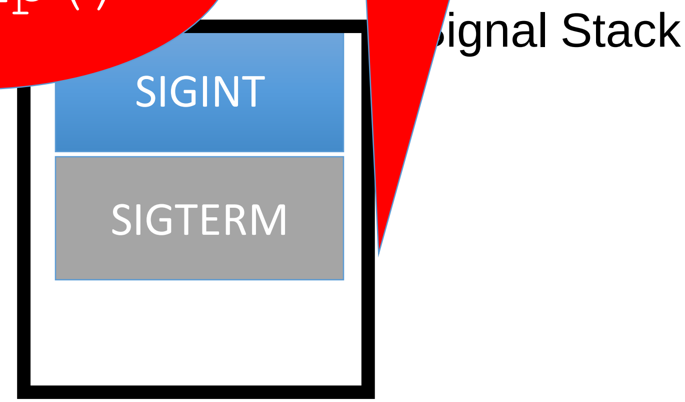
```
int main() {
      /* ... */
            (SIGINT, &handler);
            GTERM, &handler);
      /       . */
}
int handler() {
      free(buf1);
      free(buf2);
}
```

Double free!

PC

Calls munmap()

Another signal delivered on return from munmap()



Nested Signals

- The original `signal()` specification was a total mess!
  - Now deprecated — do not use!
- New `sigaction()` API lets you specify this in detail
  - What signals are blocked (and delivered on `sigreturn`)
  - Similar to disabling hardware interrupts
- As you might guess, blocking system calls inside of a signal handler are only safe with careful use of `sigaction()`

RT Signals

- Default signals are only in 2 states: signaled or not
  - If I send 2 SIGUSR1's to a process, only one may be delivered
  - If system is slow and I furiously hit Ctrl+C over and over, only one SIGINT delivered
- Real time (RT) signals keep a count
  - Deliver one signal for each one sent

Other IPC

- Pipes, FIFOs, and Sockets
- System V IPC

Pipes

- Stream of bytes between two processes
  - Stored in a buffer in the kernel
- Read and write like a file descriptor
  - But not anywhere in the hierarchical file system
  - And not persistent
  - And no cursor or seek()-ing
  - Actually, 2 handles: a read handle and a write handle
- Primarily used for parent/child communication
  - Parent creates a pipe, child inherits it

Example

```
int pipe_fd[2];

int rv = pipe(pipe_fd);

int pid = fork();

if (pid == 0) {

        close(pipe_fd[1]);      // Close unused write end

        dup2(pipe_fd[0], 0);    // Make the read end stdin

        exec("grep", "quack");

} else {

        close (pipe_fd[0]);     // Close unused read end …
```

FIFOs (a.k.a. Named Pipes)

- Existing pipes can't be opened---only inherited
  - Or passed over a Unix Domain Socket (beyond today's lec)
- FIFOs, or Named Pipes, add an interface for opening existing pipes

Sockets

- Similar to pipes, except for network connections
- Setup and connection management is a bit trickier
  - A topic for another day (or class)

select() and poll()

- What if I want to block until one of several handles has data ready to read?
- Read will block on one handle, but perhaps miss data on a second…
- Select will block a process until a handle has data available
  - Useful for applications that use pipes, sockets, etc.

Synthesis Example: The Shell

- Almost all ‘commands’ are really binaries
  - /bin/ls
- Key abstraction: Redirection using standard file descriptors 0, 1, and 2
  - 0: standard input
  - 1: standard output
  - 2: standard error
  - ‘>’, ‘<‘, and ‘|’ implemented by the shell itself

Shell Example

- Example: `ls | grep foo`

- Implementation sketch:
  - Shell parses the entire string
  - Sets up chain of pipes
  - Forks and exec's 'ls' and 'grep' separately
  - Wait on output from 'grep', print to console

Job Control in a Shell

- Shell keeps its own “scheduler” for background processes
- How to:
  - How to suspend the foreground process?
    - SIGTSTP default handler catches Ctrl-Z
    - Send SIGSTOP to current foreground child
  - Resume execution (**fg**)?
    - Send SIGCONT to paused child, use ***waitpid()*** to block until finished
  - Execute in background (**bg**)?
    - Send SIGCONT to paused child, but block on terminal input

Other Pipe-related API

- `splice()`, `tee()`, and similar calls are useful for connecting pipes together
  - Avoid copying data into and out-of application

System V IPC (1)

- Semaphores – Lock
  - Kernel-managed semaphore identified with a system-wide ID
  - `semget(), semctl(), semop()`
- Message Queues – Like a mail box, “small” messages
  - A linked list in the kernel, identified with a system-wide ID
  - `msgget(), msgctl(), msgsnd(), msgrcv()`

System V IPC (2)

- Shared Memory – particularly useful
  - A region of non-COW anonymous memory, identified with a system-wide ID
  - `shmget()`, `shmat()`, `shmdt()`
  - Get using `shmget()` and map at a given address using `shmat()`
- Can persist longer than an application
  - Must be explicitly deleted using `shmdt()`
  - Can leak at system level
  - But cleared after a reboot