CSE 410: Systems Programming

POSIX Signals

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POSIX Signals

POSIX signals are another form of interprocess communication.

They are also a way to create concurrency in programs.

For these two reasons, they are rather complicated and subtle!

Signals provide a simple message passing mechanism.

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Signals as Messages

POSIX signals are asynchronous messages.

Asynchronous means that their reception can occur at any time.[1]

The message is the reception of the signal itself.

Each signal has a number, which is a small integer.

POSIX signals carry no other data.

[1] Almost. We'll see how to control it later.

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Signal Types

There are two basic types of POSIX signals:

- Reliable signals
- Real-time signals

Real-time signals are much more complicated.

In particular, they can carry data.

We will discuss only reliable signals in this lecture.

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Asynchronous Reception

From the point of view of the application:

- Signals can be blocked or ignored
- Enabled signals may be received between any two processor instructions
- A received signal can run a user-defined function called a signal handler

This means that enabled signals and program code must very carefully manipulate shared or global data!

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Signals

POSIX defines a number of signals by name and number.

A few of those are:

- `SIGHUP`, 1 (sent when a terminal disconnects)
- `SIGINT`, 2 (sent when you push Ctrl-C)
- `SIGKILL`, 9 (uncatchable, terminates the process)
- `SIGSEGV`, 11 (sent on invalid memory access)
- `SIGCHLD`, 17 (sent when a child process exitsx)

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Signal Handlers

A process indicates that it wishes to receive a signal by installing a signal handler.

Each signal has a default handler that either:

- Ignores the signal
- Stops the process
- Continues the process
- Terminates the process
- Terminates the process and dumps core

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Signal Handlers II

A process can install a signal handler for any signal except:

- SIGKILL
- SIGSTOP

A signal handler is a function.

That function is called when the signal is received.

Signal handlers are of type `sighandler_t`:

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


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Typedef

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

A typedef declares a new type.

It looks like a variable declaration.
The name of the variable becomes the type.

`sighandler_t` is a function pointer.

It is a function returning `void` and accepting one `int` argument.

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Installing a Handler

```
sighandler_t signal(int signum, sighandler_t handler);
```

The `signal` function accepts

- a signal number and
- a handler function

and binds the function to the signal.

Therefter, receipt of the signal will call the bound function.

It also returns the old signal handler.

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Special Handlers

There are two special signal handlers:

- SIG_IGN: ignore a signal
- SIG_DFL: restore default behavior

These values may be passed to signal instead of a function.

```
signal(SIGCHLD, SIG_DFL);
```


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Signal Portability

The `signal()` function has some portability problems:

- Some systems reset the handler to `SIG_DFL` upon receipt
- Some systems allow signals to arrive during a handler set by `signal()`

For this reason, there is a POSIX function `sigaction()`.

The behavior of `sigaction()` is more tightly defined.

Linux `signal()` semantics are appropriate for your shell project.

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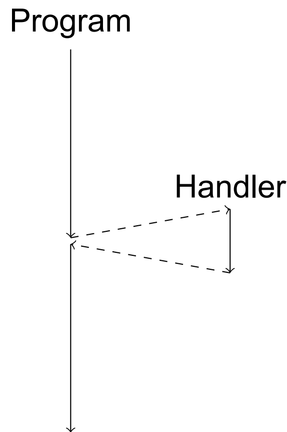
Signal Reception

The kernel may deliver a signal at any time.

When receiving a signal, a process will:

- Push its current program counter onto the stack
- Jump to the signal handler
- Execute the signal handler
- Pop the saved PC and return



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Blocking Signals

A signal can be blocked by the program.

A blocked signal will be delivered when it is unblocked.

Signals may be:

- implicitly blocked because a handler for that signal is currently executing
- explicitly blocked by the programmer using `sigprocmask()`

Signal blocking allows the program to restrict signal reception, since it otherwise cannot predict when they will be received.

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sigprocmask()

```
#include <signal.h>

int sigprocmask(int how, const sigset_t *set,
    sigset_t *oldset);
int sigemptyset(sigset_t *set);
int sigaddset(sigset_t *set, int signum)
```

`sigprocmask()` blocks or unblocks signals given by a `signal set`.

A `signal set` contains zero or more signals.

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Using sigprocmask()

```
sigset_t mask, oldmask;

sigemptyset(mask);
sigaddmask(mask, SIGCHLD);
sigprocmask(SIG_BLOCK, &mask, &oldmask);

/* SIGCHLD is blocked here */

sigprocmask(SIG_SETMASK, &oldmask, NULL);

/* SIGCHLD restored to its state before the block */
/* If it is unblocked and pending, the handler will
   run now (or shortly). */
```


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Shared Data

Signals introduce concurrency into programs.

Because signal handlers run at unpredictable times, accessing shared data from signal handlers is dangerous.

If data is in an inconsistent state when a handler accesses it, corruption or program errors might occur.

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Signal Concurrency

```
void prepend(struct ListNode *node) {
    node->next = list;
    list = node;
}

void handler(int sig) { prepend(new_listnode()); }

int main(int argc, char *argv[]) {
    signal(SIGINT, &handler);
    prepend(new_listnode());

    return 0;
}
```


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Corruption

```
1 void prepend(struct ListNode *node) {
2     node->next = list;
3     list = node;
4 }
```

If the signal arrives …	*The result is …*
Before line 2	The list contains 2 items
Between 2 & 3	The list contains only the main node
After 3	The list contains both nodes

If the handler node is lost, memory is leaked.

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Sending Signals

Signals are sent to a process with the `kill()` function.

```
#include <sys/types.h>
#include <signal.h>

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

Note that kill may or may not actually kill the receiving process!

A process can generally only kill:

- itself
- other processes owned by the same user

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Summary

- Signals are interprocess communication.
- Each signal is a message.
- Signals are handled by functions.
- Signal handlers introduce concurrency.
- Shared data must be manipulated carefully when signals are in use.

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Next Time …

- …

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References I

Required Readings

[1] Randal E. Bryant and David R. O'Hallaron. *Computer Science: A Programmer's Perspective*. Third Edition. Chapter 8: 8.5. Pearson, 2016.

Optional Readings

[2] "Overview of Signals". In: *Linux Programmer's Manual*. `man 7 signal`.

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