Function pointers, Signals and low level file I/O

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Function Pointers

- So far all variables are exposed as having an address

- Compiled binary code is no different

```
if ( != 0 ) {
    execute statement;
} else {
    execute other statement;
}
```

Function Pointers

```c
int x = 33;
if (x == 33)
{
    x = 480+7;
}
x += 768;
```

```
movl $33, -4(%rbp)
cmpl $33, -4(%rbp)
jne .L2
movl $487, -4(%rbp)
.L2:
  addl $768, -4(%rbp)
```

- JUMP!
- Same with loops
- rbp is the stack frame pointer on x86_64

Function Pointers

```c
int x = 33;
if (x == 33)
{
    x = 480+7;
    foo();
}
x += 768;
```

```
movl $33, -4(%rbp)
cmpl $33, -4(%rbp)
jne .L4
movl $487, -4(%rbp)
movl $0, %eax
call foo
.L4:
  addl $768, -4(%rbp)
```

› Call? If not a jump, how do we get back?

Function Pointers

```c
int x = 33;
if (x == 33)
{
    x = 480+7;
    foo();
}
x += 768;
```

```
movl $33, -4(%rbp)
cmpl $33, -4(%rbp)
jne .L4
movl $487, -4(%rbp)
movl $0, %eax
call foo
.L4:
  addl $768, -4(%rbp)
```

- Call? If not a jump, how do we get back?
- Stack is being managed here. Callee or caller will setup and teardown the stack

Function Pointers

```
int (*fptr)() = foo;

int x = 33;
if (x == 33) {
    x = 480+7;
    fptr();
}
x += 768;
```

```
subq $16, %rsp
leaq foo(%rip), %rax
movq %rax, -16(%rbp)
movl $33, -4(%rbp)
cmpl $33, -4(%rbp)
jne .L4
…
```

- If we `jump`, or `call`, all we need is an address

Function Pointers

```
int (*fptr)() = foo;

int x = 33;
if (x == 33)
{
    x = 480+7;
    fptr();
}
x += 768;
```

```
…
movl $33, -4(%rbp)
cmpl $33, -4(%rbp)
jne .L4
movl $487, -4(%rbp)
movq -16(%rbp), %rdx
movl $0, %eax
call *%rdx
.L4:
  addl $768, -4(%rbp)
```

› Call a function, jump to address is (almost) the same process

Function pointer

- A function pointer is an address that refers to an area of memory with executable code
- Typically the first instruction of the function call^
- Are useful for conventional programming patterns
- Examples
  - Do something, and when you are finished call this function
  - Do something, and if it goes wrong, call this function
  - I am a data source, give me an function to send new bits of data to
  - I want to sort a list of objects, here is the address of a function to perform comparison of two elements

^ Depends on callee/caller conventions

- The declaration of the function pointer parameter looks like:

  type (*f)(param declaration…)

- and the call of the function looks like:

  f(params…)

Function pointer: Example

- Call functionA if x is true, or functionB otherwise

```
if (x)
  funcA();
else
  funcB();
```

Function pointer: Example

› Call functionA if x is true, or functionB otherwise

```
if (x)
  funcA();
else
  funcB();
```

› What if we don't know what funcA and funcB are at compile time?

```
void do_process(int x, funcA?, funcB?) {
  if (x)
    funcA(x); // print X
  else
    funcB(x); // delete elem X
}
```

Function pointer: Example

› What if we don't know what funcA and funcB are at compile time?

```
void deleteX(int x);
void printX(int x);

void do_process(int x,
     void __funcA__(int),
     void __funcB__(int))
{
  if (x)
    funcA(x); // print X
  else
    funcB(x); // delete elem X
}
```

Function pointer: Example

› What if we don't know what funcA and funcB are at compile time?

```
void deleteX(int x);
void printX(int x);

void do_process(int x,
        void (*funcA)(int),
        void (*funcB)(int))
{
  if (x)
    funcA(x); // print X
  else
    funcB(x); // delete elem X
}
```

Function pointer: Example

› Write less code. Allow option to change implementation choices at runtime. E.g. heuristics, look and feel, plugins

```
void printX_1(int x) { printf("%d", x); }
void printX_2(int x) { printf("%d\n", x); }
void printX_3(int x) { printf("x: %d\n", x); }

// delegate which fn pointer
if (user_style == PRETTY)
      print_style = printX_3;
…
// generic code
do_process(value1, print_style, remove_style);
do_process(value2, print_style, remove_style);
do_process(value3, print_style, remove_style);
```

Signals

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Signals

- a process can communicate with another using a *signal*
- these are a form of *software interrupt*
- execution is interrupted and a function call is made at that point to a user specified function
- when the function returns, execution is resumed

Signals

- signals can be generated by one process to another using the *kill* system call

- signals are also generated by the operating system, eg when an access outside memory bounds is attempted (Segmentation Fault)

SIGHUP	1	Hangup
SIGINT	2	Interrupt
SIGQUIT	3	Quit
SIGILL	4	Illegal Instruction
SIGTRAP	5	Trace or Breakpoint Trap
SIGABRT	6	Abort
SIGEMT	7	Emulation Trap
SIGFPE	8	Arithmetic Exception
SIGKILL	9	Kill
SIGBUS	10	Bus Error
SIGSEGV	11	Segmentation Fault
SIGSYS	12	Bad System Call
SIGPIPE	13	Broken Pipe
SIGALRM	14	Alarm Clock
SIGTERM	15	Terminated
SIGUSR1	16	User Signal 1
SIGUSR2	17	User Signal 2

kill

- You can send a signal to a running process from the command line using the kill command

- Eg `kill -9 12345`

Will send the SIGKILL signal to process 12345.

- Some signals can be *caught* and handled by a user supplied function
- Some signals (such as SIGKILL) cannot be caught and caused the process to be terminated

kill

- You can send a signal to a running process using the kill system call function

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

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

Where pid is the process ID of the process to be signaled and sig is the signal to be sent.

Catching Signals

- You can "catch" a signal by specifying a function that is called when the signal is received
- This is done using the signal function:

```
#include <signal.h>
sighandler_t signal(int signum, sighandler_t handler);
void (*signal(int sig, void (*catch)(int)))(int);
```

This complicated looking declaration means that signal is called with 2 arguments: the first is the signal to catch, the second is a pointer to the function that will be called when the signal is received. The signal function returns a pointer to the function that previously caught the signal ….phew.

Signal: Catch SIGINT

```
volatile int interrupted = 0;
void impatient(int sigval) {
    interrupted = 1;
}

int main() {
    signal(SIGINT, impatient);
    printf(”Now we wait…\n");
    while (!interrupted)
        usleep(10);
    printf("Oh..you didn't like waiting\n");
    printf("Program terminated\n");
    return 0;
}
```

Does it work?

errno

errno

- Most C functions report errors via return values, or their parameters
- However, there is still an error reporting mechanism using a global variable called `errno`

- Failed system calls typically set `errno` to be an integer value representing the type of error.

- A companion function, `strerror` and `perror`, will print a textual description of the errno code.

errno

- The <errno.h> header file defines the integer variable

```
#include <errno.h>
#include <stdio.h>

int main() {
    FILE *fp = fopen("doesn't exist", "r");
    printf("errno: %d\n", errno);
    return 0;
}
```

- `errno` is set by the **last** function call that will set `errno`.
- There is only one errno value
- It can be overridden by subsequent function calls
- It is important to save this value immediately following

Low level file I/O

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Low Level File Descriptors

- Low level I/O is performed on file descriptors that are small integers indicating an open file
- When a process is started file descriptor 0 is standard input, 1 is standard output, 2 is standard error output (UNIX)
- System call functions operate on file descriptors

Low Level File Descriptors

- low level I/O functions in C wrap system calls:
  - creat, open, close
  - read, write
  - ioctl
  - umask
- eg read 100 characters from standard input into array "buffer"

```
ssize_t result = read(0, buffer, 100);
```

$ man 2 open

"If I was to change anything in Unix it would be to spell creat with an e"
Ken Thompson

Low Level File Descriptors

› read()

On error, -1 is returned, and errno is set appropriately. In this case, it is left unspecified whether the file position (if any) changes.

› This may be interrupted by a signal. The way to check is to use `errno`

```
ssize_t result = read(…);
if (result < 0)
     error_val = errno;
if (EINTR == error_val) // reattempt
```

› These operations are blocking. There may be a need to interrupt them upon a new event.

Working with read and write

› Error checking

- errno is set to an error value
- signal can be sent by operating system

```
#include <errno.h>
…
signal(SIGINT, interrupted);
char buffer[100];
ssize_t result = read(0, buffer, 100);
// check for errors
int error_val = errno;
if (0 != error_val) {
   printf("read() was interrupted by signal\n");
}
```

Does it work?

Catching Signals

› You can "catch" a signal by specifying a function that is called when the signal is received

› This is done using the **sigaction()** function:

```
#include <signal.h>
int sigaction(int signum, const struct sigaction *act,
       struct sigaction *oldact);
struct sigaction {
   void     (*sa_handler)(int);
   void     (*sa_sigaction)(int, siginfo_t *, void *);
   sigset_t   sa_mask;
   int        sa_flags;
   void     (*sa_restorer)(void);
};
```

Working with read and write

- Error checking
  - errno is set to an error value
  - signal can be sent by operating system

```
#include <errno.h>
…
// setup new handler
new_sig_int.sa_handler = interrupted;
new_sig_int.sa_flags = 0;
// install the new handler
sigaction(SIGINT, &new_sig_int, NULL);

char buffer[100];
ssize_t result = read(0, buffer, 100);
// check for errors
int error_val = errno;
if (error_val != 0) {
   printf("read() was interrupted by signal\n");
}
```

It works

Low Level File Descriptors

- Extra attention is needed when working with files at this level
  - Buffering
  - Sharing vs exclusive access (resource locking)
  - Errors and interruptions
  - Notifications (Linux)
  - Resource limit setting
  - Performance

- fcntl - manipulate file descriptors

- Valuable to have very fine control of file operations

Quiz