What to go over

- Processes and Threads
- Linking and Loading
- System Calls
- Completely Fair Scheduler
Motivation

```c
#include <pthread.h>

void* hello_thread(void *payload) {
    write(1, "Hello world!", 12);
    return NULL;
}

int main() {
    pthread_create(NULL, hello_thread, NULL, NULL);
    pthread_exit();
}
```
Motivation

```c
#include <pthread.h>  // Dynamic Linked Library

void* hello_thread(void *payload) {  // Pthread
    pthread_write(1, "Hello world!", 12);  // Sys Call
    return NULL;
}

int main() {  // Process Start
    pthread_create(NULL, hello_thread, NULL, NULL);
    pthread_exit();  // Some kind of scheduling
}```
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- **void * kmalloc(size_t size, int flags)** size is the number bytes of what you want to malloc; flags are one of many options the kernel handles. We can have an entire lecture on this one call so just believe that this call returns pages of memory that are greater than size. A page is usually 4KB, so it’ll be the smallest multiple of that.
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- **void kfree(const void* objp)**: Self explanatory, frees the pages for later usage.

- **mmap(void *addr, size_t length, int prot, int flags, int fd, off_t offset)**: Takes a file, puts in to memory (it’s a vast simplification, we can and have had another lecture on this).
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- The first thing the kernel does is start init (the main process for your operating system).
- Init does a lot of things. One important thing it does is initializing fork(), the magical library call that starts the entire process.
- Then init sees what run level you are running at. Init then runs the appropriate startup scripts to start all the processes for your operating system.
Starting a process

Here’s how to start a process:

1. Fork off of an existing process (bash, terminal, init, ...)
2. Fork copies the file descriptors, page tables, signal handlers using kmalloc.
3. Imagine in the Linux kernel there is a struct with all of this stuff – that is what a process essentially is.
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Starting a process

**Process Creation — Copy-on-Write**

```
fork()
Only copy the page table

copy-on-write
Delay or altogether prevent copying of data
```

```
Parent

A

B

C

D

Child

Parent

A

B

C

D

Child

Parent

A

B'

C

D

Child
```

5
Starting a process

Fork

```
ret = fork();
switch(ret)
{
  case -1:
    perror("fork");
    exit(1);
  case 0: // I am the child
    <code for child >
    exit(0);
  default: // I am parent ...
    <code for parent >
    wait(&child_status);
}
```
Now Exec-ing

- Exec takes an executable and uses the appropriate executable loader (ELF format for UNIX) to reorganize the file into memory. The kernel may mmap into new address spaces.
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The kernel then dynamically links libraries (to be explained later). The kernel also sets the pages that the old processes had to be destroyed on exec.

The kernel resets registers and sets the stack pointer to the entry point of the main function. And finally, does the jump to the entrypoint. Your program is started!
Threads!

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- We use pthreads! Threads in user-space.
- But to the kernel, there are no things as threads.
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This abstraction is really cool – that is why in the systems literature/papers *everything* is a process.
Threading Start - pthread_create

![Diagram of threading process and library interaction]

User, Kernel, and Hardware layers are depicted with various threads and processes.
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Then the pthread is added to the pthread table, and returns out of the pthread function. Scheduling the process is left up to the completely fair scheduler.
Thread creation with `pthread_create`
Acts like another process, that’s why you can signal to it.
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- You can sleep just like another process and use shared mutexes and whatnot because it resides in the same memory.
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Race conditions! All the fun stuff from processes
Pthread is running

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- You can sleep just like another process and use shared mutexes and whatnot because it resides in the same memory.
- Race conditions! All the fun stuff from processes
- (The kernel does know it’s supposed to be treated as a thread and uses group scheduling for efficiency)
Pthread join

- Gets return values from the process
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- Gets return values from the process
- We get rid of the stack space and the entry from the table.
- Return the stack back to the program.
Linking and Loading
#include <pthread.h> //Dynamic Linked Library

void* hello_thread(void* payload){ //Pthread
write(1, "Hello world!", 12); //Sys Call
return NULL;
}

int main(){ //Process Start
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pthread_exit() //Some kind of scheduling
}
What are we even talking about?

There are two types of libraries, those compiled with your programs and those that are linked dynamically at runtime. There are many benefits to use programs that get compiled with your program, but some drawbacks.
Benefits

- You have the source code/debug checking
- All code is in your code segment
- You can modify the library
Cost-Benefit Analysis: Compile-Time Libraries

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- You have the source code/debug checking
- All code is in your code segment
- You can modify the library

Drawbacks
- Updating is often tedious
- Your executable is bigger
- Your library cannot be reused by other applications
What if we have one library that a bunch of programs can use (make it read only) and have it dynamically link the function calls in the program?
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What if we have one library that a bunch of programs can use (make it read only) and have it dynamically link the function calls in the program?

- Updating your executable’s library is a piece of cake
- Reduce the size of your executable
- That library can be used by other applications.
Dynamic Lookup table?

- Any problem in computer science and be solved with another layer of abstraction.
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Dynamic Lookup table?

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- Have the functions in your code point to pointer where the functions are going to be.
- Have your code jump to the pointer and the pointer jump to the actual function.
"In Unix-like systems that use ELF for executable images and dynamic libraries, such as Solaris, 64-bit versions of HP-UX, Linux, FreeBSD, NetBSD, OpenBSD, and DragonFly BSD, the path of the dynamic linker that should be used is embedded at link time into the .interp section of the executable’s PT_INTERP segment. In those systems, dynamically loaded shared libraries can be identified by the filename suffix .so (shared object)."

- Wikipedia
Exec fills in the references to the library calls in the lookup table in the PT_INTERP segment of the program. Whenever the program makes a call to that library then the program will jump to the lookup table which will jump to the appropriate place in memory, executing the function and return control back to your function.
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So about that library

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If not, then mmap the library into memory. Set the executable bit (memory can either be executable or writeable) and then link the function. Store this library’s location in case another program needs the same library.
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If not, then mmap the library into memory. Set the executable bit (memory can either be executable or writeable) and then link the function. Store this library’s location in case another program needs the same library.

When a process is done, reduce the reference count and return the page back to the system if need be.
So about that library

```c
#include <Boffo/Boffo.h>
#include "main.h"
#include "doThat.h"

int main() {
    a();
    doThat(1);
    return 0;
}
...
```

```c
#include <Boffo/Boffo.h>
#include "doThat.h"

void doThat (int n) {
    b();
    if (!n);
    c();
}
```

```c
#include "a.h"
void a() {
    ...
}
```

```c
#include "b.h"
void b() {
    ...
}
```

```c
#include "c.h"
void c() {
    ...
}
```
One of the problems, inherently, with DLLs is that you have to trust the library you are linking to. Moreover you have to trust the user that the library has not been hacked.
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- Some viruses come prepackaged with libraries and if you set the LD_PRELOAD variable with a library when you execute commands that the user wouldn’t even know.
- An example if we have time.
Another problem with a DLL is that if there is a bug in the DLL there is a bug in your program.
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- libc had a buffer overflow bug not too long ago, any application that uses libc which is 99% of them were affected and could have been hacked away.
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- libc had a buffer overflow bug not too long ago, any application that uses libc which is 99\% of them were affected and could have been hacked away.
- But there are always tradeoffs so DLLs are here to stay.
System Calls
#include <pthread.h>   //Dynamic Linked Library

void* hello_thread(void *payload) {   //Pthread
    write(1, "Hello world!", 12);   //Sys Call
    return NULL;
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int main(){   //Process Start
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- System calls are called with interrupts control goes to the kernel and then gets bounced back to the program.
- System calls need to do that because some calls require elevated privileges but within the bounds of the kernel - like accessing devices or doing I/O.
- These are vital to change the state of the system, or to communicate with other processes for example.
User Space and Kernel Space

- Userspace is where you run your programs in, the user runs their programs using the kernel’s system calls.
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- We need this separation because the Kernel can do anything. If you don’t have this separation, any program could potentially change the state of the system in undefined ways – a huge security hole.
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Kernel space is also lower level meaning that you don’t get the nice abstractions like sbrk(2) or write(2). The kernel has to route each of the requests to the appropriate drivers or handlers.
Userspace is where you run your programs in, the user runs their programs using the kernel’s system calls.

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Kernel space is also lower level meaning that you don’t get the nice abstractions like sbrk(2) or write(2). The kernel has to route each of the requests to the appropriate drivers or handlers.

Kernel Space still needs to be exposed to system calls.
How do we call a system call?

Typically C library calls call system calls but here is some x86 to get the job done.

```assembly
_start:
movl $4, %eax ; use the write syscall
movl $1, %ebx ; write to stdout
movl $msg, %ecx ; use string "Hello World"
movl $12, %edx ; write 12 characters
int $0x80 ; make syscall

movl $1, %eax ; use the _exit syscall
movl $0, %ebx ; error code 0
int $0x80 ; make syscall
```
How do we call a system call?

User space

User space

Kernel space

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- Then the kernel traps the signal, routes to the appropriate system call, looks at the registers and executes the system call in Kernel space.
How do we call a system call?

- We have to load all of the system call parameters in registers. Then we program a software interrupt that takes control back to the kernel.
- Then the kernel traps the signal, routes to the appropriate system call, looks at the registers and executes the system call in Kernel space.
- The kernel stores the result in a register and returns back to userspace – we have a system call.
Completely Fair Scheduler
I promise last time.

```c
#include <pthread.h>    // Dynamic Linked Library

void* hello_thread(void *payload) {    // Pthread
    write(1, "Hello world!", 12);    // Sys Call
    return NULL;
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int main() {    // Process Start
    pthread_create(NULL, hello_thread, NULL, NULL);    // Some kind of scheduling
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Okay let’s backtrack to threads and stuff

- It is not a secret, we have more processes than CPUs – more threads than CPUs even
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- So how does the CPU run all these processes? It switches between them really fast using what we call a scheduler.
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- So how does the CPU run all these processes? It switches between them really fast using what we call a scheduler.
- This is essentially a dining philosopher problem that is solved by pre-emption. The kernel tells processes when they can hog resources like CPUs and tells them to stop whenever else.
Deadlock solved, now starvation

- We want to make sure that all processes are chugging along smoothly – we don’t want our networking process to be starved when our process needs networking or our daemon to be starving either.
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- (Nice values are the kernel’s way of giving priority to certain processes, the lower the higher priority)
- The kernel chooses the lowest one based on this metric and schedules that process to run next, taking it off the queue. Since the red-black tree is self balancing this operation is guaranteed \( O(\log(n)) \) (selecting the min process is the same runtime)
Red-Black-Tree
self balancing
binary search tree
O(logN) operations

vruntime
used as key in the RB-Tree

gravest need for CPU

virtual runtime
struct task_struct {
    volatile long state;
    void *stack;
    unsigned int flags;
    int prio, static_prio normal_prio;
    const struct sched_class *sched_class;
    struct sched_entity se;
    ...
};

struct sched_entity {
    struct load_weight load;
    struct rb_node run_node;
    struct list_head group_node;
    ...
};

struct ofs_rq {
    ...
    struct rb_root tasks_timeline;
    ...
};

struct rb_node {
    unsigned long rb_parent_color;
    struct rb_node *rb_right;
    struct rb_node *rb_left;
};
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- The CFS tends to schedule groups of processes together – taking advantage of cache coherency, open files, open sockets etc.
- The CFS handles higher priority and long running processes fairly so no process fades away into the scheduling abyss.
CFS Problems

- Groups of processes that are scheduled may have imbalanced loads so the scheduler roughly distributes the load. When another CPU gets free it can only look at the average load of a group schedule not the individual cores. So the free CPU may not take the work from a CPU that is burning so long as the average is fine.
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- If a group of processes is running, on non adjacent cores then there is a bug. If the two cores are more than a hop away, the load balancing algorithm won’t even consider that core. Meaning if a CPU is free and a CPU that is doing more work is more than a hop away, it won’t take the work (may have been patched).
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After a thread goes to sleep on a subset of cores, when it wakes up it can only be scheduled on the cores that it was sleeping on. If those cores are now bus
Any questions? Thanks for sticking along!