CS 241 Honors
Kernel

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What to go over

- What does the (linux) kernel actually do?
- System Calls
- Linking and Loading
- Processes and Threads
- Completely Fair Scheduler

Motivation

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#include <pthread.h>

void* hello_thread(void *payload){
    write(1, "Hello world!", 12);
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int main(){
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- Exposed kernel calls are called system calls.

Kernel Call Example

- **void * kmalloc(size_t size, int flags)**
- Flags allow to users to use special kernel actions
- flags are one of many options the kernel handles.
  - `GFP_ATOMIC` - Cannot be interrupted, will not sleep. (Useful inside interrupt handlers)
  - `GFP_NOIO` - No disk I/O can be performed during request.
- 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.

Kernel Call Example

- **mmap(void *addr, size_t length, int prot, int flags, int fd, off_t offset)** Takes a file, puts in to memory.

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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 checks run level and runs the appropriate startup scripts.

System Calls

Motivation, Again

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How do we call a system call?

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

```
_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
```

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- Return value is stored in a register and returned back to userspace – we have a system call.

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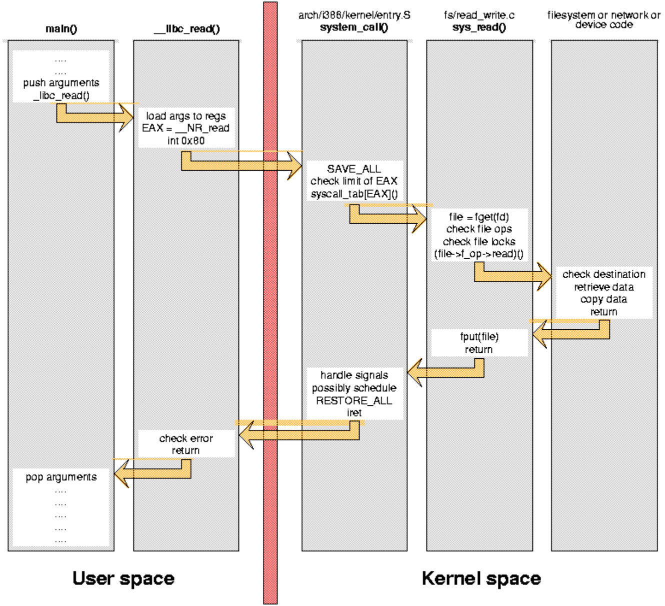

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- Other permissions accomplished via linux's capabilities macros.

Checking parameters

- CAP_SYS_BOOT - Can reboot
- CAP_CHOWN - Can arbitrarily change file UIDs
- etc... see capabilities(7)

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- Define the syscall number in <asm/unistd.h>
- Compile the syscall into the kernel image

unistd.h

```c
#ifndef _UAPI_ASM_IA64_UNISTD_H
#define _UAPI_ASM_IA64_UNISTD_H
#include <asm/break.h>
#define __BREAK_SYSCALL
    __IA64_BREAK_SYSCALL
#define __NR_ni_syscall                1024
#define __NR_exit                      1025
#define __NR_read                      1026
#define __NR_write                     1027
#define __NR_open                      1028
#define __NR_close                     1029
#define __NR_creat                     1030
#define __NR_link                      1031
#define __NR_unlink                    1032
#define __NR_execve                    1033
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Linking and Loading

Motivation, Again, Again

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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.

Cost-Benefit Analysis: Compile-Time Libraries

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Drawbacks

- Updating is often tedious
- Your executable is bigger
- Your library cannot be reused by other applications

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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?

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- Reduce the size of your executable
- That library can be used by other applications.

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- Have your code jump to the pointer and the pointer jump to the actual function

Where is the table stored

"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

So what does that mean?

- Exec generates lookup-table (PT_INTERP segment)
- Calls to a library will cause a jump to the lookup table
- Lookup table entry will redirect the program to the library function
- After execution, returns back to your program

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

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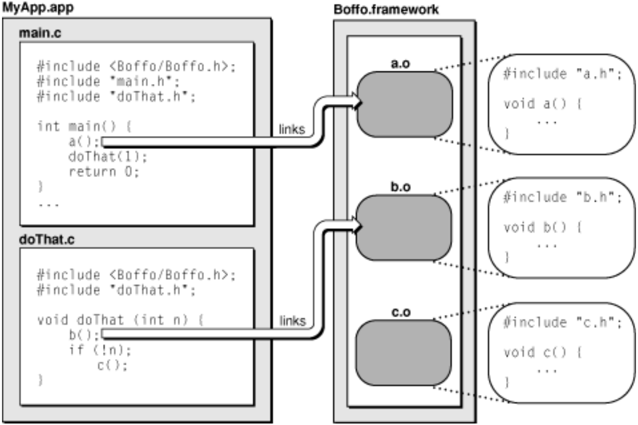

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- Some viruses redirect library calls (hint: LD_PRELOAD) thus, executing commands that the user is not aware of.

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- But the pros outweigh the cons so DLLs are here to stay.

Drawbacks: Hacking with Bugs

- Demo time!

Processes and Threads

Processes

Starting a process

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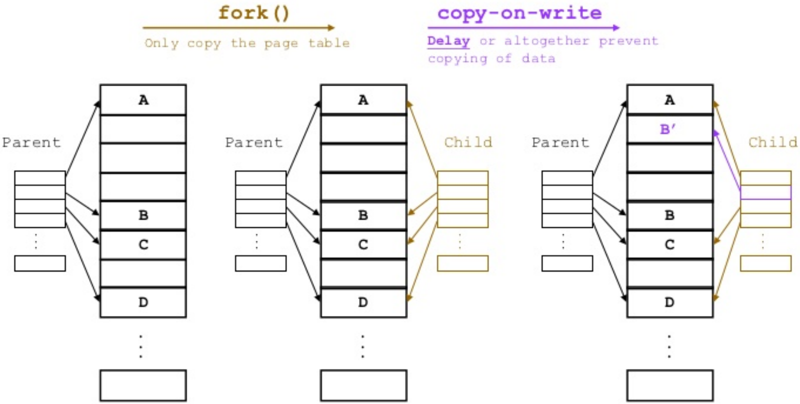
- Imagine in the linux kernel there is a struct with all of this stuff – that is what a process essentially is.

Starting a process

Process Creation – Copy-on-Write



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- 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!

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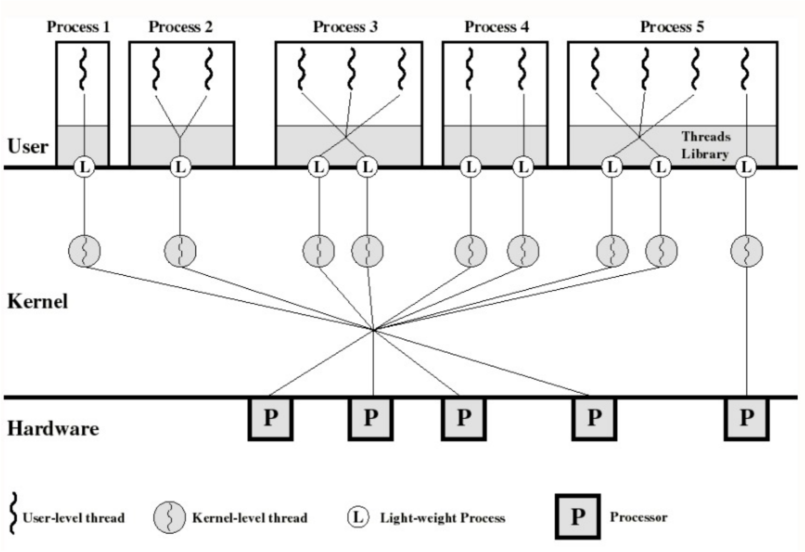
- A thread is just a process that happens to share resources (such as memory, signal disposition, open files etc.) the original process.
- This abstraction is really cool – that is why in the systems literature/papers *everything* is a process.

Threading Start - pthread_create



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- Scheduling the process is left up to the completely fair scheduler.

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- Here's a quick demo of clone!

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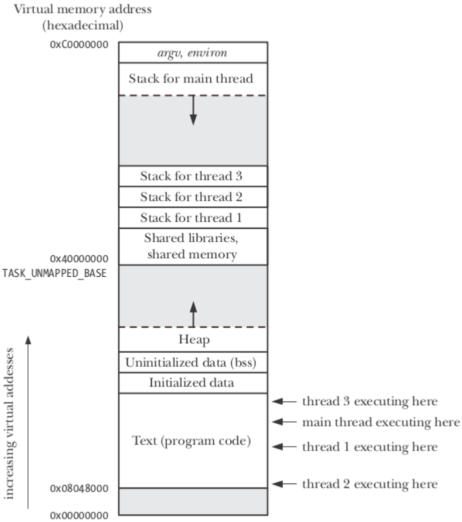

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- Race conditions! All the fun stuff from processes
- (The kernel does know it's supposed to be treated as a thread and uses group scheduling for efficiency)

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Completely Fair Scheduler

I promise last time.

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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.

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  - This way when an IO-bound process sleeps, it has a high priority when it wakes up.
- The CPU creates a Red-Black tree with the processes virtual runtime (runtime / nice_value) and sleeper fairness (if the process is waiting on something give it the CPU when it is done waiting). Since the red-black tree is self balancing pop operation is guaranteed $O(log(n))$.

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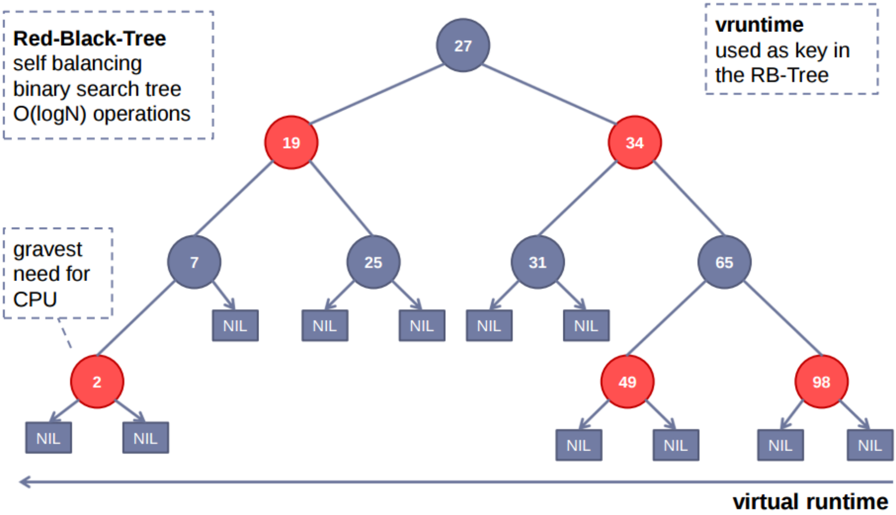
- Run top to see examples!

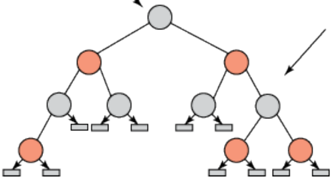

Red-Black-Tree
self balancing
binary search tree
O(logN) operations
vruntime
used as key in
the RB-Tree
27
19
34
7
25
31
65
gravest
need for
CPU
NIL
NIL
NIL
NIL
NIL
2
49
98
NIL
NIL
NIL
NIL
NIL
NIL
virtual runtime

Threads!

```
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.

CFS Problems

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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

Conclusion

Any questions? Thanks for sticking along!

Edit history

- Bhuvan Venkatesh
- Aneesh Durg

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