CS 3204
Operating Systems

Lecture 3

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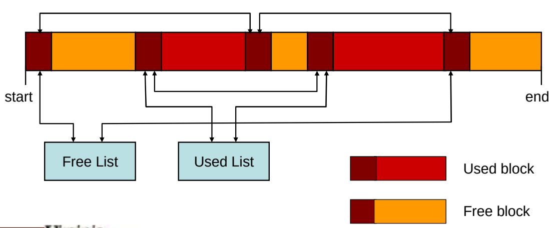
Announcements

- Submit prerequisite forms by end of class
- TA office hours posted
- Reading assignment is Chapter 1-3
- Project 0 due Sep 3, 11:59pm
- Project 1 help sessions next week, time TBA

Project 0

- Implement User-level Memory Allocator
  – Use address-ordered first-fit



Intermezzo

Just enough on concurrency to get through Project 0

A lot more later.

Concurrency

- Access to shared resources must be mediated
  – Specifically shared (non-stack) variables
- Will hear a lot more about this
- For now, simplest way to protection is mutual exclusion via locks (aka mutexes)
- For Project 0, concurrency is produced by using PThreads (POSIX Threads), so must use PThread's mutexes.
  – Just an API, idea is the same everywhere

pthread_mutex example

```
/* Define a mutex and initialize it. */
static pthread_mutex_t lock = PTHREAD_MUTEX_INITIALIZER;

static int counter = 0; /* A global variable to protect. */

/* Function executed by each thread. */
static void *
increment(void *_)
{
    int i;
    for (i = 0; i < 1000000; i++) {
        pthread_mutex_lock(&lock);
        counter++;
        pthread_mutex_unlock(&lock);
    }
}
```

Core OS Functions

- Hardware abstraction through interfaces
- Protection:
  - Preemption
  - Interposition
  - Privilege (user/kernel mode)
- Resource Management
  - Virtualizing of resources
  - Scheduling of resources

OS and Performance

- Time spent inside OS code is wasted, from user's point of view
  - In particular, applications don't like it if OS does B in addition to A when they're asking for A, only
  - Must minimize time spend in OS – how?
- Provide minimal abstractions
- Efficient data structures & algorithms
  - Example: O(1) schedulers
- Exploit application behavior
  - Caching, Replacement, Prefetching

Common Performance Tricks

- Caching
  - Pareto-Principle: 80% of time spent in 20% of the code; 20% of memory accessed 80% of the time.
  - Keep close what you predict you'll need
  - Requires replacement policy to get rid of stuff you don't
- Use information from past to predict future
  - Decide what to evict from cache: monitor uses, use least-recently-used policies (or better)
- Prefetch: Think ahead/speculate:
  - Application asks for A now, will it ask for A+1 next?

Final thought: OS aren't perfect

- Still way too easy to crash an OS
- Example 1: "fork bomb"
  - main() { for(;;) fork(); } stills brings down most Unixes
- Example 2: livelock
  - Can be result of denial-of-service attack
  - OS spends 100% of time servicing (bogus) network requests
- Example 3: buffer overflows
  - Either inside OS, or in critical system components – read most recent Microsoft bulletin.

Things to get out of this class

- (Hopefully) deep understanding of OS
- Understanding of how OS interacts with hardware
- Understanding of how OS kernel interacts with applications
- Kernel Programming Experience
  - Applies to Linux, Windows, Mac OS-X
  - Debugging skills
- Experience with concurrent programming
  - Useful in many other contexts (Java, C#, …)

Processes & Threads

Overview

- Definitions
- How does OS execute processes?
  - How do kernel & processes interact
  - How does kernel switch between processes
  - How do interrupts fit in
- What's the difference between threads/processes
- Process States
- Priority Scheduling

Process

- These are all possible definitions:
  – A program in execution
  – An instance of a program running on a computer
  – Schedulable entity (*)
  – Unit of resource ownership
  – Unit of protection
  – Execution sequence (*) + current state (*) + set of resources

(*) can be said of threads as well

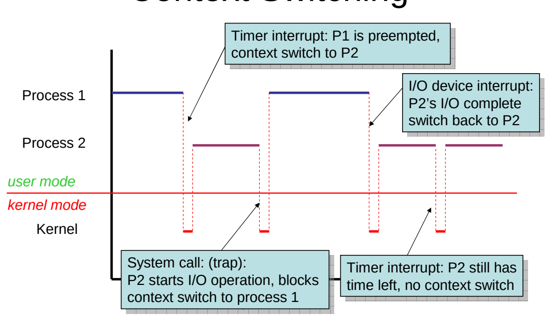
Alternative definition

- Thread:
  – Execution sequence + CPU state (registers + stack)
- Process:
  – n Threads + Resources shared by them (specifically: accessible heap memory, global variables, file descriptors, etc.)
- In most contemporary OS, n >= 1.
- In Pintos, n=1: a process is a thread – as in traditional Unix.
  – Following discussion applies to both threads & processes.

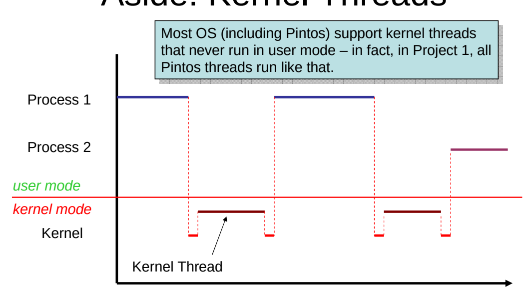
Context Switching

- Multiprogramming: switch to another process if current process is (momentarily) blocked
- Time-sharing: switch to another process periodically to make sure all process make equal progress
  – this switch is called a context switch.
- Must understand how it works
  – how it interacts with user/kernel mode switching
  – how it maintains the illusion of each process having the CPU to itself (process must not notice being switched in and out!)

Context Switching



Aside: Kernel Threads



Careful: "kernel thread" not the same as kernel-level thread (KLT) – more on KLT later

Mode Switching

- User → Kernel mode
  - For reasons external or internal to CPU
- External (aka hardware) interrupt:
  - timer/clock chip, I/O device, network card, keyboard, mouse
  - asynchronous (with respect to the executing program)
- Internal interrupt (aka software interrupt, trap, or exception)
  - are synchronous
  - can be intended: for system call (process wants to enter kernel to obtain services)
  - or unintended (usually): fault/exception (division by zero, attempt to execute privileged instruction in user mode)
- Kernel → User mode switch on iret instruction

Context vs Mode Switching

- Mode switch guarantees kernel gains control when needed
  - To react to external events
  - To handle error situations
  - Entry into kernel is controlled
- Not all mode switches lead to context switches
  - Kernel code's logic decides when – subject of scheduling
- Mode switch always hardware supported
  - Context switch (typically) not – this means many options for implementing it!