**Administrivia**

- Project 2: Userprog was due last night
- Midterm: *Tuesday, Feb 8*
- Project 3: VM is due *Thursday, Feb 24*

- In-class midterm, same place, same time
  - Local SCPD students are encouraged to take exam in person
- Midterm is open book and notes, closed computers
- Exam grade is max, but you must take the midterm max
  \( \text{max}( \text{midterm} > 0 \ ? \ \text{final} : 0, \ (\text{midterm} + \text{final}) / 2) \)
- Covers all material up to now.

**Lectures**

- Introduction
- Processes & Threads
- Concurrency
- Scheduling
- Advanced scheduling
- Synchronization
- Linking
- Virtual memory HW
- Virtual memory OS
- Memory allocation

**Introduction**

- O Ses make hardware useful to the programmer
- O Ses Provide:
  - Well-defined hardware abstraction (through syscalls)
  - Resource allocation (e.g. CPU time, files)
  - Protection (e.g. memory)
- Execution Contexts:
  - user level
  - kernel process context (e.g. syscalls)
  - kernel w/o process context (e.g. timer interrupt)
- Throughput vs Fairness

**Processes & Threads**

- A process is an instance of a program running
  - Process Control Block (PCB)
  - Allocated Resources (e.g. files, memory mappings)
  - Credentials (user, group)
- A thread is a schedulable execution context
  - Stack, registers, etc. Context Switch!
  - Provide concurrency
  - 1 : 1 – multiprocessor, everything goes through kernel (slow)
  - n : 1 – single processor, user library
  - n : m – multiprocessor, managing multiple schedulers
- Scheduling – How to pick which process to run
  - balance fairness, priority, deadlines, throughput, efficiency

**Concurrency**

- Sequential Consistency (SC): execute in order written
  - Maintain program order in processor, ensure write atomicity
  - SC thwarts hardware and compiler optimizations
- Data races (examples in lecture)
- mutual exclusion, progress, and bounded waiting
  - Peterson’s Solution works (for only fixed n threads)
- synchronization primitives (mutex)
  - multiple synch primitives (e.g. lock, sema, condvar in pintos)
  - implementation abstracted away from programmer
  - disable interrupts (only works in uniprocessor)
  - spinlocks need atomic read-write ops, (test_and_set(), xchg())

**Scheduling**

- Criteria: throughput, turnaround time, response time
  - secondary criteria: CPU utilization, waiting time
- processes exhibit bursts of I/O and computation
- strawman examples (analyze in terms of criteria)
  - FCFS: simple, but problematic (e.g. convoy effect)
  - SJF: minimizes waiting time (and RT), but starves longer jobs
  - RR: fair and prevents starvation (bad for same size jobs)
- Costs of context switching
  - CPU, cache, TLB, page swapping, buffer cache, etc.
- Priority Scheduling
  - inter-thread dependencies, priority donation (inversion!)
  - BSD: tunable, prevents starvation, no donation
Advanced Scheduling

- Linux 2.6 scheduler, task lists
- Lottery Scheduling: tickets for CPU usage
  - ticket donation, compensation, splitting, etc.
  - latency prediction? (multimedia) error?
- Stride Scheduling: ideas from lottery and WFQ
  - lessens error and latency
- Borrowed Virtual Time:
  - effective virtual time, weights, warp factor
- SMART: separate importance and urgency
  - manages real-time conventional tasks
  - schedules based on (priority, biased virtual finishing time)
- Linux today: pluggable schedulers (real-time, CFS)

Synchronization

- deal with multiple readers and writers
- shared locks: multiple reader, single writer
  - implemented with spinlocks; may lead to starvation
- relaxed consistency model: memory barriers in locks
- cc-NUMA: each CPU has fast access to close memory
  - spinlocks are unfair, and cause lots of traffic on mem bus
  - either avoid spinlocks: single writer, non-blocking (CAS)
  - or use better spinlock: MCS lock (spins on local memory)
- Locks & scheduling, expensive to switch to kernel
  - futex: ask kernel to sleep only if mem hasn’t changed
- Deadlock: mutex, no preempt, hold and wait, cycle

Linking

- referring to and merging separate name spaces
- Compiler produces:
  - Symbolic references to external data/functions
  - Table of locally defined data/functions
- Linker
  - Pass 1: Arrange segments in memory
  - Pass 2: Patch addresses (relocate, replace symbols)
- Dynamic vs Static
  - dynamic linking: defer loading code until needed
  - static libs: at same address in programs
  - dynamic libs: let any library be loaded at any VA
- code and data segments

Virtual Memory HW

- issues of protection, transparency, resources
- Give each program its own virtual address space
- Segmentation: base + bounds registers
  - simple, not transparent, external fragmentation
- Paging: map virtual pages to physical pages
  - simplifies alloc and free, transparent, internal fragmentation
- x86 page translation

Virtual Memory OS

- more virtual memory than physical memory
  - save unused virtual pages to disk
  - on use, swap them in
  - what to fetch? what to eject?
- LRU: Least Recently Used
  - clock algorithm: use accessed bit
- Global vs Local allocation
- Memory Mapping: mmap
- Thrashing and working set

Memory Allocation

- dynamic allocation’s main problem is fragmentation
  - different lifetimes, different sizes
- decisions: where in free memory to put a block?
  - there will always be pathological cases
  - best fit: allocate to leave the smallest fragment
  - first fit: pick the rst block that fits
- Other:
  - memory usage patterns (peaks, ramp)
  - fault resumption = power
  - distributed shared memory
  - garbage collection
  - reference counting