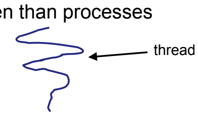
CSE 451: Operating Systems
Autumn 2013

Module 5a
User-Level Threads & Scheduler Activations

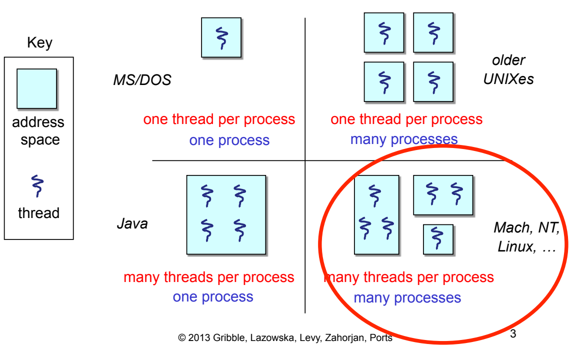
Dan Ports
drkp@cs.washington.edu
276 Allen Center

Threads

- Support concurrency/parallelism within an application, e.g., a web server that handles multiple concurrent requests
- Key idea:
  - separate the concept of a process (address space, OS resources)
  - … from that of a minimal "thread of control" (execution state: stack, stack pointer, program counter, registers)
- Threads are more lightweight, so much faster to create and switch between than processes



The design space



Implementing Threads

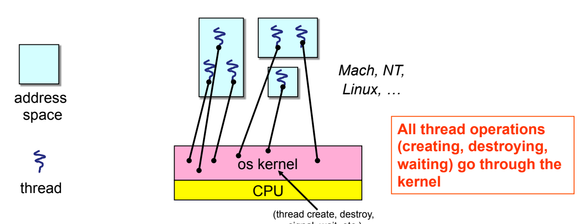
Two approaches to implementing threads:
- Kernel threads
- User-level threads

Today:
- quick review of kernel threads
- more about user-level threads
- scheduler activations: adding kernel support for better user-level threads

Kernel threads

- OS now manages threads *and* processes / address spaces
  - all thread operations are implemented in the kernel
  - OS schedules all of the threads in a system, just like processes
- Kernel threads are cheaper than processes
  - less state to manage: just the processor context (PC, SP, registers)
- Switching between kernel threads
  - trap into kernel
  - kernel saves running thread's processor context in TCB
  - kernel picks new thread to run
  - kernel loads new thread's registers, jumps to its saved PC
- Call this **1:1 scheduling**
  - 1 app thread per 1 kernel scheduled entity

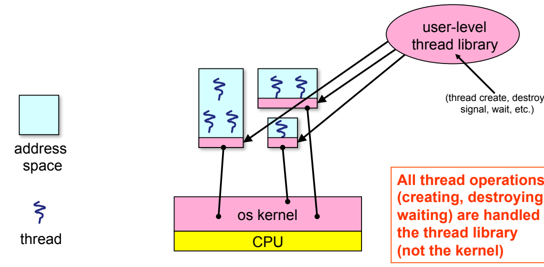
Kernel threads



User-level threads

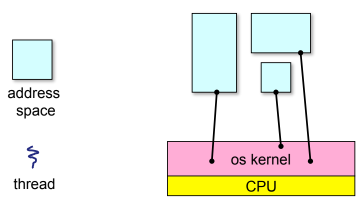
- Can implement threading entirely in user space
  - run many user-level threads in ***one*** kernel thread
  - call this **N:1 threading**
- Keep separate stack & processor context for each thread, in user space
- User-level thread lib schedules and switches threads
- Switching between threads entails:
  - library saves running thread's processor context
  - library picks a new thread to run
  - library restores new thread's context, jumps to saved PC
- Pretty much same as before, but kernel not involved!

User-level threads



All thread operations (creating, destroying, waiting) are handled by the thread library (not the kernel)

User-level threads: what the kernel sees



Kernel is oblivious to user-level threads!

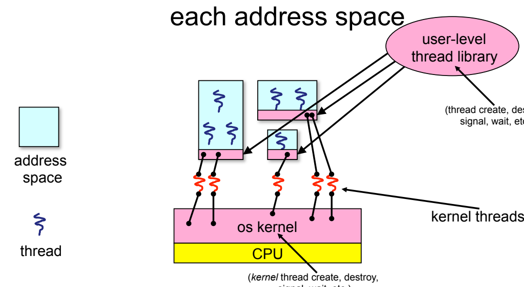
User-level vs. kernel threads

- User level threads are faster
  - Faster to switch between threads
    - Round-trip to kernel: about 500 ns
    - Switching in user space: closer to 5 ns (like a function call)
  - Faster to create and destroy threads
- Some problems with user-level threads
  - Can we take advantage of more than one processor?
  - What if one of the threads does I/O, and blocks?
- Basic problem: lack of information in each scheduler
  - Kernel doesn't know about user-level threads
  - User-level scheduler doesn't know about other processes

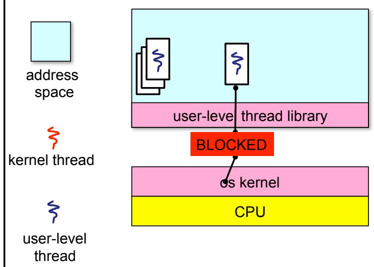
User-level scheduling, multiprocessor style

- If all user-level threads run in one kernel thread, only one can run at a time!
- Most machines have more than 1 CPU core now…
- Solution: use more than one kernel thread!
  1 kernel thread per processor (N:M threading)
- User-level scheduler in each kernel thread chooses which user-level thread to run
- Kernel schedules the kernel-level threads, but is still oblivious to what's going on at user level

Multiple kernel threads "powering" each address space



What if a thread tries to do I/O?



- **The kernel thread "powering" it is lost for the duration of the I/O operation!**
- Even if other user-level threads are ready, can't run them!
- Kernel doesn't know there's anything else ready to run
- Same problem with other blocking ops (e.g. page faults)

Scheduler Activations

- Support for user-level threads without these problems
- Basic idea:
  - let the kernel scheduler and the user-level scheduler coordinate with each other
  - involves communication from user-level to OS *and back*
- From UW: [Anderson, Bershad, Lazowska, Levy, '92]
- Lots of impact on practical systems (more info later)

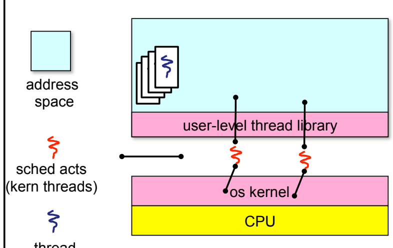
Scheduler Activations: 2-way communication

- OS and user-level schedulers give each other hints
- User-level scheduler tells the kernel what it needs
  - request more CPUs (might not get them!) or release them
- Kernel calls user-level scheduler to notify it of events
  - more/fewer CPUs available to process
  - thread blocked on I/O, or unblocked when I/O finished
- Kernel to user-space communication: *upcall*
  - A bit unusual: usually user-space makes syscalls to kernel!
  - But this is also how signals work, and like an interrupt

Scheduler Activations

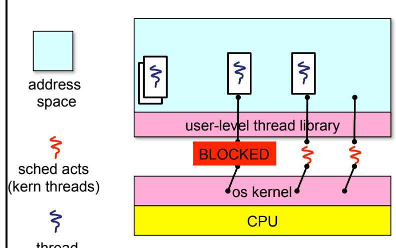
- "Scheduler activations" replace kernel threads
- A scheduler activation is like a kernel thread
  - has a separate stack and processor context
  - can be scheduled on a CPU
- …but different:
  - If the kernel interrupts an activation, it doesn't restart it where it left off (like a thread)
  - Instead, it restarts execution *in the user-level scheduler*
  - User-level scheduler can then decide which thread it wants to run on that CPU

Starting a new process



- New thread starts executing in thread lib
- User-level sched picks thread to run, starts it
- Can reschedule a different user-level thread later

Blocking I/O



- Thread blocked on I/O
- Kernel creates *new* activation – starts in the thread lib, and picks a new thread to run
- When I/O finishes, old thread doesn't resume
  - Kernel interrupts an activation, lets the scheduler pick what to run

Performance

- Is all that really faster than kernel-level threads?
  - Not really – lots of upcalls, not especially cheap
- **But what we just saw were the uncommon cases!**
- When threads aren't blocking on I/O, it's just user-level thread management!
  - orders of magnitude faster than kernel-level threads
  - and now we have an answer for the blocking I/O problem
- **"Optimize the common case" is a key lesson of computer system design!**

The state of threading today

- Scheduler activations pretty widely used:
  - Various Unixes: FreeBSD, NetBSD, Solaris, Digital UNIX (some now defunct)
  - Windows 7 User-Mode Scheduling
  - Recent research on multicore Oses
- Trend back to kernel-scheduled threads
  - Linux, FreeBSD
  - performance getting better, and less complex
- User-level threading still popular in massively-parallel applications

Summary

- You really want multiple threads per address space
- Kernel threads are much more efficient than processes, but they're still not cheap
  - all operations require a kernel call and parameter validation
- User-level threads are:
  - really fast/cheap
  - great for common-case operations
    - creation, synchronization, destruction
  - can suffer in uncommon cases due to kernel obliviousness
    - I/O and other blocking operations
- Scheduler activations are an answer

- The problem that scheduler activations solve:
  - Remember: I/O operations are blocking
  - If a user-level thread does I/O, the kernel thread "powering" it is lost for the duration of the I/O operation!
    - The kernel thread blocks in the OS, as always
    - Can't run a different user-level thread
  - Same problem w/ other blocking ops (e.g., page faults)
  - Again: kernel doesn't know there are user threads, so doesn't know there's something else it could run
  - Scheduler activations return control to the user address space (to the user-level thread scheduler)