

CSE 451: Operating Systems

Winter 2025

Module 6

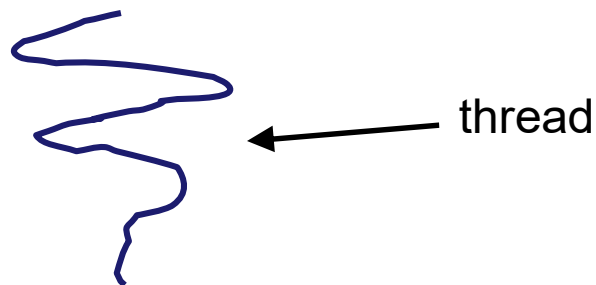
User-Level Threads &

Scheduler Activations

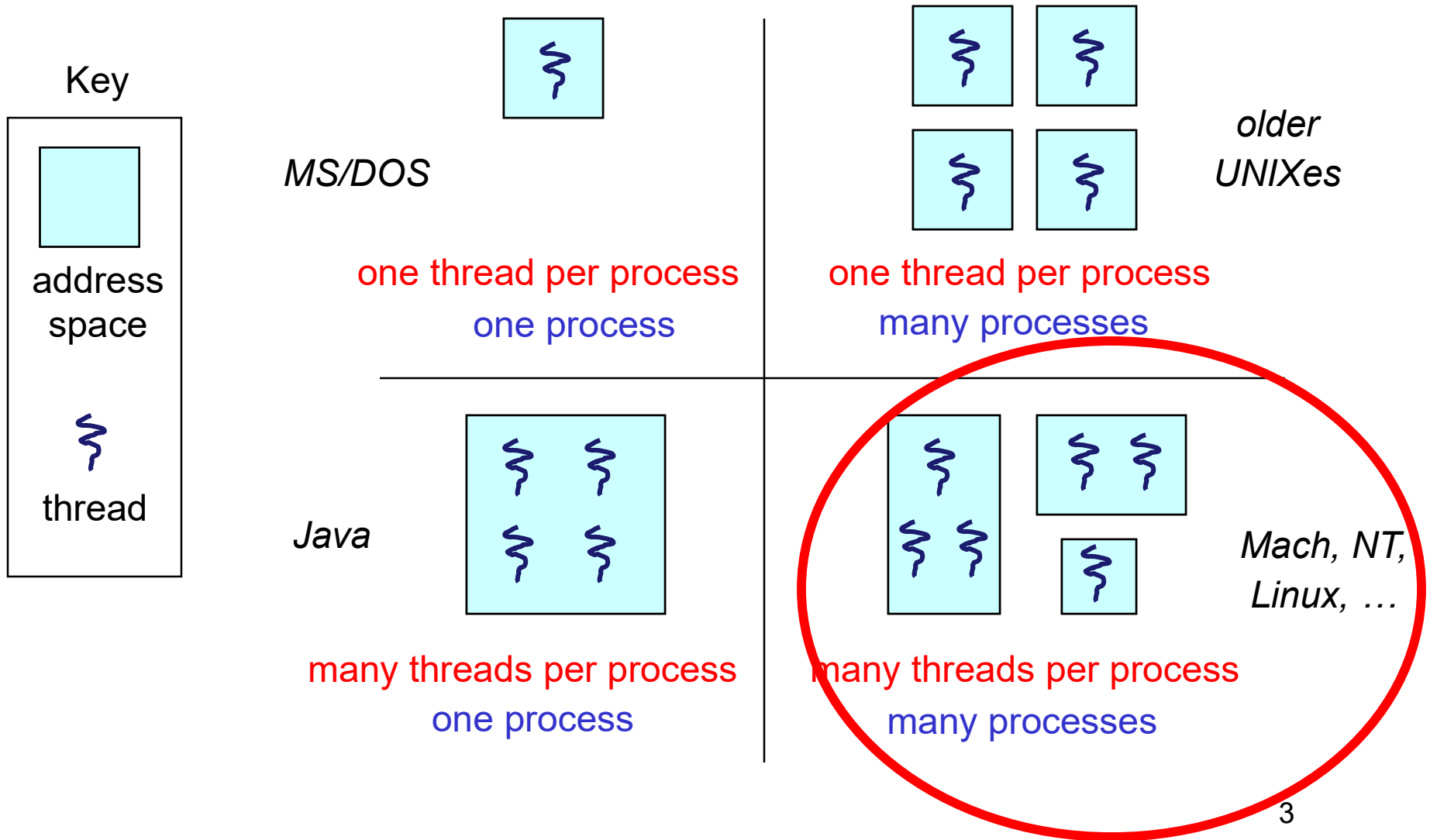
Gary Kimura

Threads

- Support concurrency/parallelism within an application e.g. a web server that
- 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

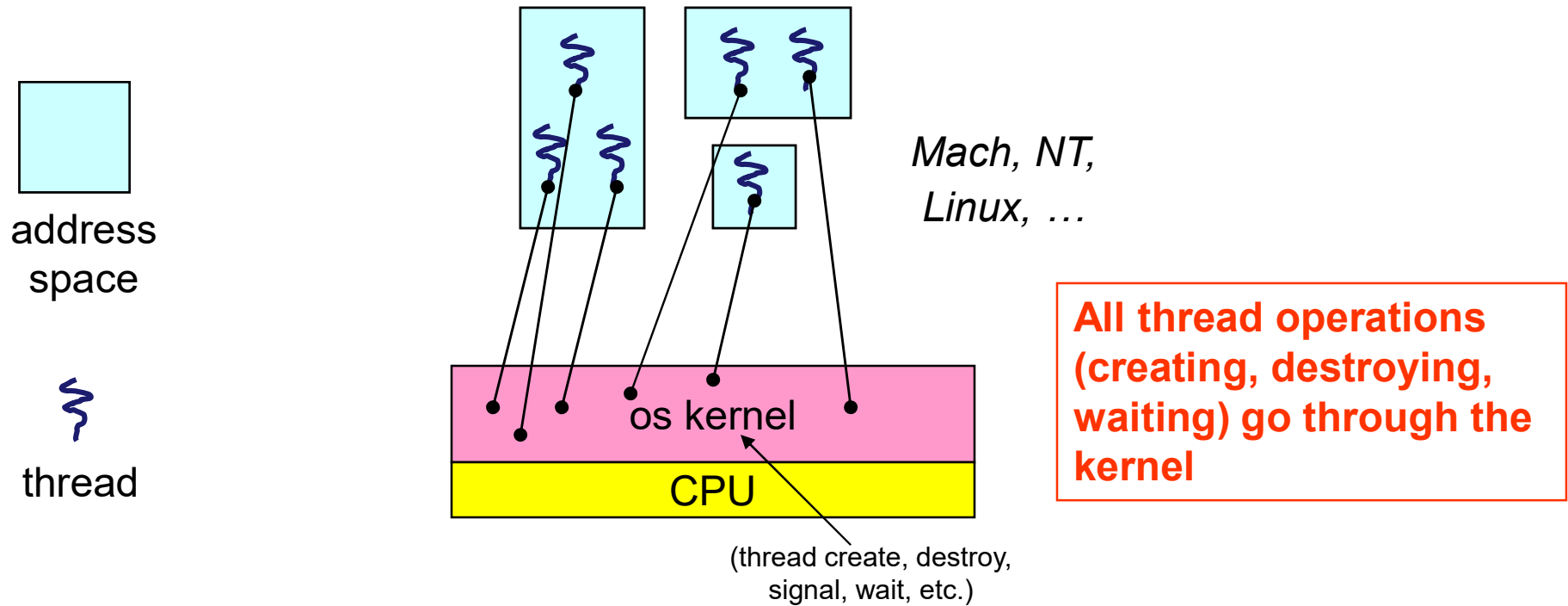
Today:

- 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

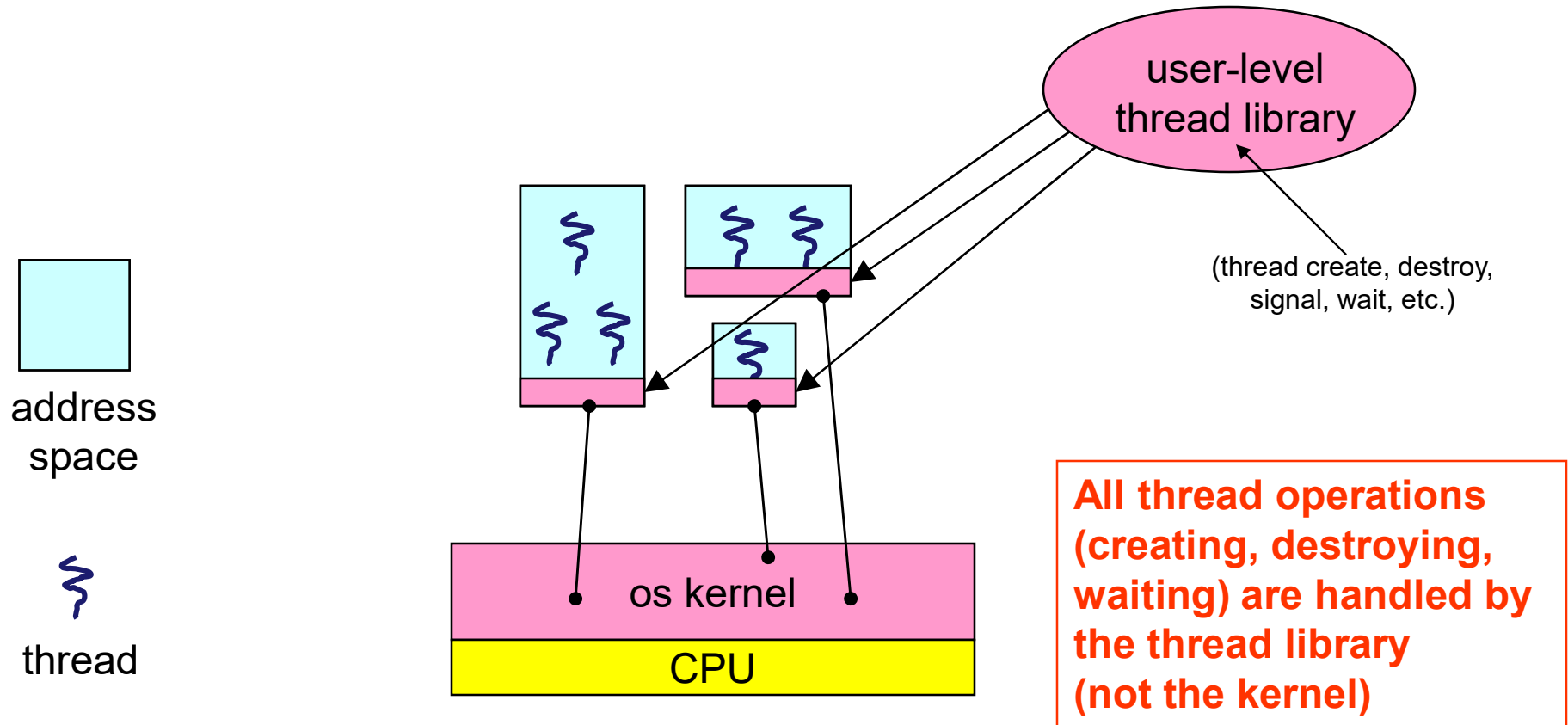
Kernel threads



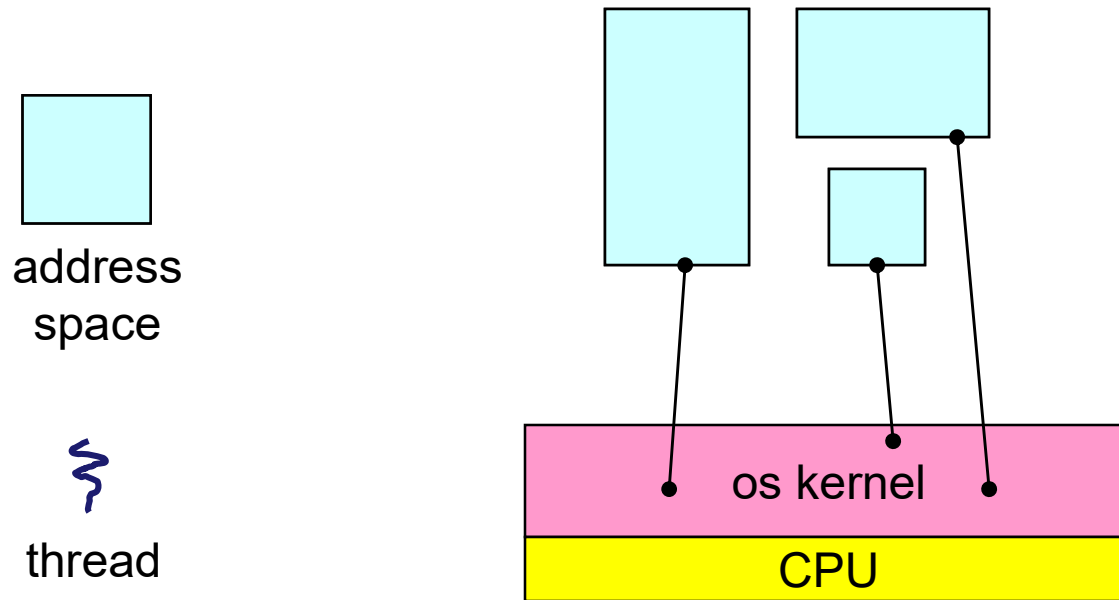
User-level threads

- 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



User-level threads: what the kernel sees



Kernel is oblivious to user-level threads!

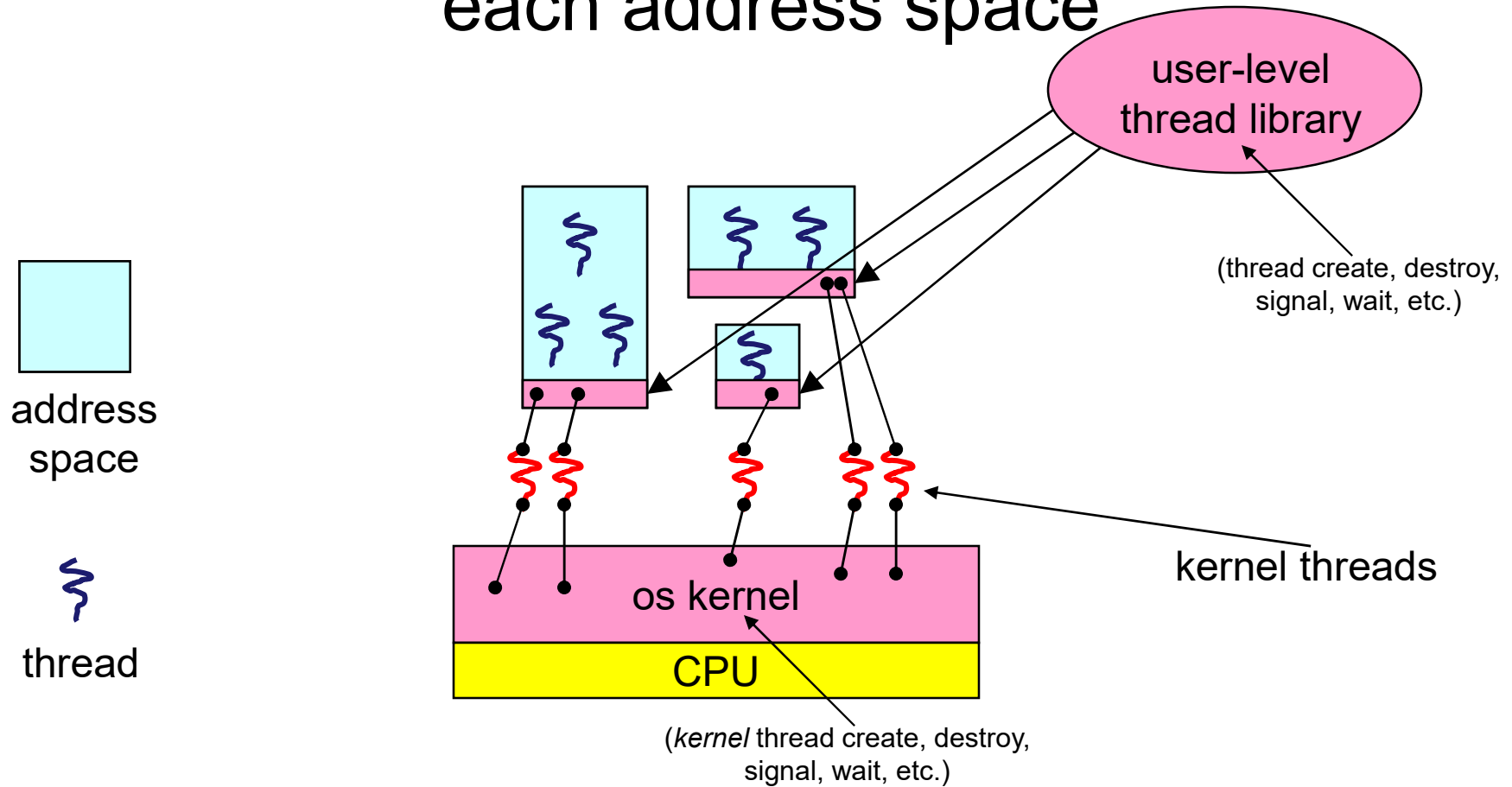
User-level vs kernel threads

- 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

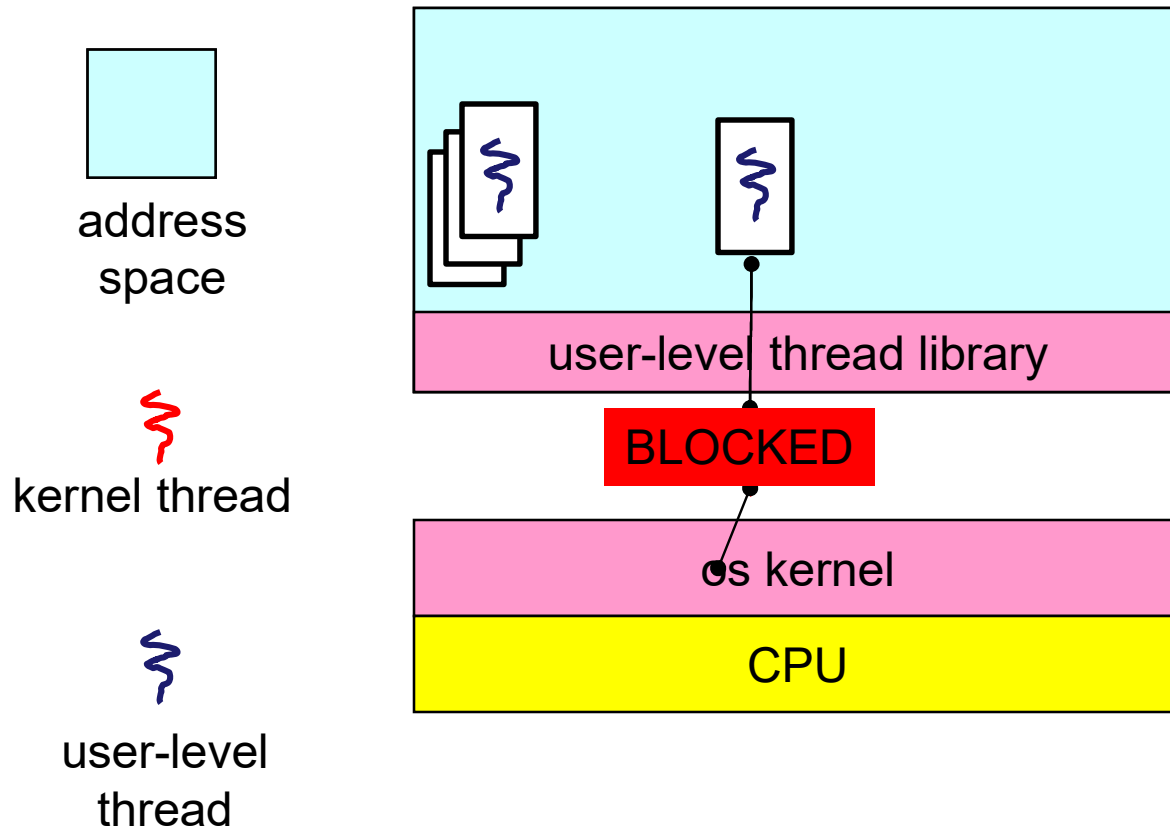
User-level scheduling, multiprocessor style

- 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, '92]
- Lots of impact on practical systems (more info later)

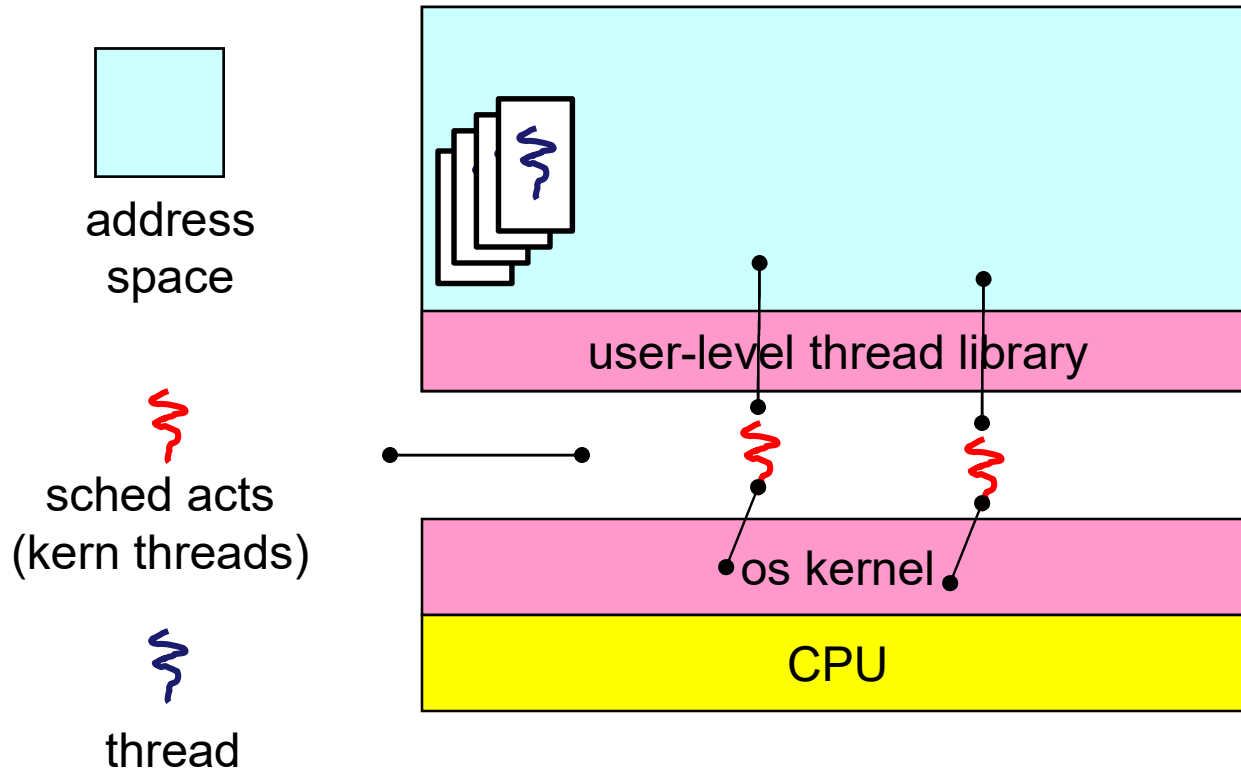
Scheduler Activations: 2-way communication

- 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

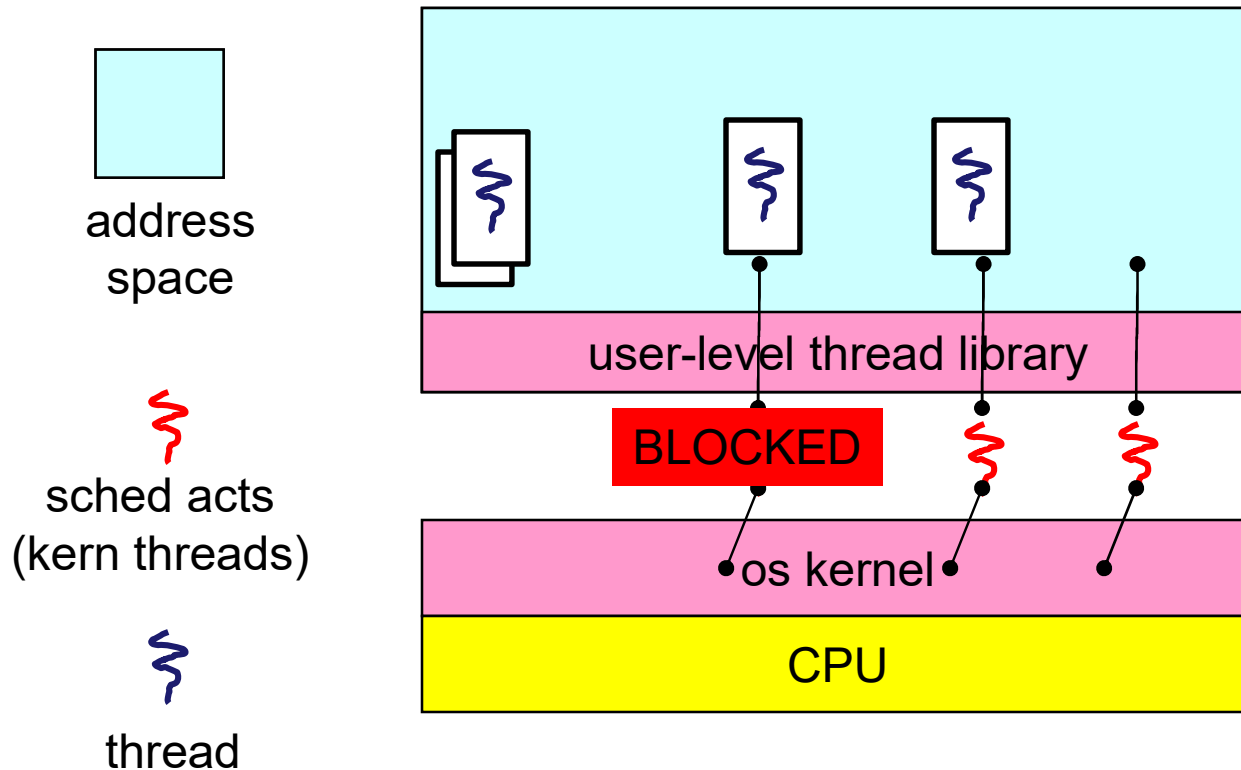
- “Scheduler activations” replace kernel threads
- A scheduler activation is like a kernel thread
 - has a separate stack and processor context
 - can be scheduled on a CPU
- ...but different:
 - If the kernel interrupts an activation, it doesn't restart it where it left off (like a thread)
 - Instead, 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

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

- 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

What if a thread tries to do I/O?

- Remember: I/O operations are blocking
- 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