THE UNIVERSITY of EDINBURGH informatics

Operating Systems (INFR10079)

2020/2021 Semester 2

Threads

(User and kernel level threading)

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Chapter 4.3 (all), 4.4, 4.4.1, 4.5, 4.5.1, 4.5.2, 4.5.3, 4.6, 4.6.1, 4.6.2, 4.6.3, 4.6.4, 4.7, 4.7.2

Overview

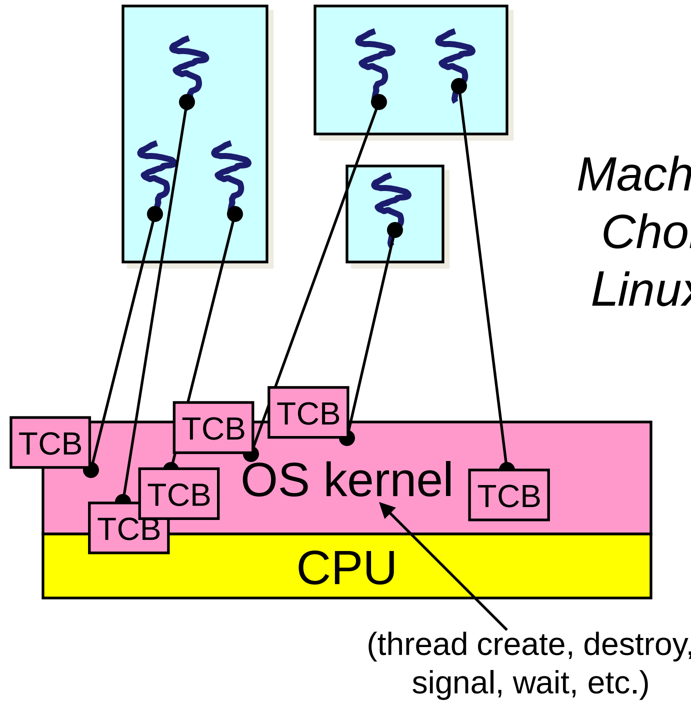
- Kernel-level Threading
- User-level Threading
- Explicit and Implicit Thread Interfaces

Who is Creating/Managing Threads?

- **OS kernel** is responsible for creating/managing threads
  - The kernel call to create a new thread would
    1. Allocate an execution stack within the process address space
    2. Create and initialize a Thread Control Block (TCB)
       - Stack pointer, program counter, register values
    3. Stick it on the ready queue

- This is **kernel-level threading**, or **1:1** threading
  - There is a “thread name space”
    - Thread’s identifier (TID)
    - TIDs are integers, similar to PIDs
    - For each thread, a TCB, similar to PCB

Kernel-level Threading #1



Mach, NT, Chorus, Linux, …

There are still PCBs to describe each address space and their OS resources

Kernel-level Threading #2

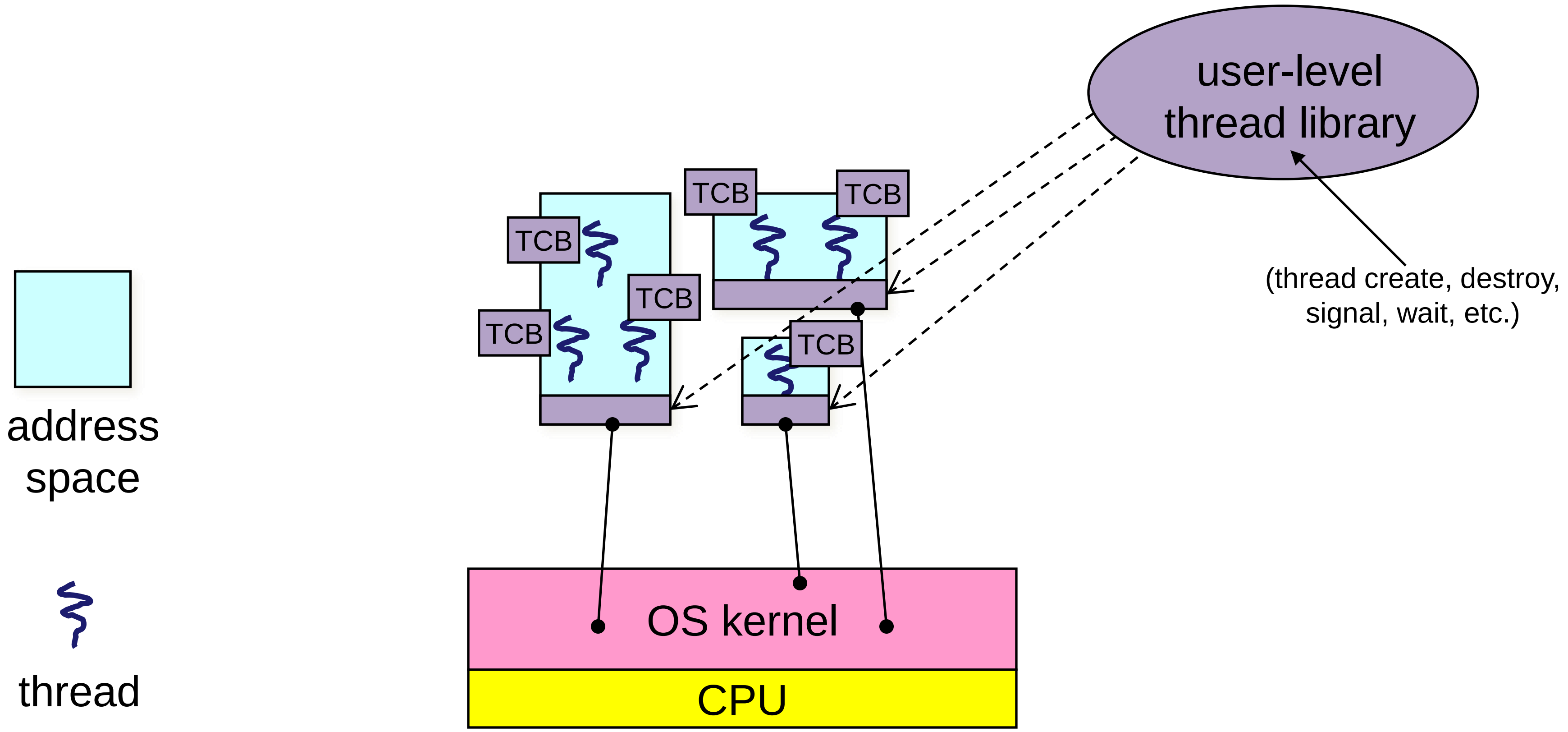
- OS manages **threads and processes**
  - All thread operations implemented in the kernel
  - OS schedules all threads in a system
    - If one thread in a process blocks (e.g., on I/O)
      - the OS knows about it, can run other threads from that process
    - Possible to **overlap I/O** and computation **within a process**
- (Kernel-managed) **Threads** are **cheaper than processes**
  - Less state to allocate and initialize
- But, **pretty expensive** for fine-grained use
  - Orders of magnitude more expensive than a procedure call
  - Thread operations are **system calls**
    - Context switch
    - Argument checks
  - Must maintain kernel state for each thread

User-level Threading

- **Alternative** to kernel-level threading
- Threads managed at the user level, **within the process**
  - **A library** into the program manages the threads
    - The thread manager **doesn’t** need to manipulate **address spaces** (which only the kernel can do)
    - Threads differ (roughly) only in hardware contexts (PC, SP, registers), which can be manipulated by user-level code
    - The **thread package** multiplexes user-level threads in a process

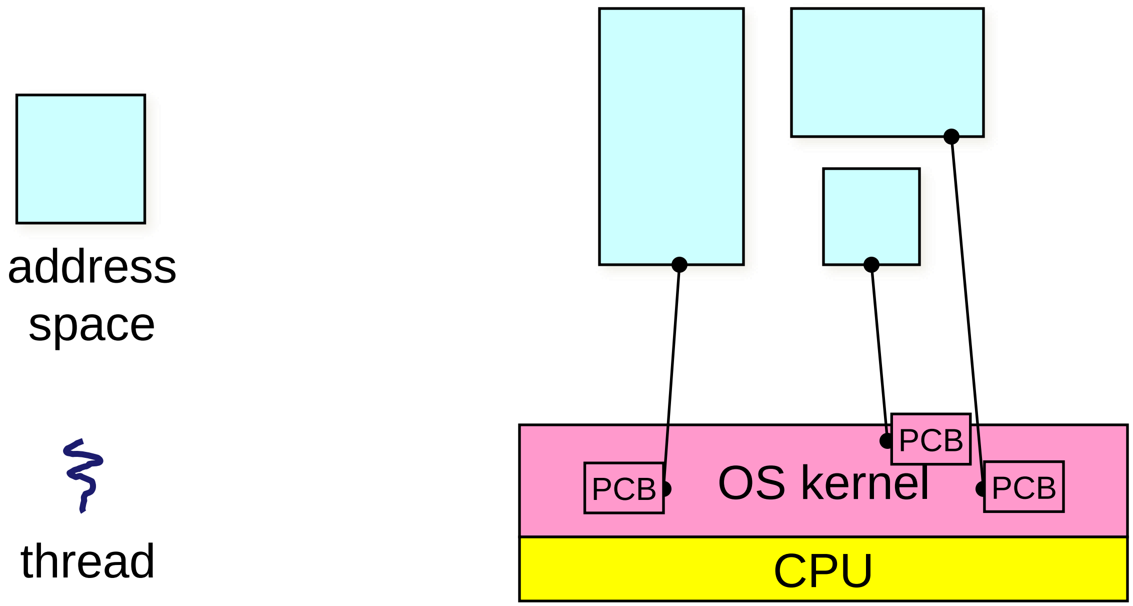
- This is **user-level threading**, or **1:N** threading
  - Kernel is unaware of threads existence
  - Thread control blocks (TCBs) at user level

User-level Threading



Now thread id is unique within the context of a process, not unique system-wide

User-level Threading: What the Kernel Sees



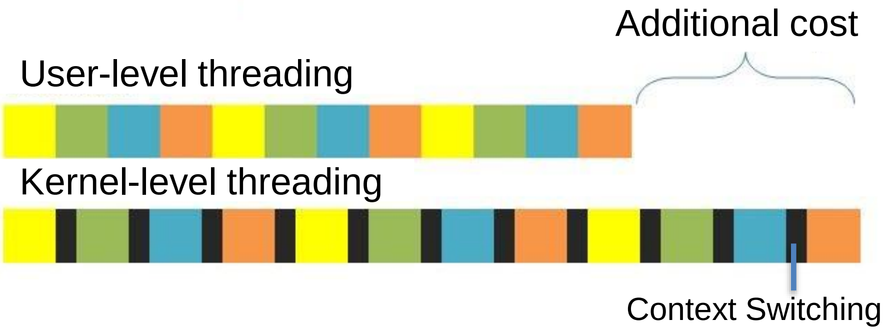
Why User-level Threading?

- User-level threading is **lightweight** and **fast**
  - Managed entirely by user-level library
  - Each thread is represented simply by
    - PC, registers, a stack
    - Small thread control block
  - Creating a thread, switching between threads, and synchronizing threads are done via procedure calls
    - **No kernel involvement** is necessary

- User-level threading **operations** can be 10-100x faster than kernel threads

(Old) Performance Example

- On a 700MHz Intel Pentium, running Linux 2.2.16 (only the relative numbers matter; ignore the ancient CPU and kernel)



  – Processes
    - **`fork/exit`**: 251 μs
  – Kernel-level threading
    - **`pthread_create()/pthread_join()`**: 94 μs **(2.5x faster)**
  – User-level threading
    - **`pthread_create()/pthread_join`**: 4.5 μs **(another 20x faster)**

User-level Threading Implementation

1. **OS schedules** the process
2. Process executes user code (at user-level)
   - Including the thread support library and its thread scheduler
3. **Thread scheduler** determines when a user-level thread runs
   - Uses queues to keep track of what threads do (run, ready, wait, …)
     - Like the OS, but in user-space as a library
4. **Context switch** at the user-level
   1. Save context of currently running thread
      - push CPU state onto thread stack
   2. Restore context of the next thread
      - pop CPU state from next thread's stack
   3. Return as the new thread
      - execution resumes at PC of next thread
   - It works at the level of the **procedure calling convention**
     - **No changes** to memory mapping required

How to Keep a User-level Thread from Hogging the CPU?

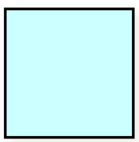
- Strategy 1: **force everyone** to cooperate
  - A thread willingly gives up the CPU by calling **`yield()`**
  - **`yield()`** calls into the scheduler, which context switches to another ready thread
  - What happens if a thread never calls **`yield()`**?

- Strategy 2: use **preemption**
  - Scheduler requests that a **timer interrupt** be delivered by the OS periodically
    - Usually delivered as a UNIX signal (`man signal`)
    - Signals are just like software interrupts, but delivered to user-level by the OS instead of delivered to OS by hardware
  - At each timer interrupt, scheduler gains control and context switches as appropriate

What if a Thread Tries to do I/O?

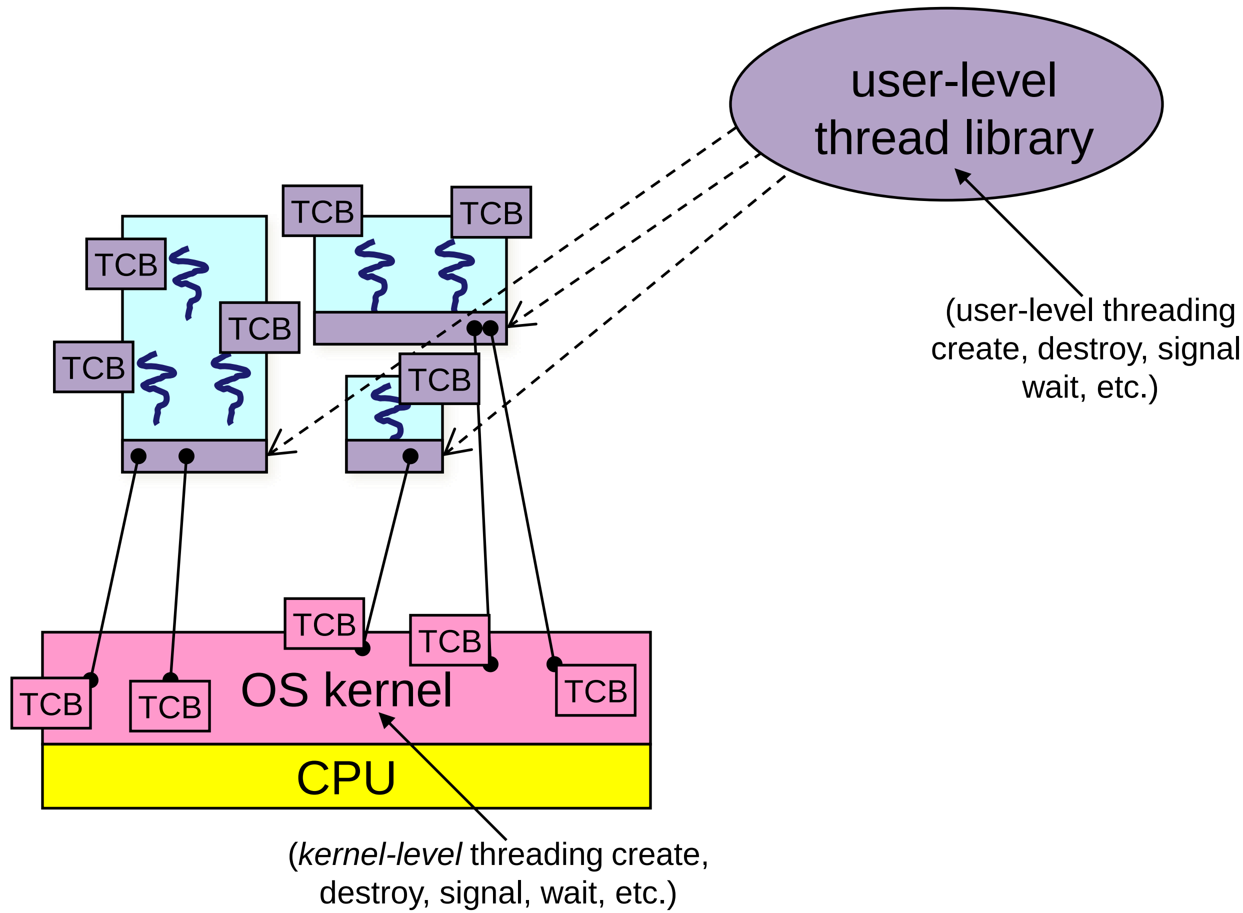
- The process “powering” it **“is lost”** for the duration of the (synchronous) I/O operation!
  - The process blocks in the OS
  - The OS is not aware of the threads, OS sees one thread/process
  - No process’ thread makes progress
  - Other processes can progress tho
- This is **not the case** with kernel-level threading
  - Kernel knows about each process’ thread
  - Another thread can be schedule
- *Can kernel-level threading and user-level threading be merged?*

The N:M Threading Model
(Merges 1:1 and 1:N Models)



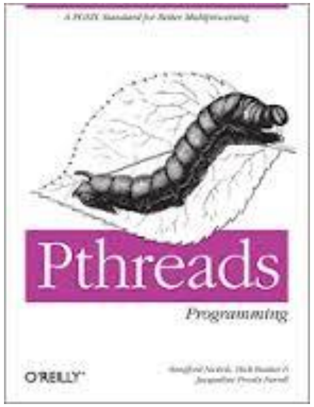
address space

thread



Explicit Thread Interface (User- or Kernel- level)

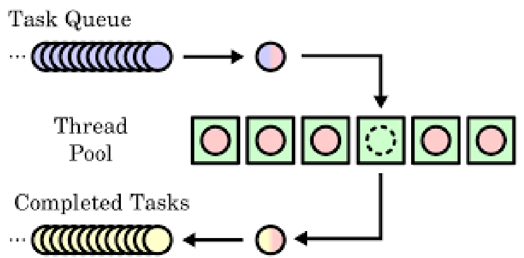
- POSIX Thread (pthread) APIs
  - `ret = pthread_create(&t, attributes, start_procedure)`
    - Creates a new thread of control
    - New thread begins executing at start_procedure
  - `pthread_cond_wait(condition_variable, mutex)`
    - The calling thread blocks on a conditional variable
  - `pthread_signal(condition_variable)`
    - Starts a thread waiting on the condition variable
  - `pthread_exit()`
    - Terminates the calling thread
  - `pthread_join(t)`
    - Waits for the named thread to terminate



Implicit Thread Interface (User-level)

- Thread management to library/runtime
- Identify application's tasks, not threads
- Compiler-level support (in most cases)
  - Code annotation
  - Pragmas
  - Templates

- Examples
  - Thread pools
  - Fork-join
  - OpenMP
  - Grand Central Dispatch
  - Intel Thread building blocks



Summary

- Multiple threads per process (and address space)
  - **Real resource sharing** for multiple instruction flows
- **Kernel-level threading (1:1)** implemented in OS kernel
  - All operations require a kernel call and parameter validation
  - Enables concurrency and parallelism
- **User-level threading (1:N)** implemented in application
  - Cheaper and faster
  - Enables concurrency
  - Great for common-case operations
    - Creation, synchronization, destruction
  - May block all threads on the same process
    - Blocking IO
- **N:M threading**
  - Best of both the previous