Part II
Processes and Threads
Threads Basics

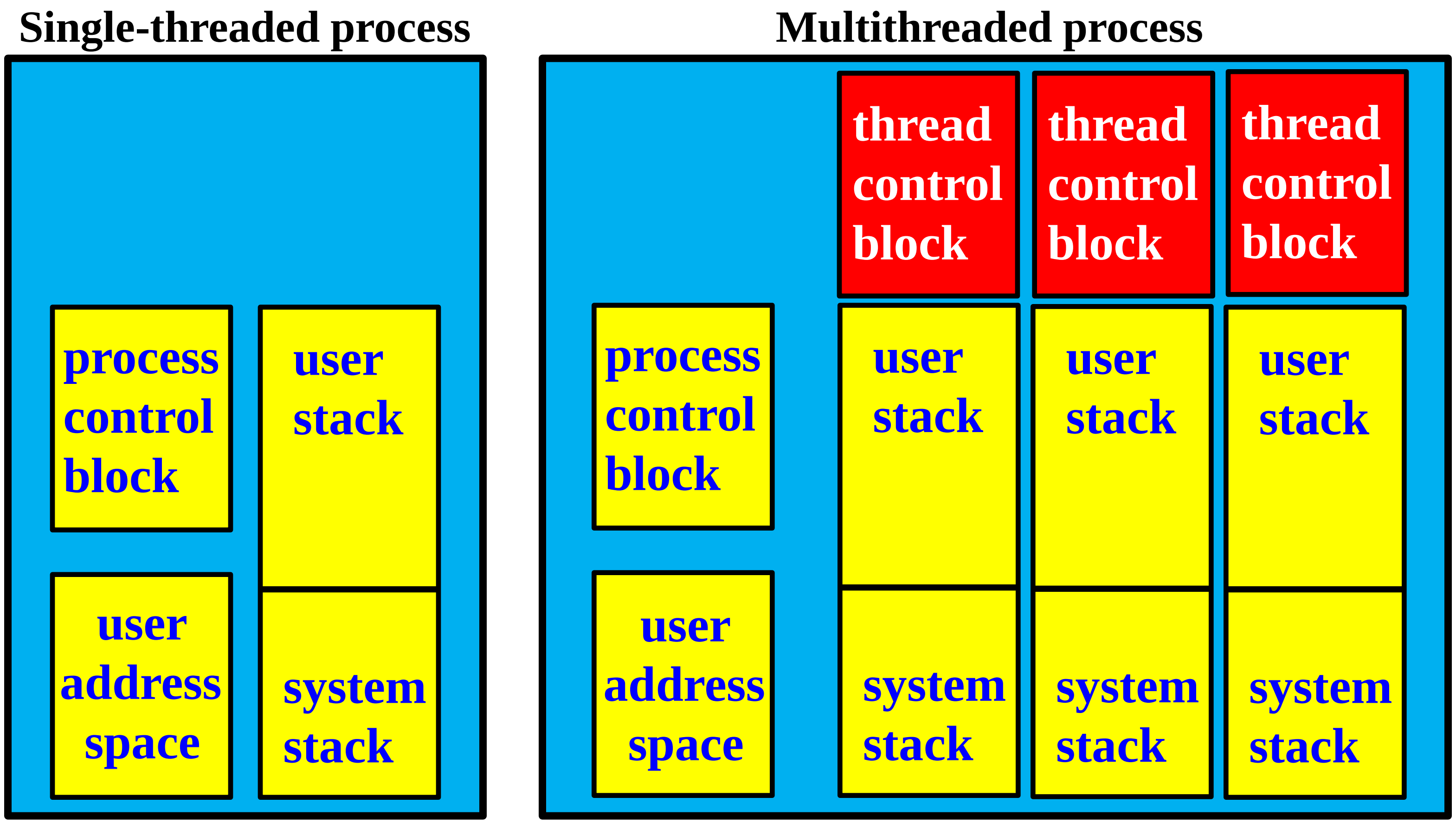
You think you know when you learn, are more sure when you can write,
even more when you can teach, but certain when you can program.

Alan J. Perlis

What Is a Thread?

- **A *thread*, also known as *lightweight process* (LWP), is a basic unit of CPU execution, and is created by a process.**
- **A thread has a thread ID, a program counter, a register set, and a stack. Thus, it is similar to a process.**
- **However, a thread *shares* with other threads in the *same* process its code section, data section, and other OS resources (e.g., files and signals).**
- **A process, or heavyweight process, has a *single* thread of control.**

Single Threaded and Multithreaded Process



Benefits of Using Threads

- **Responsiveness: Other part (i.e., threads) of a program may still be running even if one part (e.g., a thread) is blocked.**
- **Resource Sharing: Threads of a process, by default, share many system resources (e.g., files and memory).**
- **Economy: Creating and terminating processes, allocating memory and resources, and context switching processes are very time consuming.**
- **Utilization of Multiprocessor Architecture: Multiple CPUs may run multiple threads of the same process. No program change is necessary.**

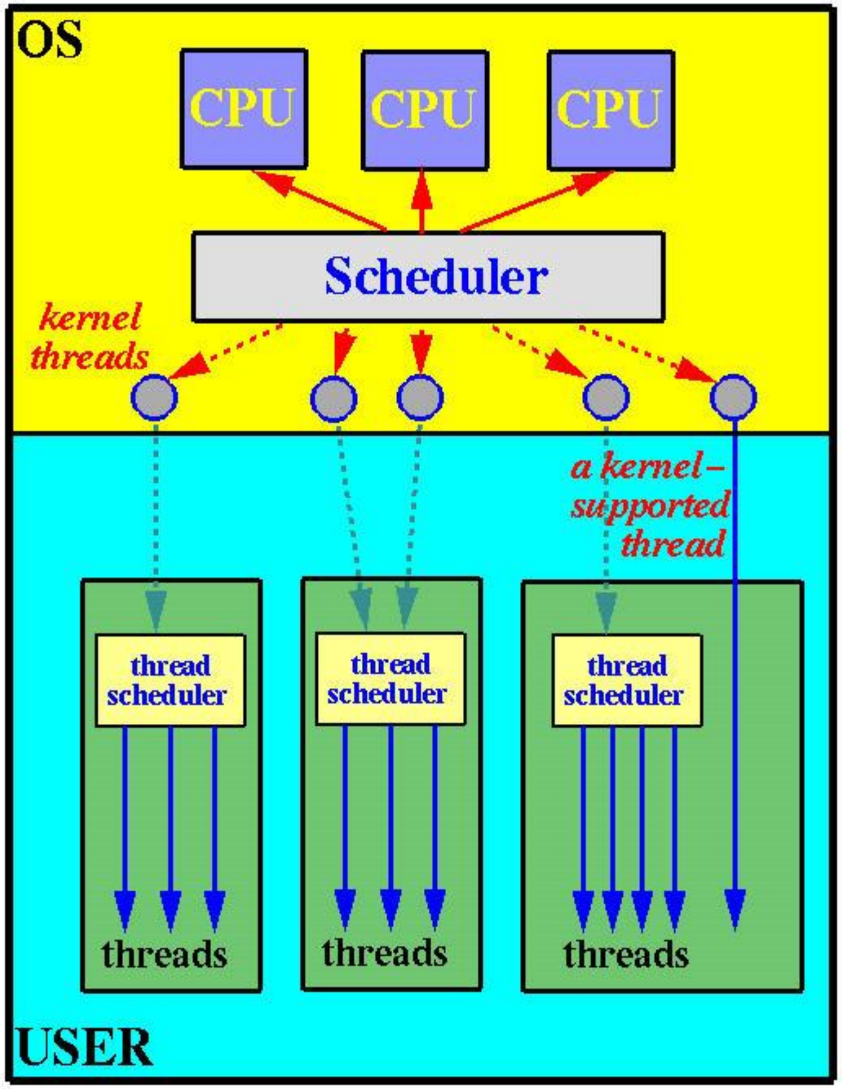
User and Kernel Threads: 1/3

- ***User Threads***:
  - User threads are supported at the user level. The kernel is not aware of user threads.
  - A library provides all support for thread creation, termination, joining, and scheduling.
  - Since there is no kernel intervention, user threads are usually more efficient.
  - Unfortunately, since the kernel only recognizes the containing process (of the threads), ***if one thread is blocked, all threads of the same process are also blocked*** because the containing process is blocked.

User and Kernel Threads: 2/3

- ***Kernel threads***:
  - Kernel threads are supported by the kernel. The kernel does thread creation, termination, joining, and scheduling in kernel space.
  - Kernel threads are usually slower than user threads due to system overhead.
  - However, ***blocking one thread will not cause other threads of the same process to block***. The kernel simply runs other kernel threads.
  - In a multiprocessor environment, the kernel may run threads on different processors.

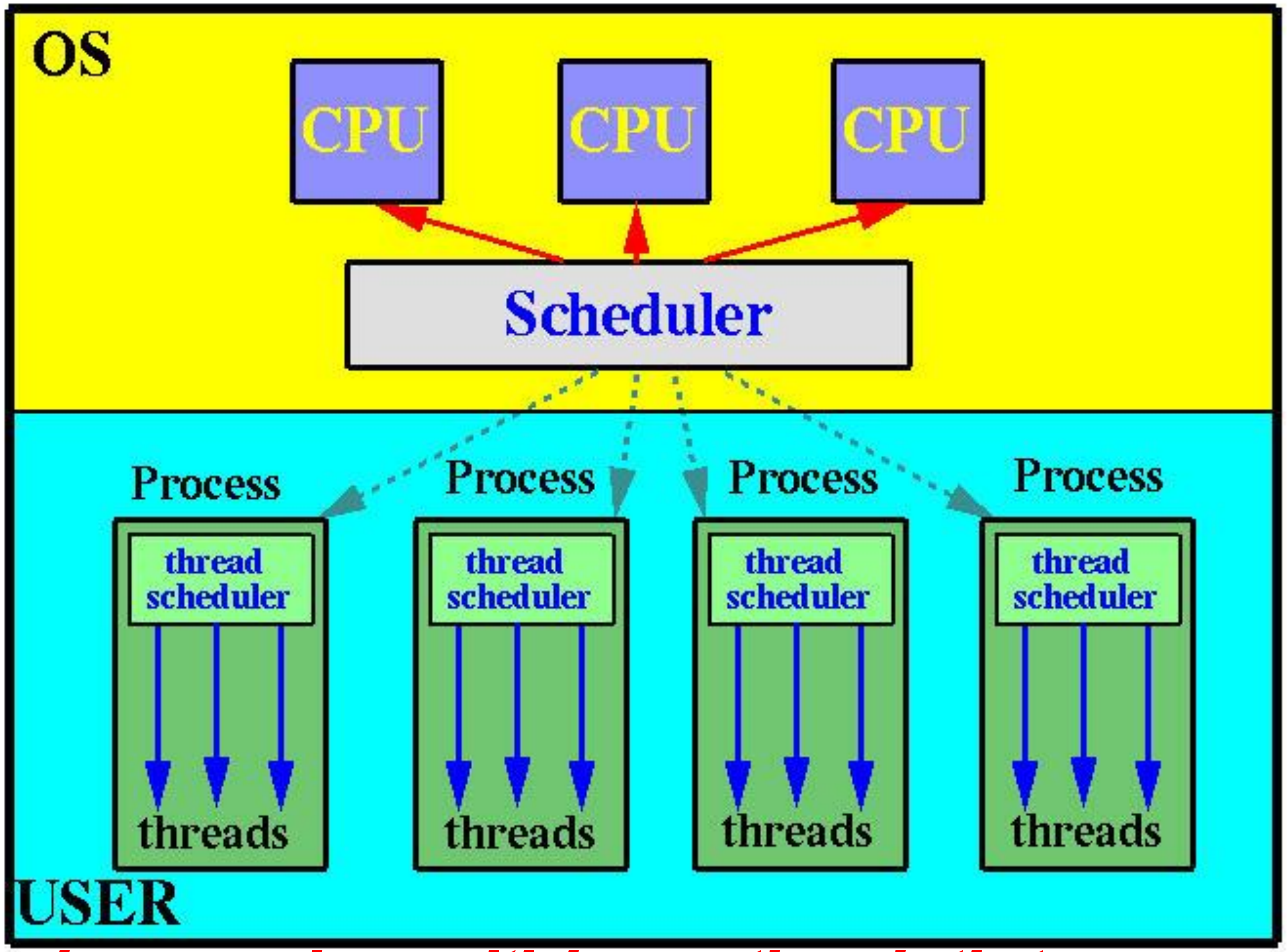
User and Kernel Threads: 3/3



Multithreading Models

- Different systems support threads in different ways. Here are three commonly seen thread models:
  - ***Many-to-One Model***: One kernel thread (or process) has multiple user threads. Thus, this is a user thread model.
  - ***One-to-One Model***: One user thread maps to one kernel thread (e.g., old Unix/Linux and Windows systems).
  - ***Many-to-Many Model***: Multiple user threads map to a number of kernel threads.

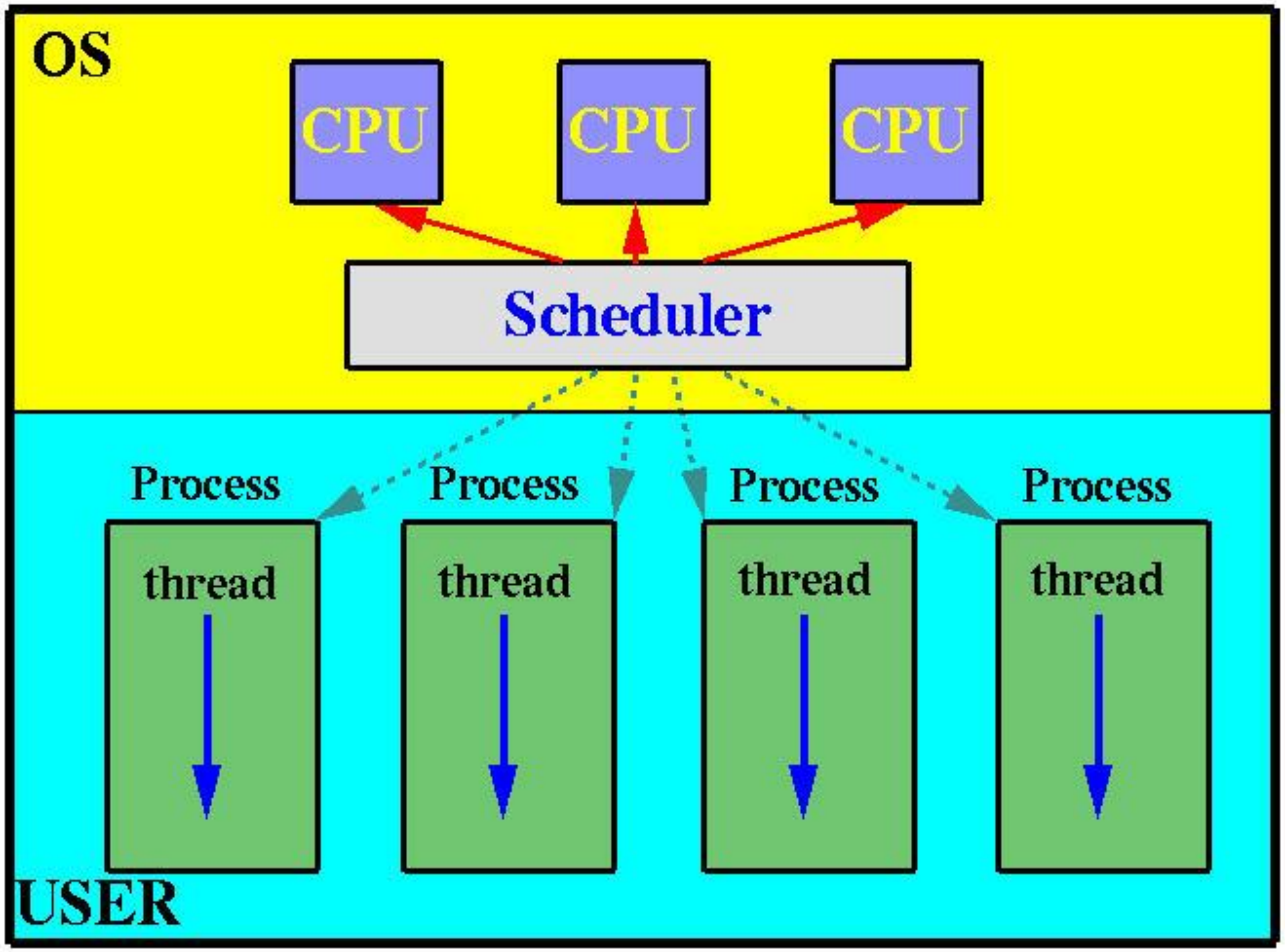
Many-to-One Model



Each process has multiple user threads that are associated with one kernel threads. If a process is blocked, all user threads of that process are blocked.

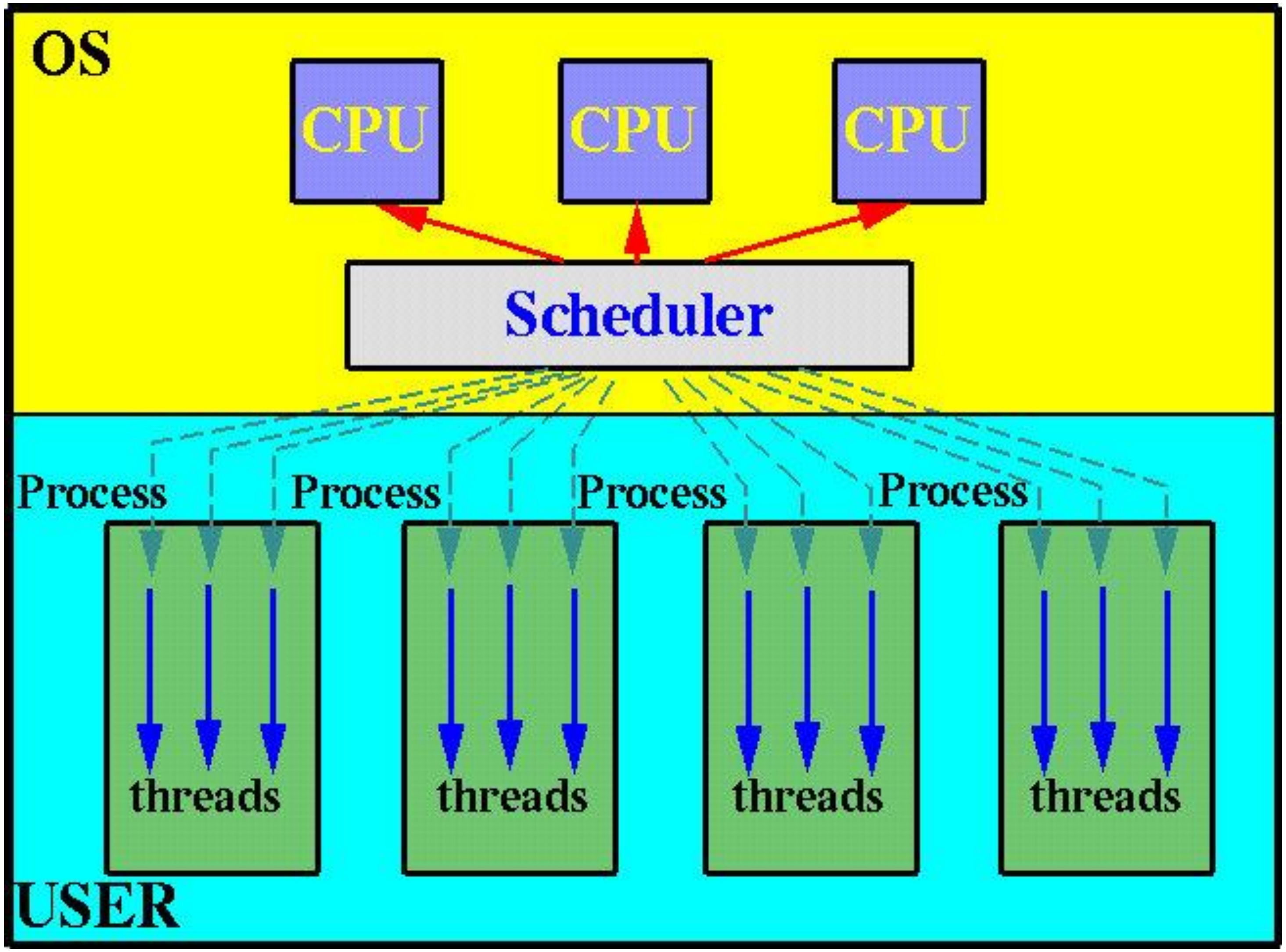
One-to-One Model: 1/2

An Extreme Case: Traditional Unix



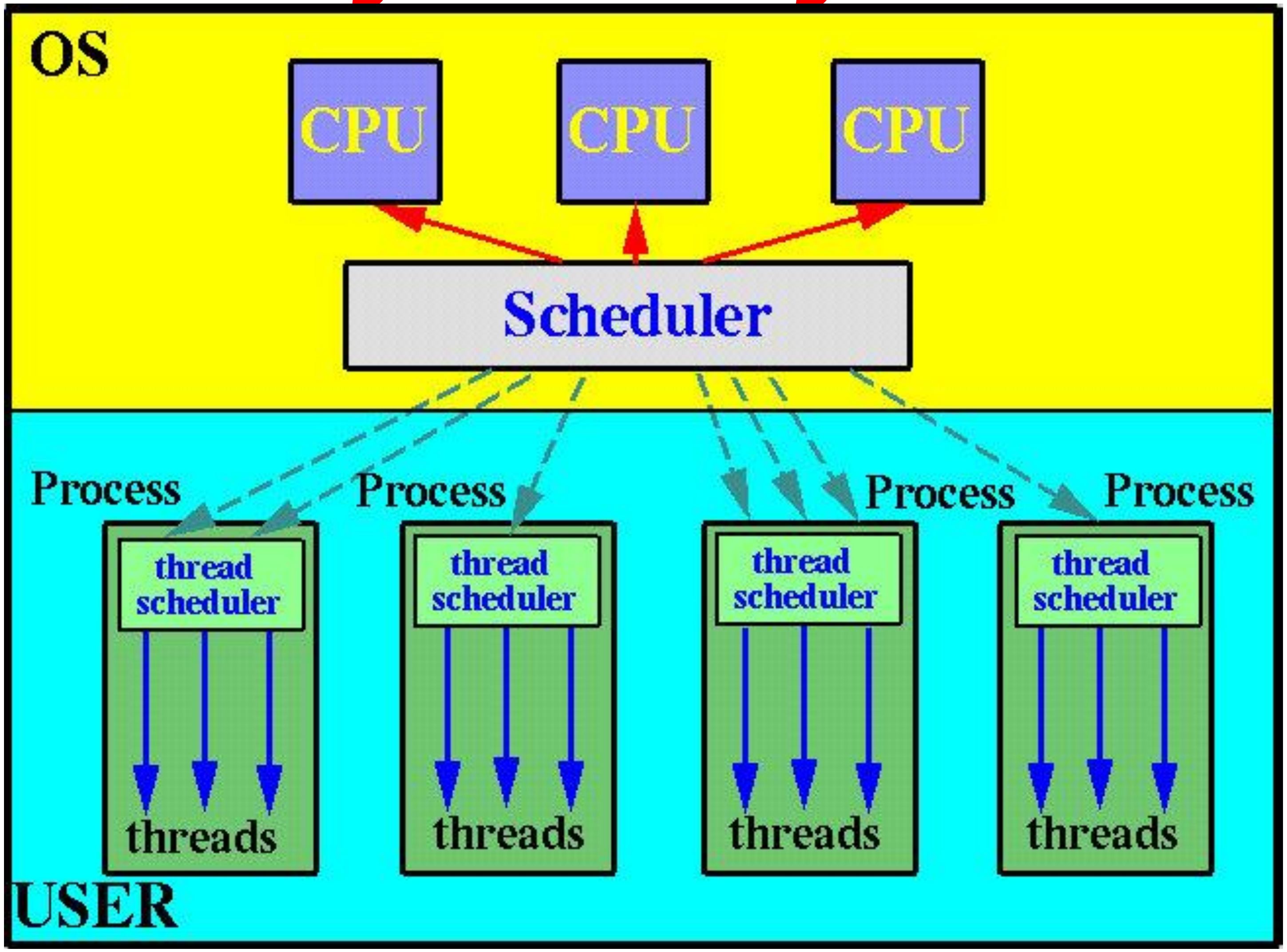
Each process has only one user thread that is associated with exactly one kernel thread

One-to-One Model: 2/2



Each process has multiple user threads each of which is associated with one kernel thread. If a kernel thread is blocked, the associated user thread is blocked.

Many-to-Many Model



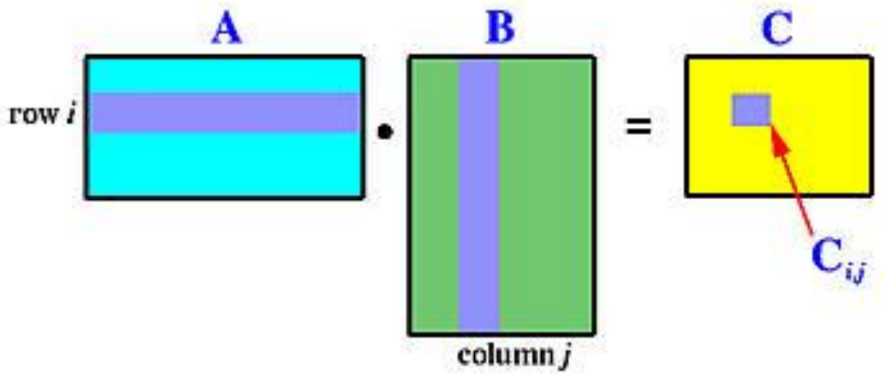
Each process has multiple threads that are associated with multiple kernel threads. If a kernel thread is blocked, all user threads associated with that kernel thread are blocked.

Multicore Programming: 1/6

- With a single-core CPU, threads are scheduled by a scheduler and can only run one at a time.
- With a multicore CPU, multiple threads may run at the same time, one on each core.
- Therefore, system design becomes more complex than one may expect.
- Five issues have to be addressed properly: dividing activities, balance, data splitting, data dependency, and testing and debugging.

Multicore Programming: 2/6

- ***Dividing Activities***: Since each thread can run on a core, one must study the problem in hand so that program activities can be divided and run concurrently.
- **Matrix multiplication is a good example.**
- **Unfortunately, some problems are *inherently sequential* (e.g., DFS).**



$$C_{i,j} = \sum_{k=1}^{n} A_{i,k} \times B_{k,j}$$

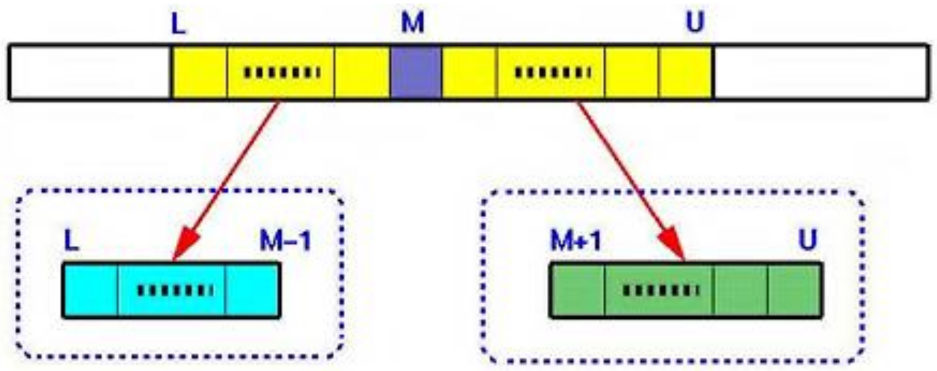
We may create a thread for each C_{ij}

Multicore Programming: 3/6

- ***Balance***: Make sure that each thread has *equal* contribution, if possible, to the whole computation.
- If an insignificant thread runs frequently, occupying a core, other more useful threads would have less chance to run.

Multicore Programming: 4/6

- ***Data Splitting***: Data may also be split into different sections so that each of which can be processed separately.
- Matrix multiplication is a good example.
- Quicksort is another. After partitioning, the two sections can be sorted separately.



After partitioning `a[L..U]` into `a[L..M-1]` and `a[M+1..U]`, we may create two threads, one for each section. Then, each thread sorts its own section. Threads are created in a binary tree.

Multicore Programming: 5/6

- ***Data Dependency***: **Watch for data items that are used by different threads. For example, two threads may update a common variable at the same time.**
- **Should this happen, unexpected results may occur. As a result, the execution of threads has to be *synchronized* so that only one thread can update a shared variable at any time.**
- **This is a very difficult issue in threaded programming.**

Multicore Programming: 6/6

- ***Testing and Debugging***: The behavior of a threaded program is *dynamic*. A bug that appears in this test run may not occur in the next. Some bugs may never surface throughout the life-span of a threaded program, or may appear at an unexpected time.
- Some debugging issues (e.g., race condition – updating a shared resource at the same time, and system deadlock) do not have efficient solutions.
- Thus, testing and debugging is an art, and requires a careful design and planning.

Thread Cancellation: 1/2

- ***Thread cancellation*** **means terminating a thread before its completion. The thread to be cancelled is the target thread.**
- **There are two types:**
  - ❖ ***Asynchronous Cancellation*****: the target thread terminates immediately.**
  - ❖ ***Deferred Cancellation*****: The target thread can periodically check if it should terminate, allowing the target thread an opportunity to terminate itself in an orderly way. The point a thread can terminate itself is a cancellation point.**

Thread Cancellation: 2/2

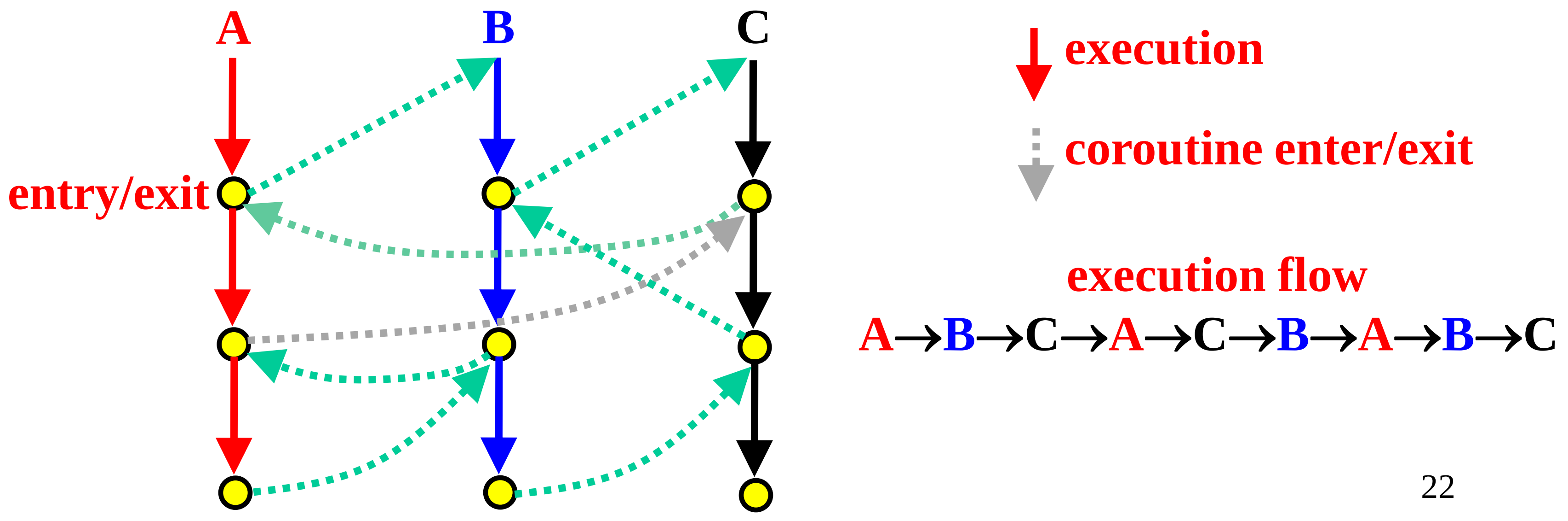
- With asynchronous cancellation, if the target thread owns some system-wide resources, the system may not be able to reclaim these recourses because other threads may be using them.
- With deferred cancellation, the target thread determines the time to terminate itself. Reclaiming resources is not a problem.
- Many systems use asynchronous cancellation for processes (e.g., system call `kill`) and threads.
- POSIX Threads (i.e., Pthreads) supports deferred cancellation.

Thread-Specific Data/Thread-Safe

- Data that a thread needs for its own operation are thread-specific.
- Poor support for thread-specific data could cause problems. For example, while threads have their own stacks, they share the heap.
- What if two `malloc()`s are executed at the same time requesting for memory from the heap? Or, two `printf`s are run simultaneously?
- A library that can be used by multiple threads properly is a thread-safe one.

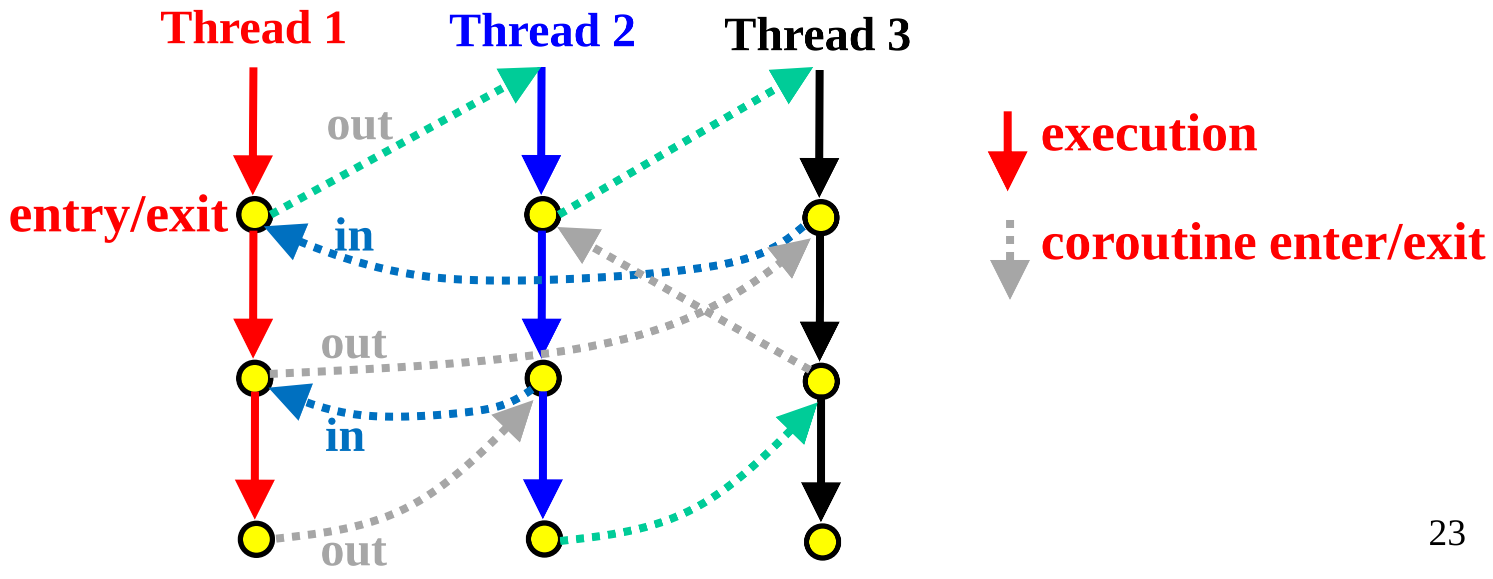
Coroutines and Fibers: 1/3

- A conventional call to a function always starts from the very beginning of that function.
- A ***coroutine*** has multiple entry points and exits so that the next "call" to a coroutine resumes its execution from the statement/instruction following the previous exit point.



Coroutines and Fibers: 2/3

- Do the enter and exit activities look like what a scheduler does?
- Yes, an exit is a switching out, and an enter/re-enter is a switching in.
- Hence, coroutines resemble scheduling activities.



Coroutines and Fibers: 3/3

- **A *fiber* is a lightweight thread just like a thread is a lightweight process.**
- **A fiber is created in a thread and shares resource with other fibers of that thread.**
- **A fiber has a stack, a subset of registers, and data (or local storage) provided when it is created.**
- **Fibers are scheduled with co-operative scheduling.**
- **Co-operative scheduling means a fiber voluntarily and explicitly yields its execution to another fiber with a `YIELD` or similar function call.**
- **Thus, fibers are simpler than threads, and resemble coroutines.**

The End