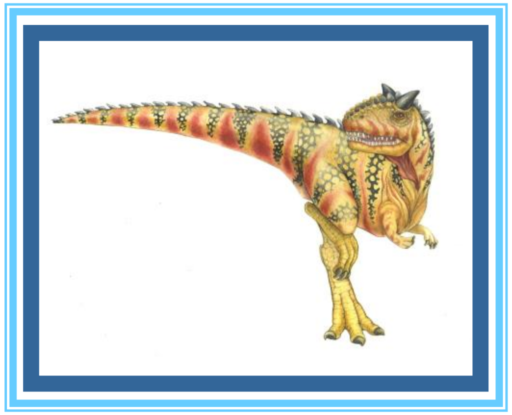
Chapter 4: Threads & Concurrency



Outline

- Overview
- Multicore Programming
- Multithreading Models
- Thread Libraries
- Operating System Examples

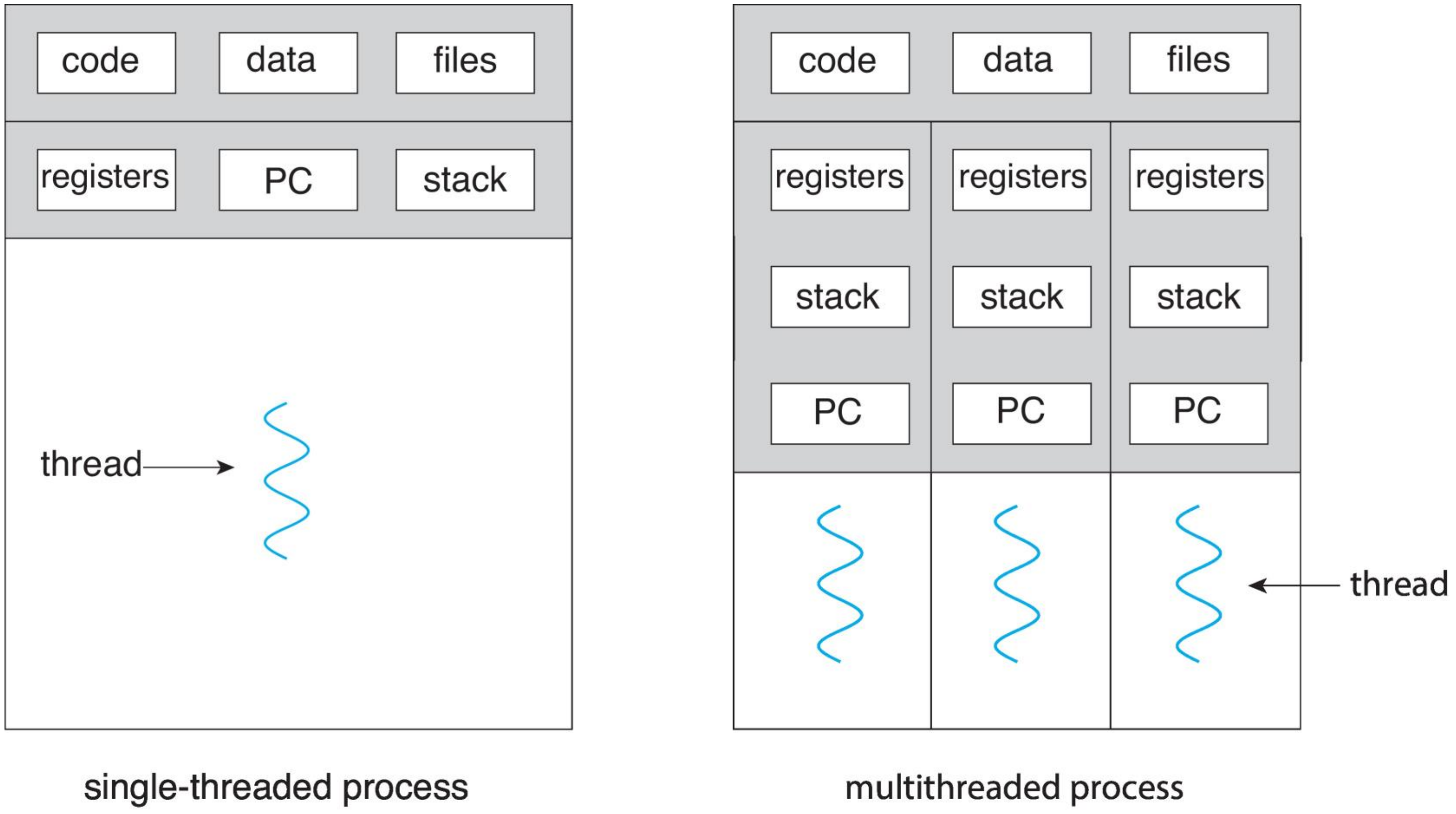
Objectives

- Identify the basic components of a thread, and contrast threads and processes
- Describe the benefits and challenges of designing multithreaded applications
- Designing multithreaded applications using the Pthreads

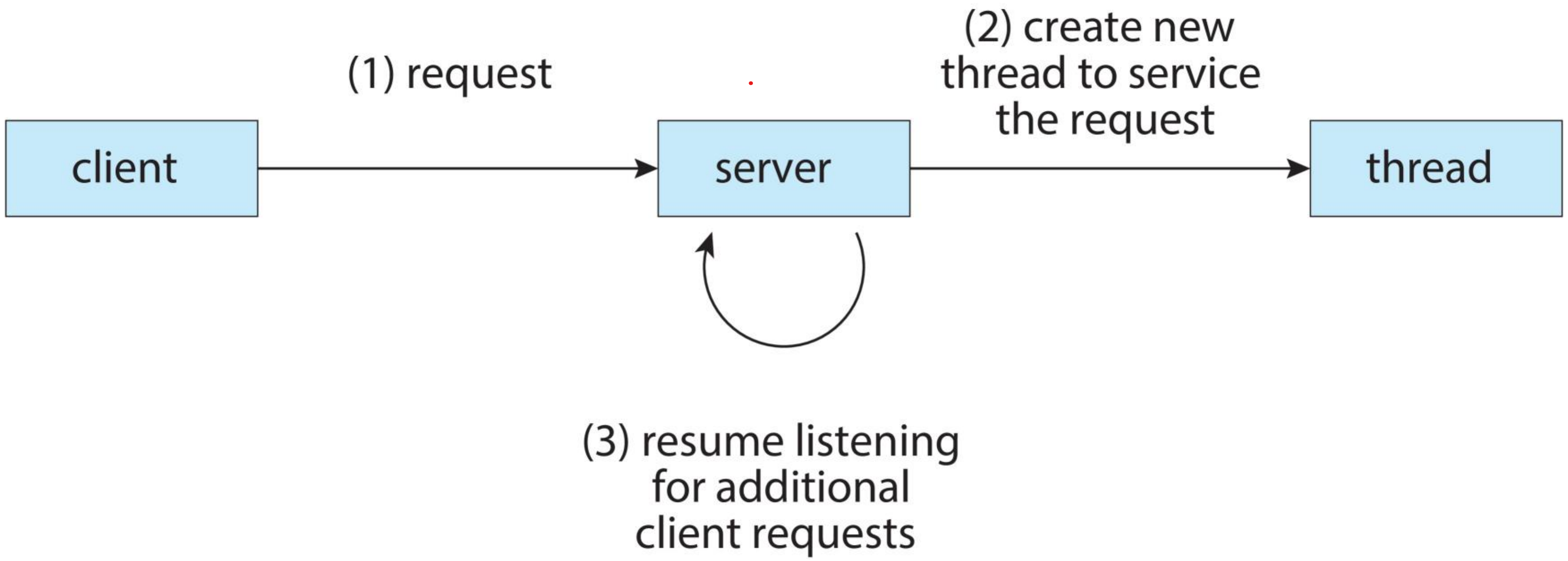
Motivation

- Most modern applications are multithreaded
- Threads run within application
- Multiple tasks with the application can be implemented by separate threads
  - Update display
  - Fetch data
  - Spell checking
  - Answer a network request
- Process creation is heavy-weight while thread creation is light-weight
- Can simplify code, increase efficiency
- Kernels are generally multithreaded

Single and Multithreaded Processes



Multithreaded Server Architecture


(1) request
(2) create new thread to service the request
client
server
thread
(3) resume listening for additional client requests

Benefits

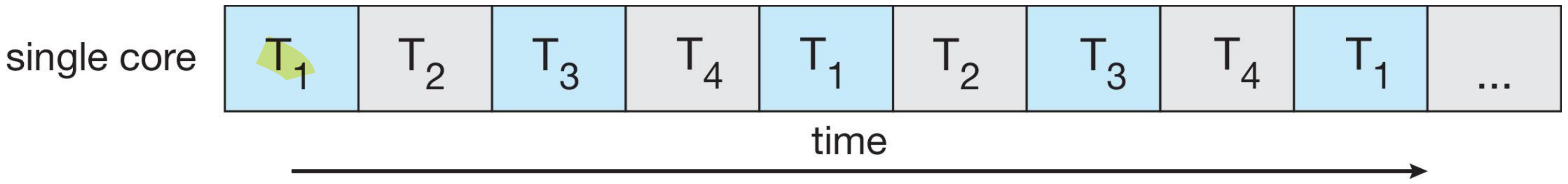
- **Responsiveness –** may allow continued execution if part of process is blocked, especially important for user interfaces
- **Resource Sharing –** threads share resources of process, easier than shared memory or message passing
- **Economy –** cheaper than process creation, thread switching lower overhead than context switching
- **Scalability –** process can take advantage of multicore architectures

Multicore Programming

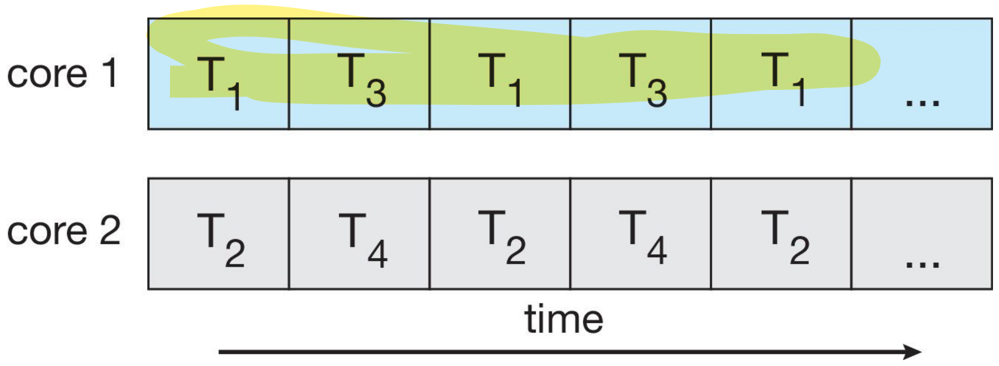
- In response to the need for more computing performance, single-CPU systems evolved into multi-CPU systems.
  - Current trend in system design is to place multiple computing cores on a single processing chip
- ***Parallelism*** implies a system can perform more than one task simultaneously
- ***Concurrency*** supports more than one task making progress
  - Single processor / core, scheduler providing concurrency

Concurrency vs. Parallelism

- **Concurrent execution on single-core system:**

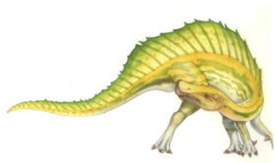


- **Parallelism on a multi-core system:**



Multicore Programming

- **Multicore** or **multiprocessor** systems puts pressure on programmers, challenges include:
  - **Dividing activities**
  - **Balance**
  - **Data splitting**
  - **Data dependency**
  - **Testing and debugging**

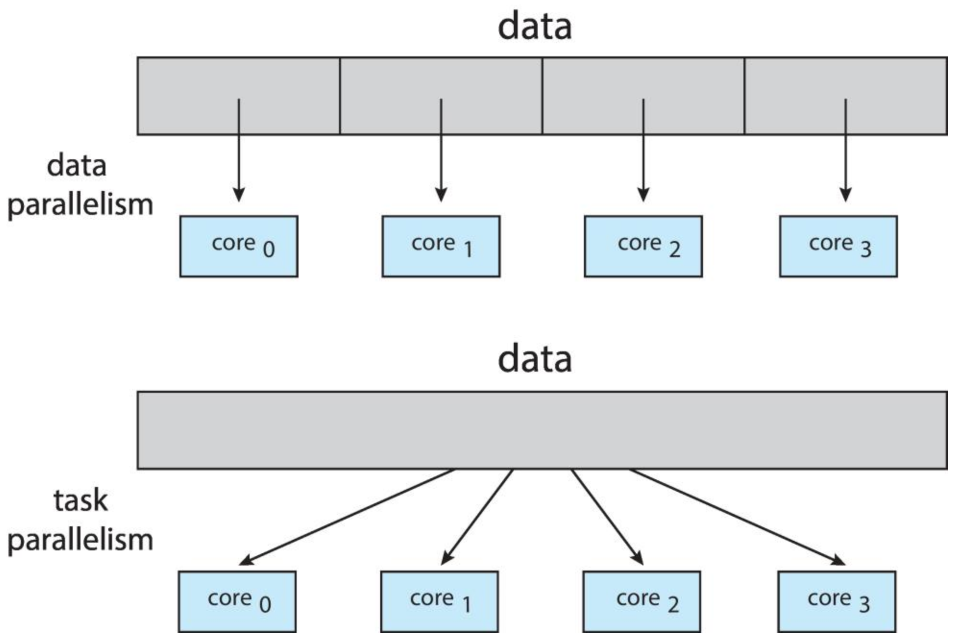


Multicore Programming

In data parallelism, the same task is performed on different sets of data in parallel. Each processor works on its own subset of the data, and the results are combined after processing.

- Types of parallelism
  - **Data parallelism** – distributes subsets of the same data across multiple cores, same operation on each
  - **Task parallelism** – distributing threads across cores, each thread performing unique operation

    The processors perform different operations or functions, potentially on the same or different sets of data.



Amdahl's Law

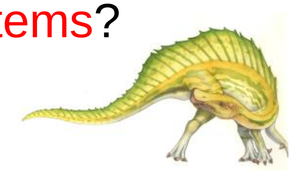
- Identifies performance gains from adding additional cores to an application that has both serial and parallel components
- *S* is serial portion
- *N* processing cores

$$speedup \le \frac{1}{S + \frac{(1-S)}{N}}$$

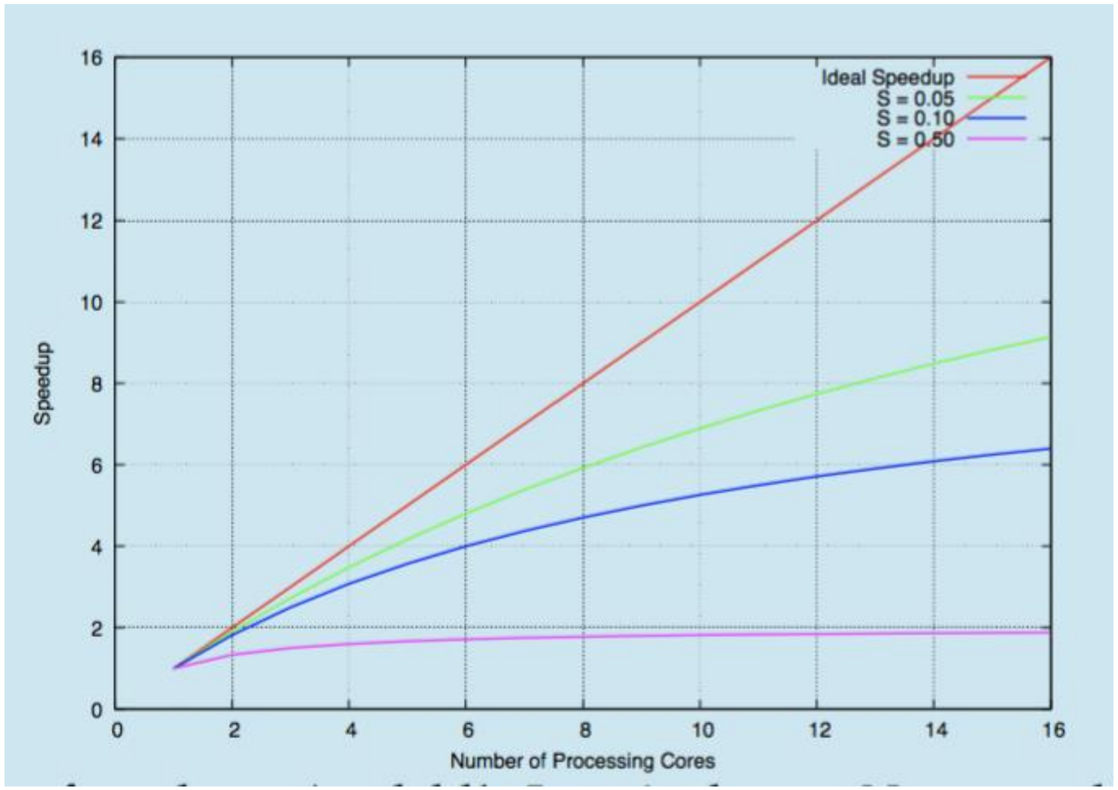
- That is, if application is 75% parallel / 25% serial, moving from 1 to 2 cores results in speedup of 1.6 times
- As *N* approaches infinity, speedup approaches 1 / *S*

Serial portion of an application has disproportionate effect on performance gained by adding additional cores

- But does the law take into account contemporary multicore systems?



Amdahl's Law


Ideal Speedup
S = 0.05
S = 0.10
S = 0.50
Speedup
Number of Processing Cores
0
2
4
6
8
10
12
14
16

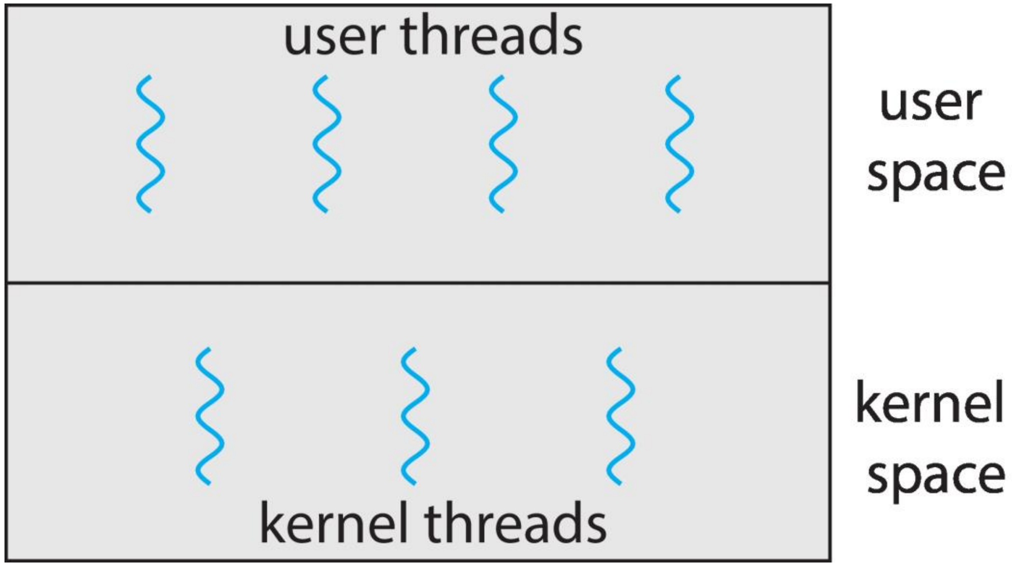
Thread Libraries

- Thread libraries provide programmers with an API for creating and managing threads.
- Thread libraries may be implemented either in user or in kernel space.
  - User space; API functions implemented solely within user space, with no kernel support.
  - Kernal space; involves system calls, and requires a kernel with thread library support.
  - A few well established primary thread libraries
    - POSIX Pthreads - may be provided as either a user or kernel library
    - Win32 threads - provided as a kernel-level library on Windows systems.
    - Java threads – May be Pthreads or Win32 depending on the OS and hardware the JVM is running.

User Threads and Kernel Threads

- **User threads** - management done by user-level threads library
- **Kernel threads** - Supported by the Kernel
  - Exists virtually in all general purpose OS:
    - Windows, Linux, Mac OS X, iOS, Android
- Even user threads will ultimately need kernel thread support (Why??)

User threads need access to hardware resources like CPU, memory, and I/O devices, which are managed by the kernel.



Multithreading Models

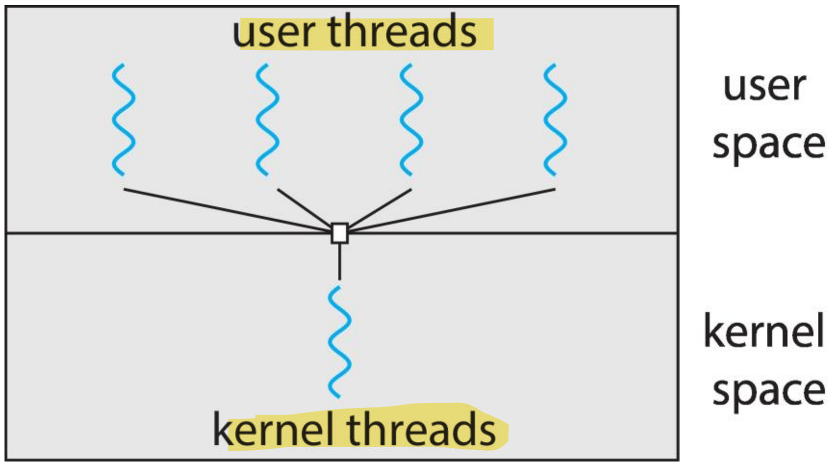
- Many-to-One
- One-to-One
- Many-to-Many

The kernel is responsible for scheduling CPU time among all processes and threads running on the system. User threads alone cannot directly schedule CPU time without kernel intervention, as the kernel decides when and for how long a thread (user or kernel) can run on the processor.

Some privilege instructions need interventions of kernel so we need kernel threads to support the user threads

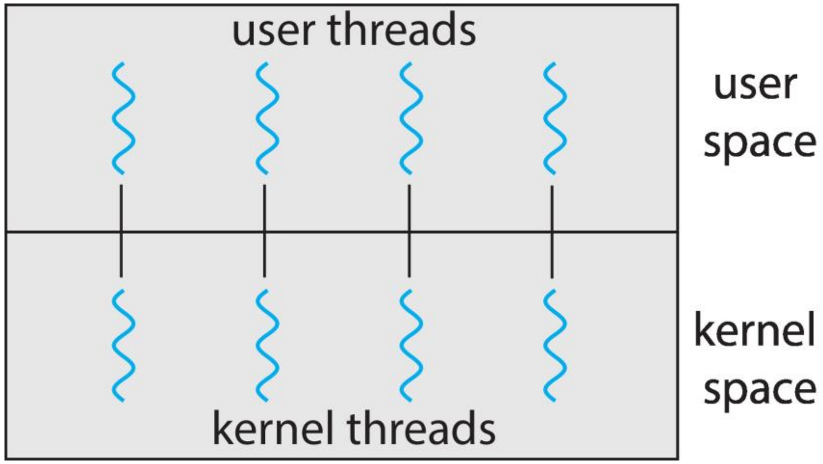
Many-to-One

- Many user-level threads mapped to single kernel thread
- Blocking one thread causes all to block
- Multiple threads may not run in parallel on multicore system because only one may be in kernel at a time
- Old approach: Few systems currently use this model
- Examples:
  - **Solaris Green Threads**
  - **GNU Portable Threads**



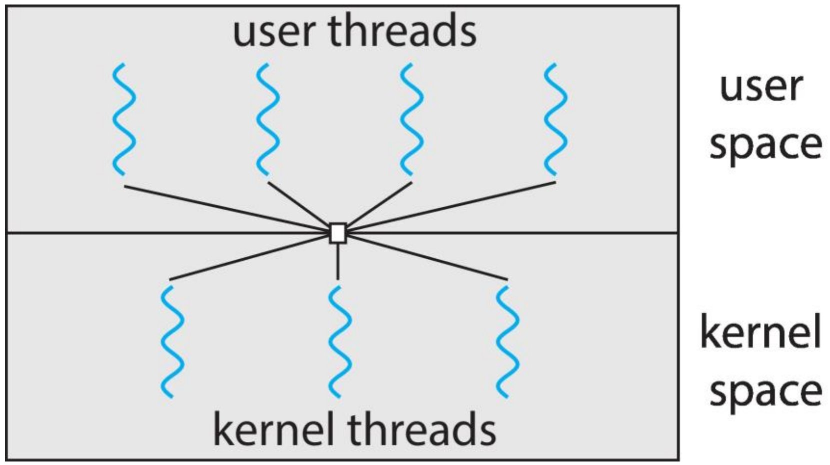
One-to-One

- Each user-level thread maps to kernel thread
- Creating a user-level thread creates a kernel thread
- More concurrency than many-to-one
- Number of threads per process sometimes restricted due to overhead
- Examples
  - Windows
  - Linux



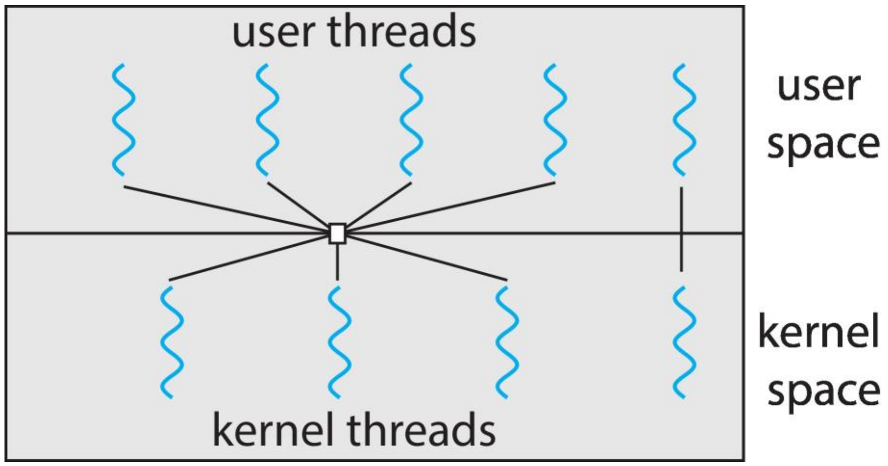
Many-to-Many Model

- Allows many user level threads to be mapped to many kernel threads
- Allows the operating system to create a sufficient number of kernel threads
- Windows with the *ThreadFiber* package
- Otherwise not very common



Two-level Model

- Similar to M:M, except that it allows a user thread to be **bound** to kernel thread

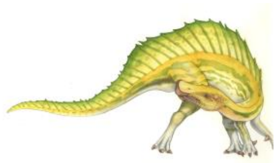


Pthreads

- May be provided either as user-level or kernel-level
- A POSIX standard API for thread creation and synchronization
- ***Specification***, not ***implementation***
  - API specifies behavior of the thread library, implementation is up to development of the library
- Example: Sum of N natural numbers
- Global data: Any variable declared globally are shared among all threads of the same process
- Local data: Data local to a function (running in a thread) are stored in thread stack

Pthreads Example: Code

```
#include<stdio.h>
#include<pthread.h>
```



Pthreads Example: Code

```
#include<stdio.h>
#include<pthread.h>

int sum; // global variable shared over threads
```

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void *runner (void *param); // threads begin execution in a specified function
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int main(int argc, char *argv[]){
        pthread_t tid; \\ declares the identifier for the thread





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            pthread attr t attr; \\ set of thread attributes






}
```

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int sum; // global variable shared over threads
void *runner (void *param); // threads begin execution in a specified function
int main(int argc, char *argv[]){
        pthread_t tid; \\ declares the identifier for the thread
        pthread attr t attr; \\ set of thread attributes
        pthread attr init(&attr); \\ set the default attributes of the thread




}
```

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void *runner (void *param); // threads begin execution in a specified function
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        pthread create(&tid, &attr, runner, argv[1]); \\ create the thread


}
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Pthreads Example: Code

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            pthread create(&tid, &attr, runner, argv[1]); \\ create the thread
            pthread join(tid,NULL); \\ wait for the thread to exit

}
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Pthreads Example: Code

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int sum; // global variable shared over threads
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            pthread attr init(&attr); \\ set the default attributes of the thread
            pthread create(&tid, &attr, runner, argv[1]); \\ create the thread
            pthread join(tid,NULL); \\ wait for the thread to exit
            printf("sum = %d\n",sum);
}
```

Pthreads Example: Code

```
#include<stdio.h>
#include<pthread.h>

int sum; // global variable shared over threads
void *runner (void *param); // threads begin execution in a specified function
/* The thread will execute in this function */
void *runner(void *param) {
        int i, upper = atoi(param);
        sum = 0;
        for (i = 1; i <= upper; i++)
                sum += i;
                pthread exit(0);  \\ thread terminates
}
```

Pthreads Example: Code

- Growing dominance of multicore systems, writing programs containing several threads has become common.
- Simple method for waiting on several threads using the **pthread_join()** function is to enclose the operation within a simple for loop

```
#define NUM_THREADS 10
/* an array of threads to be joined upon */
Pthread_t workers[NUM THREADS];
for (int i = 0; i < NUM THREADS; i++)
          pthread join(workers[i], NULL);
```

OpenMP

- Collection of compiler directives and an API for C, C++, FORTRAN
- Provides support for parallel programming in shared-memory environments
- Identifies **parallel regions** – blocks of code that can run in parallel

`#pragma omp parallel`

- Create as many threads as there are cores

```
#include <omp.h>
#include <stdio.h>

int main(int argc, char *argv[])
{
   /* sequential code */

   #pragma omp parallel
   {
      printf("I am a parallel region.");
   }

   /* sequential code */

   return 0;
}
```

End of Chapter 4