CSC139 Operating System Principles

Fall 2021, Part 2-2

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Session Plan

- Overview
- Multicore Programming
- Multithreading Models
- Thread Libraries
- Implicit Threading
- Threading Issues
- Operating System Examples

Thread

- A process, as defined so far, has only *one thread of execution*
- Idea: allow multiple threads of execution within the same process environment, to a large degree independent of each other

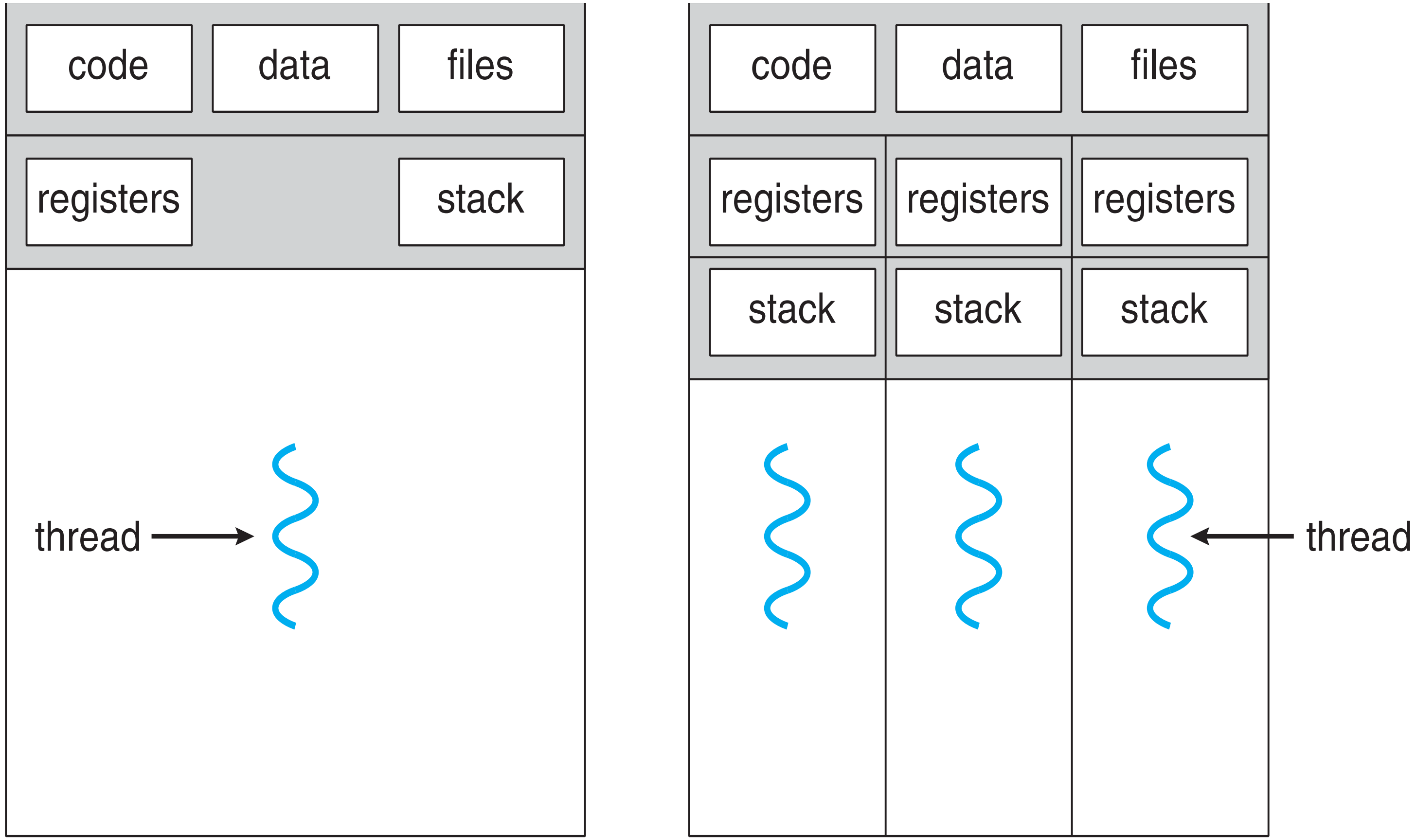
Process vs. Thread

- Multiple threads within a process will share
  - The address space
  - Open files
  - Other resources
- Why thread?
  - Great potential for efficient and close cooperation

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



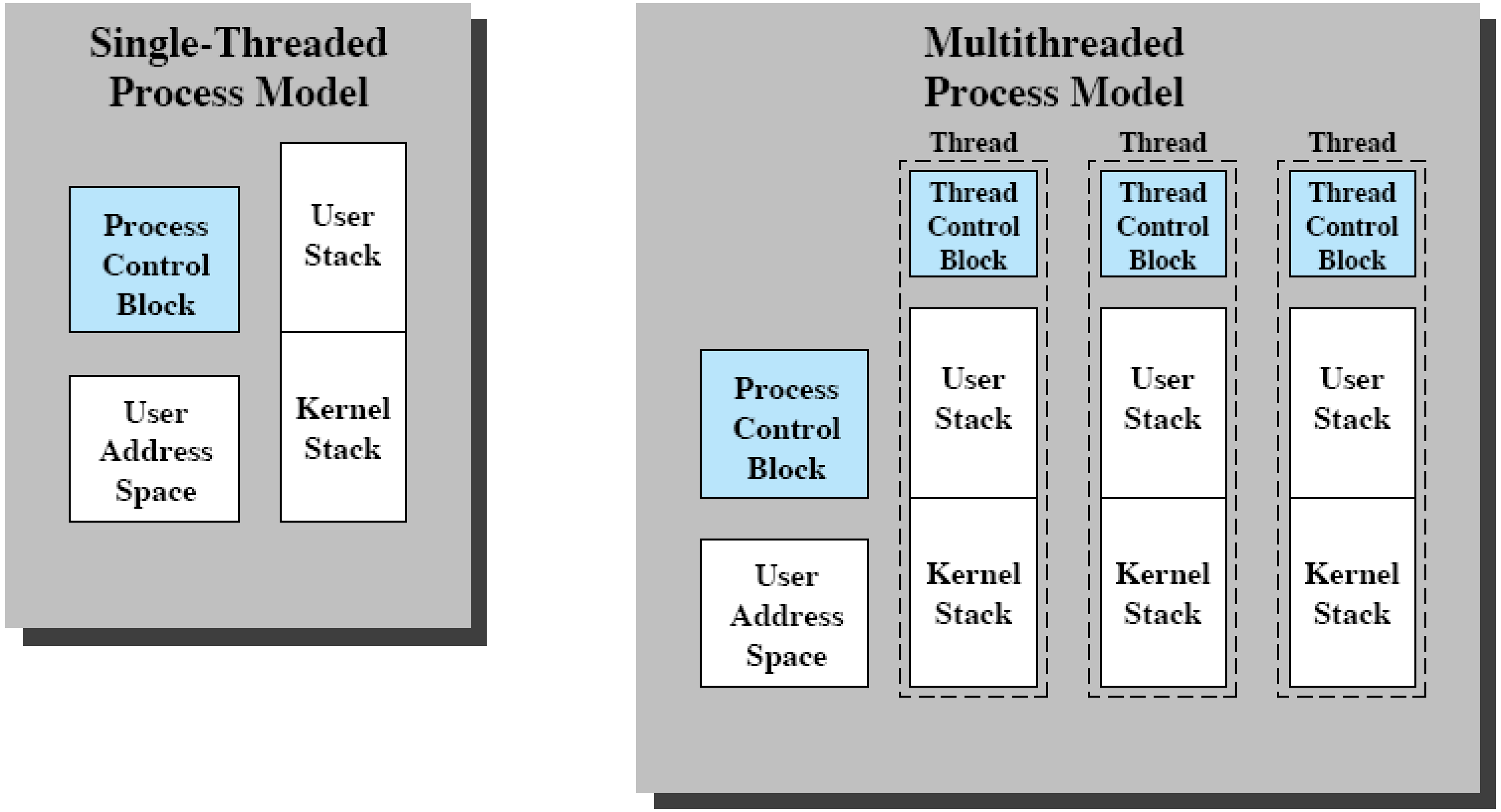
single-threaded process

multithreaded process

Multithreading

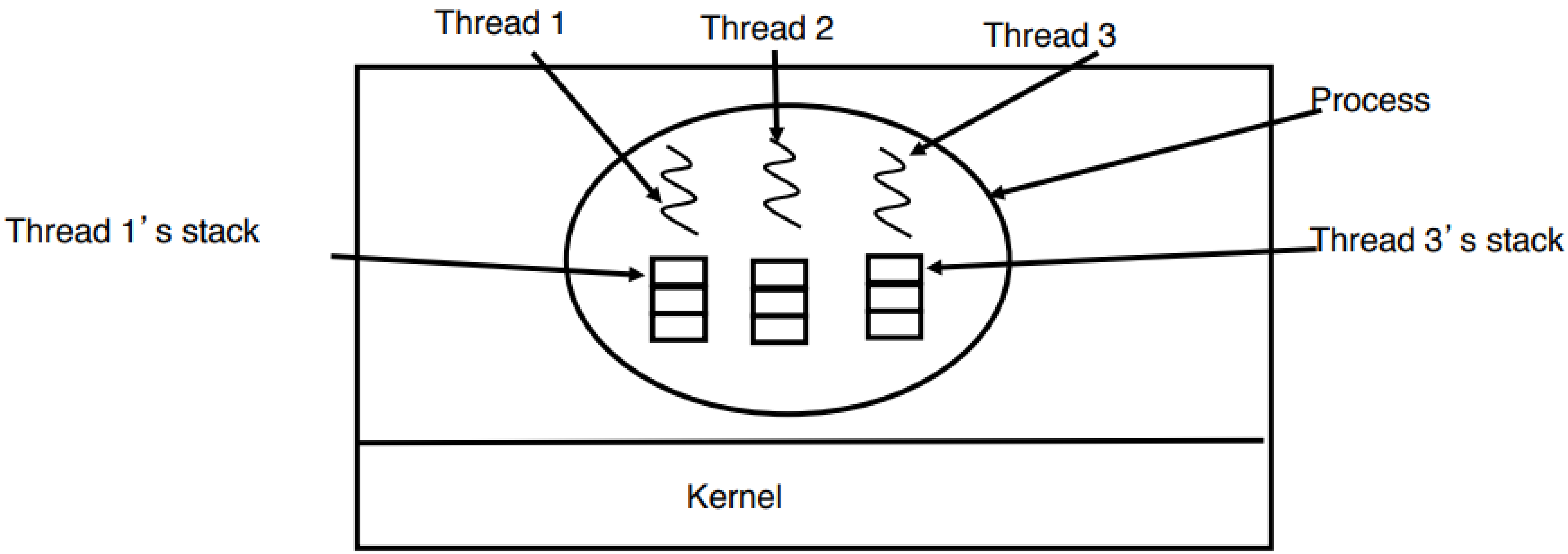
Per Process Items	Per Thread Items
Address space	Program counter
Global variables	Registers
Open files	Stack
Accounting information	State

Single- and Multi-threaded Process Models

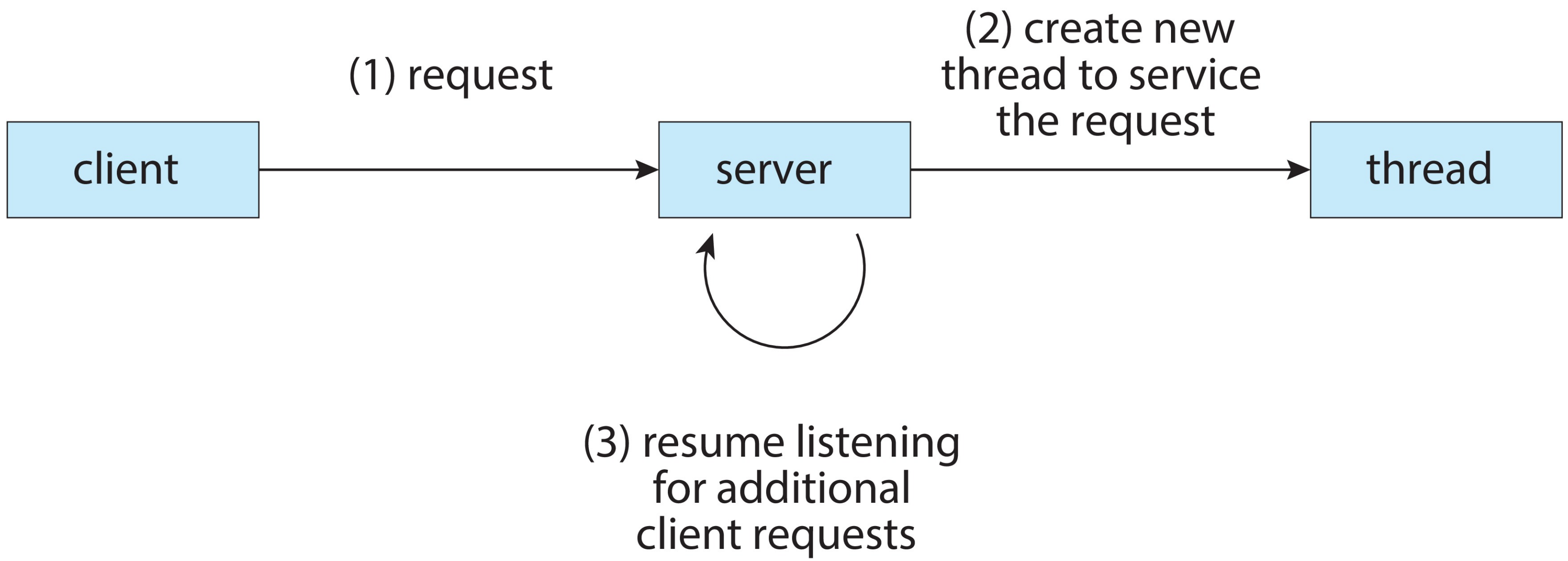


Multithreading (cont.)

- Each thread can be in any one of the several states, just like processes: Ready, Running, Blocked
- Each thread has its own stack



Multithreaded Server Architecture



Benefits

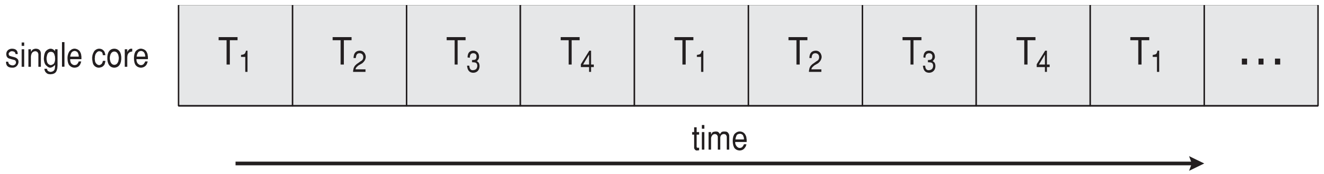
- **Responsiveness –** may allow continued execution if part of process is blocked, especially important for user interfaces
- **Resource Sharing –** threads share resources of process, easier than shared memory or message passing
- **Economy –** cheaper than process creation, thread switching lower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

Multicore Programming

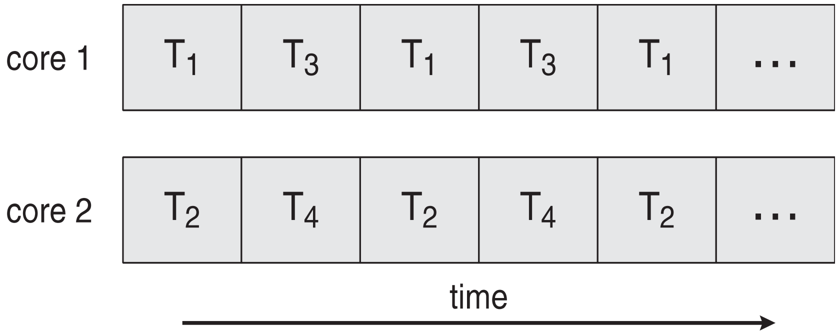
- Multicore or multiprocessor systems putting pressure on programmers, challenges include:
  - Dividing activities
  - Balance
  - Data splitting
  - Data dependency
  - Testing and debugging
- *Parallelism* implies a system can perform more than one task simultaneously
- *Concurrency* supports more 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:



User Threads and Kernel Threads

- User threads - management done by user-level threads library
- Three primary thread libraries:
  - POSIX Pthreads
  - Windows threads
  - Java threads
- Kernel threads - Supported by the Kernel
- Examples – virtually all general purpose operating systems, including:
  - Windows
  - Solaris
  - Linux
  - Tru64 UNIX
  - Mac OS X

Kernel Threads

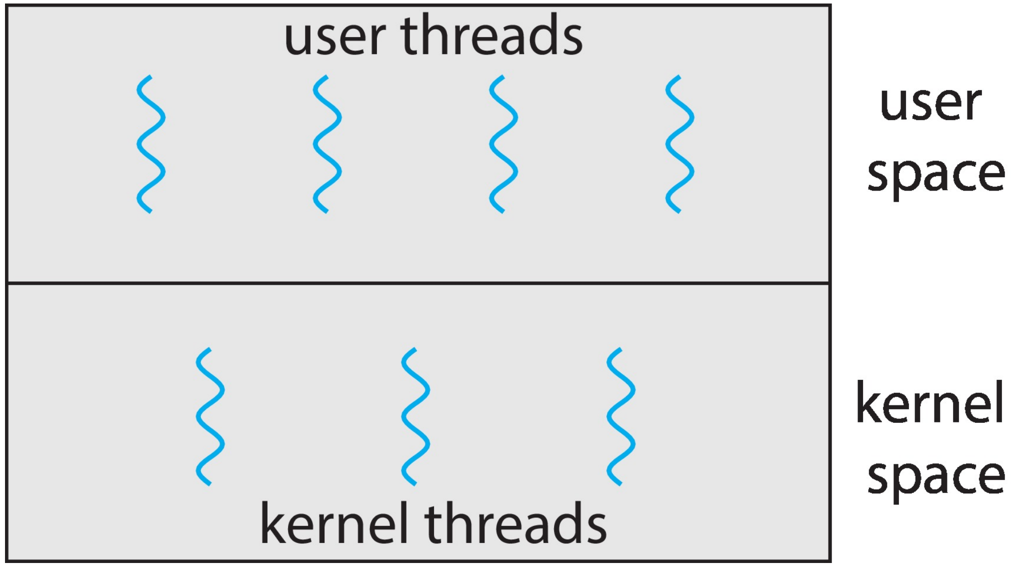
- A kernel thread, also known as a lightweight process, is a thread that the operating system knows about.
- Switching between kernel threads of the same process requires a small context switch.
  - The values of registers, program counter, and stack pointer must be changed.
  - Memory management information does not need to be changed since the threads share an address space.
- The kernel must manage and schedule threads (as well as processes), but it can use the same process scheduling algorithms.

→ Switching between kernel threads is faster than switching between processes

User-level Threads

- A user-level thread is a thread that the OS does not know about.
- The OS only knows about the process containing the threads.
- The OS only schedules the process, not the threads within the process.
- The programmer uses a *thread library* to manage threads (create and delete them, synchronize them, and schedule them).

User and Kernel Threads



User-Level Threads: Advantages

- There is no context switch involved when switching threads.
- User-level thread scheduling is more flexible
  - A user-level code can define a problem dependent thread scheduling policy.
  - Each process might use a different scheduling algorithm for its own threads.
  - A thread can voluntarily give up the processor by telling the scheduler it will yield to other threads.
- User-level threads do not require system calls to create them or context switches to move between them

→ User-level threads are typically much faster than kernel threads

User-Level Threads: Disadvantages

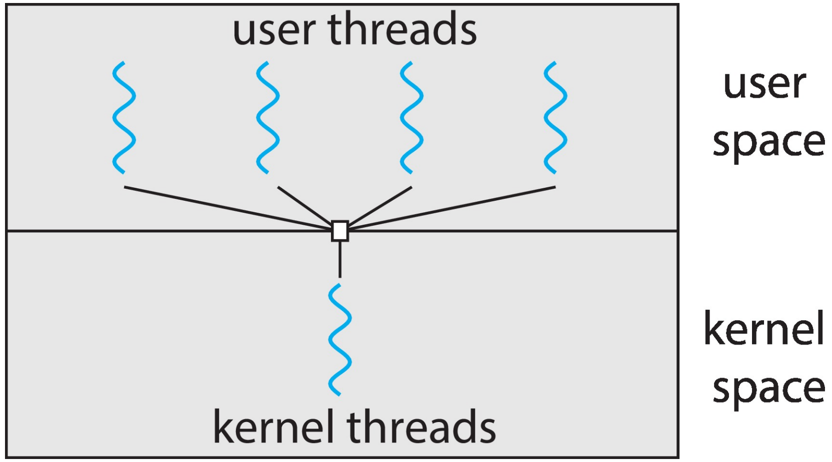
- No true parallelism - Multiple threads in process cannot run concurrently
- Since the OS does not know about the existence of the user-level threads, it may make poor scheduling decisions:
  - It might run a process that only has idle threads.
  - If a user-level thread is waiting for I/O, the entire process will wait.
  - Solving this problem requires communication between the kernel and the user-level thread manager.
- Since the OS just knows about the process, it schedules the process the same way as other processes, regardless of the number of user threads.
- For kernel threads, the more threads a process creates, the more time slices the OS will dedicate to it.

Multithreading Models

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

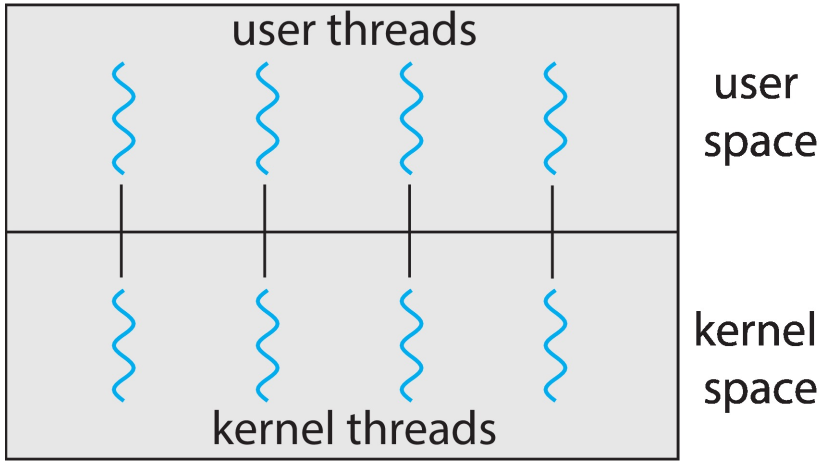
Many-to-One

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



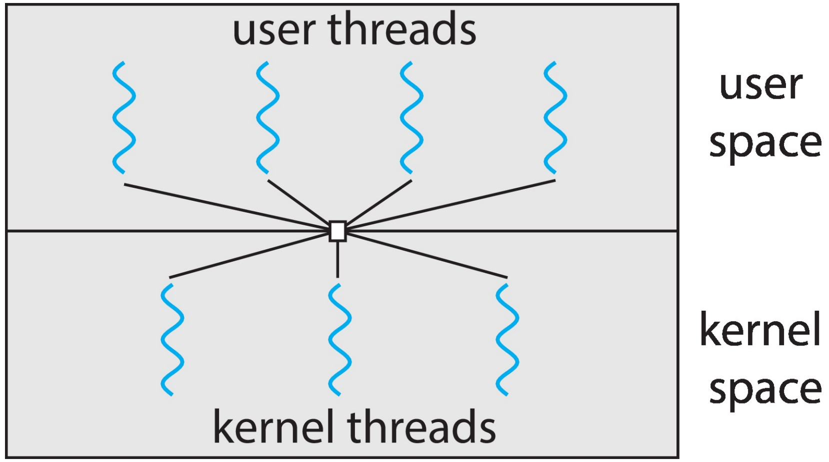
One-to-One

- 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
  - Solaris 9 and later



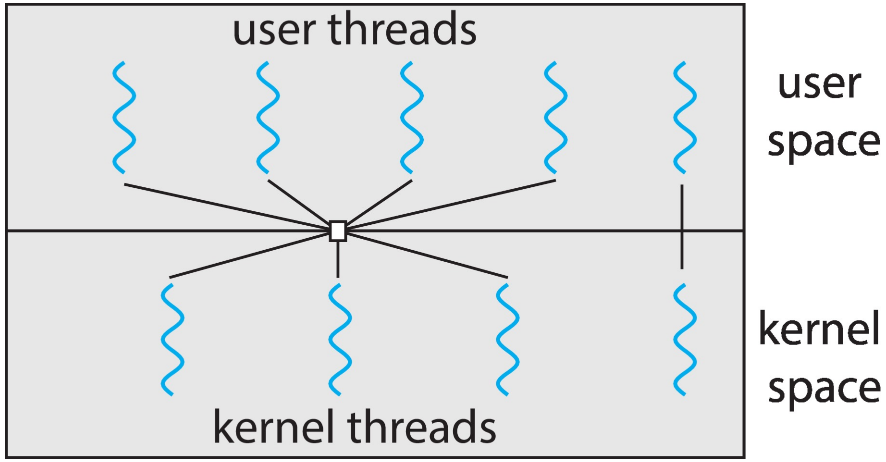
Many-to-Many Model

- Allows many user level threads to be mapped to many kernel threads
- Allows the operating system to create a sufficient number of kernel threads
- Solaris prior to version 9
- Windows with the *ThreadFiber* package



Two-Level Model

- Similar to M:M, except that it allows a user thread to be **bound** to kernel thread
- Examples
  - IRIX
  - HP-UX
  - Tru64 UNIX
  - Solaris 8 and earlier



Thread Libraries

- Thread library provides programmer with API for creating and managing threads
- Two primary ways of implementing
  - Library entirely in user space
  - Kernel-level library supported by the OS

Pthreads

- May be provided either as user-level or kernel-level
- A POSIX standard (IEEE 1003.1c) API for thread creation and synchronization
- *Specification*, not *implementation*
- API specifies behavior of the thread library, implementation is up to development of the library
- Common in UNIX operating systems (Solaris, Linux, Mac OS X)

Pthreads Example

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

#include <stdlib.h>

int sum; /* this data is shared by the thread(s) */
void *runner(void *param); /* threads call this function */

int main(int argc, char *argv[])
{
  pthread_t tid; /* the thread identifier */
  pthread_attr_t attr; /* set of thread attributes */

  /* set the default attributes of the thread */
  pthread_attr_init(&attr);
  /* create the thread */
  pthread_create(&tid, &attr, runner, argv[1]);
  /* wait for the thread to exit */
  pthread_join(tid,NULL);

  printf("sum = %d\n",sum);
}
```

Pthreads Example (cont.)

```
/* 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);
}
```

Pthreads Code for Joining 10 Threads

```
#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);
```

Windows Multithreaded C Program

```
#include <windows.h>
#include <stdio.h>
DWORD Sum; /* data is shared by the thread(s) */

/* The thread will execute in this function */
DWORD WINAPI Summation(LPVOID Param)
{
   DWORD Upper = *(DWORD*)Param;
   for (DWORD i = 1; i <= Upper; i++)
      Sum += i;
   return 0;
}
```

Windows Multithreaded C Program (cont.)

```
int main(int argc, char *argv[])
{
   DWORD ThreadId;
   HANDLE ThreadHandle;
   int Param;

   Param = atoi(argv[1]);
   /* create the thread */
   ThreadHandle = CreateThread(
      NULL, /* default security attributes */
      0, /* default stack size */
      Summation, /* thread function */
      &Param, /* parameter to thread function */
      0, /* default creation flags */
      &ThreadId); /* returns the thread identifier */

    /* now wait for the thread to finish */
   WaitForSingleObject(ThreadHandle,INFINITE);

   /* close the thread handle */
   CloseHandle(ThreadHandle);

   printf("sum = %d\n",Sum);
}
```

Java Threads

- Java threads are managed by the JVM
- Typically implemented using the threads model provided by underlying OS
- Java threads may be created by:

```
public interface Runnable
{
    public abstract void run();
}
```

  - Extending Thread class
  - Implementing the Runnable interface

Java Multithreaded Program

```
class Sum
{
  private int sum;

  public int getSum() {
   return sum;
  }

  public void setSum(int sum) {
   this.sum = sum;
  }
}

class Summation implements Runnable
{
  private int upper;
  private Sum sumValue;

  public Summation(int upper, Sum sumValue) {
   this.upper = upper;
   this.sumValue = sumValue;
  }

  public void run() {
   int sum = 0;
   for (int i = 0; i <= upper; i++)
     sum += i;
   sumValue.setSum(sum);
  }
}
```

Java Multithreaded Program (cont.)

```
public class Driver
{
  public static void main(String[] args) {
   if (args.length > 0) {
    if (Integer.parseInt(args[0]) < 0)
     System.err.println(args[0] + " must be >= 0.");
    else {
     Sum sumObject = new Sum();
     int upper = Integer.parseInt(args[0]);
     Thread thrd = new Thread(new Summation(upper, sumObject));
     thrd.start();
     try {
       thrd.join();
       System.out.println
               ("The sum of "+upper+" is "+sumObject.getSum());
    } catch (InterruptedException ie) { }
    }
   }
   else
    System.err.println("Usage: Summation <integer value>"); }
}
```

Implicit Threading

- Growing in popularity as numbers of threads increase, program correctness more difficult with explicit threads
- Creation and management of threads done by compilers and run-time libraries rather than programmers
- Three methods explored
  - Thread Pools
  - OpenMP
  - Grand Central Dispatch
- Other methods include Microsoft Threading Building Blocks (TBB), `java.util.concurrent` package

Thread Pools

- Create a number of threads in a pool where they await work
- Advantages:
  - Usually slightly faster to service a request with an existing thread than create a new thread
  - Allows the number of threads in the application(s) to be bound to the size of the pool
  - Separating task to be performed from mechanics of creating task allows different strategies for running task
    - i.e., Tasks could be scheduled to run periodically
- Windows API supports thread pools:

```
DWORD WINAPI PoolFunction(AVOID Param) {
    /*
     * this function runs as a separate thread.
     */
}
```

OpenMP

- Set 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

```
#pragma omp parallel for
for(i=0;i<N;i++) {
    c[i] = a[i] + b[i];
}
```

Run for loop in parallel

```
#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;
}
```

Grand Central Dispatch

- Apple technology for Mac OS X and iOS operating systems
- Extensions to C, C++ languages, API, and run-time library
- Allows identification of parallel sections
- Manages most of the details of threading
- Block is in “^{ }” - `^{ printf("I am a block"); }`
- Blocks placed in dispatch queue
    - Assigned to available thread in thread pool when removed from queue

Grand Central Dispatch

- Two types of dispatch queues:
  - serial – blocks removed in FIFO order, queue is per process, called main queue
    - Programmers can create additional serial queues within program
  - concurrent – removed in FIFO order but several may be removed at a time
    - Three system wide queues with priorities low, default, high

```
dispatch_queue_t queue = dispatch_get_global_queue
   (DISPATCH_QUEUE_PRIORITY_DEFAULT, 0);

dispatch_async(queue, ^{ printf("I am a block."); });
```

Threading Issues

- Semantics of fork() and exec() system calls
- Signal handling
  - Synchronous and asynchronous
- Thread cancellation of target thread
  - Asynchronous or deferred
- Thread-local storage
- Scheduler Activations

Semantics of fork() and exec()

- Does `fork()` duplicate only the calling thread or all threads?
  - Some UNIXes have two versions of fork
- `exec()` usually works as normal – replace the running process including all threads

Thread-Local Storage

- Thread-local storage (TLS) allows each thread to have its own copy of data
- Useful when you do not have control over the thread creation process (i.e., when using a thread pool)
- Different from local variables
  - Local variables visible only during single function invocation
  - TLS visible across function invocations
- Similar to `static` data
  - TLS is unique to each thread

Summary

- Thread: a single execution stream within a process
- Switching between user-level threads is faster than between kernel threads since a context switch is not required

Exit Slips

- Take 1-2 minutes to reflect on this lecture
- On a sheet of paper write:
  - One thing you learned in this lecture
  - One thing you didn’t understand

Next class

- We will discuss:
  - CPU Scheduling
- Reading assignment:
  - SGG: Ch. 5

Acknowledgment

- The slides are partially based on the ones from
  - The book site of *Operating System Concepts (Tenth Edition)*: http://os-book.com/