

CSC139 Operating System Principles

Fall 2019, 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

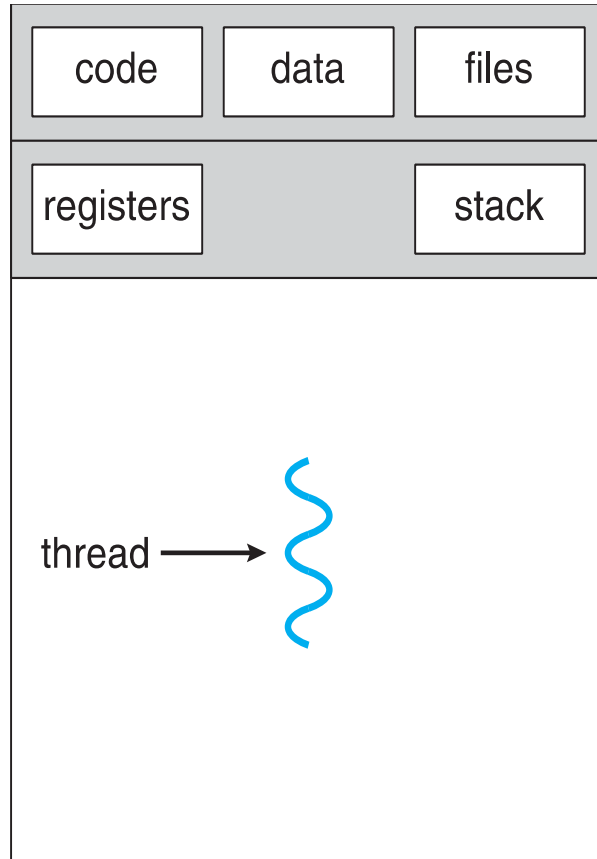
Process vs. Thread

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

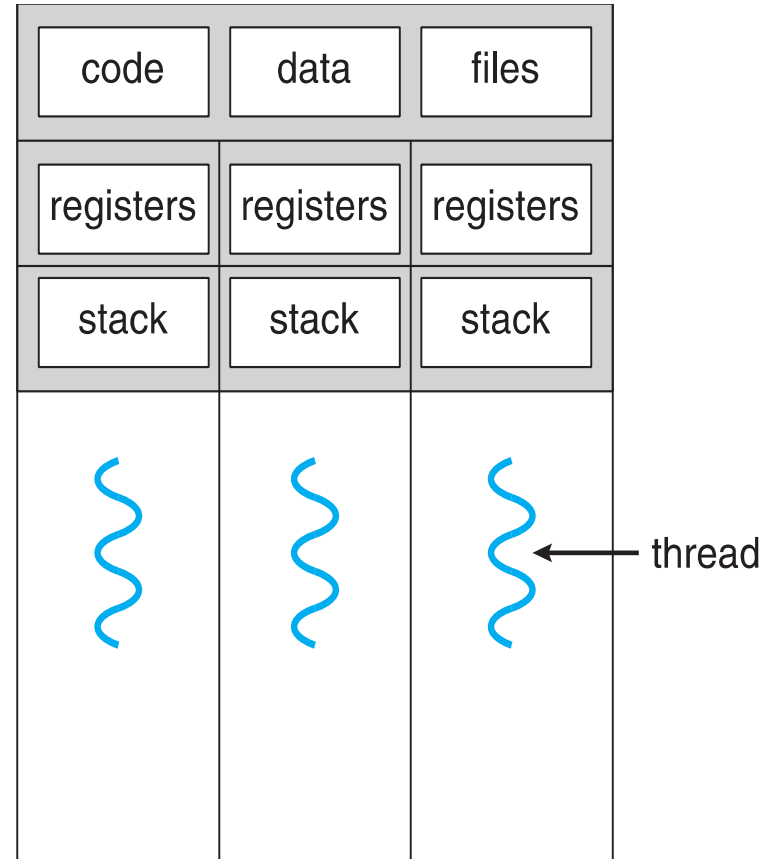
Motivation

- 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

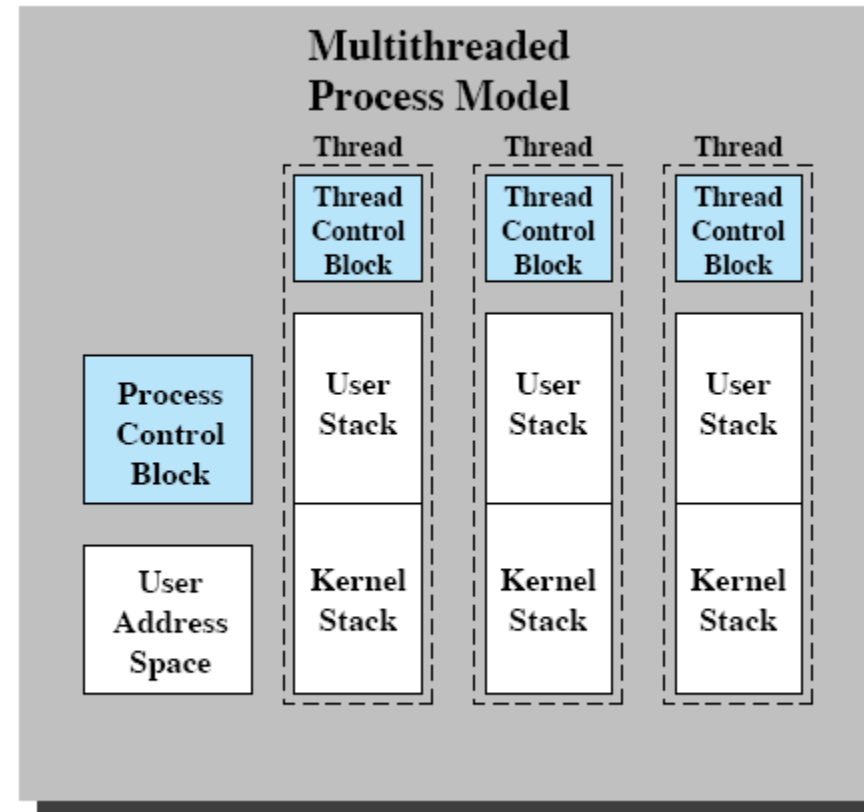
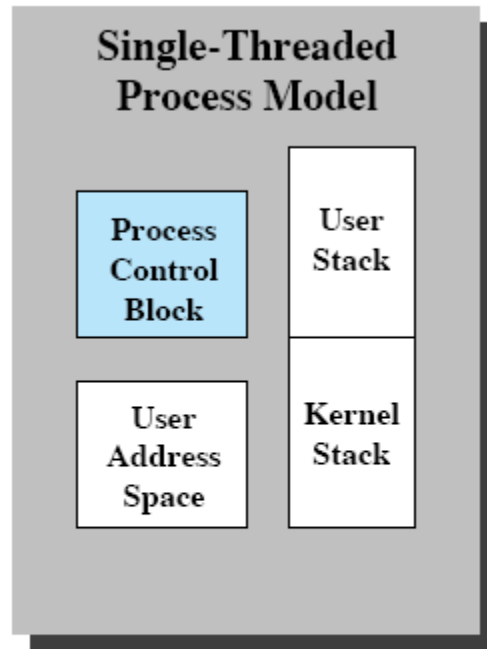
Per Process Items

- Address space
- Global variables
- Open files
- Accounting information

Per Thread Items

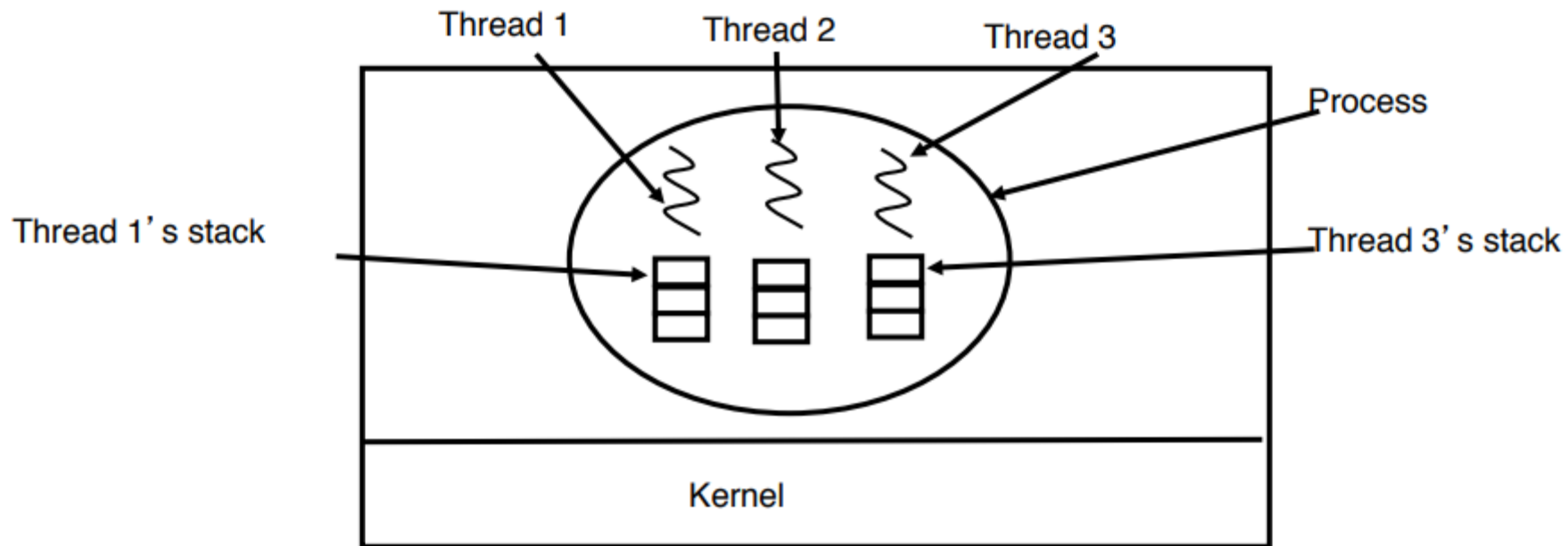
- Program counter
- Registers
- Stack
- State

Single- and Multi-threaded Process Models

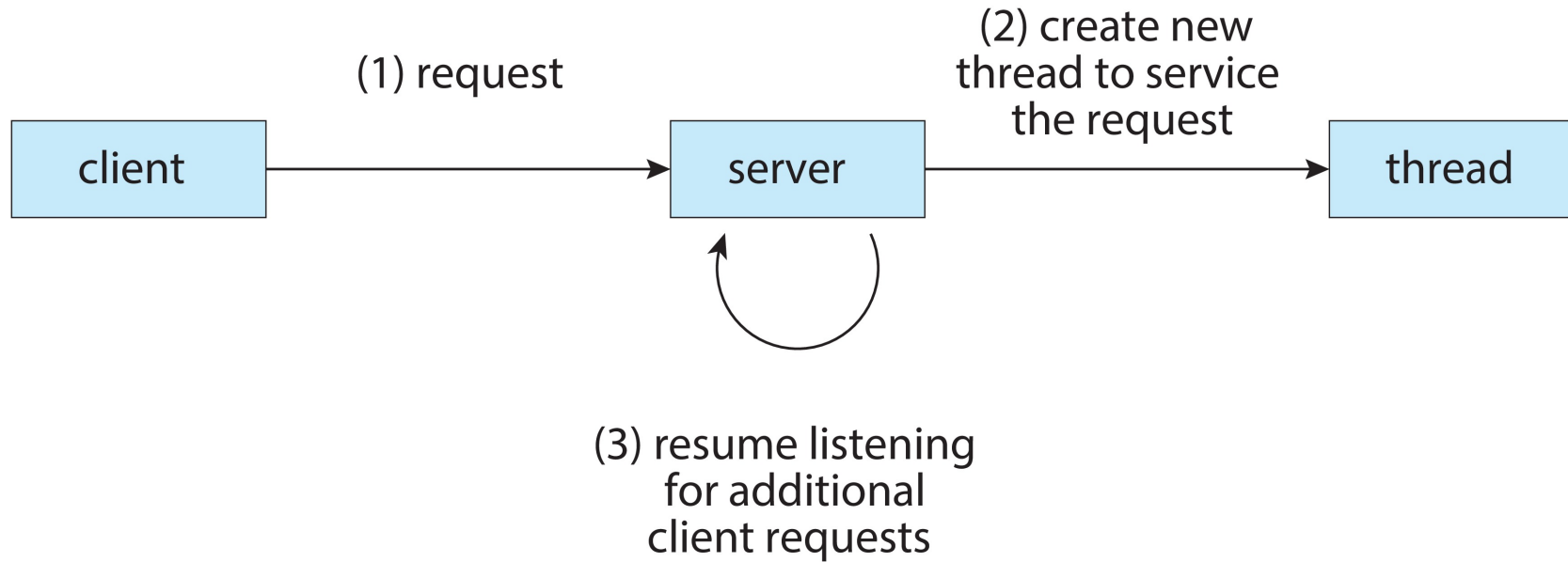


Multithreading (cont.)

- 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

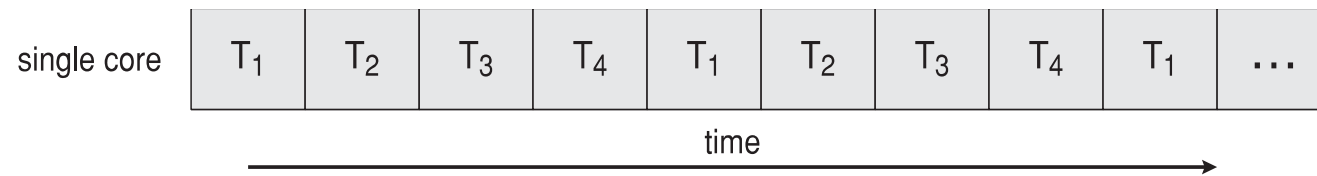
- **Responsiveness** – may allow continued execution if part of process is blocked, especially important for user interfaces
- **Resource Sharing** – threads share resources of process, easier than shared memory or message passing
- **Economy** – cheaper than process creation, thread switching lower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

Multicore Programming

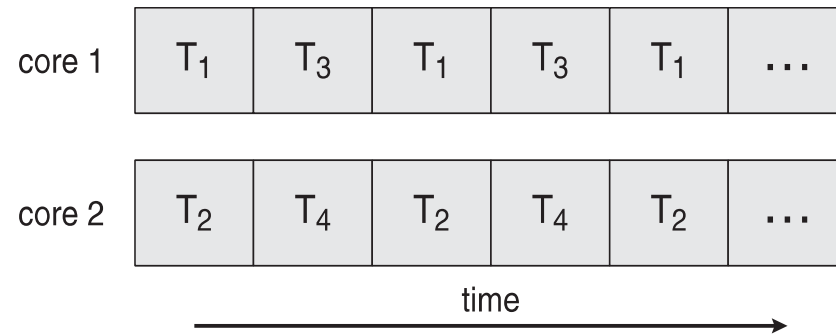
- **Multicore** or **multiprocessor** systems putting pressure on programmers, challenges include:
 - Dividing activities
 - Balance
 - Data splitting
 - Data dependency
 - Testing and debugging
- **Parallelism** implies a system can perform more than one task simultaneously
- **Concurrency** supports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

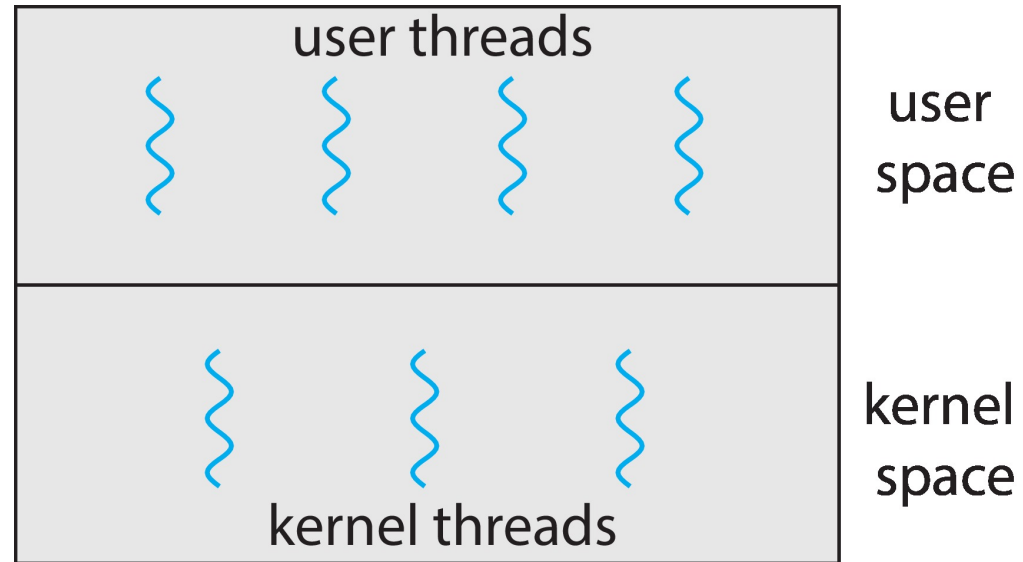
Kernel Threads

- 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

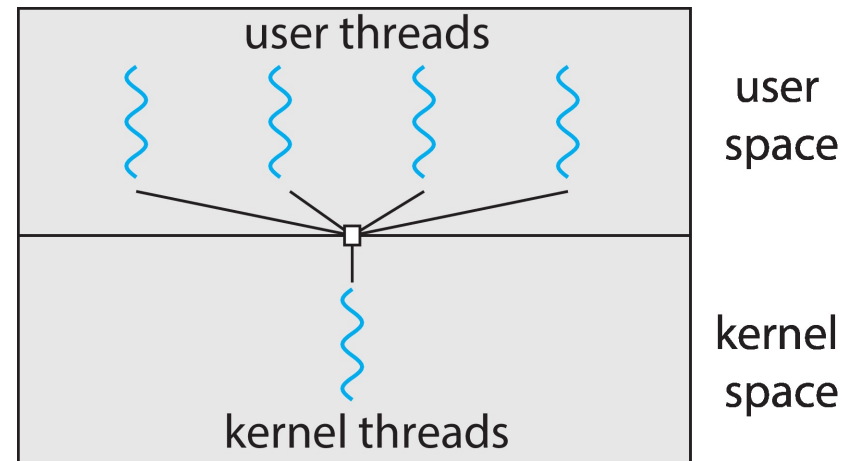
- No true parallelism - Multiple threads in process cannot run concurrently
- Since the OS does not know about the existence of the user-level threads, it may make poor scheduling decisions:
 - It might run a process that only has idle threads.
 - If a user-level thread is waiting for I/O, the entire 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

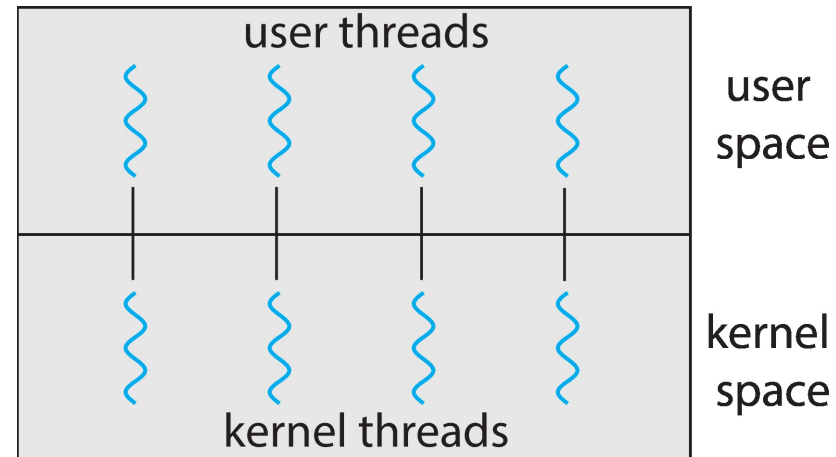
Many-to-One

- 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



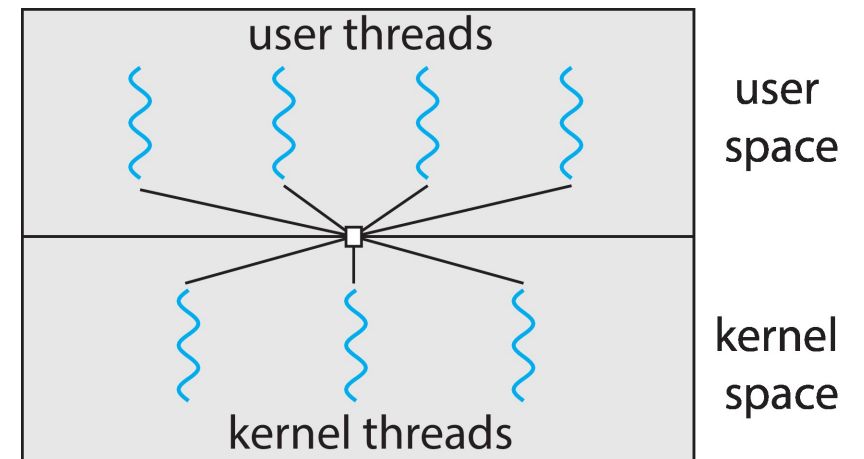
One-to-One

- 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



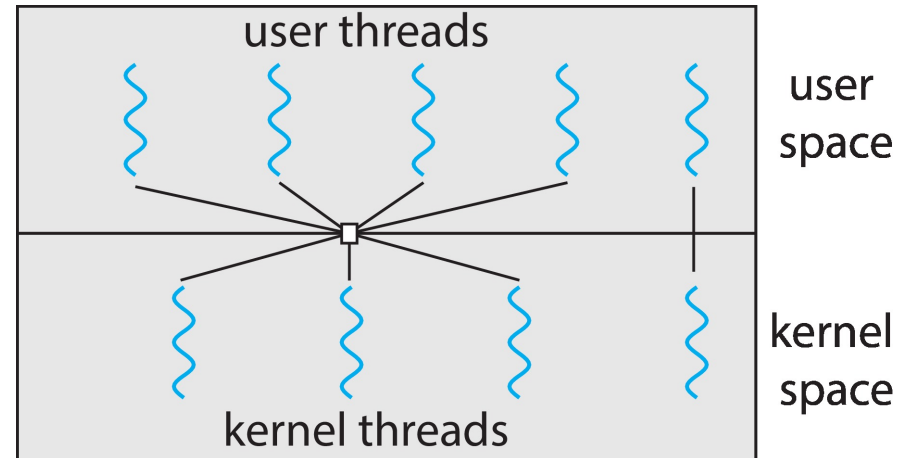
Many-to-Many Model

- 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

Signal Handling

- **Signals** are used in UNIX systems to notify a process that a particular event has occurred.
- A **signal handler** is used to process signals
 1. Signal is generated by particular event
 2. Signal is delivered to a process
 3. Signal is handled by one of two signal handlers:
 1. default
 2. user-defined
- Every signal has **default handler** that kernel runs when handling signal
 - **User-defined signal handler** can override default
 - For single-threaded, signal delivered to process

Signal Handling

- Where should a signal be delivered for multi-threaded?
 - Deliver the signal to the thread to which the signal applies
 - Deliver the signal to every thread in the process
 - Deliver the signal to certain threads in the process
 - Assign a specific thread to receive all signals for the process

Signal Cancellation

- Terminating a thread before it has finished
- Thread to be canceled is **target thread**
- Two general approaches:
 - **Asynchronous cancellation** terminates the target thread immediately
 - **Deferred cancellation** allows the target thread to periodically check if it should be cancelled
- Pthread code to create and cancel a thread:

```
pthread_t tid;

/* create the thread */
pthread_create(&tid, 0, worker, NULL);

. . .

/* cancel the thread */
pthread_cancel(tid);
```

Signal Cancellation (cont.)

- Invoking thread cancellation requests cancellation, but actual cancellation depends on thread state

Mode	State	Type
Off	Disabled	–
Deferred	Enabled	Deferred
Asynchronous	Enabled	Asynchronous

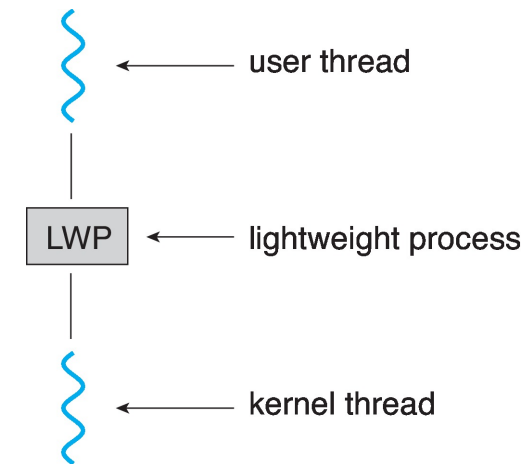
- If thread has cancellation disabled, cancellation remains pending until thread enables it
- Default type is deferred
 - Cancellation only occurs when thread reaches [cancellation point](#)
 - i.e. `pthread_testcancel()`
 - Then [cleanup handler](#) is invoked
- On Linux systems, thread cancellation is handled through signals

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

Scheduler Activations

- Both M:M and Two-level models require communication to maintain the appropriate number of kernel threads allocated to the application
- Typically use an intermediate data structure between user and kernel threads – **lightweight process (LWP)**
 - Appears to be a virtual processor on which process can schedule user thread to run
 - Each LWP attached to kernel thread
 - How many LWPs to create?
- Scheduler activations provide **upcalls** - a communication mechanism from the kernel to the **upcall handler** in the thread library
- This communication allows an application to maintain the correct number kernel threads



Operating System Examples

- Windows Threads
- Linux Threads

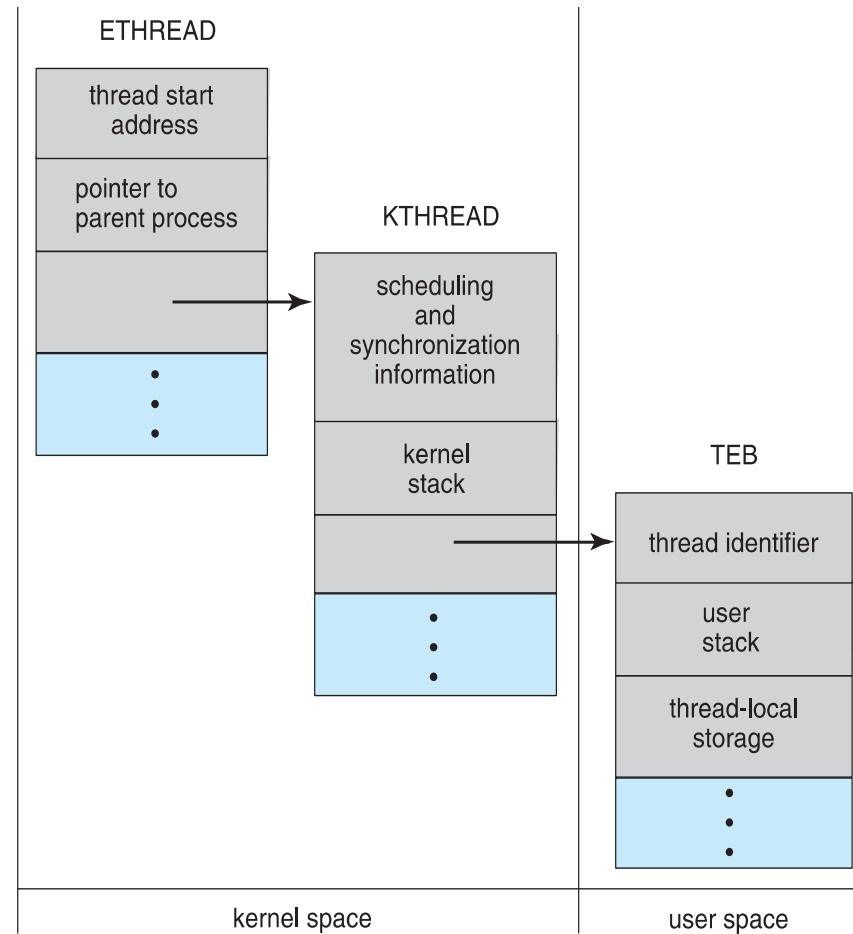
Windows Threads

- Windows implements the Windows API – primary API for Win 98, Win NT, Win 2000, Win XP, and Win 7
- Implements the one-to-one mapping, kernel-level
- Each thread contains
 - A thread id
 - Register set representing state of processor
 - Separate user and kernel stacks for when thread runs in user mode or kernel mode
 - Private data storage area used by run-time libraries and dynamic link libraries (DLLs)
- The register set, stacks, and private storage area are known as the **context** of the thread

Windows Threads (cont.)

- The primary data structures of a thread include:
 - ETHREAD (executive thread block) – includes pointer to process to which thread belongs and to KTHREAD, in kernel space
 - KTHREAD (kernel thread block) – scheduling and synchronization info, kernel-mode stack, pointer to TEB, in kernel space
 - TEB (thread environment block) – thread id, user-mode stack, thread-local storage, in user space

Windows Threads Data Structures



Linux Threads

- Linux refers to them as *tasks* rather than *threads*
- Thread creation is done through `clone()` system call
- `clone()` allows a child task to share the address space of the parent task (process)
 - Flags control behavior

flag	meaning
CLONE_FS	File-system information is shared.
CLONE_VM	The same memory space is shared.
CLONE_SIGHAND	Signal handlers are shared.
CLONE_FILES	The set of open files is shared.

- `struct task_struct` points to process data structures (shared or unique)

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/>