

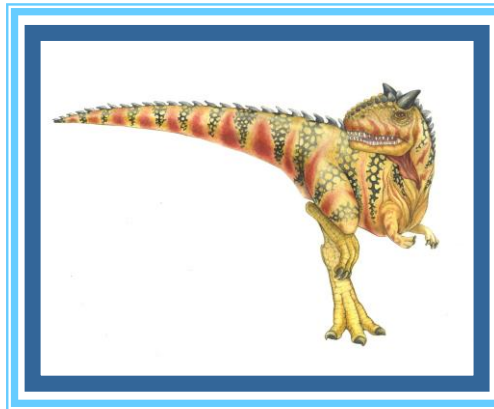
# **CSE-309**

## **Operating Systems**

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# Chapter 4: Threads

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# Chapter 4: Threads

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





# Objectives

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- To introduce the notion of a thread—a fundamental unit of CPU utilization that forms the basis of multithreaded computer systems
- To discuss the APIs for the Pthreads, Windows, and Java thread libraries
- To explore several strategies that provide implicit threading
- To examine issues related to multithreaded programming
- To cover operating system support for threads in Windows and Linux





# Motivation

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- 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





# Thread

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- What is thread?

A thread is the smallest unit of processing that can be performed in an OS. In most modern operating systems, a thread exists within a process - that is, a single process may contain multiple threads.

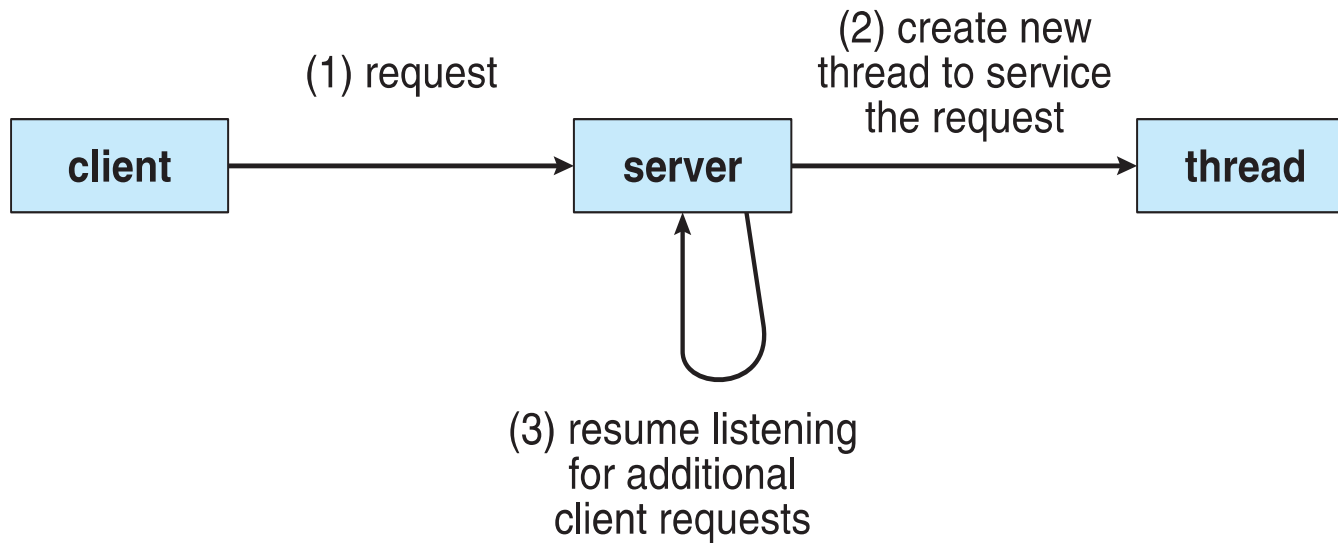
- Why multithreading?

A thread is also known as lightweight process. The idea is to achieve parallelism by dividing a process into multiple threads. For example, in a browser, multiple tabs can be different threads. MS Word uses multiple threads: one thread to format the text, another thread to process inputs, etc.





# Multithreaded Server Architecture





# Benefits

- **Responsiveness** – may allow continued execution if part of process is blocked, especially important for user interfaces
- **Resource Sharing** – By default threads share common code, data, and other resources, which allows multiple tasks to be performed simultaneously in a single address space., easier than shared memory or message passing
- **Economy** – Creating and managing threads ( and context switches between them ) is much faster than performing the same tasks for processes.
- **Scalability** – process can take advantage of multiprocessor architectures. A single threaded process can only run on one CPU, no matter how many may be available, whereas the execution of a multi-threaded application may be split amongst available processors.







# Multicore Programming

- For application programmers, there are five areas where multi-core chips present new challenges:
- **Identifying tasks** - Examining applications to find activities that can be performed concurrently.
- **Balance** - Finding tasks to run concurrently that provide equal value.
- **Data splitting** - To prevent the threads from interfering with one another.
- **Data dependency** - If one task is dependent upon the results of another, then the tasks need to be synchronized to assure access in the proper order.
- **Testing and debugging** - Inherently more difficult in parallel processing situations, as the race conditions become much more complex and difficult to identify.





# Multicore Programming (Cont.)

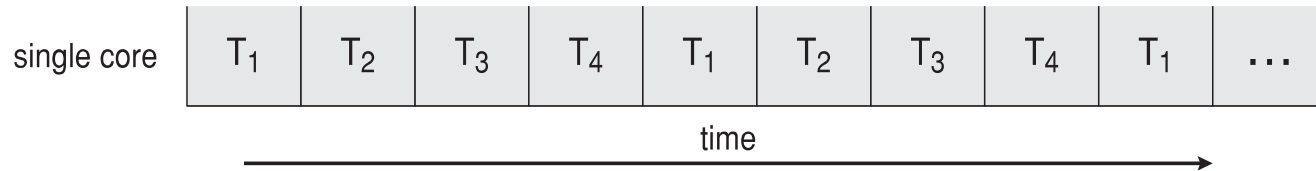
- Types of parallelism
  - **Data parallelism** – distributes subsets of the same data across multiple cores, same operation on each
  - **Task parallelism** – distributing threads across cores, each thread performing unique operation
- As # of threads grows, so does architectural support for threading
  - CPUs have cores as well as ***hardware threads***
  - Consider Oracle SPARC T4 with 8 cores, and 8 hardware threads per core



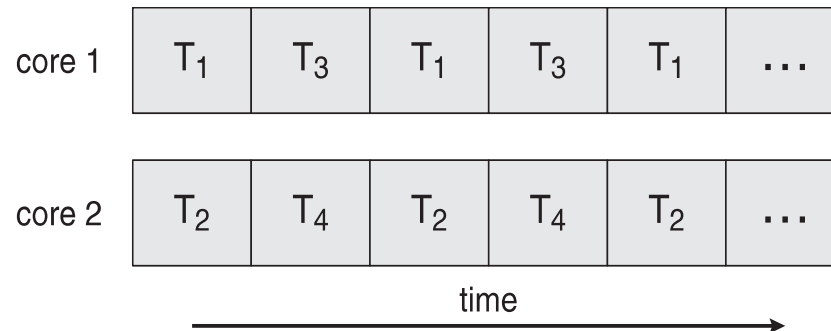


# Concurrency vs. Parallelism

## ■ Concurrent execution on single-core system:



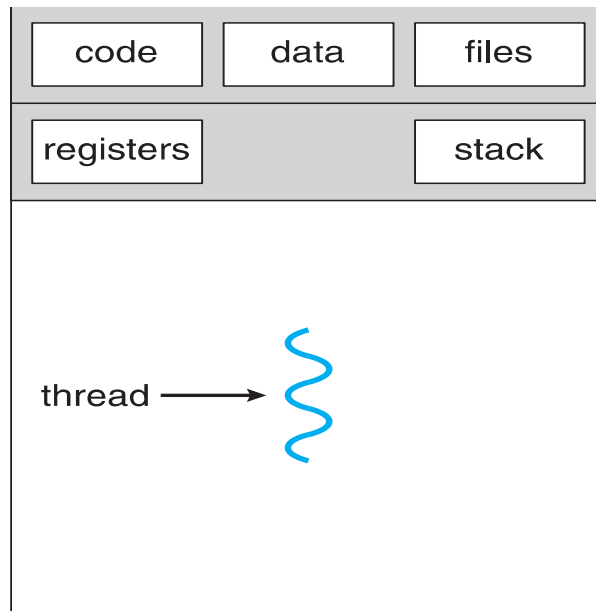
## ■ Parallelism on a multi-core system:



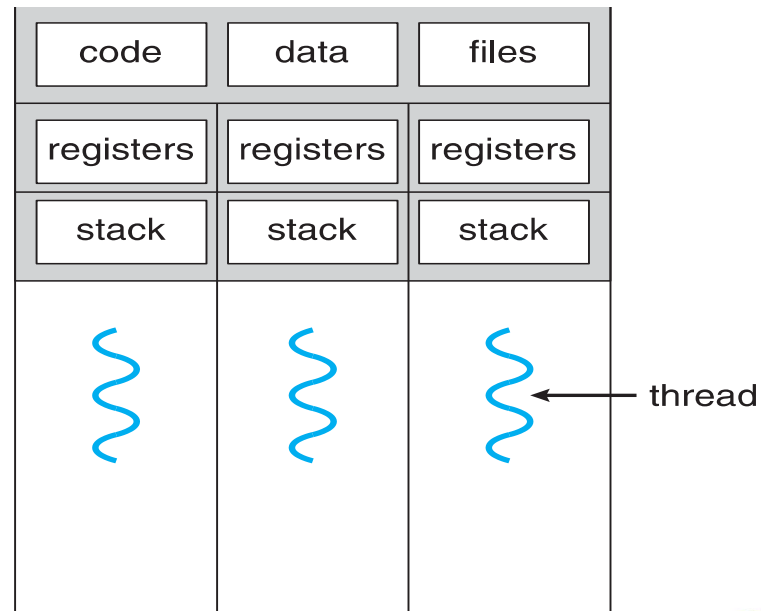


# Single and Multithreaded Processes

- A **thread** is a basic unit of CPU utilization, consisting of a program counter, a stack, and a set of registers, ( and a thread ID. )
- Traditional ( heavyweight ) processes have a single thread of control - There is one program counter, and one sequence of instructions that can be carried out at any given time.
- As shown in Figure, multi-threaded applications have multiple threads within a single process, each having their own program counter, stack and set of registers, but sharing common code, data, and certain structures such as open files.



single-threaded process



multithreaded process





# Amdahl's Law

- In parallel computing, Amdahl's law is mainly used to predict the theoretical maximum speedup for program processing using multiple processors.
- It is named after Gene Amdahl, a computer architect from IBM and the Amdahl Corporation.
- Identifies performance gains from adding additional cores to an application that has both serial and parallel components
- $S$  is serial portion
- $N$  processing cores
- 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  $1 / S$

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

**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?





# User Threads and Kernel Threads

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- **User threads** - management done by user-level threads library
- Three primary thread libraries:
  - POSIX **Pthreads** (Portable Operating System Interface)
  - 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





# User Threads and Kernel Threads

User level thread	Kernel level thread
User thread are implemented by users.	kernel threads are implemented by OS.
OS doesn't recognize user level threads.	Kernel threads are recognized by OS.
Implementation of User threads is easy.	Implementation of Kernel thread is complicated.
Context switch time is less.	Context switch time is more.
Context switch requires no hardware support.	Hardware support is needed.
If one user level thread perform blocking operation then entire process will be blocked.	If one kernel thread perform blocking operation then another thread can continue execution.
Example : Java thread, POSIX threads.	Example : Window Solaris.





# Multithreading Models

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

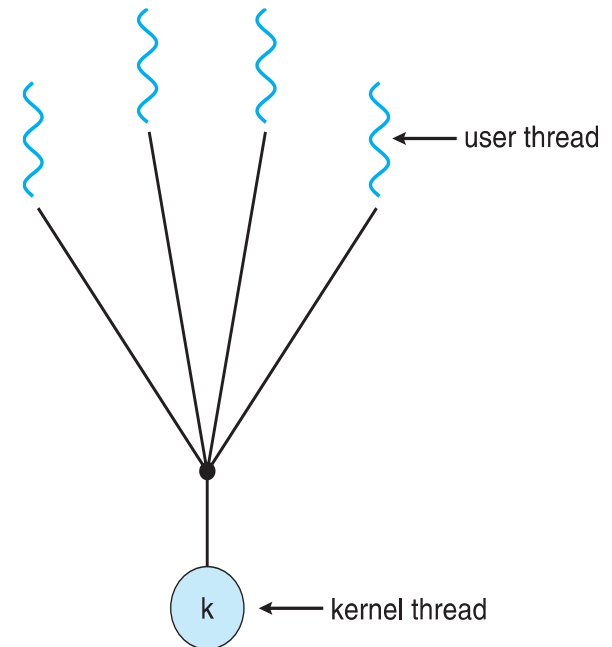






# Many-to-One

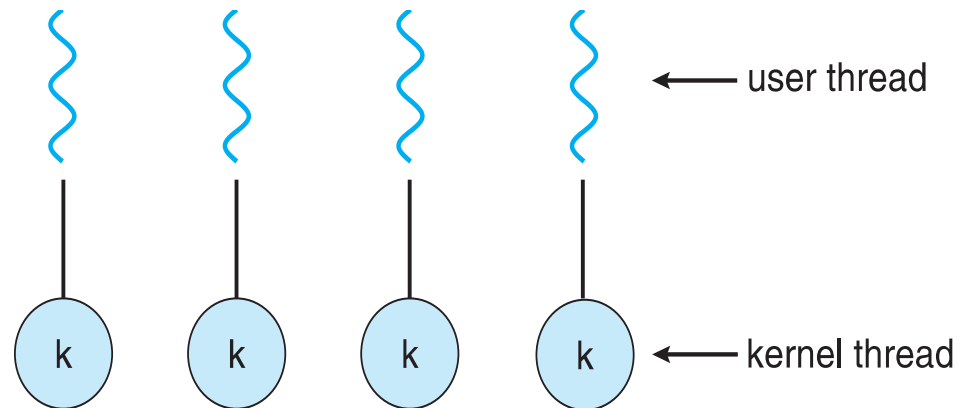
- Many user-level threads mapped to single kernel thread
- One thread blocking causes all to block
- Multiple threads may not run in parallel on multicore system because only one may be in kernel at a time
- Few systems currently use this model
- Examples:
  - **Solaris Green Threads**
  - **GNU Portable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





# One-to-One

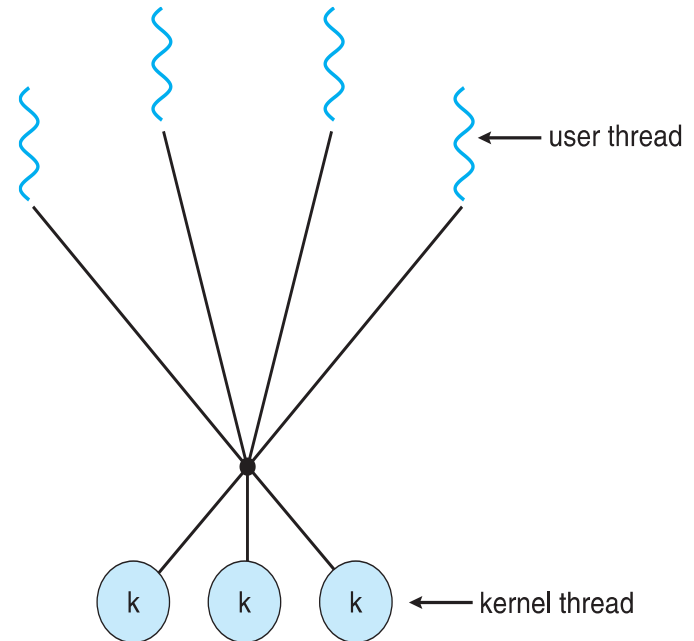
- Each user-level thread maps to kernel thread
- Creating a user-level thread creates a kernel thread
- More concurrency than many-to-one
- Number of threads per process sometimes restricted due to overhead
- Examples
  - Windows
  - Linux
  - Solaris 9 and later





# Many-to-Many Model

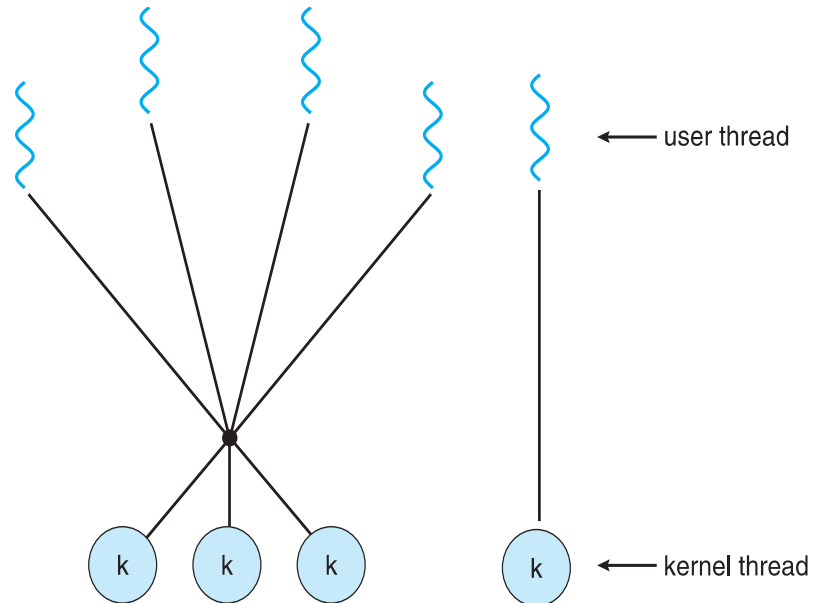
- Allows many user level threads to be mapped to many kernel threads
- Allows the operating system to create a sufficient number of kernel threads
- Solaris prior to version 9
- Windows with the *ThreadFiber* package





# Two-level Model

- One popular variation of the many-to-many model is the two-tier model, which allows either many-to-many or one-to-one operation.
- Examples
  - IRIX
  - HP-UX
  - Tru64 UNIX
  - Solaris 8 and earlier





# Thread Libraries

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- **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

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- 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>

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 */

    if (argc != 2) {
        fprintf(stderr, "usage: a.out <integer value>\n");
        return -1;
    }
    if (atoi(argv[1]) < 0) {
        fprintf(stderr, "%d must be >= 0\n", atoi(argv[1]));
        return -1;
    }
}
```





# Pthreads Example (Cont.)

```
/* get the default attributes */
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);
}

/* The thread will begin control 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

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```
#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 runs in this separate function */
DWORD WINAPI Summation(LPVOID Param)
{
    DWORD Upper = *(DWORD*)Param;
    for (DWORD i = 0; i <= Upper; i++)
        Sum += i;
    return 0;
}

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

    if (argc != 2) {
        fprintf(stderr, "An integer parameter is required\n");
        return -1;
    }
    Param = atoi(argv[1]);
    if (Param < 0) {
        fprintf(stderr, "An integer >= 0 is required\n");
        return -1;
    }
}
```





# Windows Multithreaded C Program (Cont.)

```
/* 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 */

if (ThreadHandle != NULL) {
    /* now wait for the thread to finish */
    WaitForSingleObject(ThreadHandle, INFINITE);

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

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





# Java Threads

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- 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

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- 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

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- 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

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- 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

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- 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()`

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- 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

- n **Signals** are used in UNIX systems to notify a process that a particular event has occurred.
- n 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
- n 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 (Cont.)

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- n 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





# Thread 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);
```







# Thread 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

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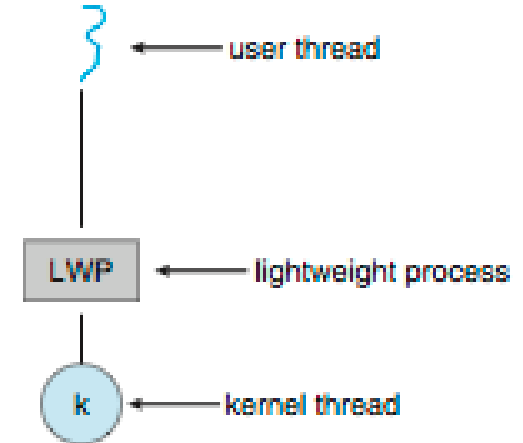
- **Thread-local storage (TLS)** allows each thread to have its own copy of data
- Useful when you do not have control over the thread creation process (i.e., when using a thread pool)
- Different from local variables
  - Local variables visible only during single function invocation
  - TLS visible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

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- Windows Threads
- Linux Threads





# Windows Threads

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- 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.)

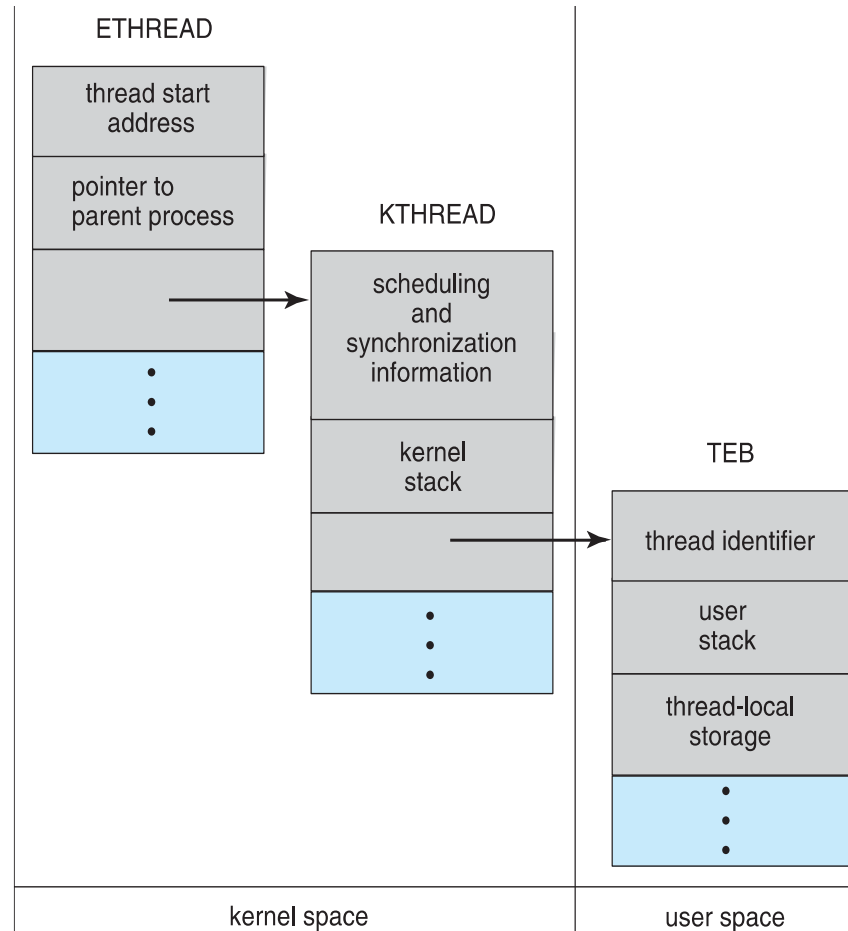
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- The primary data structures of a thread include:
  - ETHREAD (executive thread block) – includes pointer to process to which thread belongs and to KTHREAD, in kernel space
  - KTHREAD (kernel thread block) – scheduling and synchronization info, kernel-mode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





# End of Chapter 4

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