操作系统原理及应用

李　伟

xchlw@seu.edu.cn

计算机科学与工程学院、软件学院

江苏省网络与信息安全重点实验室

Chapter 4 Threads

Outline

- Overview
- Multithreading Models
- Thread Libraries
- Threading Issues
- Operating System Examples

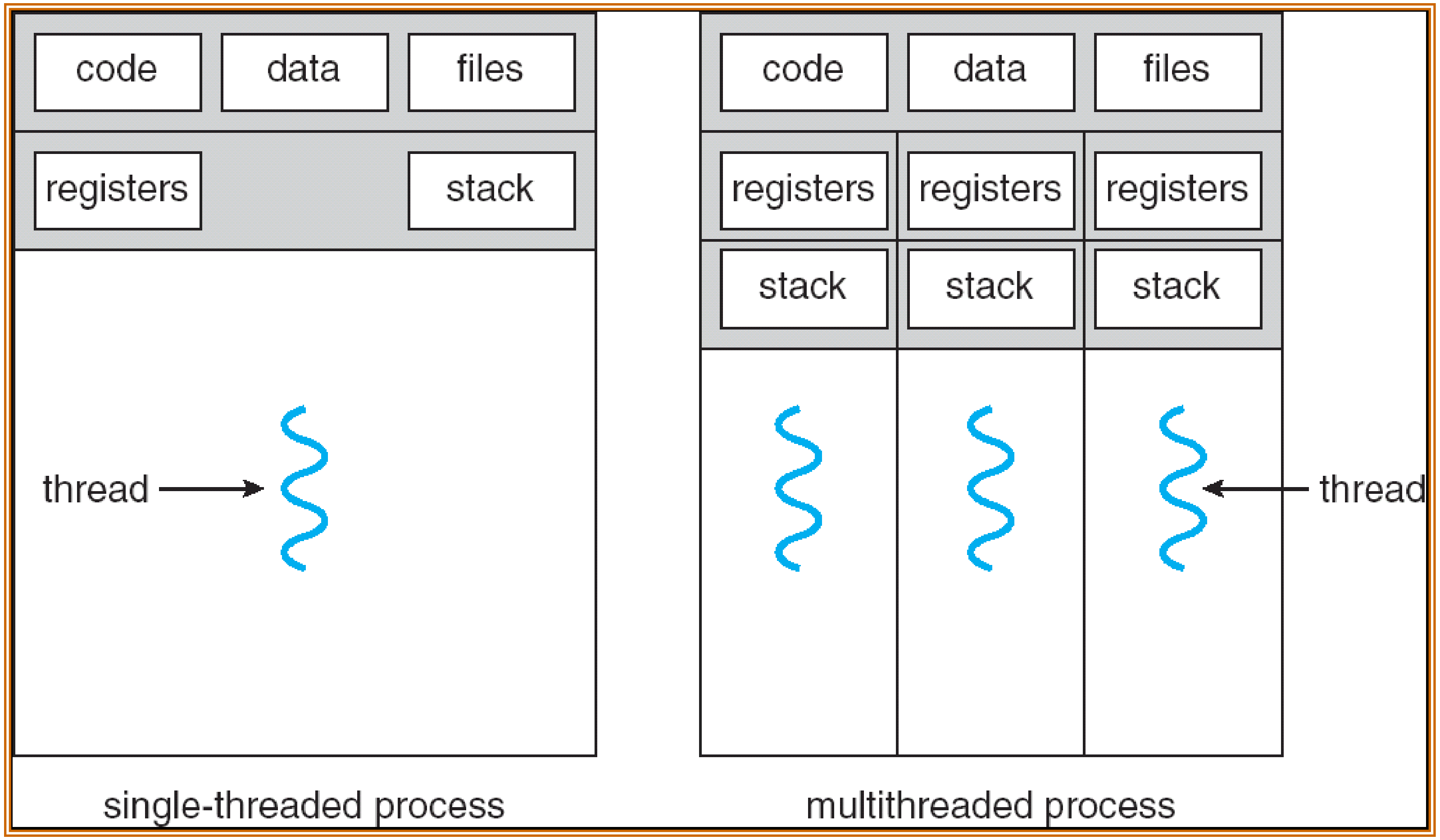
What is a thread? (1/2)

- A thread is a flow of control within a process.
- A *thread*, also known as *lightweight process* (LWP), is a basic unit of CPU execution.
- A traditional process, or heavyweight process, has a *single* thread of control.
- A multithreaded process contains several different flows of control within the same address space.

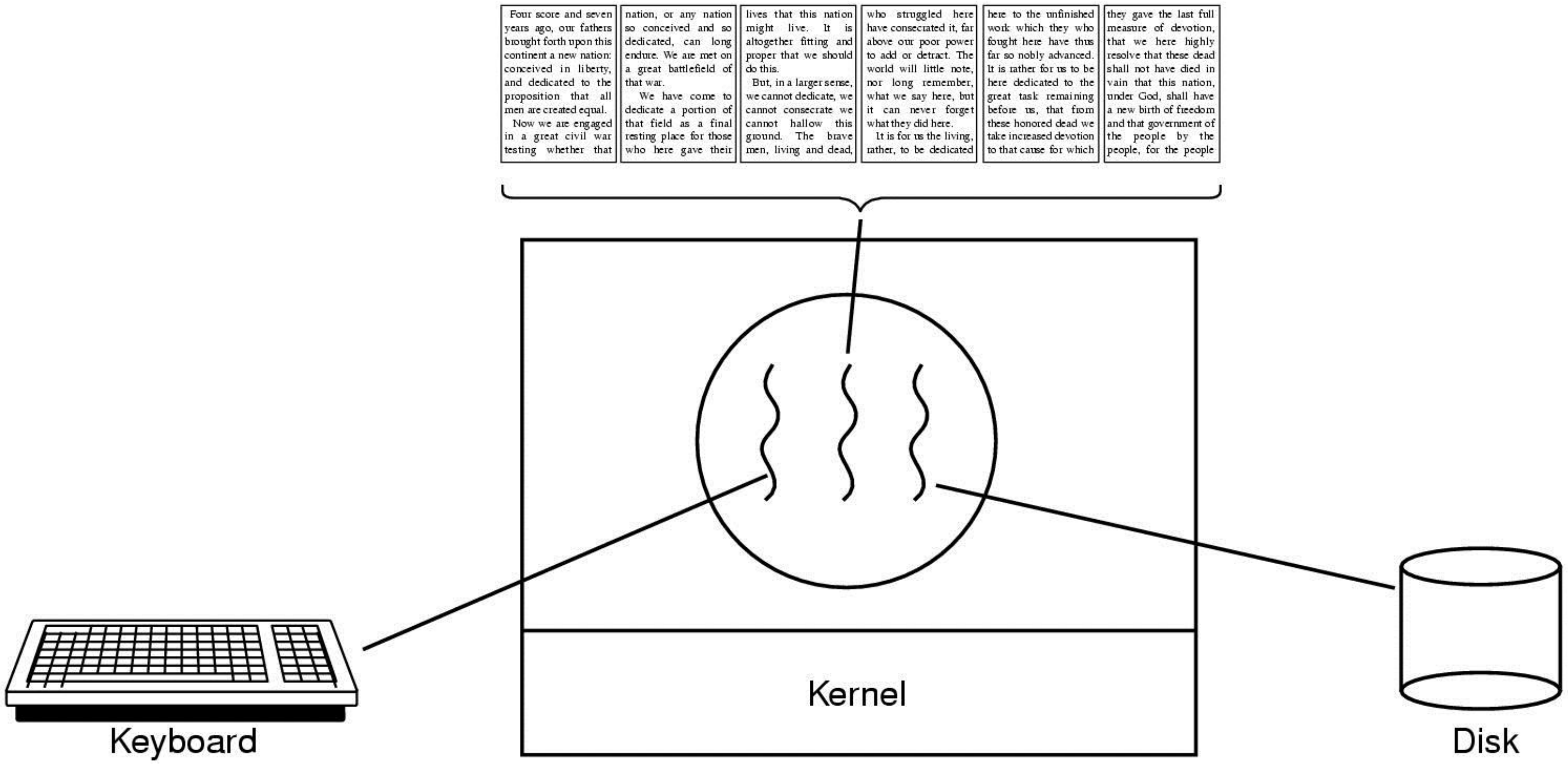
What is a thread? (2/1)

- A thread has a **thread ID**, a **program counter**, a **register set**, and a **stack**. Thus, it is similar to a process has.
- 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).

Single and Multithreaded Processes



Thread Usage (1/2)


Four score and seven years ago, our fathers brought forth upon this continent a new nation: conceived in liberty, and dedicated to the proposition that all men are created equal.

Now we are engaged in a great civil war testing whether that

nation, or any nation so conceived and so dedicated, can long endure. We are met on a great battlefield of that war.

We have come to dedicate a portion of that field as a final resting place for those who here gave their

lives that this nation might live. It is altogether fitting and proper that we should do this.

But, in a larger sense, we cannot dedicate, we cannot consecrate we cannot hallow this ground. The brave men, living and dead,

who struggled here have consecrated it, far above our poor power to add or detract. The world will little note, nor long remember, what we say here, but it can never forget what they did here.

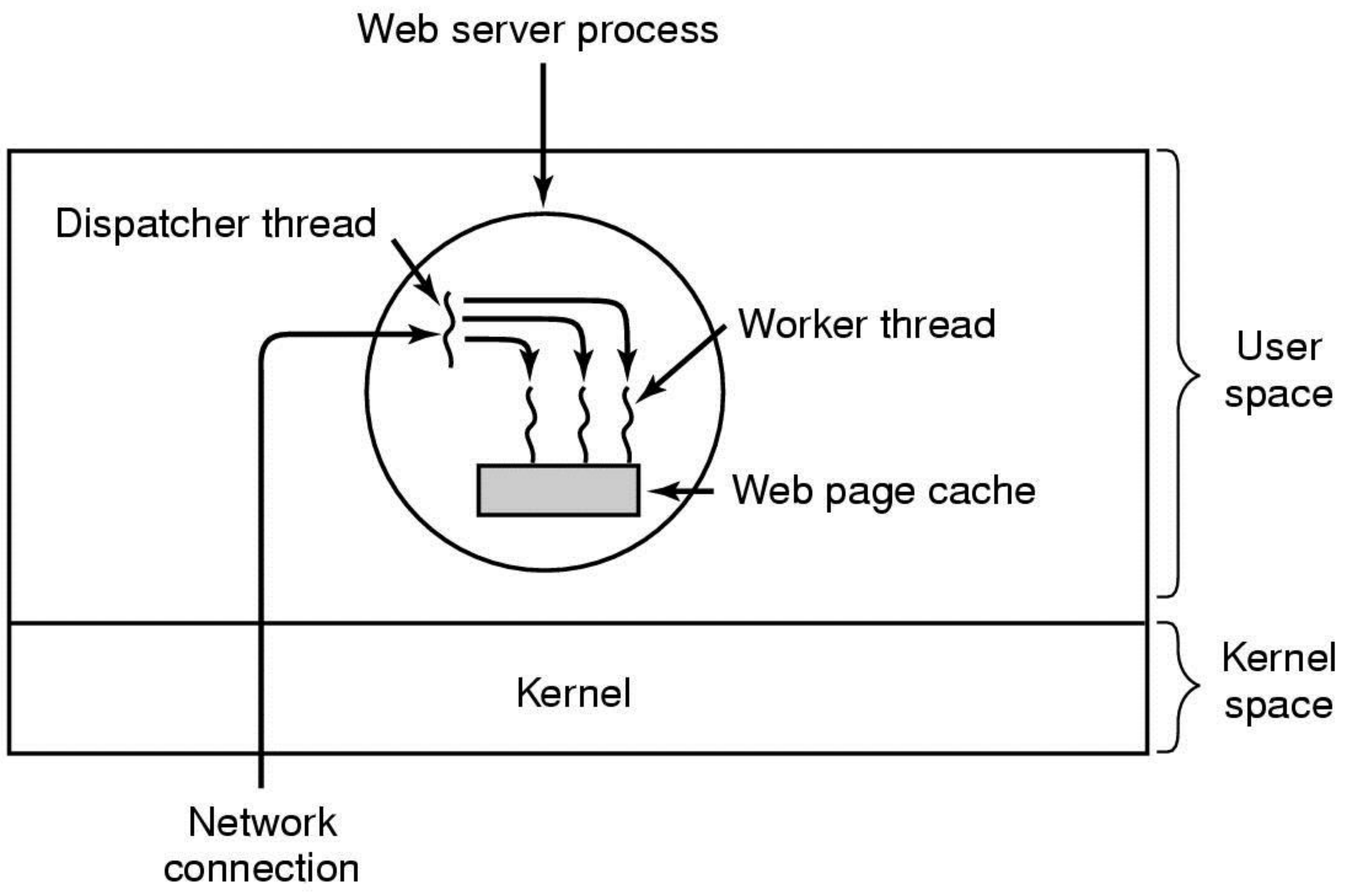
It is for us the living, rather, to be dedicated

here to the unfinished work which they who fought here have thus far so nobly advanced. It is rather for us to be here dedicated to the great task remaining before us, that from these honored dead we take increased devotion to that cause for which

they gave the last full measure of devotion, that we here highly resolve that these dead shall not have died in vain that this nation, under God, shall have a new birth of freedom and that government of the people by the people, for the people

A word processor with three threads

Thread Usage (2/2)



A multithreaded Web server

Benefits

- Responsiveness
  - For instance, multithreaded web browser
- Resource Sharing
  - Threads share the memory and the resources of the process to which they belong
- Economy
  - Creating and context-switch threads
- Utilization of Multiprocessor Architectures

User Threads

- Thread management done by user-level threads library
- Examples
  - POSIX Pthreads
  - Mach C-threads
  - Solaris UI-threads

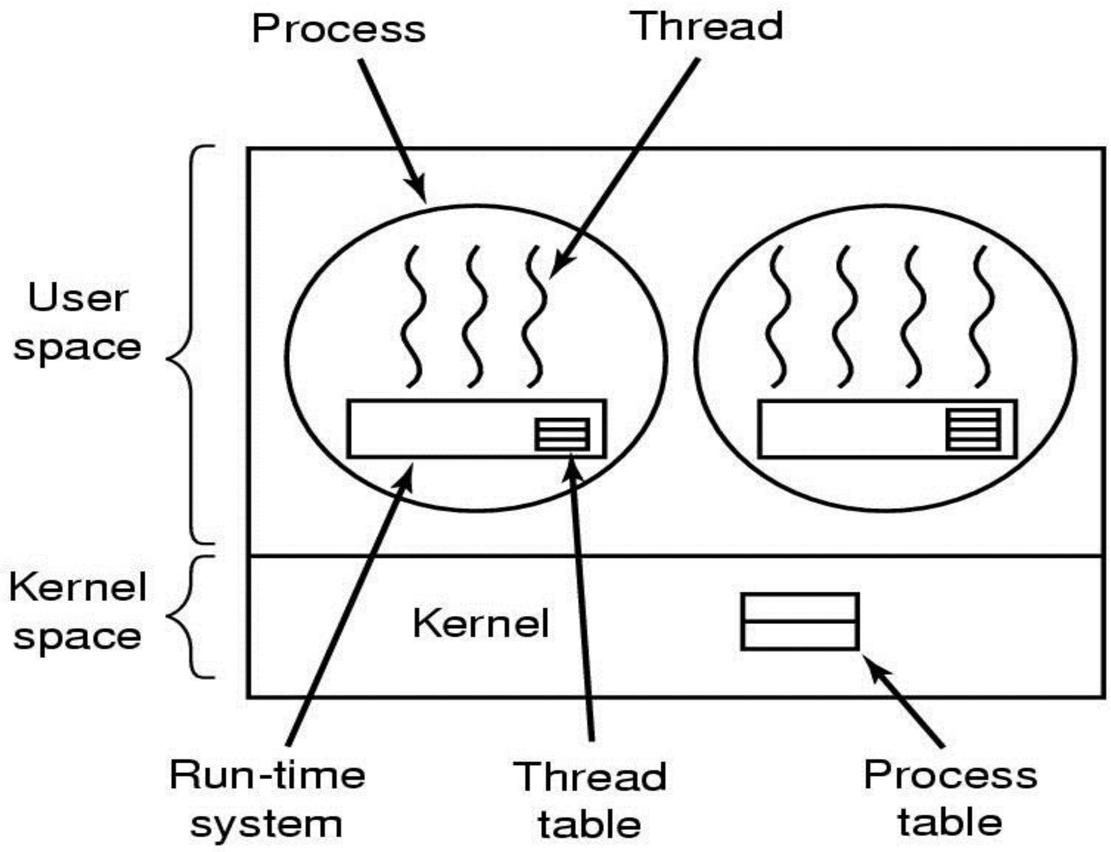
Windows OS

Kernel Version	Distribution
NT 3.51	Windows NT 3.51
NT 4.0	Windows NT 4.0
NT 5.0	Windows 2000
NT 5.1	Windows XP
NT 5.2	Windows Server 2003
NT 6.0	Windows Vista Windows Server 2008
NT 6.1	Windows 7 Windows Server 2008 R2
NT 6.2	Windows 8
NT 6.3	Windows 9

User Threads

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

Implementing Threads in User Space



A user-level threads package

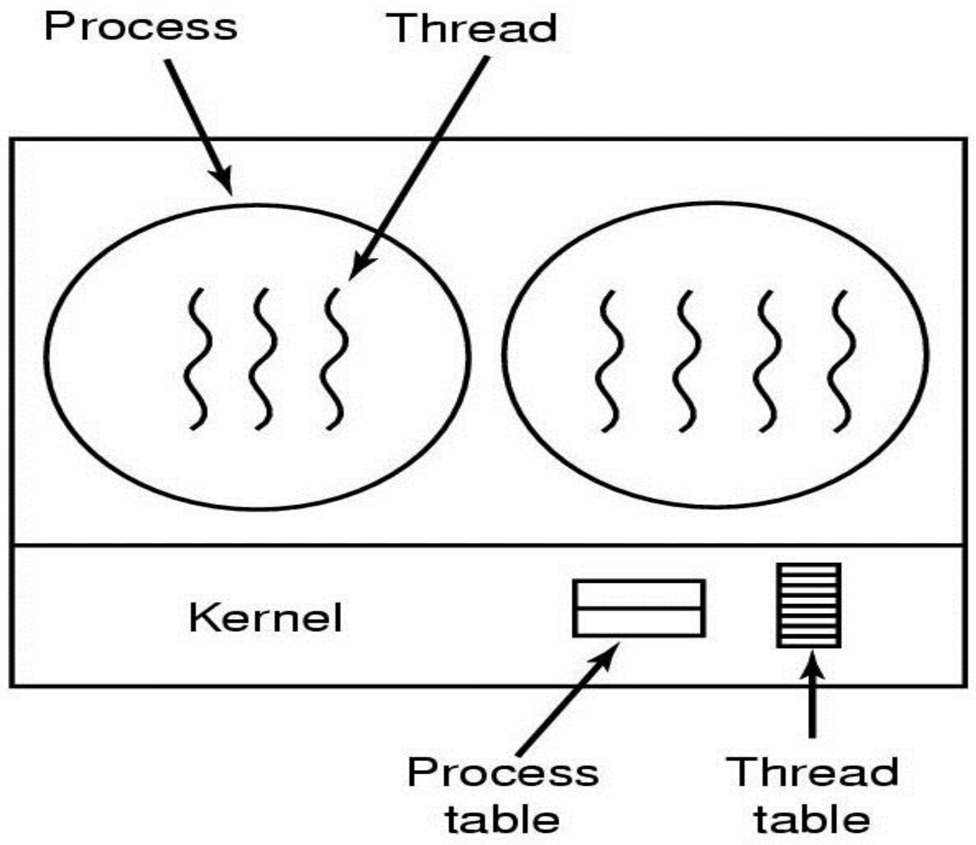
Kernel Threads

- Supported and managed by the Kernel
- Examples
  - Windows
  - Solaris
  - Mac OS X
  - Linux

Kernel Threads

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

Implementing Threads in the Kernel



A threads package managed by the kernel

作业1

1. 请阐述进程和线程之间的区别和联系。
2. 用户级线程和内核级线程有何区别？

Outline

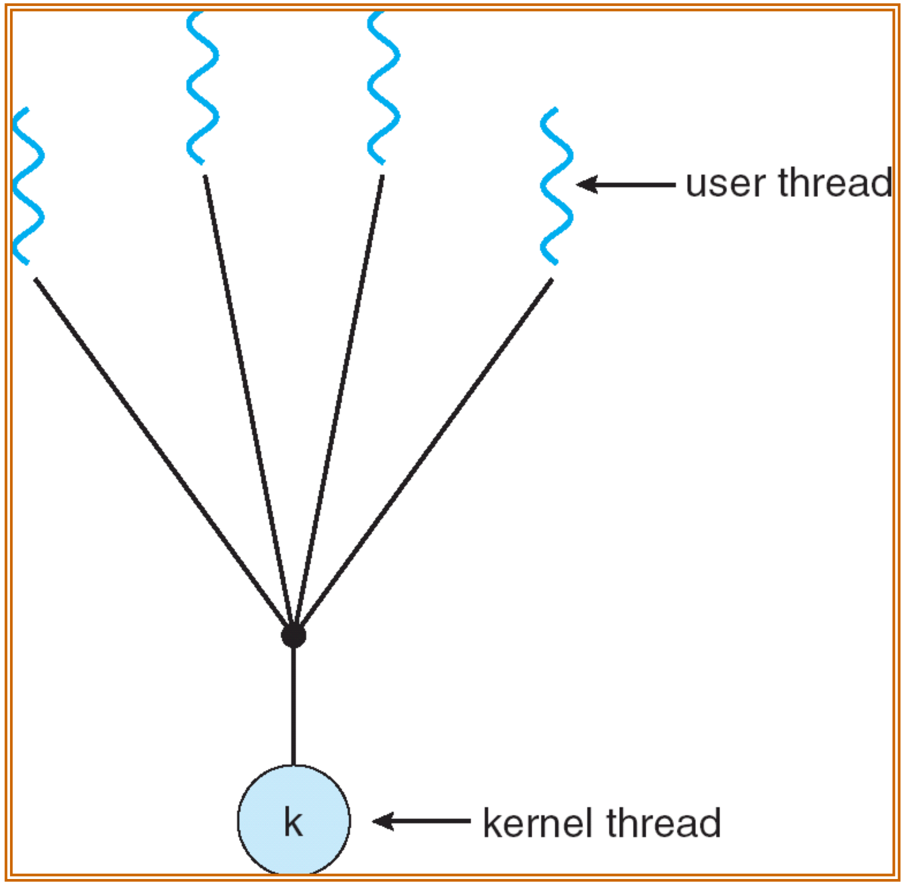
- Overview
- Multithreading Models
- Thread Libraries
- Threading Issues
- Operating System Examples

Multithreading Models

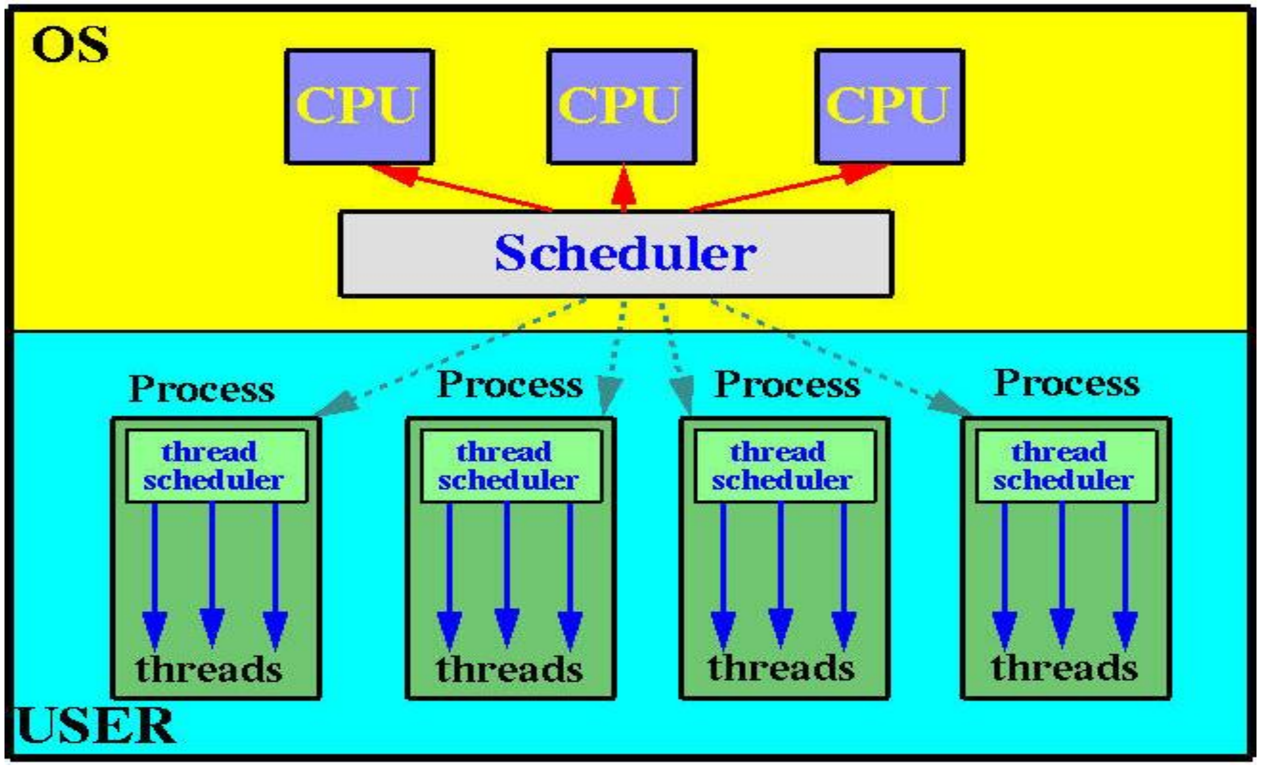
- Many-to-One
- One-to-One
- Many-to-Many

Many-to-One Model

- Many user-level threads mapped to single kernel thread.
- Used on systems that do not support kernel threads.



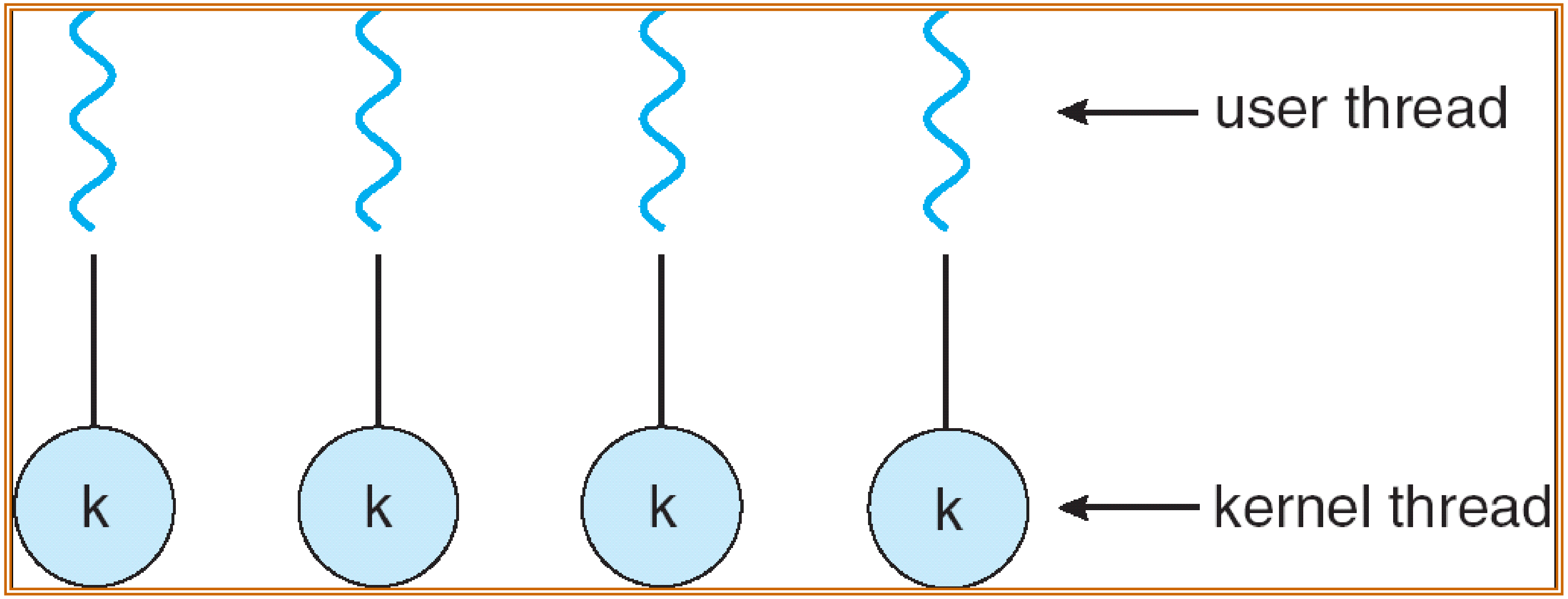
Many-to-One Model



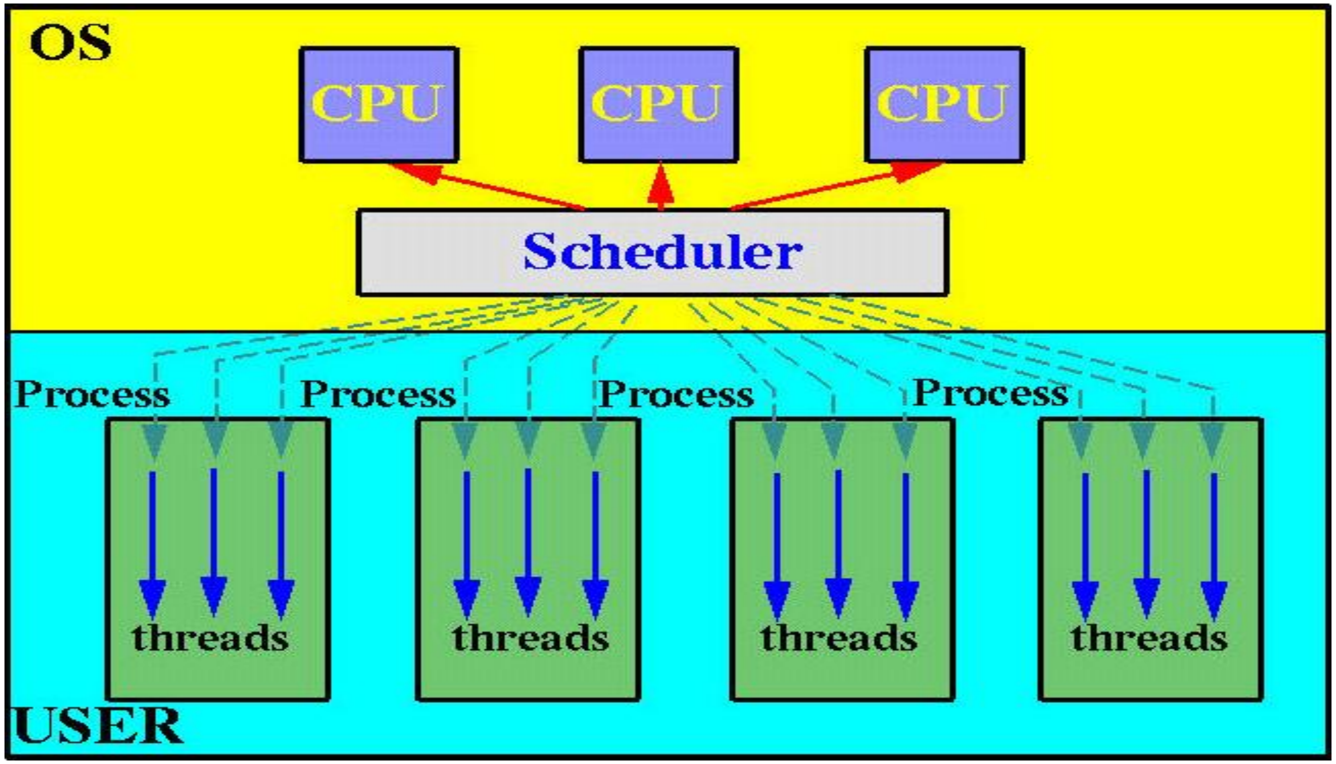
- Only one thread can access the kernel at a time.
- True concurrency is not gained.

One-to-One Model

- Each user-level thread maps to kernel thread.
- Examples: Windows & Linux



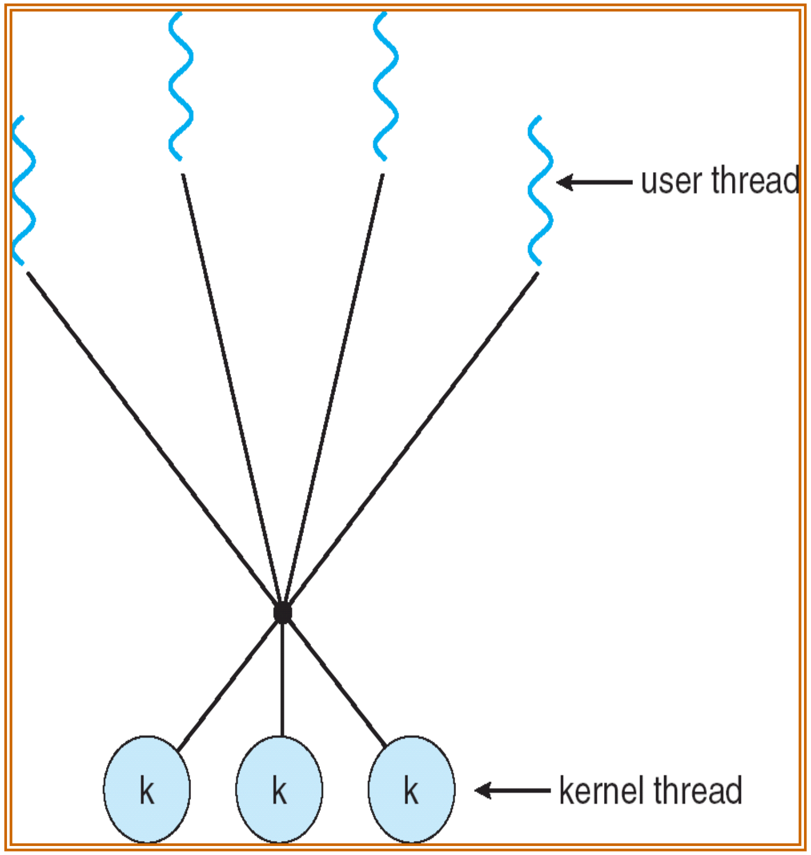
One-to-one Model



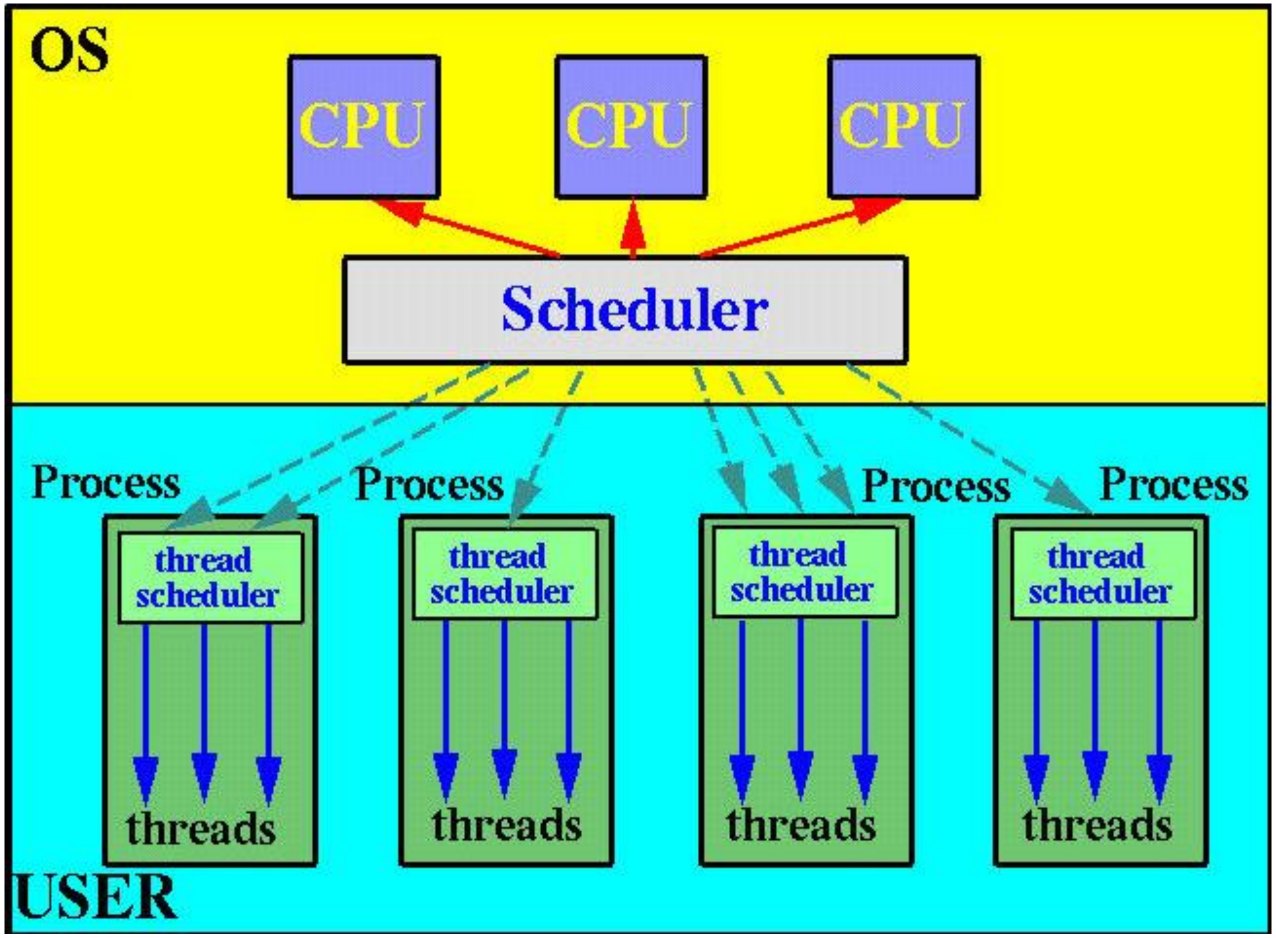
- Providing more concurrency.
- Restricting the number of threads supported by the system.

Many-to-Many Model

- Allows many user level threads to be mapped to many kernel threads.
- Solaris 2
- Windows NT/2000 with the *ThreadFiber* package

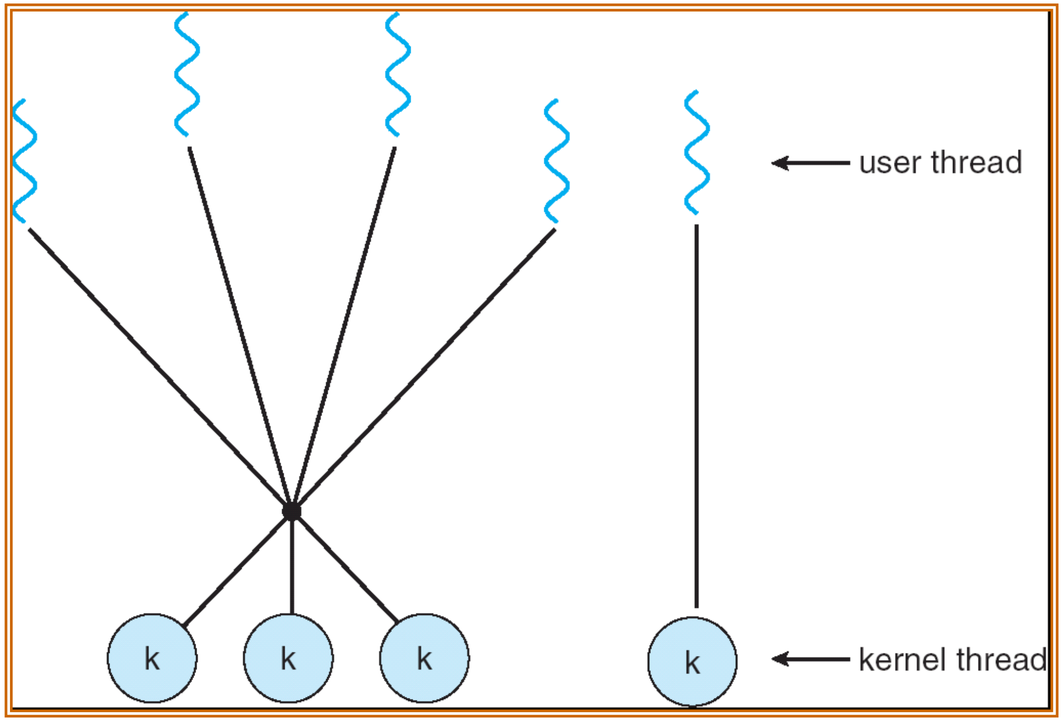


Many-to-Many Model



Two-level Model

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



Outline

- Overview
- Multithreading Models
- Thread Libraries
- Threading Issues
- Operating System Examples

Thread Libraries

- A thread library provides the programmer an API for creating and managing threads.
  - POSIX Pthreads （User Level & Kernel Level）
  - Win32 （ Kernel Level ）
  - Java （Host OS）

Pthreads

- A POSIX standard (IEEE 1003.1c) API for thread creation and synchronization.
- API specifies behavior of the thread library, implementation is up to development of the library.
- Common in UNIX operating systems.

pthread_create

int pthread_create(tid, attr, function, arg);

- pthread_t *tid
  - handle of created thread
- const pthread_attr_t *attr
  - attributes of thread to be created
- void *(*function) (void*)
  - function to be mapped to thread
- void *arg
  - single argument to function

pthread_create explained

- **spawn a thread running the function**
- **thread handle returned via pthread_t structure**
- **specify *NULL* to use default attributes**
- **single argument sent to function**
  - **If no argument to function, specify *NULL***
- **check error codes (returned value)!**

EAGAIN – insufficient resources to create thread

EINVAL – invalid attribute

Threads states

- pthread threads have two states
  - joinable and detached
- threads are joinable by default
  - Resources are kept until *pthread_join*
  - can be reset with attribute or API call
- detached thread can not be joined
  - resources can be reclaimed at termination
  - cannot reset to be *joinable*

Waiting for a thread

```
int pthread_join(tid, val_ptr);
```

- pthread_t *tid
  - handle of joinable thread
- void **val_ptr
  - exit value returned by joined thread

pthread_join explained

- calling thread waits for the thread with handle tid to terminate
- only one thread can be joined
- thread must be joinable
  - exit value is returned from joined thread
  - type returned is (void *)
  - use NULL if no return value expected

ESRCH –thread not found

EINVAL – thread not joinable

Example: Multiple threads

```
#include <stdio.h>
#include <pthread.h>
const int numThreads = 4;

void *helloFunc(void * pArg)
{   printf("Hello Thread\n"); }

main()
{   pthread_t  hThread[numThreads];
    for (int i = 0; i < numThreads; i++)
            pthread_create(&hThread[i], NULL, helloFunc, NULL);
    for (int i = 0; i < numThreads; i++)
          pthread_join(hThread[i], NULL);
    return 0;
}
```

Thread Termination

- void pthread_exit(void *status);
  - terminate the current thread
- int pthread_cancel(pthread_t thread);
  - the thread may:
    - ignore the request
    - terminated immediately (Asynchronous cancellation)
    - deferred terminated (Deferred cancellation)
- int pthread_kill(pthread_t thread, int sig);

Thread Cancellation

- int pthread_setcancelstate(int state, int *oldstate);
  - PTHREAD_CANCEL_ENABLE
  - PTHREAD_CANCEL_DISABLE
- int pthread_setcanceltype(int type, int *oldtype);
  - PTHREAD_CANCEL_ASYNCHROUS
  - PTHREAD_CANCEL_DEFERRED
- void pthread_testcancel(void);

Windows Thread APIs

- CreateThread
- GetCurrentThreadId - returns global ID
- GetCurrentThread - returns handle
- SuspendThread/ResumeThread
- ExitThread
- TerminateThread
- GetExitCodeThread
- GetThreadTimes

Windows API Thread Creation

```
HANDLE CreateThread (
    LPSECURITY_ATTRIBUTES lpsa,
    DWORD cbStack,
    LPTHREAD_START_ROUTINE lpStartAddr,
    LPVOID lpvThreadParm,
    DWORD fdwCreate,
    LPDWORD lpIDThread)
```

cbStack == 0: thread's stack size defaults to primary thread's size

lpstartAddr points to function declared as

```
DWORD WINAPI ThreadFunc(LPVOID)
```

- lpvThreadParm is 32-bit argument
- LPIDThread points to DWORD that receives thread ID non-NULL pointer !

Windows API Thread Termination

```
VOID ExitThread( DWORD devExitCode )
```

- When the last thread in a process terminates, the process itself terminates

```
BOOL GetExitCodeThread (
      HANDLE hThread, LPDWORD lpdwExitCode)
```

- Returns exit code or STILL_ACTIVE

Suspending and Resuming Threads

- Each thread has suspend count
- Can only execute if suspend count == 0
- Thread can be created in suspended state

```
DWORD ResumeThread (HANDLE hThread)
DWORD SuspendThread(HANDLE hThread)
```

- Both functions return suspend count or 0xFFFFFFFF on failure

Example: Thread Creation

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

DWORD WINAPI helloFunc(LPVOID arg ) {
        printf("Hello Thread\n");
        return 0;
}

main() {
        HANDLE hThread =
                CreateThread(NULL, 0, helloFunc,
                    NULL, 0, NULL );
        }
```

What's Wrong?

Example Explained

- Main thread is process
- When process goes, all threads go
- Need some methods of waiting for a thread to finish

Waiting for Windows Thread

```
#include <stdio.h>

#include <windows.h>

 BOOL thrdDone = FALSE;

DWORD WINAPI helloFunc(LPVOID arg ) {

       printf("Hello Thread\n");

       return 0;

}


main() {

       HANDLE hTh

              CreateThread(NULL, 0, helloFunc,

                    NULL, 0, NULL );

       }
```

thrdDone = TRUE;

Not a good idea!

while (!thrdDone);

Waiting for a Thread

Wait for one object (thread)

```
DWORD WaitForSingleObject(
      HANDLE hHandle,
      DWORD dwMilliseconds );
```

Calling thread waits (blocks) until

- Time expires
  - Return code used to indicate this
- Thread exits (handle is signaled)
  - Use `INFINITE` to wait until thread termination

Does not use CPU cycles

Waiting for Many Threads

Wait for up to 64 objects (threads)

```
DWORD WaitForMultipleObjects(
          DWORD nCount,
          CONST HANDLE *lpHandles, // array
          BOOL fWaitAll, // wait for one or all
          DWORD dwMilliseconds)
```

Wait for all: `fWaitAll==TRUE`

Wait for any: `fWaitAll==FALSE`

- Return value is first array index found

Notes on WaitFor Functions

- Handle as parameter
- Used for different types of objects
- Kernel objects have two states
  - Signaled
  - Non-signaled
- Behavior is defined by object referred to by handle
  - Thread: signaled means terminated

Example: Waiting for multiple threads

```
#include <stdio.h>
#include <windows.h>
const int numThreads = 4;

DWORD WINAPI helloFunc(LPVOID arg ) {
  printf("Hello Thread\n");
  return 0; }

main() {
  HANDLE hThread[numThreads];
  for (int i = 0; i < numThreads; i++)
    hThread[i] =
      CreateThread(NULL, 0, helloFunc, NULL, 0, NULL );
  WaitForMultipleObjects(numThreads, hThread,
                                TRUE, INFINITE);

}
```

Example: HelloThreads

- Modify the previous example code to print out
  - appropriate “Hello Thread” message
  - Unique thread number
    - use for-loop variable of CreateThread loop

Disscussion: *What’s Wrong?*

```
DWORD WINAPI threadFunc(LPVOID pArg) {
  int* p = (int*)pArg;
  int myNum = *p;
  printf( “Thread number %d\n”, myNum);
}
. . .
// from main():
for (int i = 0; i < numThreads; i++) {
  hThread[i] =
      CreateThread(NULL, 0, threadFunc, &i, 0, NULL);
}
```

What is printed for myNum?

Hello Threads Timeline

Time	*main*	*Thread 0*	*Thread 1*
T_0	i = 0	---	----
T_1	create(&i)	---	---
T_2	i++ (i == 1)	launch	---
T_3	create(&i)	p = pArg	---

T_4	i++ (i == 2)	myNum = *p
		myNum = 2
			launch

T_5	wait	print(2)	p = pArg

T_6	wait	exit	myNum = *p
			myNum = 2

Race Conditions

- Concurrent access of same variable by multiple threads
  - Read/Write conflict
  - Write/Write conflict
- Most common error in concurrent programs
- May not be apparent at all times
- How to avoid data races?
  - Local storage
  - Control shared access with critical regions

Hello Thread: Local Storage solution

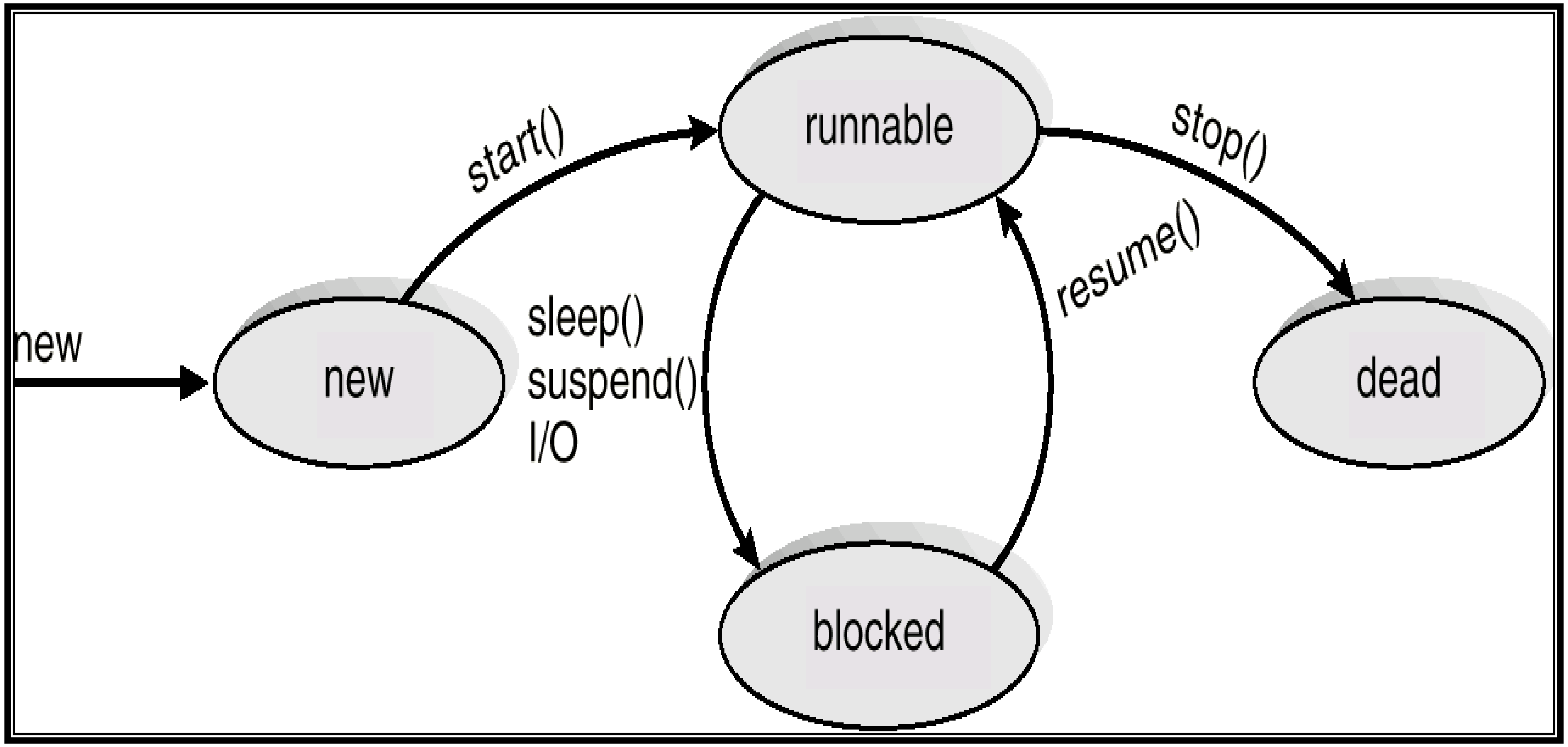
```
DWORD WINAPI threadFunc(LPVOID pArg)
{
   int myNum = *((int*)pArg);
   printf( "Thread number %d\n", myNum);
}
. . .

// from main():
for (int i = 0; i < numThreads; i++) {
   tNum[i] = i;
   hThread[i] =
      CreateThread(NULL, 0, threadFunc, &tNum[i],
                          0, NULL);
}
```

Java Threads

- Java threads may be created by
  - Extending Thread class to create a new class
  - Defining a class that Implements the Runnable interface
- Java threads are managed by the JVM.

Java Thread States



Outline

- Overview
- Multithreading Models
- Thread Libraries
- Threading Issues
- Operating System Examples

Threading Issues

- Semantics of fork() and exec() system calls
- Thread cancellation
- Signal handling
- Thread pools
- Thread specific data
- Scheduler Activations

Semantics of fork() and exec()

- Does fork() duplicate only the calling thread or all threads? *ALL OK!*
- If a thread invokes the exec(), what will be the result?

The program specified in the parameter to exec() will replace the entire process—including all threads.

Thread Cancellation

- Terminating a thread before it has finished
- Two general approaches:
  - Asynchronous cancellation terminates the target thread immediately
  - Deferred cancellation allows the target thread to periodically check if it should be cancelled
    - The point a thread can terminate itself is a *cancellation point*

Thread Cancellation

- **With asynchronous cancellation, if the target thread owns some system-wide resources, the system may not be able to reclaim all recourses.**
- **With deferred cancellation, the target thread determines the time to terminate itself. Reclaiming resources is not a problem.**
- **Most systems implement asynchronous cancellation for processes (e.g., use the kill system call) and threads.**
- **Pthread supports deferred cancellation.**

Signal Handling

- Signals are used in UNIX systems to notify a process that a particular event has occurred.
- All signals follow the same pattern:
  - Signal is generated by particular event
  - Signal is delivered to a process
  - Signal is handled
- *A signal handler* is used to process signals

Signal Handling

- Where should a signal be delivered in multithreaded programs?
  - 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

作业2

- 试比较信号机制与中断机制的异同。

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

Thread Specific Data

- **Threads belonging to a process share the data of the process.**
- **Allows each thread to have its own copy of data**
- **when using a thread pool, each thread may be assigned a unique identifier**

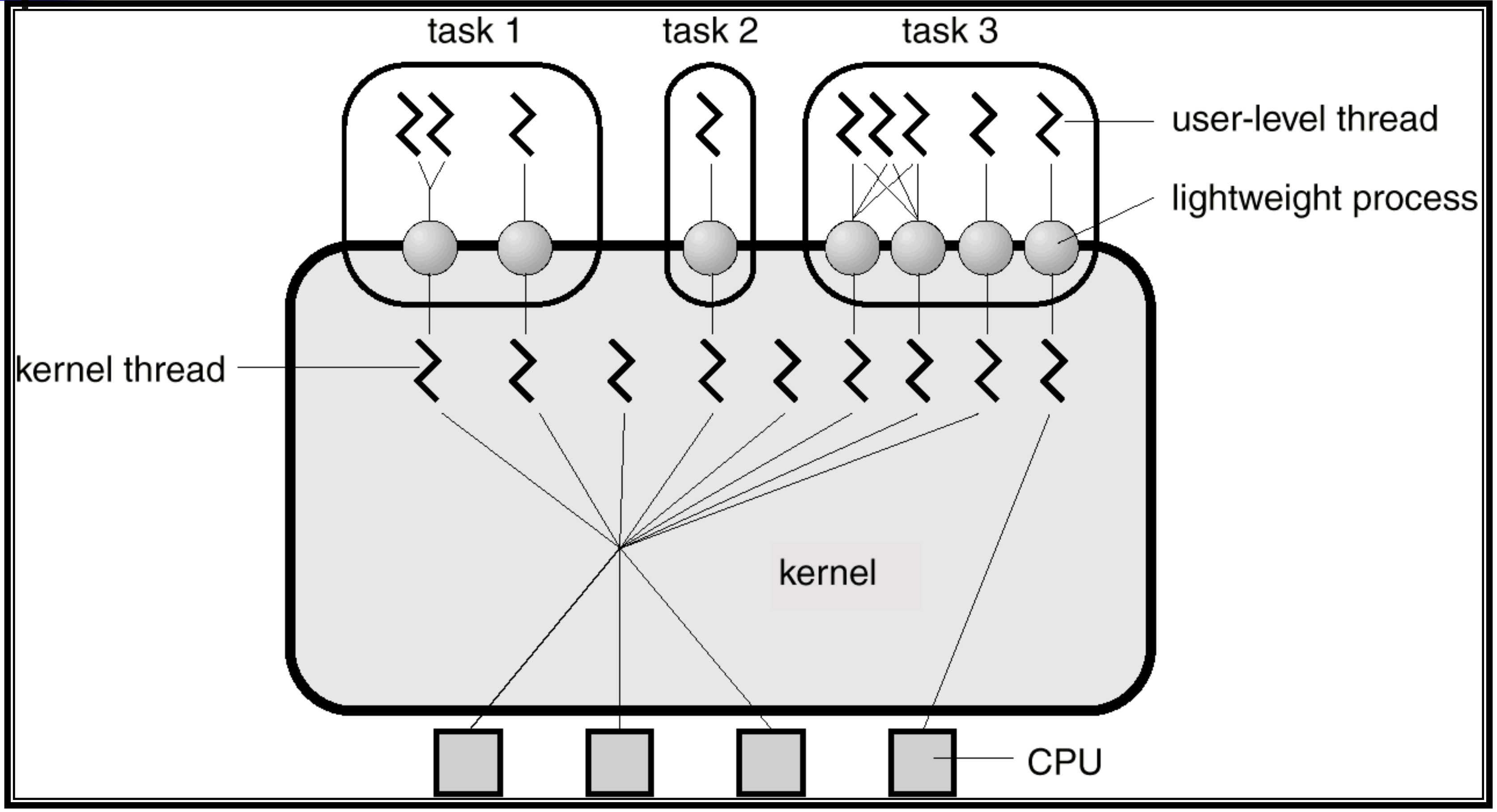
Scheduler Activations

- Both M:M and Two-level models require communication to maintain the appropriate number of kernel threads allocated to the application
- Scheduler activations provide upcalls - a communication mechanism from the kernel to the thread library
- This communication allows an application to maintain the correct number kernel threads

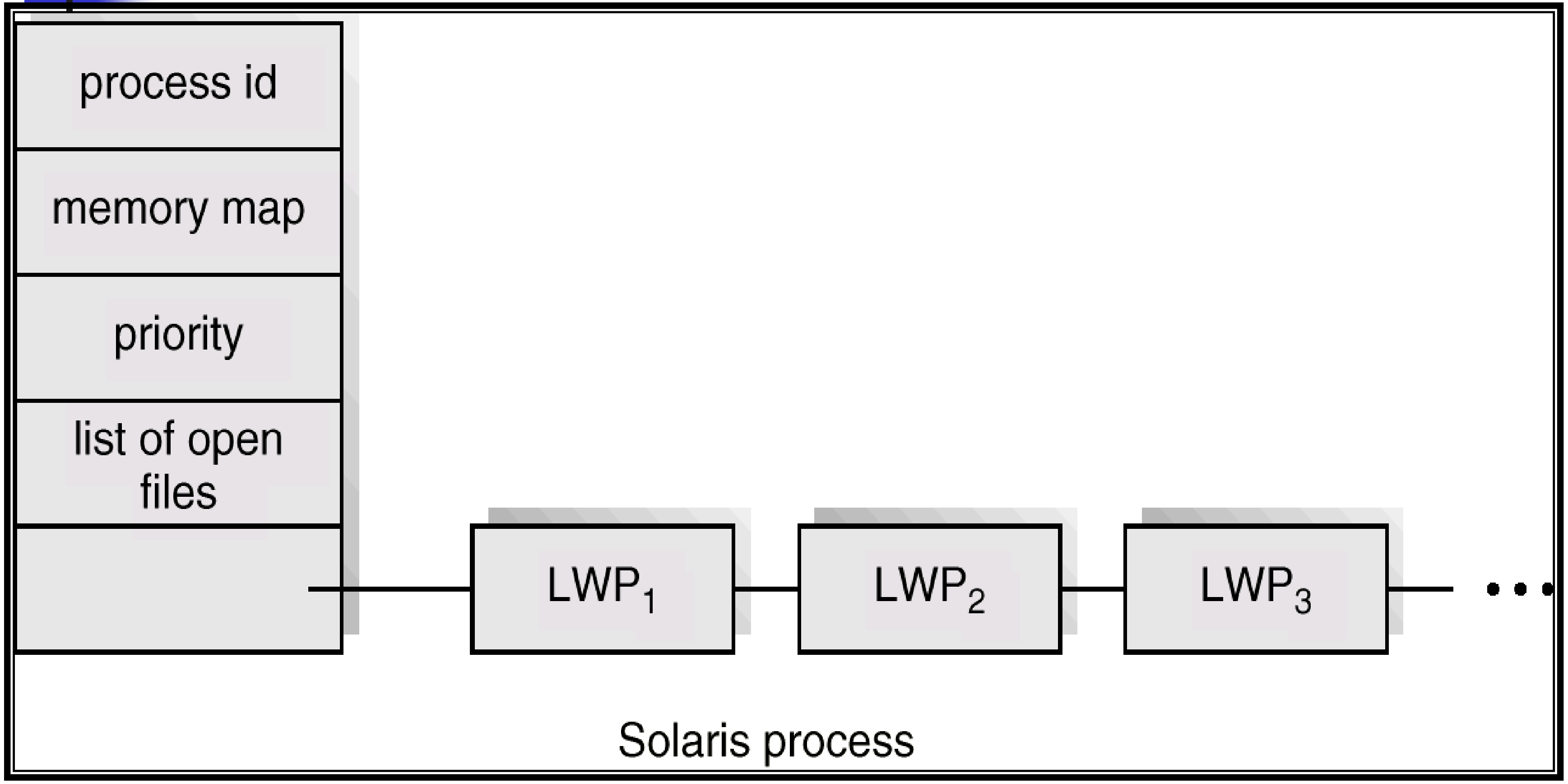
Outline

- Overview
- Multithreading Models
- Thread Libraries
- Threading Issues
- Operating System Examples

Solaris 2 Threads



Solaris Process



Windows XP Threads

- Implements the one-to-one mapping.
- Each thread contains

  - a thread id

  - register set

  - separate user and kernel stacks

  - private data storage area

Linux Threads

- **Linux does not distinguish between processes and 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)**