操作系统原理及应用

李　伟
xchlw@seu.edu.cn

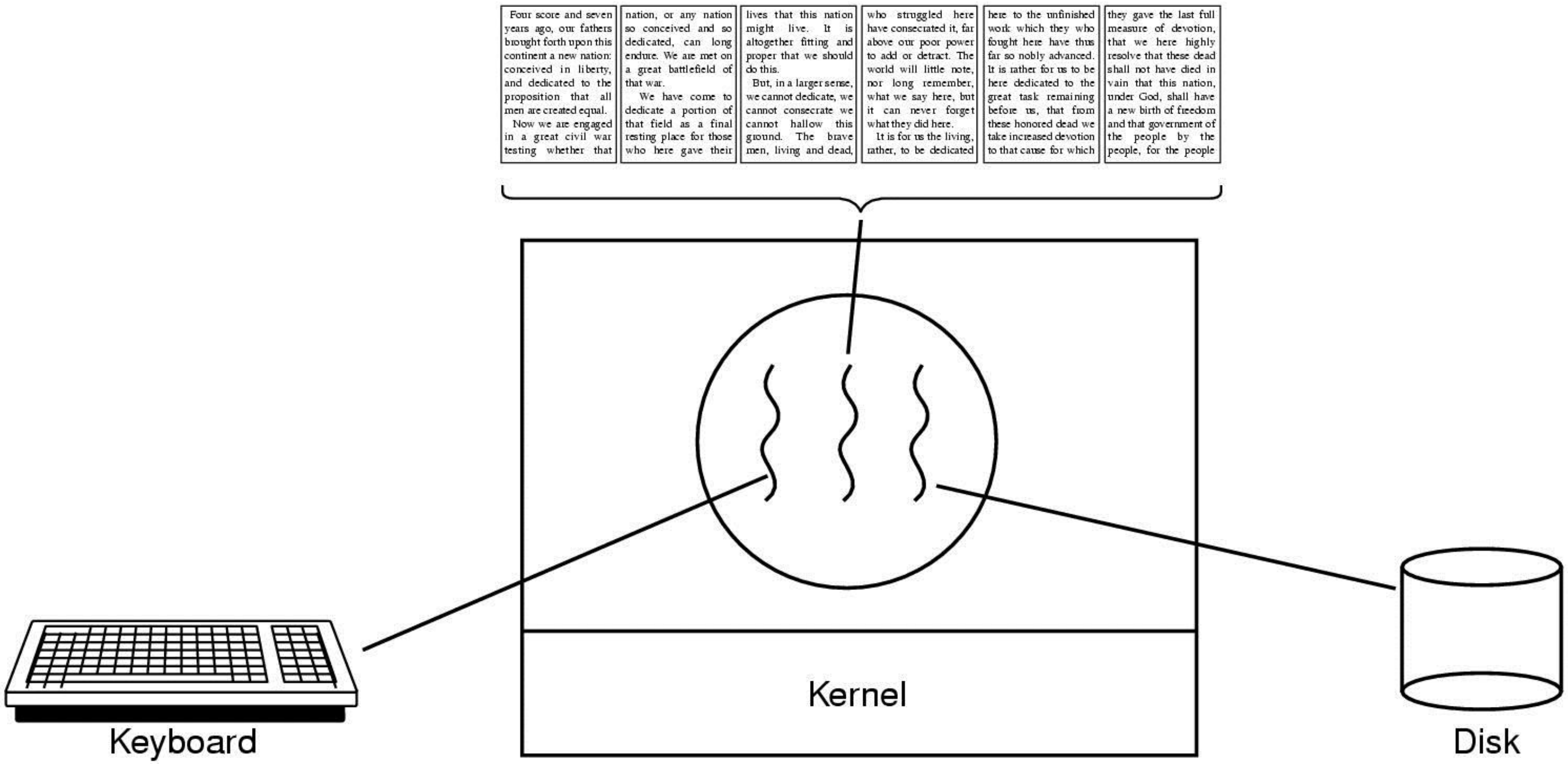
计算机科学与工程学院、软件学院
江苏省网络与信息安全重点实验室

Chapter 4 Threads

Outline

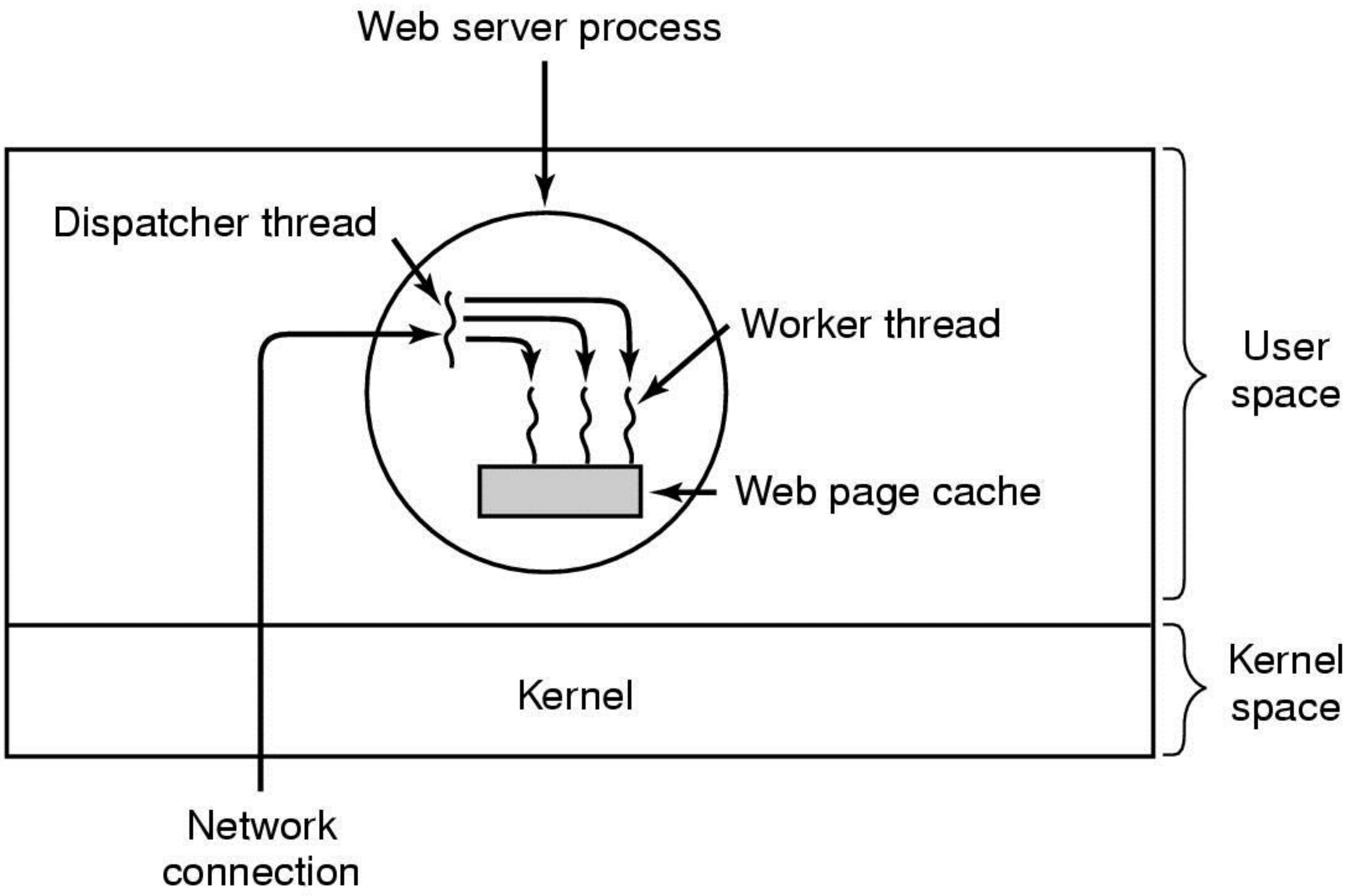
- Overview
- Multithreading Models
- Thread Libraries
- Threading Issues
- Operating System Examples

Example (1/2)



A word processor

Example (2/2)



A Web server

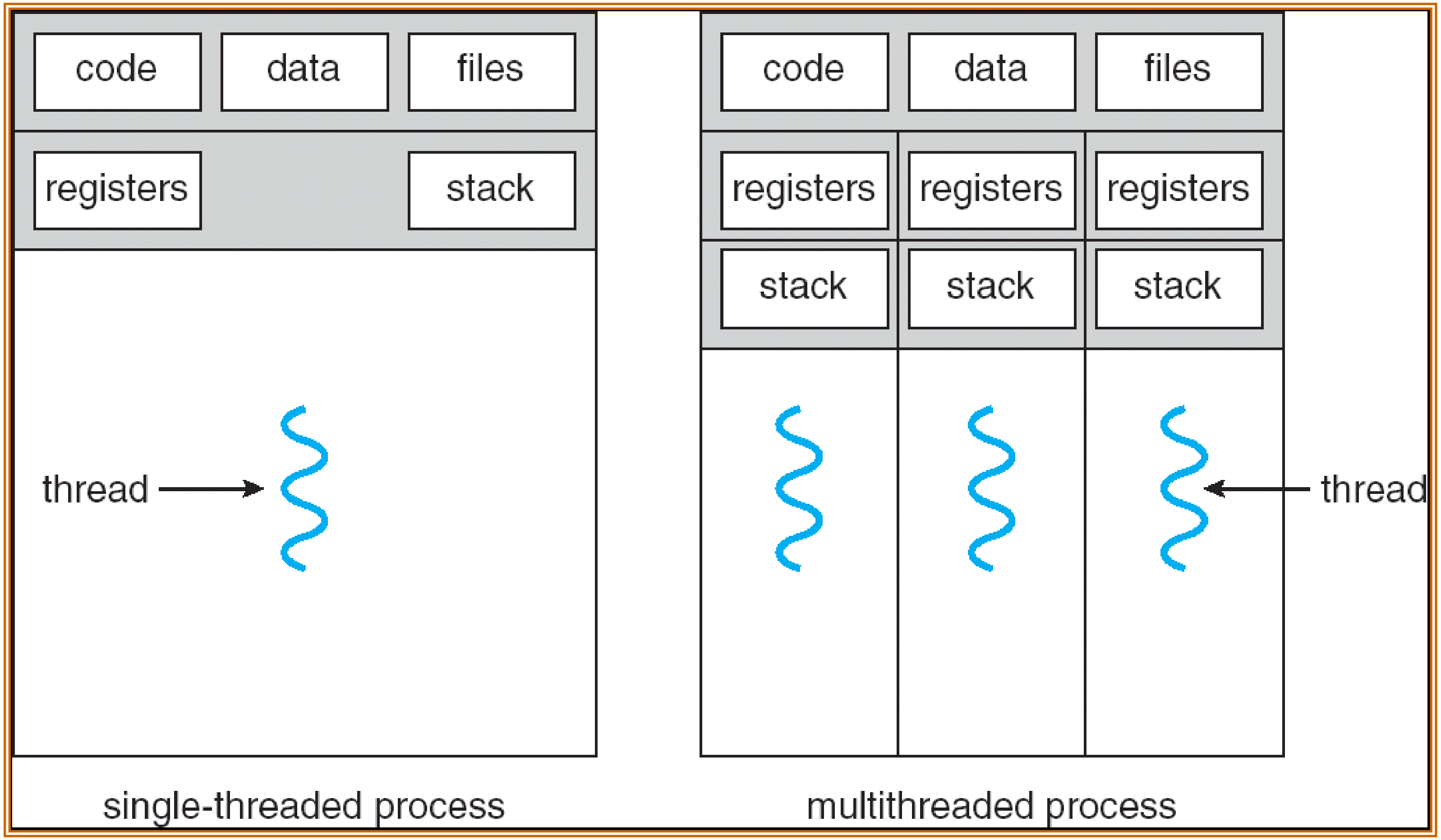
What is a thread? (1/2)

- 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? (2/2)

- 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



Benefits

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

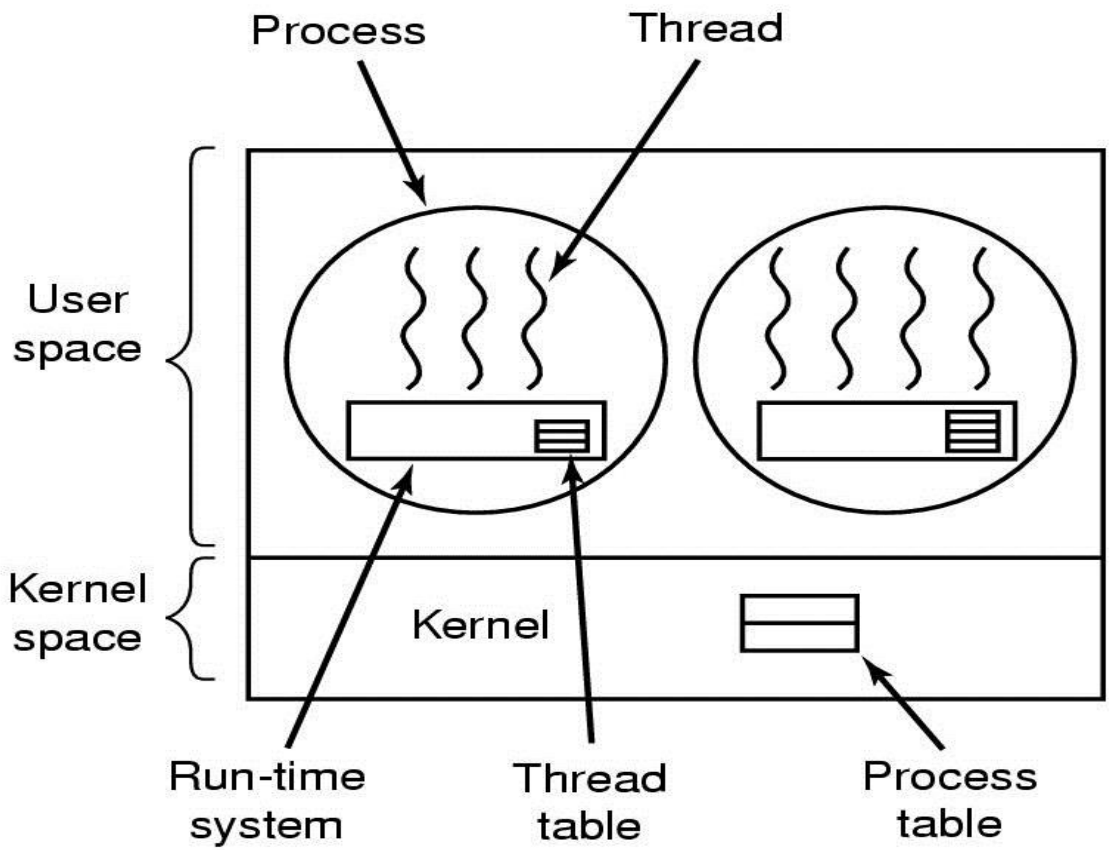
User Threads

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

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

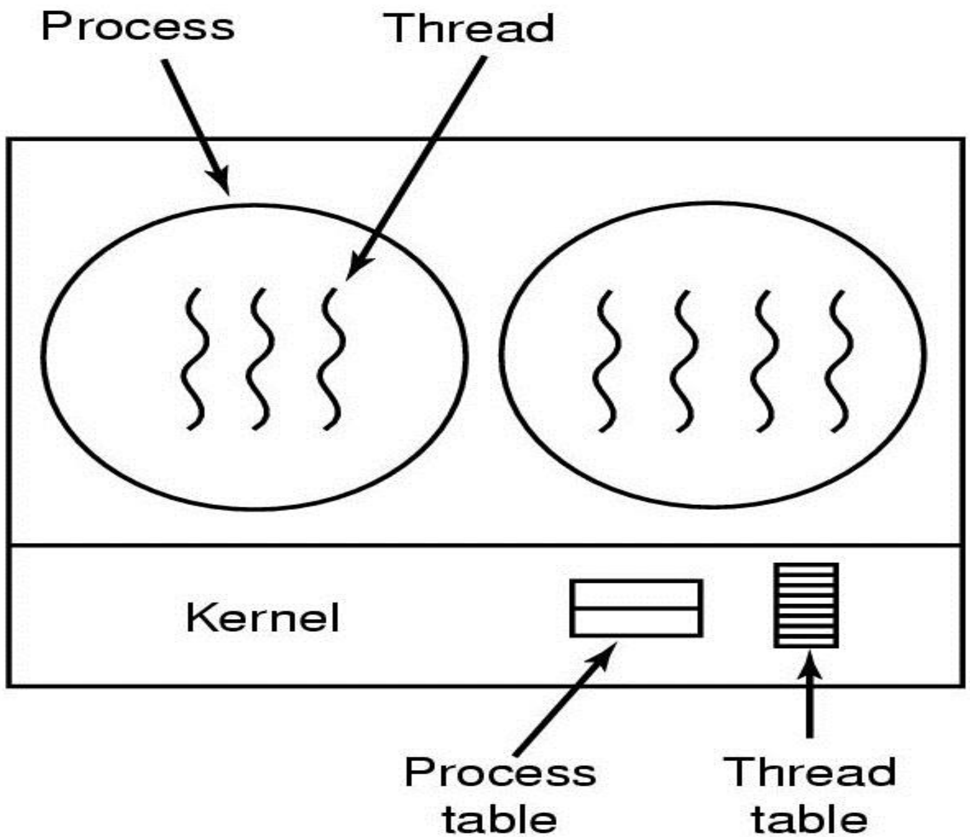
Kernel Threads

- 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?

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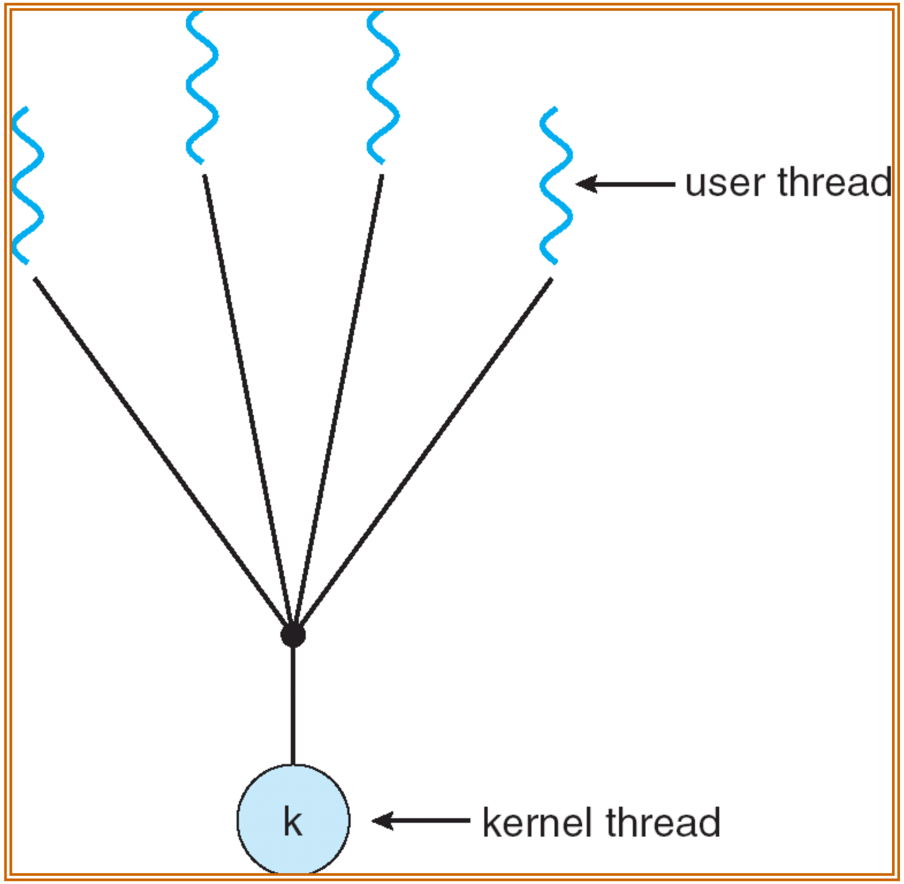
Multithreading Models

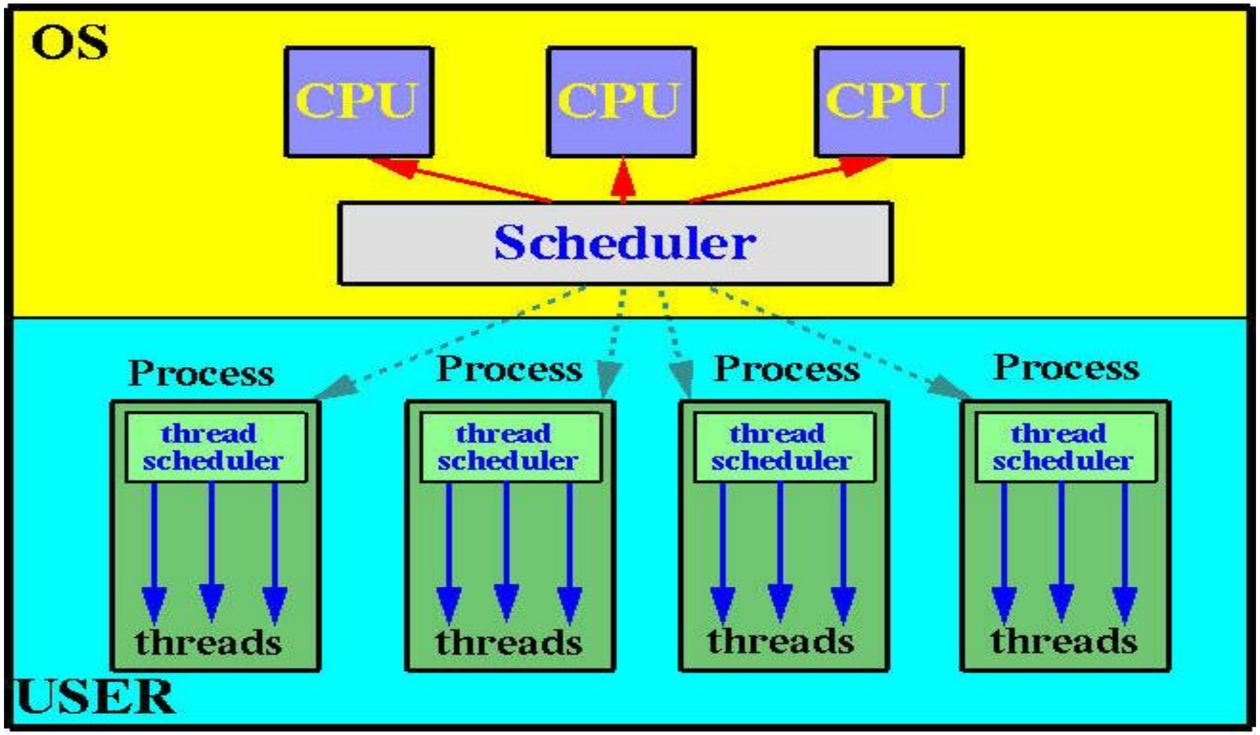
- Many-to-One
- One-to-One
- Many-to-Many

Many-to-One Model

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



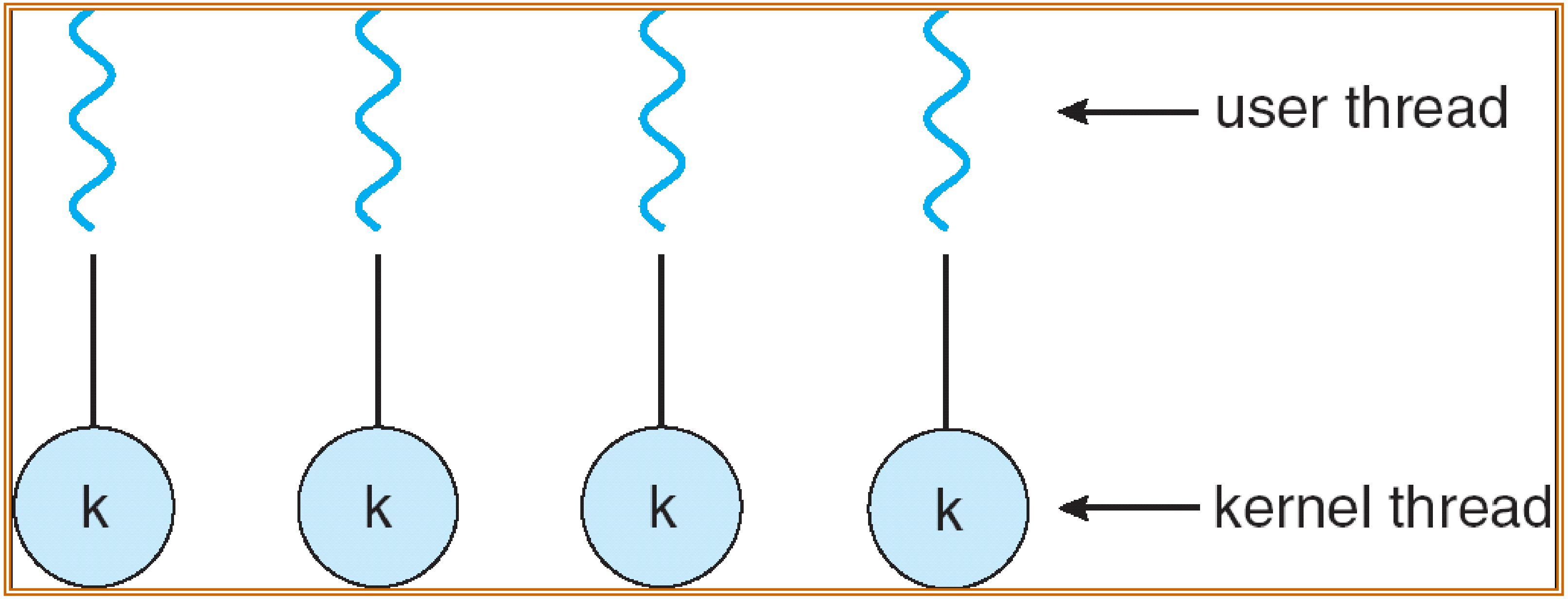
Many-to-One Model



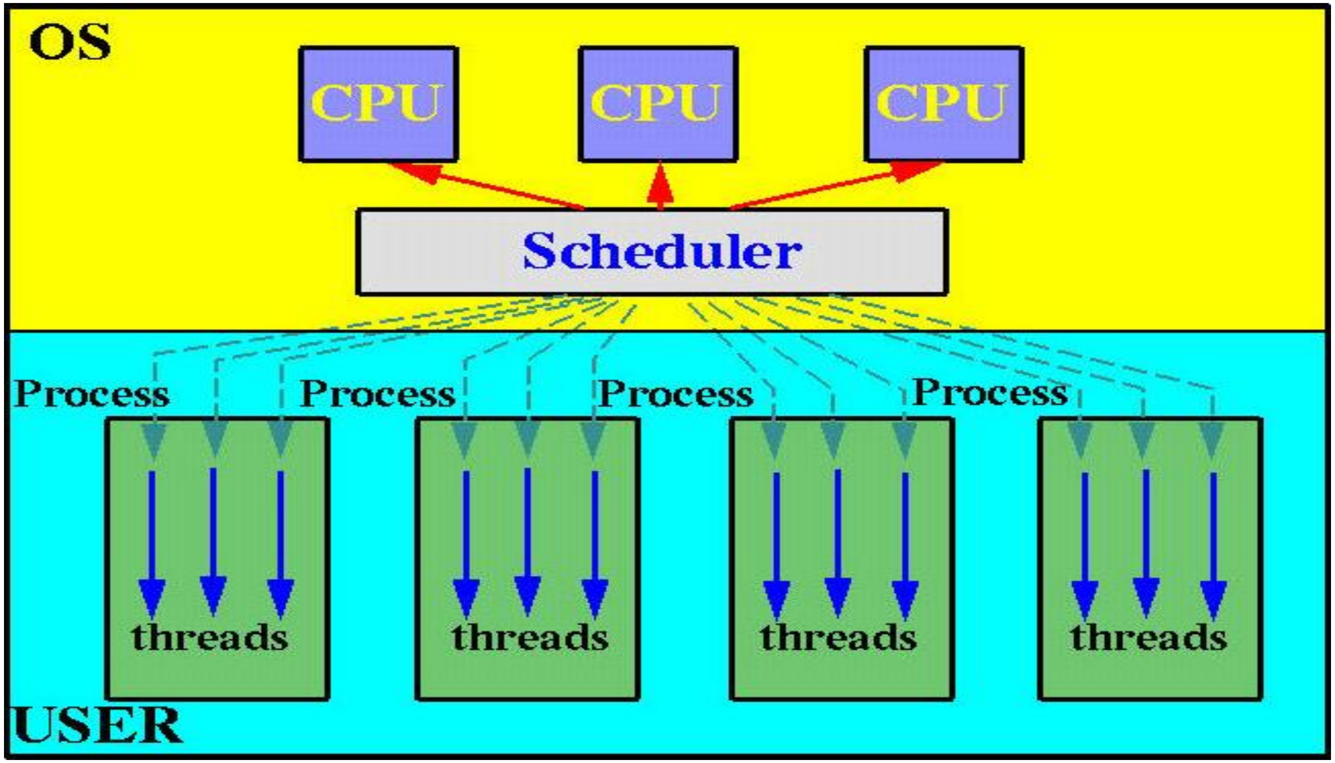
- Only one thread in the one process can access the kernel at a time.
- True concurrency is not gained.

One-to-One Model

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



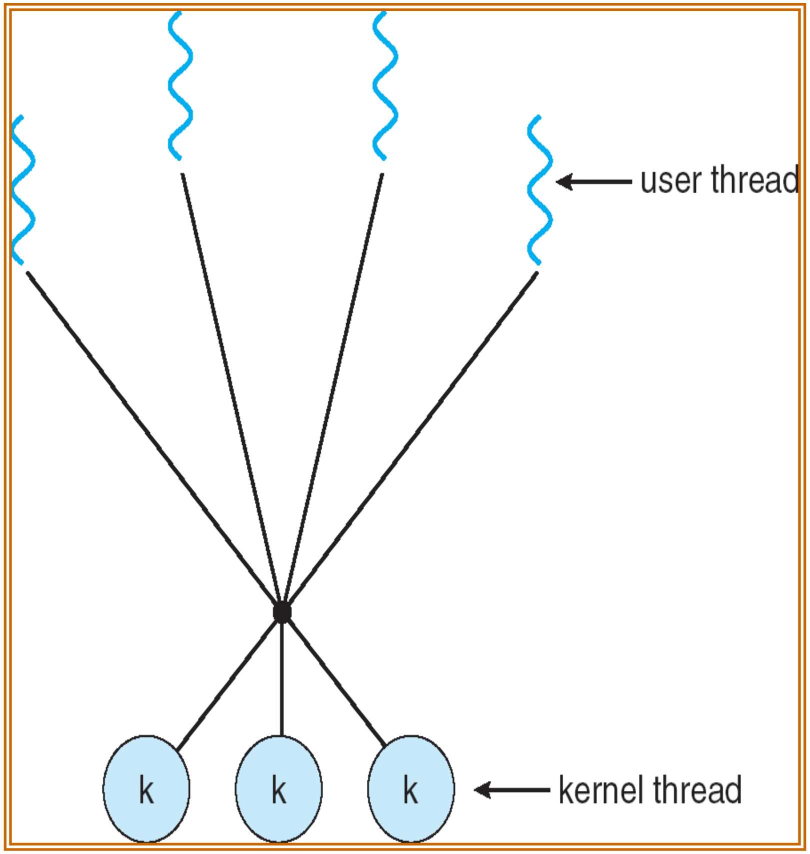
One-to-one Model



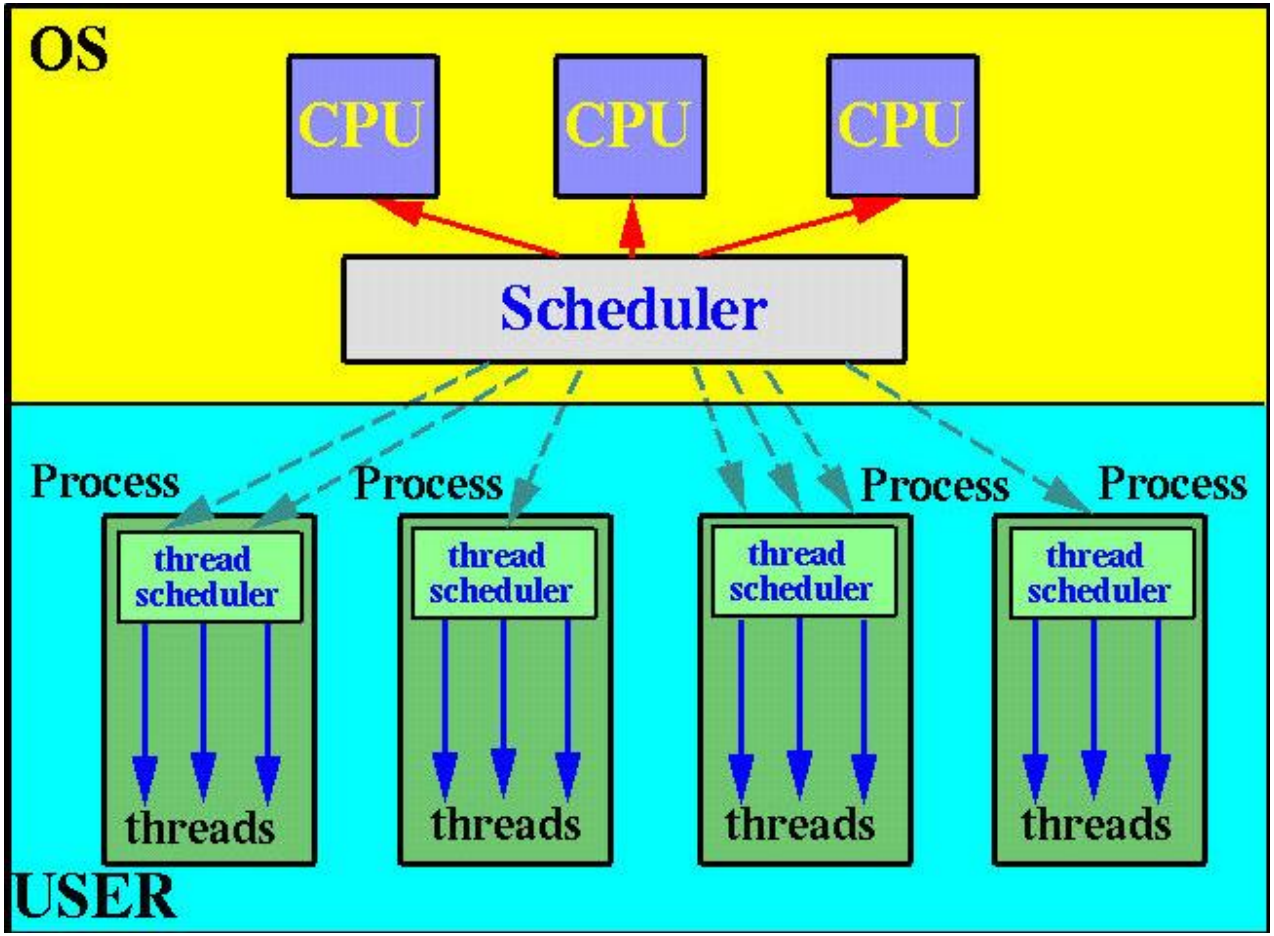
- Providing more concurrency.
- Restricting the number of threads supported by the system.

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**

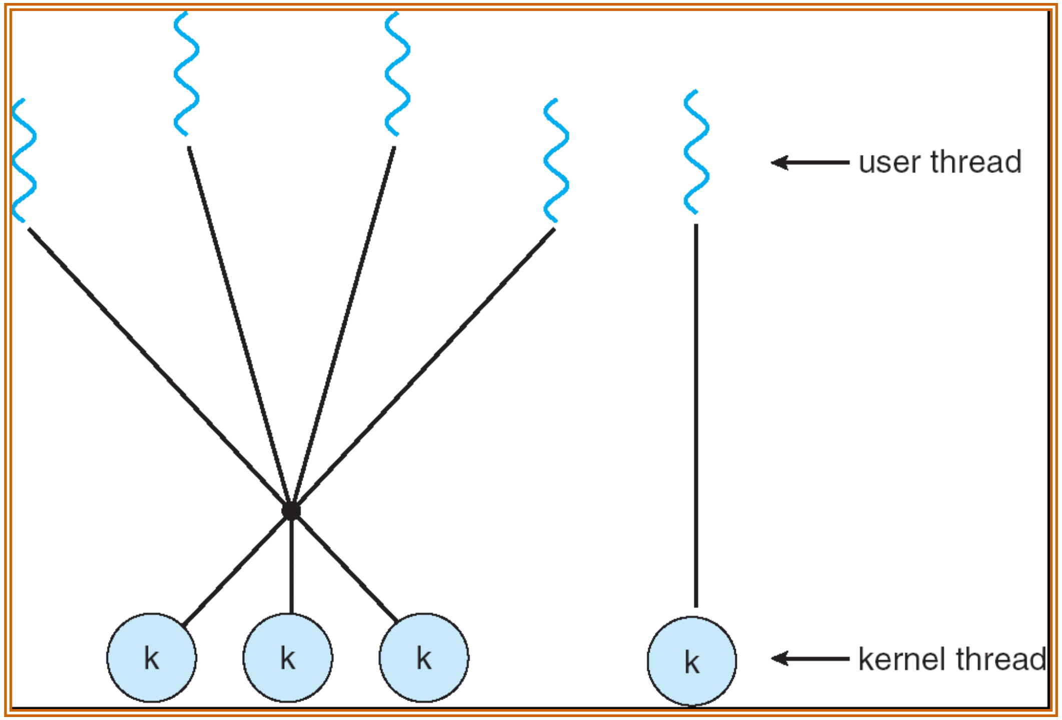


Many-to-Many Model



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**



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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

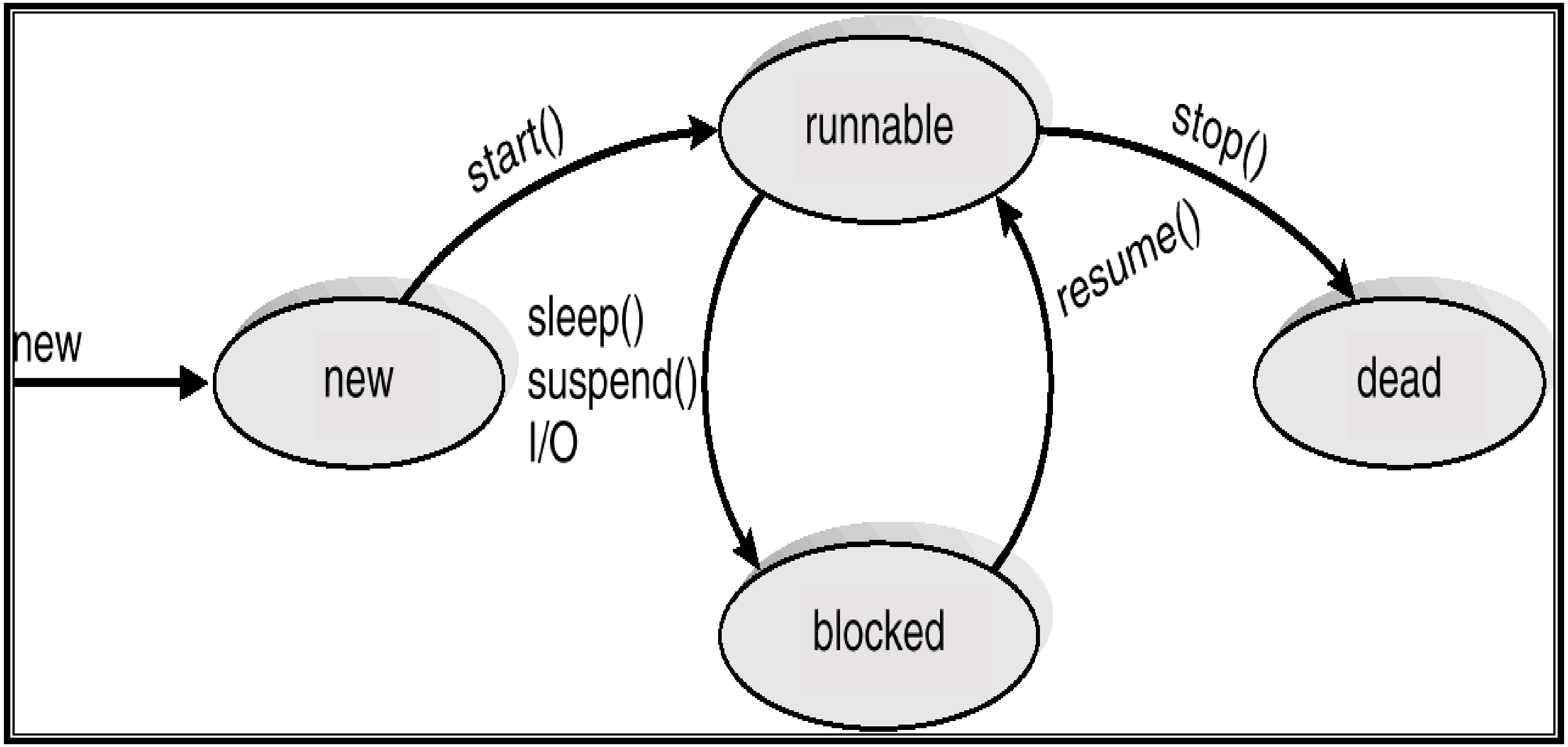
```
DWORD WINAPI threadFunc(LPVOID pArg)
{
  int myNum = *((int*)pArg);
  printf( "Thread number %d\n", myNum);
}
. . .

// 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



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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*
    - void pthread_testcancel(void);

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 of kernel threads**

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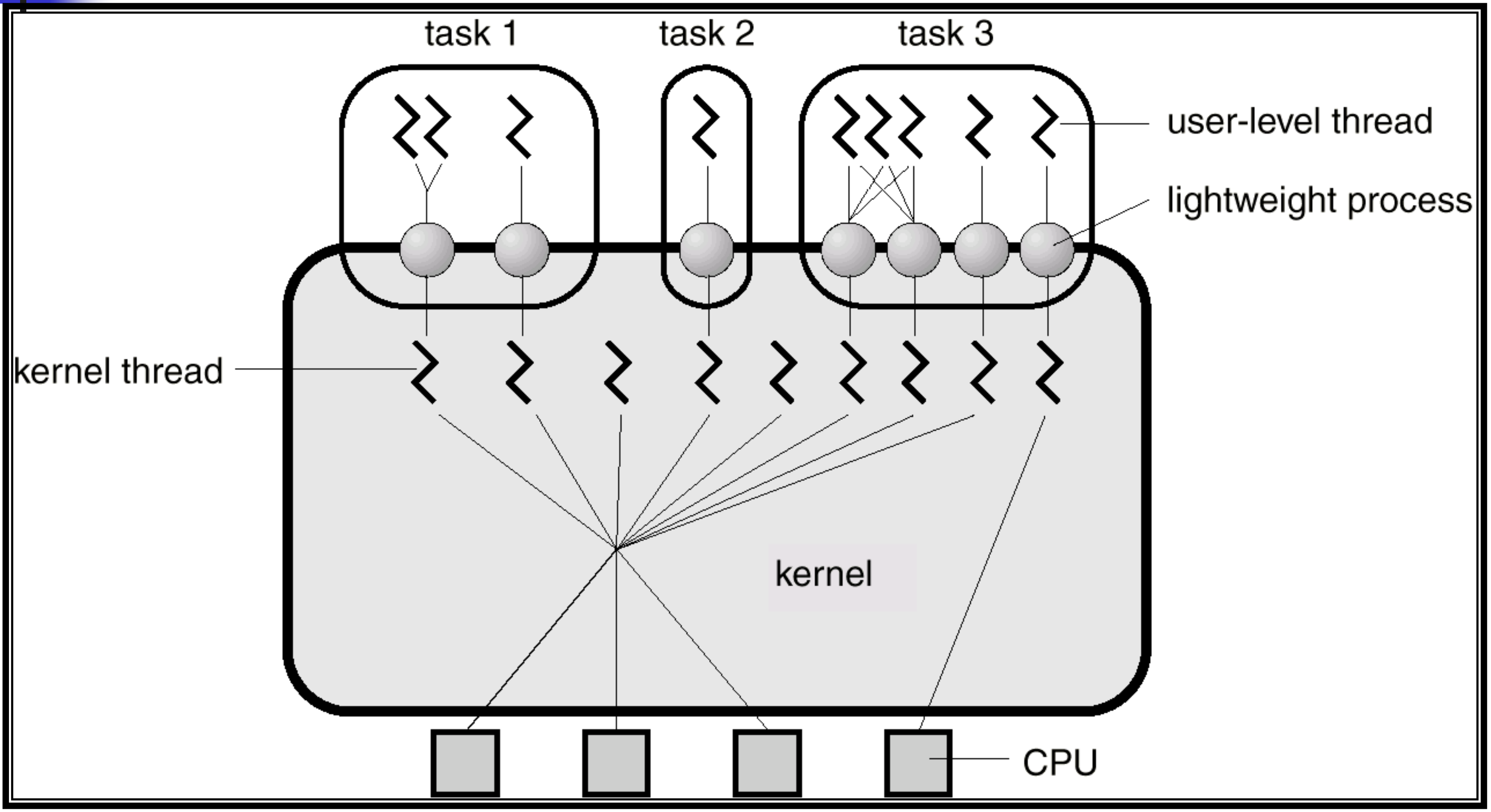
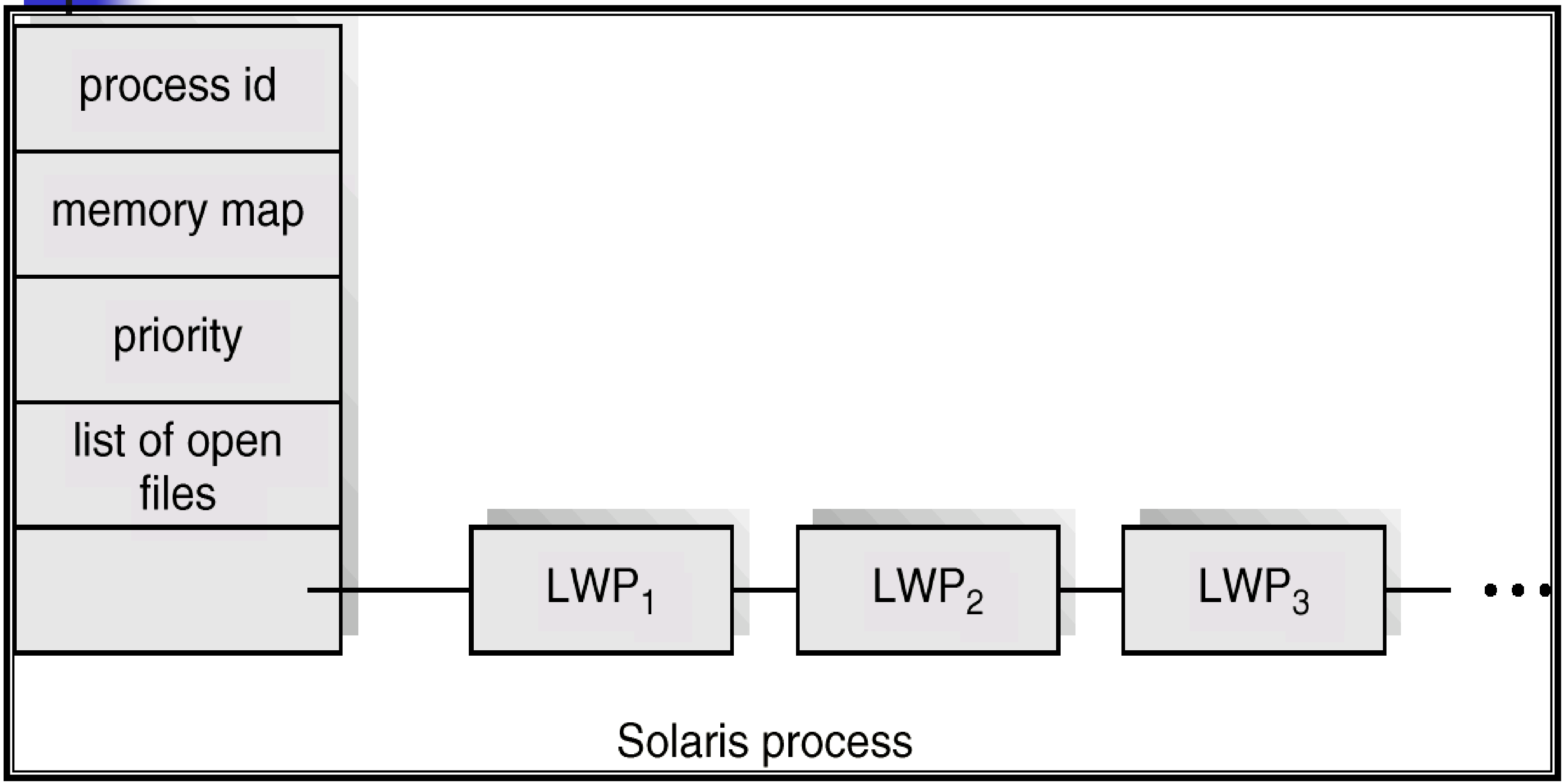
Solaris 2 Threads



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)**