0117401: Operating System
计算机原理与设计

Chapter 5: CPU scheduling

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提纲

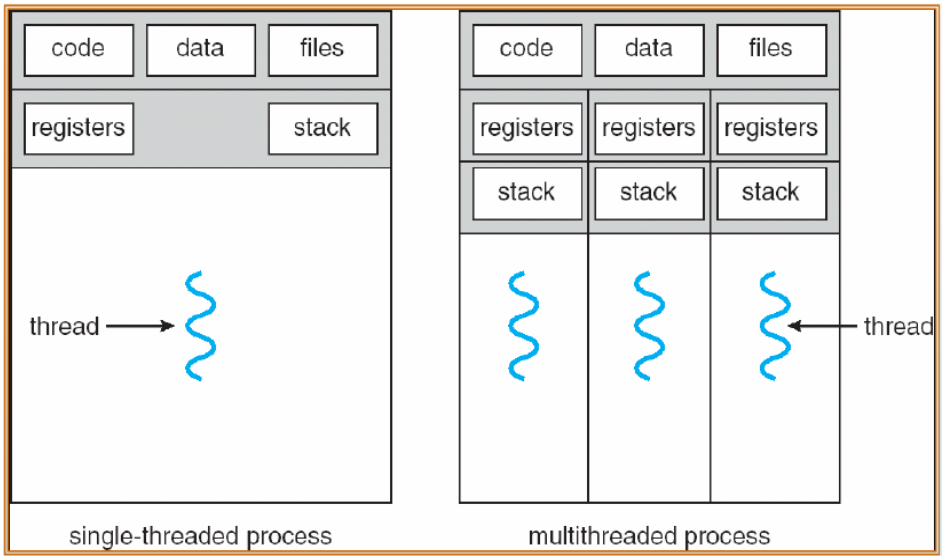
Chapter Objectives

1. To introduce the notion of a thread — a fundamental unit of CPU utiliazation that forms the basis of multithreaded computer system.
2. To discuss the APIs for Pthreads, Win32, and JAVA thread libraries.

Outline

Thread concept overview

- A thread is a basic unit of CPU utilization;
  - it comprises a thread ID, a program counter, a register set, and a stack.
  - It shares with other threads belonging to the same process the code section, the data section, and other OS resources, such as open files, signals, etc
- A traditional process has a single thread of control: heavyweight process.



Motivation

- On modern desktop PC, many APPs are multithreaded.
  - a seperate process with several threads
  - Example 1: A web browser
    - one for displaying images or text;
    - another for retrieving data from network
  - Example 2: A word processor
    - one for displaying graphics;
    - another for responding to keystrokes from the user;
    - and a third for performing spelling & grammer checking in the background

Motivation

- Motivation
  - In certain situations, a single application may be required to perform several similar tasks. Example: a web server
  - Allow a server to service several concurrent requests. Example: an RPC server and Java's RMI systems
  - The OS itself needs to perform some specific tasks in kernel, such as manging devices or interrupt handling.
    - PARTICULAR, many OS systems are now multithreaded.
    - Example: Solaris, Linux

Benefits

1. Responsiveness（响应度高）
   - Example: an interactive application such as web browser, while one thread loading an image, another thread allowing user interaction
2. Resource Sharing
   - address space, memory, and other resources
3. Economy
   - Solaris:
     creating a process is about 30 times slower then creating a thread;
     context switching is about 5 times slower
4. Utilization of MP Architectures
   - parallelism and concurrency ↑

Outline

Two Methods

Two methods to support threads

- User threads VS. Kernel threads

1. User threads
   - Thread management done by user-level threads library without kernel support
     - Kernel may be multithreaded or not.
   - Three primary thread libraries:
     1. POSIX Pthreads
     2. Win32 threads
     3. Java threads

Two Methods

Two methods to support threads

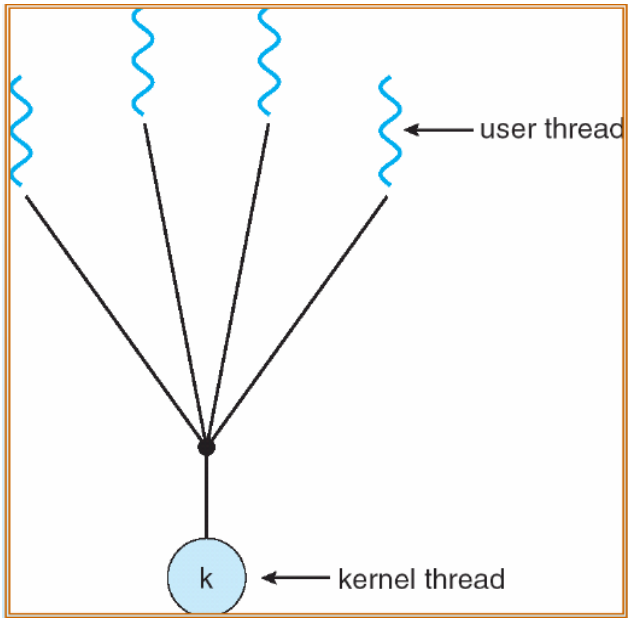
- User threads VS. Kernel threads

2. Kernel Threads
   - Supported by the Kernel, usually may be slower then user thread
   - Examples
     - Windows XP/2000
     - Solaris
     - Linux
     - Tru64 UNIX (formerly Digital UNIX)
     - Mac OS X

Multithreading Models I

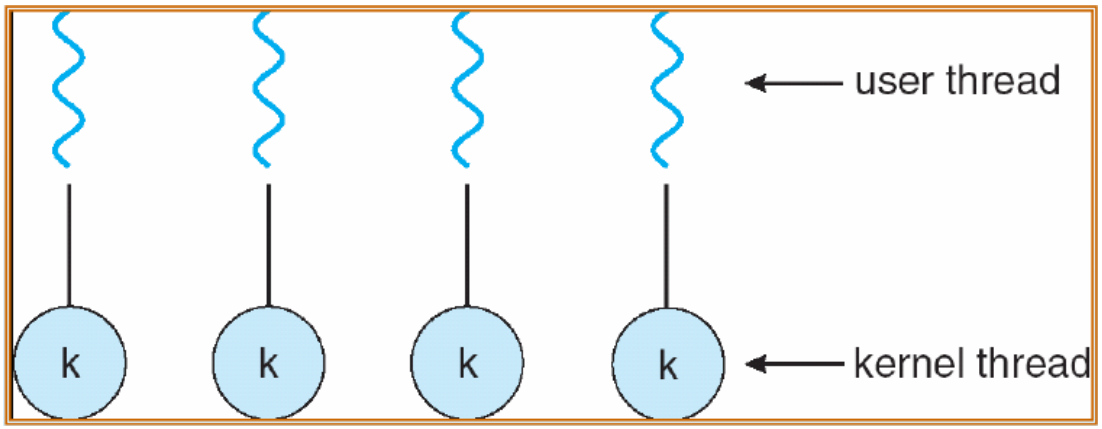
- The relationship between user threads and kernel threads
  1. Many-to-One [n:1]
  2. One-to-One [1:1]
  3. Many-to-Many [n:m]

- Many-to-One [n:1]
  - Many user-level threads mapped to single kernel thread
  - Examples:
    - Solaris Green Threads
    - GNU Portable Threads



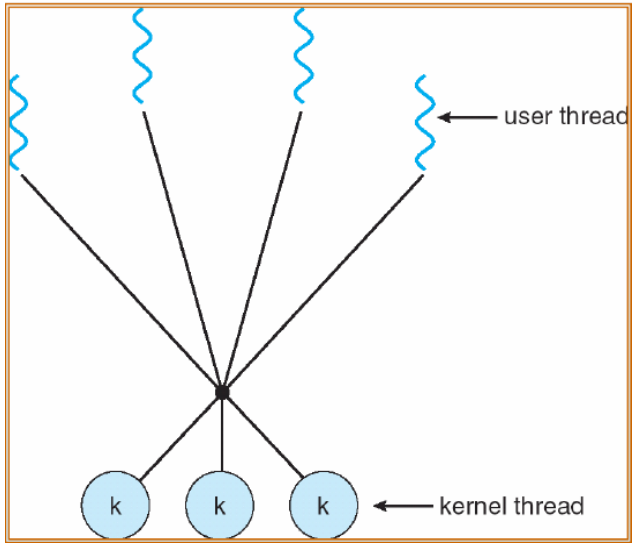
Multithreading Models II

- One-to-One [1:1]
  - Each user-level thread maps to a kernel thread
  - Examples
    - Windows NT/XP/2000
    - Linux
    - Solaris 9 and later



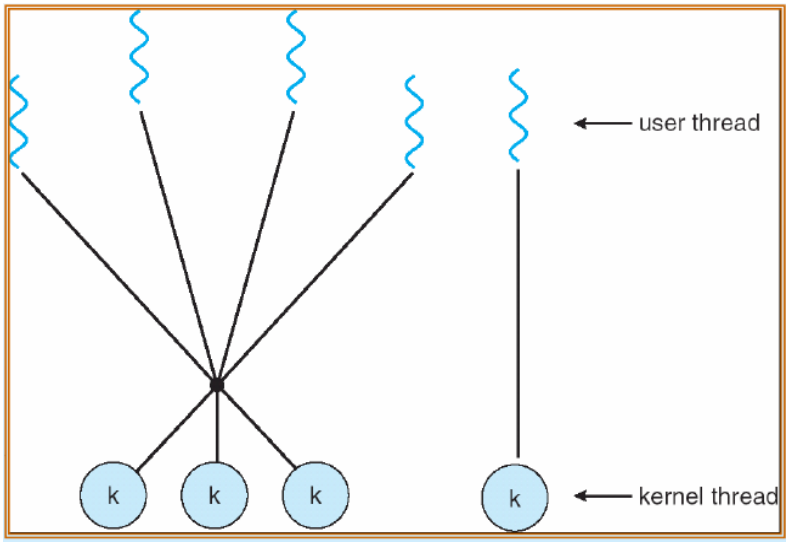
Multithreading Models III

- Many-to-Many [n:m]
  - Allows many user level threads to be mapped to many kernel threads
  - Allows the operating system to create a sufficient number of kernel threads
  - Examples
    - Solaris prior to version 9
    - Windows NT/2000 with the ThreadFiber package



Multithreading Models IV

- Two-level Model, a popular variation on many-to-many model
  - Similar to n:m, except that it allows a user thread to be bound to a kernel thread
  - Examples
    - IRIX
    - HP-UX
    - Tru64 UNIX
    - Solaris 8 and earlier



Outline

Thread Libraries

- A thread library provides an API for creating and managing threads.

  Two primary ways

  1. to provide a library entirely in user space with no kernel support
  2. to implement a kernel-level library supported directly by the OS

library	code & data	API	invoking method inside API
user-level	entirely in user space	user space	a local function call
kernel-level	kernel space	user space	system call

- Three main thead libraries

  1. POSIX Pthreads
  2. Win32 threads
  3. Java threads

Pthreads

- 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 OSes (Solaris, Linux, Mac OS X)

Multithreaded C program using the Pthreads API I

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

int sum; /* this data is shared by the thread(s) */

/* The thread will begin control in this function */
void *runner(void *param) {
    int i, upper = atoi(param);
    sum = 0;

    if (upper > 0) {
        for (i = 1; i <= upper; i++)
            sum += i;
    }
    pthread_exit(0);
}

int main(int argc, char *argv[]) {
    pthread_t tid; /* the thread identifier */
```

Multithreaded C program using the Pthreads API II

```
    pthread_attr_t attr; /* set of attributes for the thread */

    if (argc != 2) {
        fprintf(stderr, "usage: a.out <integer value>\n" );
        return -1;
    }

    if (atoi(argv[1]) < 0) {
        fprintf(stderr, "Argument %d must be non-negative\n" ,atoi(argv[1]));
        return -1;
    }

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

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

pthread_attr_init

NAME
pthread_attr_init, pthread_attr_destroy - initialise and destroy threads attribute object

SYNOPSIS

```
#include <pthread.h>
int pthread_attr_init(pthread_attr_t *attr);
int pthread_attr_destroy(pthread_attr_t *attr);
```

DESCRIPTION
The function pthread_attr_init() initialises a thread attributes object attr with the default value for all of the individual attributes used by a given implementation.
...
The pthread_attr_destroy() function is used to destroy a thread attributes object.

RETURN VALUE
Upon successful completion, both return a value of 0.
Otherwise, an error number is returned to indicate the error.
...

pthread_create()

NAME
pthread_create - thread creation

SYNOPSIS
#include <pthread.h>
int pthread_create(pthread_t *thread, const pthread_attr_t *attr,
                   void *(*start_routine)(void*), void *arg);

DESCRIPTION
The pthread_create() function is used to create a new thread, with attributes specified by attr, within a process. ...Upon successful completion, pthread_create() stores the ID of the created thread in the location referenced by thread.
The thread is created executing start_routine with arg as its sole argument.
...
...
If pthread_create() fails, no new thread is created and the contents of the location referenced by thread are undefined.

RETURN VALUE
If successful, the pthread_create() function returns zero.

pthread_join

NAME
pthread_join - wait for thread termination

SYNOPSIS
```
#include <pthread.h>
int pthread_join(pthread_t thread, void **value_ptr);
```

DESCRIPTION
The pthread_join() function suspends execution of the calling thread until the target thread terminates, unless the target thread has already terminated. ... The results of multiple simultaneous calls to pthread_join() specifying the same target thread are undefined. ...

RETURN VALUE
If successful, the pthread_join() function returns zero.
Otherwise, an error number is returned to indicate the error.
...

pthread_exit

NAME
pthread_exit - thread termination

SYNOPSIS
#include <pthread.h>
void pthread_exit(void *value_ptr);

DESCRIPTION
The pthread_exit() function terminates the calling thread and makes the value value_ptr available to any successful join with the terminating thread. ...
...

RETURN VALUE
The pthread_exit() function cannot return to its caller.

Win32 Threads Example I

- Similar to the Pthreads technique.
- Multithreaded C program using the Pthreads API

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

/* the thread runs in this separate function */
DWORD WINAPI Summation(PVOID 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;
```

Win32 Threads Example II

```
// do some basic error checking
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;
}

// create the thread
ThreadHandle = CreateThread(NULL,    //default security attribute
                            0,    //default stack size
                            Summation,     //thread function
                            &Param,    //parameter to thread function
                            0,    //default creation flags
                            &ThreadId);
```

Win32 Threads Example III

```
    if (ThreadHandle != NULL){
        WaitForSingleObject(ThreadHandle, INFINITE);
        CloseHandle(ThreadHandle);

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

Java Threads

- Java Threads
  - Threads are the fundamental model for program execution.
  - Java threads may be created by:
    - Extending Thread class
      to create a new class that is derived from the Thread class and override its run() method.
    - Implementing the Runnable interface

Java Thread Example I

```
class Sum {
    private int sum;

    public int get() {
        return sum;
    }

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

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

    public Summation(int upper, Sum
sumValue) {
        if (upper < 0) throw new
IllegalArgumentException();
        this.upper = upper;
        this.sumValue = sumValue;
    }

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

Java Thread Example II

```
public class Driver {
    public static void main(String[] args) {
        if (args.length != 1) {
            System.err.println( “Usage Driver <integer>” );
            System.exit(0);
        }

        Sum sumObject = new Sum();
        int upper = Integer.parseInt(args[0]);
        Thread worker = new Thread(new Summation(upper, sumObject));
        worker.start();
        try {
            worker.join();
        } catch (InterruptedException ie) { }

        System.out.println( “The sum of” + upper + “ is “ +
sumObject.get());
    }
}
```

Outline

Threading Issues

- Semantics of fork() and exec() system calls
  - Does fork() duplicate only the calling thread or all threads?
  - Some UNIX system have chosen to have two versions
  - Which one version to use? Depend on the APP.
- 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

Threading Issues

- Signal Handling
  - Signals are used in UNIX systems to notify a process that a particular event has occurred :
    - Synchronous: illegal memory access, division by 0
    - Asynchronous: Ctrl+C
  - All signals follow the same pattern:
    1. Signal is generated by particular event
    2. Signal is delivered to a process
    3. Signal is handled
  - Signal handler may be handled by
    - a default signal handler, or
    - a user-defined signal handler
  - When multithread, where should a signal be delivered?
    - 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

Threading Issues

- 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
  - 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)
- Scheduler Activations
  - Both n: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

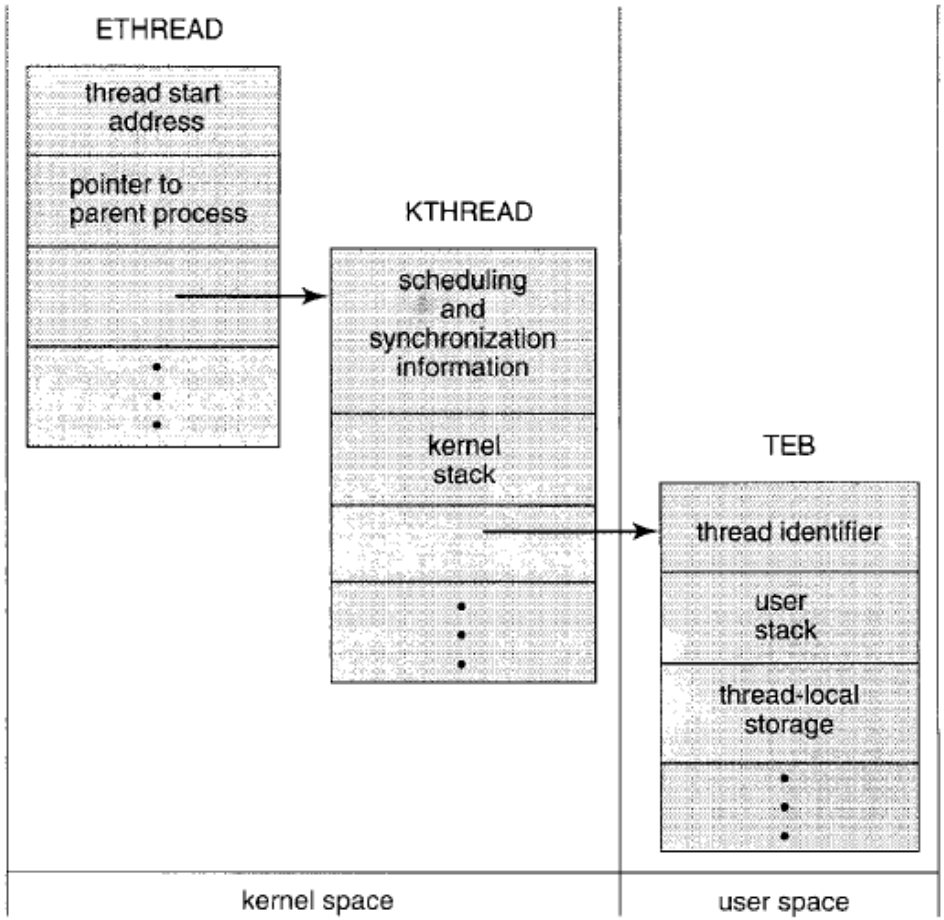
Outline

Windows XP Threads

- An Windows XP application runs as a seperate process, and each process may contain one or more threads.
- Implements the one-to-one mapping
  - each user-level thread maps to an assotiated kernel thread
  - any thread belonging to a process can access the address space of the process
- Each thread contains
  - A thread id
  - Register set
  - Separate user and kernel stacks
  - Private data storage area
- The register set, stacks, and private storage area are known as the context of the threads

Windows XP Threads

- The primary data structures of a thread include:
  - ETHREAD (executive thread block)
  - KTHREAD (kernel thread block)
  - TEB (thread environment block)



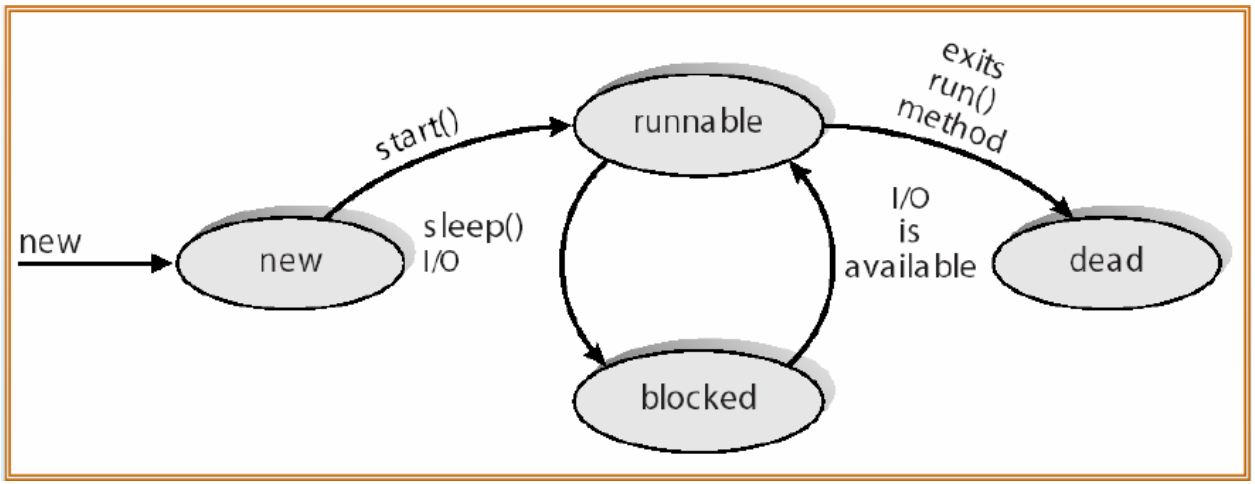
Linux Threads

- 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)
- clone() VS. fork()

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

Java Threads

- Java在语言级提供线程创建和管理支持功能
  - Java threads are managed by the JVM, not user-level library or kernel
- Java threads may be created by:
  - Extending Thread class
  - Implementing the Runnable interface Java



Thread States

Outline

Thread Scheduling

- user-level thread VS. kernel-level thread (or LWP)
- Local Scheduling — How the threads library decides which thread to put onto an available LWP
  - many-to-one, many-to-many models
  - process-contention scope, PCS
- Global Scheduling — How the kernel decides which kernel thread to run next
  - many-to-one, many-to-many & one-to-one models
  - system-contention scope, SCS

Pthread Scheduling API I

- POSIX Pthread API allows specifying either PCS or SCS during thread creation
  - PTHREAD_SCOPE_PROCESS, many-to-many
  - PTHREAD_SCOPE_SYSTEM, one-to-one
    - create and bind an LWP for each user-level thread

- example

```
#include <pthread.h>
#include <stdio.h>
#define NUM THREADS 5

int main(int argc, char *argv[]) {
        int i;
        pthread_t tid[NUM THREADS];
        pthread_attr_t attr;

        pthread_attr_init(&attr);        /* get the default attributes */
```

Pthread Scheduling API II

```
        /* set the scheduling algorithm to PROCESS or SYSTEM */
        pthread_attr_setscope(&attr, PTHREAD_SCOPE_SYSTEM);

        /* set the scheduling policy - FIFO, RT, or OTHER */
        pthread_attr_setschedpolicy(&attr, SCHED_OTHER);

        for (i = 0; i < NUM_THREADS; i++)       /* create the threads */
              pthread_create(&tid[i],&attr,runner,NULL);

        for (i = 0; i < NUM THREADS; i++)       /* now join on each thread
*/
              pthread_join(tid[i], NULL);
}

/* Each thread will begin control in this function */
void *runner(void *param) {
        printf( “I am a thread\n” );
        pthread_exit(0);
```

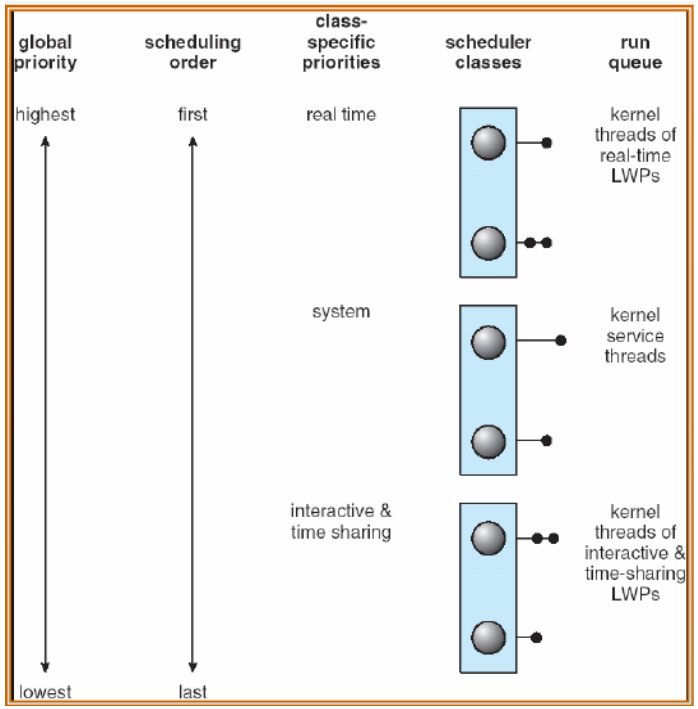
Pthread Scheduling API III

```
}
```

Outline

Solaris scheduling I

- Solaris: priority-based thread scheduling
- 4 classes of scheduling, in order of priority.
  Within each class there are different priorities and different scheduling algorithms.
  - Real time
  - System (do not change the priority)
  - Time sharing (default, with a multilevel feedback queue)
  - Interactive, the same as time sharing, but higher priority



Solaris scheduling II

priority	time quantum	time quantum expired	return from sleep
0	200	0	50
5	200	0	50
10	160	0	51
15	160	5	51
20	120	10	52
25	120	15	52
30	80	20	53
35	80	25	54
40	40	30	55
45	40	35	56
50	40	40	58
55	40	45	58
59	20	49	59

Solaris Dispatch Table

Windows XP scheduling

- Dispatcher:
  priority-based, preemptive scheduling algorithm
  uses a 32-level priority scheme to determine the order of thread execution
  - 0: idle thread
  - 1~15: variable classes priorities
  - 16~31: real-time class
  - a queue for each priority

	real-time	high	above normal	normal	below normal	idle priority
time-critical	31	15	15	15	15	15
highest	26	15	12	10	8	6
above normal	25	14	11	9	7	5
normal	24	13	10	8	6	4
below normal	23	12	9	7	5	3
lowest	22	11	8	6	4	2
idle	16	1	1	1	1	1

Windows XP Priorities (policy classes, relative priority)

Outline

小结

作业和上机

- 参见课程主页

谢谢！