CS 370: OPERATING SYSTEMS
[THREADS]

Shrideep Pallickara
Computer Science
Colorado State University

COMPUTER SCIENCE DEPARTMENT   COLORADO STATE UNIVERSITY

1

Frequently asked questions from the previous class survey

- Say the main thread creates threads `T1` and `T2`. When those threads are running, is the main thread running?
- When writing threads, do you specify the number of cores to use?
- How can threads access a document: but three separate processes cannot?
- Hyperthreading and its relation to execution of threads

COLORADO STATE UNIVERSITY   Professor: SHRIDEEP PALLICKARA COMPUTER SCIENCE DEPARTMENT   THREADS   L8.2

2

Topics covered in this lecture

- User- and kernel-level threads
- Thread Models
- Thread Libraries

Going about writing multithreaded programs [1/2]

- The key idea is to write a **concurrent program** — one with many simultaneous activities
  - As a set of sequential streams of execution, or threads, that interact and share results in very precise ways
- **Subdivide** functionality into multiple separate & concurrent tasks
- Threads let us define a set of tasks that run concurrently *while* the code for each task is sequential

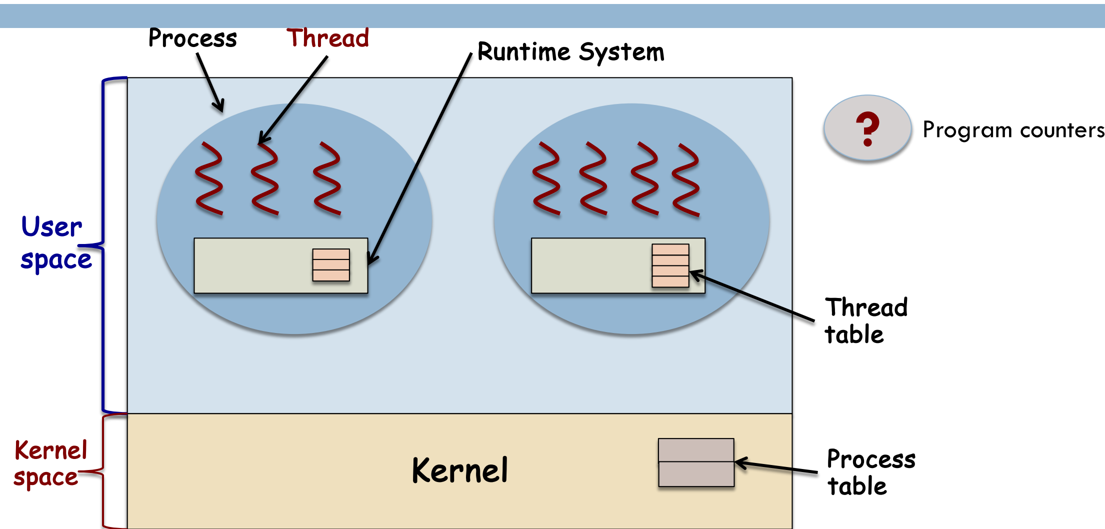
Going about writing multithreaded programs [2/2]

- Managing **data** manipulated by tasks
  - Split to run on separate cores. BUT
    - Examine data dependencies between the tasks
- Threaded programs on many core systems have many different **execution paths**
  - Which may or may not reveal **bugs**
  - Testing and debugging is inherently harder

5

6

User-level threads: Overview



7

User threads are invisible to the kernel and have low overhead

- **Compete among themselves** for resources allocated to their encapsulating process
- Scheduled by a *thread runtime* system that is **part** of the process code
- Programs link to a special library
  - Each library function is enclosed by a **jacket**
  - Jacket function calls thread runtime to do thread management
    - Before (and possibly after) calling jacketed library function

8

User level thread libraries: Managing blocking calls

- **Replace** potentially blocking calls with non-blocking ones
- If a call does not block, the runtime invokes it
- If the call *may block*
  1. Place thread on a list of *waiting* threads
  2. Add call to list of actions to *try later*
  3. Pick another thread to run
- ALL control is **invisible** to user and OS

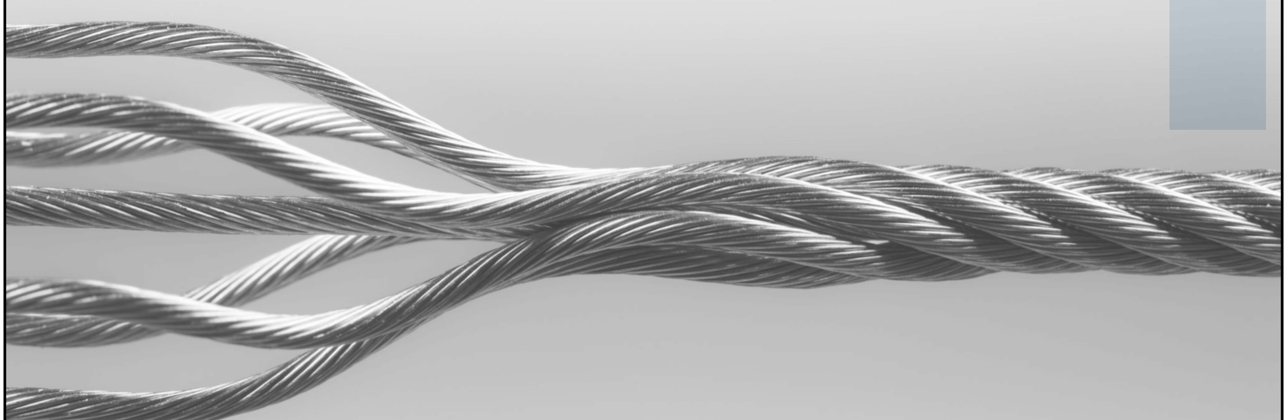
Disadvantages of the user level threads model [1/2]

- Assumes that the runtime will **eventually regain** control, this is thwarted by:
  - CPU bound threads
  - Thread that *rarely* performs library calls …
    - Runtime can't regain control to schedule other threads
- Programmer must avoid **lockout** situations
  - Force CPU-bound thread to *yield* control

Disadvantages of the user level threads model [2/2]

- Can only share processor resources allocated to encapsulating process
  - **Limits** available parallelism

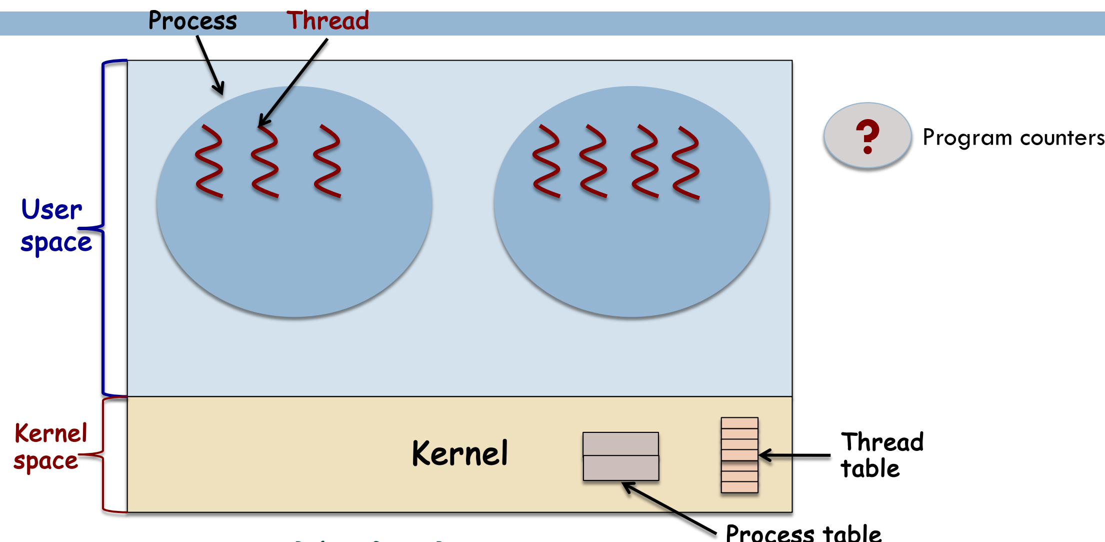
11



KERNEL THREADS

12

Kernel-level threads: Overview



13

Kernel threads

- Kernel is aware of kernel-level threads as **schedulable entities**
  - Kernel maintains a thread table to keep track of all threads in the system
- **Compete system wide** for processor resources
  - Can take advantage of multiple processors

14

Kernel threads: Management costs

- Scheduling is **almost as expensive** as processes
  - Synchronization and data sharing *less expensive* than processes
- More expensive to manage than user-level threads

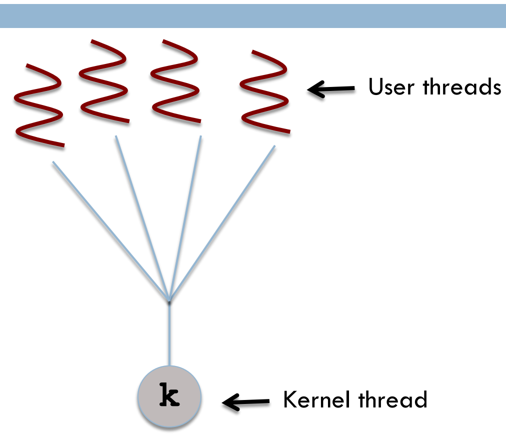
Hybrid thread models

- Write programs in terms of user-level threads
- Specify number of schedulable entities associated with process
  - **Mapping at runtime** to achieve parallelism
- Level of user-control over mapping
  - Implementation dependent

THREAD MODELS

17

The Many-to-One threading model



COLORADO STATE UNIVERSITY Professor: SHRIDEEP PALLICKARA COMPUTER SCIENCE DEPARTMENT THREADS L8.18

18

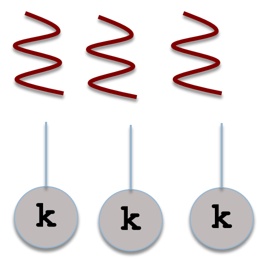
Many-to-One Model maps many user-level threads to 1 kernel thread

- Thread management done by thread library in **user-space**
- What happens when one thread makes a *blocking system call*?
  - The entire process blocks!

Many-to-One Model maps many user-level threads to 1 kernel thread

- Only 1 thread can access kernel at a time
  - Multiple threads **unable** to run in parallel on multi-processor/core system
- E.g.: Solaris Green threads, GNU Portable threads

The One-to-One threading model



21

One-to-One Model: Maps each user thread to a kernel thread

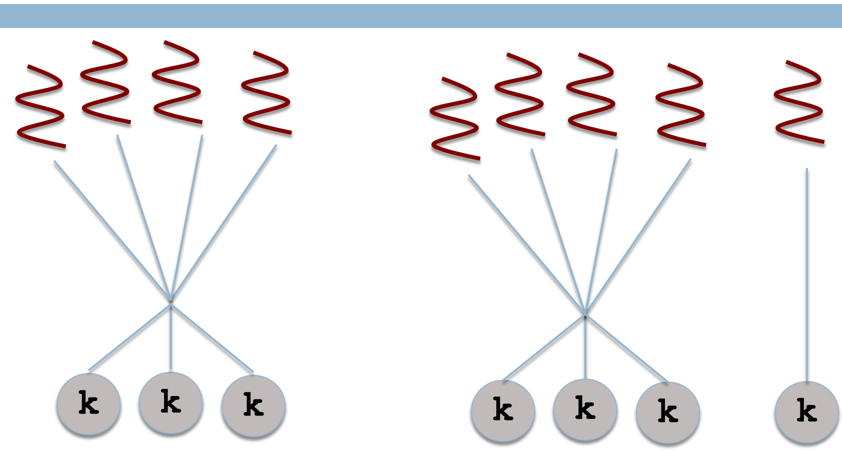
- More **concurrency**
  - Another thread can continue to run, when a thread invokes a blocking system call
- Threads run in **parallel** on multiprocessors

22

One-to-One Model: Maps each user thread to a kernel thread

- Disadvantages:
  - There is an **overhead** for kernel thread creation
    - Multiple user threads can degrade application performance
- Supported by:
  - Linux
  - Windows family: NT/XP/2000/Vista/7/8/10/11
  - Solaris 9 and up

Many-to-Many threading Model: 2-level is a variant of this



Many-to-Many **Two-level**

Many-to-Many model

- **Multiplex** many user-level threads on a smaller number of kernel threads
- Number of kernel threads may be specific to
  - Particular application
  - Particular machine
- Supported in
  - IRIX, HP-US, and Solaris (prior to version 9)

A comparison of the three models

	Many-to-one	One-to-One	Many-to-Many
True Concurrency	NO	YES	YES
During blocking system call?	Process Blocks	Process DOES NOT block	Process DOES NOT block
Kernel thread creation	Kernel thread already exists	Kernel thread creation overhead	Kernel threads available
Caveat	Use system calls (blocking) with care	Don't create too many threads	

27

Thread libraries provide an API for managing threads

- Includes functions for :
  1. Thread creation and destruction
  2. Enforcement of mutual exclusion
  3. Conditional waiting
- Runtime system to manage threads
  - Users are **not aware** of this

COLORADO STATE UNIVERSITY | Professor: SHRIDEEP PALLICKARA COMPUTER SCIENCE DEPARTMENT | THREADS | L8.28

28

User level thread libraries

- **No kernel support**
- Library code & data structures reside in user space
- Invoking a library function **does not** result in a system call
  - Local function call in user space

Kernel level thread libraries

- Library code & data structures in kernel space
- Invoking library function typically **results in a system call**

Thread libraries provide an API for creating and managing threads

	User level library	Kernel level library
Library code and data structures	Reside in user space	Reside in kernel space
Can invocation of library function result in system call?	NO	YES
OS support	NO	YES

Dominant thread libraries (1)

- POSIX pthreads
  - Extends POSIX standard (IEEE 1003.1c)
  - Provided as user- or kernel-level library
  - Linux, Mac OS X, Solaris, BSD
- Win32 thread library
  - Kernel-level library

Dominant thread libraries (2)

- Java threading API
  - Implemented using **thread library on host system**
    - On Windows: Threads use Win32 API
    - UNIX/Linux: Uses pthreads

33

34

Java threads example

- We will use a thread to perform summation of a non-negative integer

$$sum = \sum_{i=0}^{N} i$$

  - If N=5, we compute the sum of 0 through 5
    - 0 + 1 + 2 + 3 + 4 + 5 = 15

Java

- Designed from the ground-up to support **concurrent** programming
  - Basic concurrency support in the language and class libraries
- Java 1.5 (or 5) and higher
  - Powerful high-level concurrency APIs

JVMs harness the thread models of the host OS

- Windows/Linux have a one-to-one model
  - So a thread maps to a kernel thread
- Tru64 UNIX uses the many-to-many model
  - Java threads mapped accordingly
- Solaris
  - Initially, used Green Threads → many-to-one
  - Version 9 onwards: one-to-one model

COLORADO STATE UNIVERSITY | Professor: SHRIDEEP PALLICKARA, COMPUTER SCIENCE DEPARTMENT | THREADS | L8.37

37

Creating Threads in Java

1. Create a new class **derived** from `Thread`
   - Override its `run()` method
2. More commonly used: `Runnable` interface
   - Has 1 method `run()`
   - Create new `Thread` class by passing a `Runnable` object to its constructor
3. The `Executor` interface (`java.util.concurrent`)
   - Has 1 method `execute()`

COLORADO STATE UNIVERSITY | Professor: SHRIDEEP PALLICKARA, COMPUTER SCIENCE DEPARTMENT | THREADS | L8.38

38

Java Threads: Interrupts

- Invoke `interrupt()` on the Thread
- Threads must support their ***own*** interruption
- An **interruptible thread** needs to
  1. Catch the `InterruptedException`
     - Methods such as `sleep()` throw this, and are designed to cancel the operation and return
  2. Periodically invoke `Thread.interrupted()` to see if it has been interrupted

Java Threads: `joins`

- If thread object `threadA` is currently executing
- Another thread can call `threadA.join()`
  - Causes current thread to pause execution **until `threadA` terminates**
- Variants of `join()`
  - Specify a waiting period

Using Java Threads [1/3]

```
class Sum {
   private int sum;

   public int get() {
      return sum;
   }

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


Using Java Threads [2/3]

```
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.set(sum);
   }
}
```

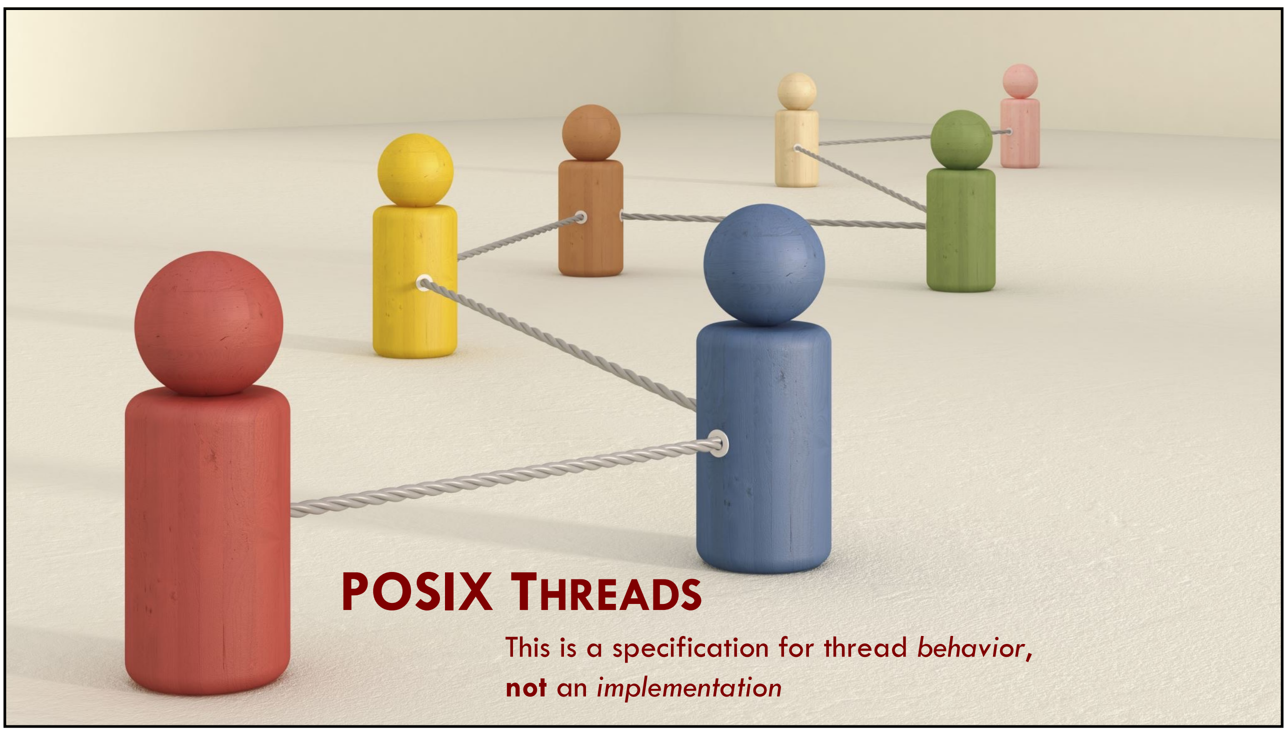
Using Java Threads [3/3]

```java
public class Driver {
    public static void main(String[] args) {

        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) {
            ie.printStacktrace()
        }
        System.out.println("The sum of " + upper + " is " +
                           sumObject.get());
    }
}
```


43



44

POSIX thread management functions: Return 0 if successful

POSIX function	Description
pthread_cancel	Terminate another thread
pthread_create	Create a thread
pthread_detach	Set thread to release resources
pthread_exit	Exit a thread without exiting process
pthread_kill	Send a signal to a thread
pthread_join	Wait for a thread
pthread_self	Find out own thread ID

Functions return a non-ZERO error code
Do NOT set `errno`

POSIX: Thread creation `pthread_create()`

- Automatically makes the thread runnable *without* a start operation
- Takes 3 parameters:
  1. Points to **ID** of newly created thread
  2. **Attributes** for the thread
     - Stack size, scheduling information, etc.
  3. Name of **function** that the thread calls when it begins execution

POSIX: Detaching and Joining

- When a thread exits it does not release its resources
  - Unless it is a **detached thread**
- `pthread_detach()`
  - Sets *internal options* to specify that storage for thread can be **reclaimed** when it exits
  - 1 parameter: Thread ID of the thread to detach

POSIX: Thread joins

- Threads that are not detached are `join`able
- Undetached threads don't release resources until
  - Another thread calls `pthread_join` for them
  - Process exits
- `pthread_join`
  - Takes ID of the thread to **wait** for
  - **Suspends** calling thread till target terminates
  - Similar to `waitpid` at the process level
  - `pthread_join(pthread_self())`?
    - **Deadlock!**

POSIX: Exiting and cancellation

- If a process calls `exit`, **all** threads terminate
- Call to `pthread_exit` causes only the calling thread to terminate
- Threads can force other threads to return through a *cancellation* mechanism
  - `pthread_cancel`: takes thread ID of target
  - Depends on *type* and *state* of thread

More info on pthread_cancel

- State: `pthread_setcancelstate` to change state
  - `PTHREAD_CANCEL_ENABLE`
  - `PTHREAD_CANCEL_DISABLE`
    - Cancellation requests are held pending
- Cancellation type allows thread to control when to exit
  - `PTHREAD_CANCEL_ASYNCHRONOUS`
    - Any time
  - `PTHREAD_CANCEL_DEFFERED`
    - Only at specified cancellation points

Using Pthreads (1)

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

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

void *runner(void *param); /* the thread */
```


Using Pthreads (2)

```
int main(int argc, char *argv[]){

   pthread_t tid;    pthread_attr_t attr;
   /* get the default attributes */
   pthread_attr_init(&attr);

   /* create the thread */
   pthread_create(&tid, &attr, runner, argv[1]);

   /* now wait for the thread to exit */
   pthread_join(tid, NULL);

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

Using Pthreads (3)

```
/**
 * 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);
}
```


Win32 Threads

- `CreateThread`
  - Security Information, size of stack, flag (start in suspended state?)
- `WaitForSingleObject`
- `CloseHandle`

The contents of this slide-set are based on the following references

- *Avi Silberschatz, Peter Galvin, Greg Gagne. Operating Systems Concepts, 9th edition. John Wiley & Sons, Inc. ISBN-13: 978-1118063330.* [Chapter 4]
- *Andrew S Tanenbaum and Herbert Bos. Modern Operating Systems. 4th Edition, 2014. Prentice Hall. ISBN: 013359162X/ 978-0133591620.* [Chapter 2].
- *Kay Robbins & Steve Robbins. Unix Systems Programming, 2nd edition, Prentice Hall ISBN-13: 978-0-13-042411-2.* [Chapter 12]
- *Thomas Anderson and Michael Dahlin. Operating Systems: Principles and Practice, 2nd Edition. Recursive Books. ISBN: 0985673524/978-0985673529. [Chapter 4]*