

CS 370: OPERATING SYSTEMS
[THREADS]

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Frequently asked questions from the previous class survey

- Is there a separate stack for a process?
- Threads
 - References to objects, when do they terminate, how many is too many, more threads than cores, code example?
- Cores and memory sharing
- Any way to predetermine order of diverse threads for accesses?
- Fork()-exec() and threads

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Topics covered in this lecture

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

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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

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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

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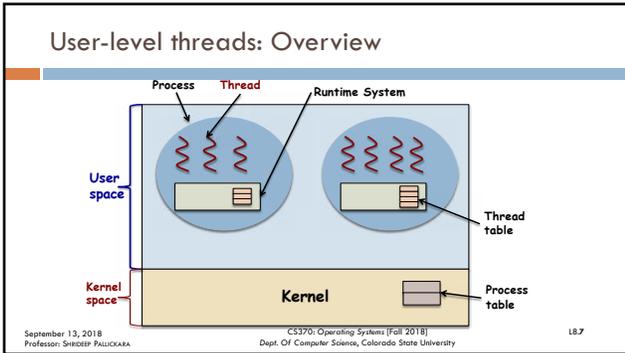
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USER-LEVEL THREADS

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- 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.
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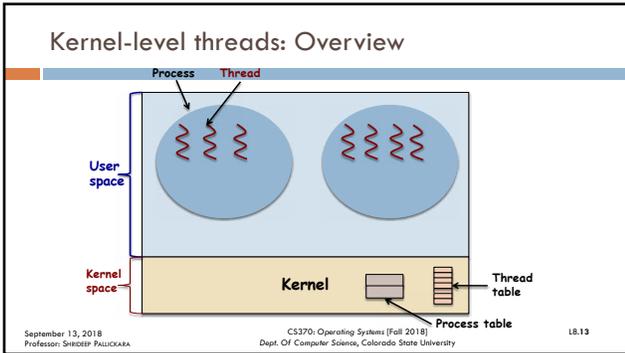
- ### User level thread libraries: Managing blocking calls
- **Replace** potentially blocking calls with non-blocking ones
 - If a call does not block, the runtime invokes it
 - If the call **may block**
 - ① Place thread on a list of **waiting** threads
 - ② Add call to list of actions to **try later**
 - ③ Pick another thread to run
 - ALL control is **invisible** to user and OS
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- ### Disadvantages of the user level threads model (1)
- 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
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- ### Disadvantages of the user level threads model (2)
- Can only share processor resources allocated to encapsulating process
 - **Limits** available parallelism
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KERNEL THREADS

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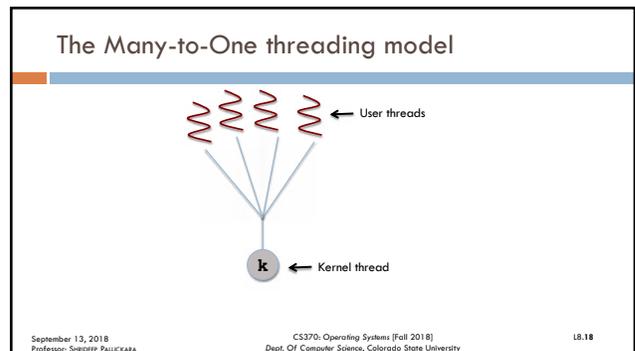
- ### Kernel threads
- Kernel is aware of kernel-level threads as **schedulable entities**
 - Kernel maintains a thread table to keep track of all threads in the system
 - **Compete system wide** for processor resources
 - Can take advantage of multiple processors
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-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

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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!

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

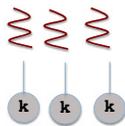
- Only 1 thread can access kernel at a time
 - ▣ Multiple threads **unable** to run in parallel on multi-processor/core system
- E.g.: Solaris Green threads, GNU Portable threads

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The One-to-One threading model



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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

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

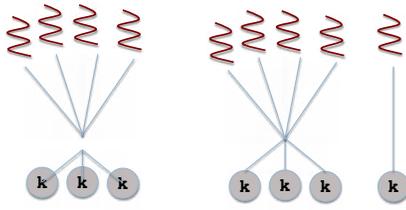
- Disadvantages:
 - ▣ There is an **overhead** for kernel thread creation
 - Multiple user threads can degrade application performance
- Supported by:
 - ▣ Linux
 - ▣ Windows family: NT/XP/2000
 - ▣ Solaris 9 and up

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



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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)

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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	

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Provide an API for creating and managing threads

THREAD LIBRARIES

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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

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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

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Kernel level thread libraries

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

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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

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Dominant thread libraries (1)

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

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Dominant thread libraries (2)

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

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JAVA THREADS

Harnesses the thread model of the host OS

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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
 - $0 + 1 + 2 + 3 + 4 + 5 = 15$

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Java

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

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JVMs harness the thread models of the host OS

- Windows XP has 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

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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()`

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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

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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

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Using Java Threads

[1/3]

```
class Sum {
    private int sum;

    public int get() {
        return sum;
    }

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

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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);
    }
}
```

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Using Java Threads [3/3]

```

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());
    }
}
    
```

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POSIX THREADS

This is a specification for thread behavior,
not an implementation

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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

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POSIX: Thread creation

pthread_create()

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

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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

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POSIX: Thread joins

- Threads that are not detached are **joinable**
- 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!**

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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

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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_DEFERRED`
 - Only at specified cancellation points

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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 */
```

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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);
}
```

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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);
}
```

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Win32 Threads

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

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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]*