CIIC 4050 / ICOM 5007
Operating Systems

Lecture 5:
Threads

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Threads (1)

- A **thread** is an execution context for a processor, which handles an execution of the instructions in a process or part of them.
- In a system that does not support multiple threads in a process, each process has only one thread.
- In a system that supports multiple threads in a process, there can be many threads executing concurrently on the same process.

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Threads (2)

- Each thread in a process
  - can be executing a different portion (method or subroutine) of the process's code.
- In a uniprocessor system,
  - they alternate execution as different processes do. In a multiprocessors system, they can execute in parallel.
- For each thread, the following data is maintained:
  - *ID, program counter, register set,* and *stack*. This is in addition to the other information maintained in PCB of the owner process.

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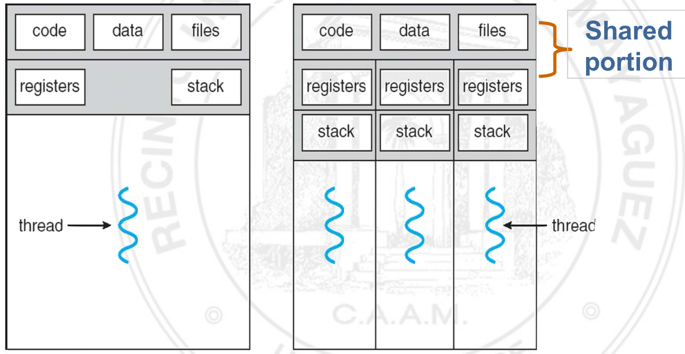
Single and Multithreaded Processes



single-threaded process
(typical process as seen so far)

multithreaded process

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Thread Content

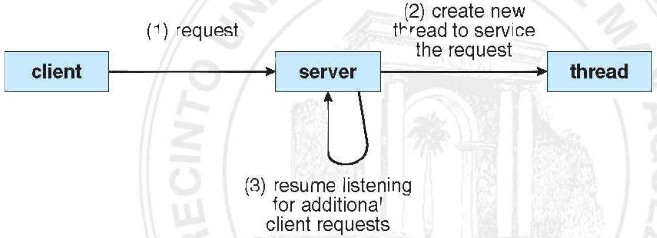
Per process items	Per thread items
Address space	Program counter
Global variables	Registers
Open files	Stack
Child processes	State
Pending alarms	
Signals and signal handlers	
Accounting information	

- **Figure 2-7.** The first column lists some items shared by all threads in a process. The second one lists some items private to each thread.

Thread use

- Potential uses of threads:
  - Word Processor – 1 thread display, 1 thread keystrokes, 1 thread spelling & grammar
  - Web browser – 1 thread display images, 1 thread network
  - Web server – ???

Example: Multithreaded Server Architecture



General Algorithm followed by server:

1. Initialization
2. While (true)
   a. get request
   b. initiate thread to serve request concurrently

Benefits (1)

- **Responsiveness** - threads allow a program to continue executing even if part of it is blocked or is performing a lengthy computation. This may result in faster responses during program execution.
- **Resource Sharing** - data and resources can be shared in an efficient manner That kind of sharing in processes is achieved by message passing or by shared memory, and at a major cost in terms of effort from the programmer.

Benefits (2)

- **Economy** - several of the overhead issues involved in creating and managing processes are highly minimized in threads.
- **Scalability** - benefits or multithreading can be greatly increased in multiprocessor architectures.

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Benefits (3)

- **Thread vs Process Cost***

	User threads	LWP/kernel threads	Processes
Creation time	52	350	1700
Synchronization with semaphores	66	390	200

* on SPARC station 2 (Solaris), from Unix Internals by Uresh Vahalia, PH 1996.

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Multicore Programming (1)

- Multicore or multiprocessor systems putting pressure on OS designers as well as on application programmers.
- Challengers for OS designers include:
  - Scheduling to allow efficient use of cores and parallel execution
  - Synchronization of threads running in different cores.

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Multicore Programming (2)

- Challengers for application programmers include:
  - **Dividing activities** - which can be parallelized
  - **Balance** - equal effort on each parallel activity
  - **Data splitting** - divide data managed by each activity
  - **Data dependency** - between different activities and properly synchronize responsible threads.
  - **Testing and debugging** - involves more effort than in sequential processes since order of execution of parallel tasks may be undetermined.

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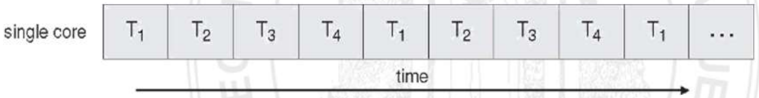
Concurrent Execution on a Single-core System



- Concurrency = Interleaved execution
(time sharing systems)

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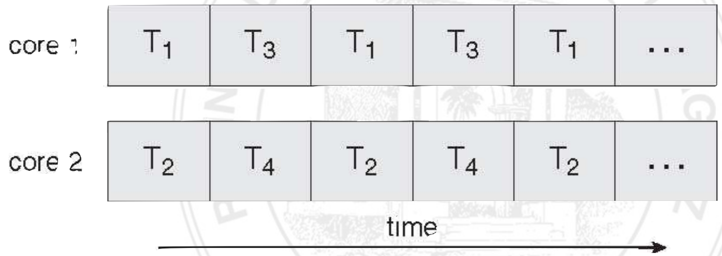
Parallel Execution on a Multicore System



- Concurrency = Parallel execution
(one thread/core + time sharing)

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Management of Threads (1)

- Thread management can be provided at either:
  - *user level* - are supported above the kernel
  - *kernel level* - are supported and managed directly by the OS.
- Virtually all modern OS's support kernel threads
  - Windows XP/2003, Solaris, Linux, Tru64 UNIX, HP-UX, Mac OS X

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Management of Threads (2)

- Ultimately, there must be a relationship between a running user thread and a kernel thread to allow the execution of that user thread
- Different models are used to match user threads to corresponding kernel threads for their execution

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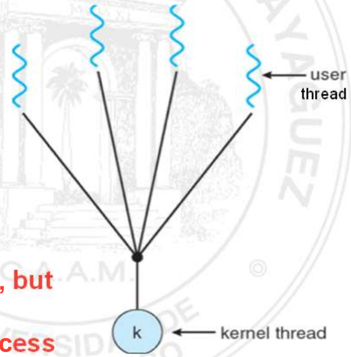
Many-to-One

- Many user-level threads mapped to single kernel thread
- Examples:
  - Solaris Green Threads
  - GNU Portable Threads



(-) Threads execute concurrently, but not in parallel…
(-) Threads are scheduled by process itself.

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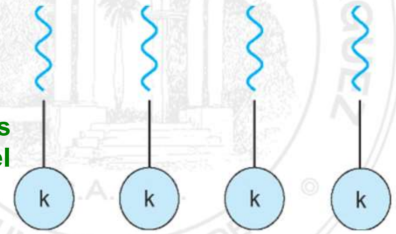
One-to-One

- Each user-level thread maps to kernel thread
- Examples
  - Windows NT/XP/2000
  - Linux
  - Solaris 9 and later



Different threads in a process can run in parallel. The kernel schedules them…
(-) more overhead since kernel needs to create one kernel thread for each user thread created

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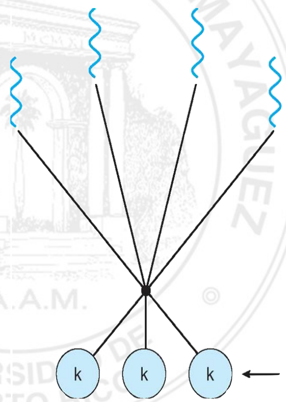
Many-to-Many Model

- Allows many user level threads to be mapped to many kernel threads (multiplexed)
- Allows the operating system to create a sufficient number of kernel threads
- Solaris prior to version 9
- Windows NT/2000 with the *ThreadFiber* package



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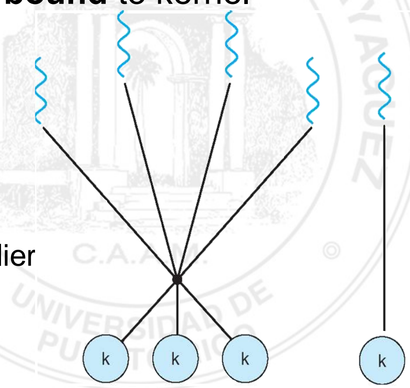
Two-level Model

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



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Thread Libraries

- Thread library provides programmer with API for creating and managing threads
- Two primary ways of implementing
  - Library entirely in user space
  - Kernel-level library supported by the OS
- Example of thread libraries:
  - POSIX Pthreads
  - Win32 threads
  - Java threads

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PTHREADS

- May be provided either as user-level or kernel-level
- A POSIX standard (IEEE 1003.1c) API for thread creation and synchronization
- API specifies behavior of the thread library (specification), implementation is up to development of the library
- Commonly implemented in UNIX operating systems (Solaris, Linux, Mac OS X)

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PTHREADS (example)

```
#include <pthread.h>
#include <stdio.h>
int sum; /* this data is shared by the thread(s) */
void *runner(void *param); /* the thread */
int main(int argc, char *argv[])
{
   pthread_t tid; /* the thread identifier */
   pthread_attr_t attr; /* set of attributes for the thread */
   if (argc != 2) {
      fprintf(stderr,"usage: a.out <integer value>\n");
      /*exit(1);*/
      return -1;
   }
   if (atoi(argv[1]) < 0) {
      fprintf(stderr,"Argument %d must be non-
   negative\n",atoi(argv[1]));
      /*exit(1);*/
      return -1;
   }
   /* get the default attributes */
   pthread_attr_init(&attr);
   /* create the thread */
   pthread_create(&tid,&attr,runner,argv[1]);
```

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PTHREADS (example)

```
 /* now wait for the thread to exit */
pthread_join(tid,NULL);
printf("sum = %d\n",sum);
}
/**
* 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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Java Threads

- Java threads are managed by the JVM
- Typically implemented using the threading model provided by underlying OS
- Java threads may be created by:
  - Extending `Thread` class
  - Implementing the `Runnable` interface (most common)

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Java Threads (1)

- Runnable Interface

```
public interface Runnable {
    void run();
}
```

- A class implementing the interface defines objects corresponding to threads
  - once instantiated, the thread object will start executing its `run()` method…

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Java Threads (2)

- To create and start the execution of a thread object of type **`Runnable`**, the following is required:

  1. Create an object of type Thread while passing an instance of the **`Runnable`** object as parameter of constructor.

  2. To that object of type **`Thread`** apply method **`start()`**.

*** The new thread will automatically start executing the `run()` method of the associated `Runnable` object.

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Java Threads States

- A Java thread may be in one of **6 possible states**
  - **New** - Thread created but run() method has not started
  - **Runnable** - when the run() method starts
  - **Blocked** - thread is waiting for a lock
  - **Waiting** - thread is waiting for an action of another thread (example: executing join())
  - **Timed waiting** - same as waiting for for a specified maximum time. Useful to eliminate the possibility of starvation…
  - **Terminated** - when the run method of the thread has finished.

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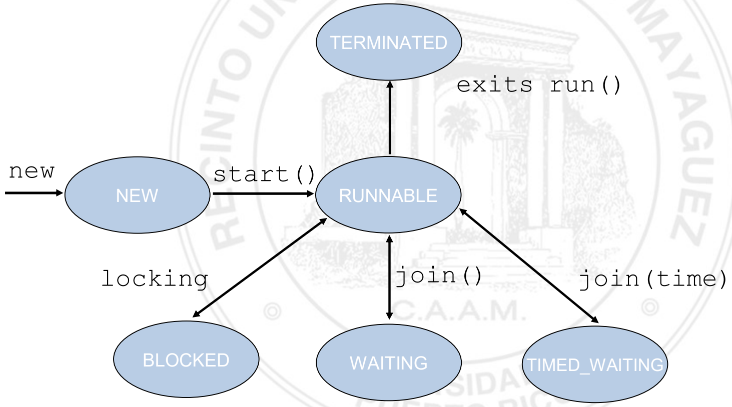
Java Threads States



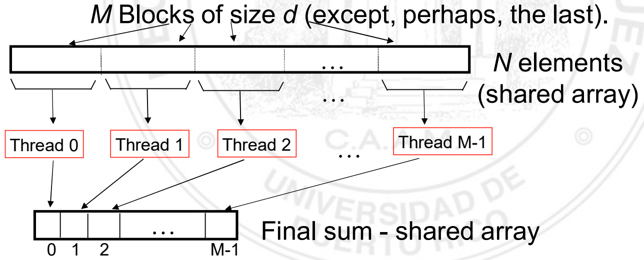
Threads: Sum of Array Elements (1)

- Given an array of *N* integers and a fixed value *d*, create
- *M* threads to add all its elements in portions of size *d*.
- One possible solution:
  - Main thread does the following
    - Create several thread
    - Each thread is assigned a portion of the array
    - Each thread computes the sum of its assigned portion
    - Results are placed in appropriate entries in a shared array

Threads: Sum of Array Elements (2)

- Given an array of *N* integers and a fixed value *d*, create *M* threads to add all its elements in portions of size *d*.

$$M = \begin{cases} N/d \text{ if } N\%d == 0 \\ N/d + 1 \text{ if not} \end{cases}$$



Java: Sum of Array Elements (1)

```
public static void main(String[] args) {
   int[] a = …; // the array to add
   int pSize = …;  // size of blocks
   int nThreads =
    (a.length % pSize == 0 ? a.length / pSize : a.length / pSize + 1);

   Barrier barrier = new Barrier(nThreads);

   int[] sum = new int[nThreads];

   for (int i=0; i<nThreads; i++) {
       Thread t =
         new Thread(new ArrayPortionAdder(a, sum, i, pSize, barrier));
       t.start();
   }

   // wait for all threads to finished as per the barrier object...
   try {
      barrier.waitForRelease();
   }
   catch(InterruptedException e) {}

   // compute the final sum from the array sum …
   …
}
```

Java: Sum of Array Elements (2)

```
public class ArrayPortionAdder implements Runnable {
   private int[] arr, sum;
   private int index, size;
   private Barrier barrier;

   public ArrayPortionAdder(int[] arr, int[] sum, int index, int size,
         Barrier b) {
        … arr is the array to sum, sum is the array were partial results are placed, …
   }
   public void run() {
      int low = index * size;
      int sup = low + size - 1;
      if (sup >= arr.length)
         sup = arr.length - 1;
      int asum = 0;

      for (int i = low; i <= sup; i++)   // thread sums its part
         asum += arr[i];

      sum[index] = asum;       // places result in shared array

      // count one more thread as finished
      …
      barrier.incCount();
      …
   }
}
```

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Java: Object Type for Synchronization

```
public class Barrier {
  private int threshold,  count = 0;
  public Barrier(int t) {
     threshold = t;
  }
  public void reset() {
     count = 0;
  }
  public synchronized void waitForRelease() throws InterruptedException {
     while (count < threshold)
        wait();
  }
  public synchronized void incCount()
  throws InterruptedException {
     count++;
     if (count==threshold)
       notifyAll();
  }
}
```

*** This an example of a class used for synchronization – we shall study this in more detail later in the course….

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Threading Issues

- Semantics of **fork()** and **exec()** system calls
- Thread cancellation of target thread
  - Asynchronous or deferred
- Signal handling
- Thread pools
- Thread-specific data
- Scheduler activations

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Semantics of fork() and exec()

- Does fork() duplicate only the calling thread or all threads?
- Some UNIX systems have two versions of fork():
  - one that duplicates all threads active in the parent process
  - one that duplicates only the thread invoking the fork()

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Thread Cancellation (1)

- Terminating a thread before it has finished
  - Multiple threads performing database search, one returns value, others might be canceled…
- Two general approaches:
  - **Asynchronous cancellation** terminates the target thread immediately
    - Case where resources have been allocated to canceled thread, thread canceled while updating data needed by other threads
    - java – stop() (deprecated)

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Thread Cancellation (2)

- **Deferred cancellation** allows the target thread to periodically check if it should be cancelled
  - pthreads – cancellation points
  - java – interrupt(), isInterrupted()

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Signal Handling

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

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Signal Handling (example)

```
/* Sample program to handle system signals */

#include <signal.h>
#include <stdio.h>

void * myhandler(int myint)
{
   printf("\nSignal Handled!!\n\n");
   exit(0);
}

int main()
{
   signal( SIGINT, (void *)  myhandler );
   signal( SIGTERM, (void *)  myhandler );

   while(1) {
       printf("Doing Nothing...\n");
       sleep(1);
   }
}
```

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Signal Handling

- Options:
  - 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

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Thread Pools (1)

- To create a new thread, although simpler than to create a process, has its impacts on the system:
  - To create a new thread consumes time
  - Too many active threads may negatively impact system's performance

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Thread Pools (2)

- An alternative is to create a number of threads in a pool where they await work. This has 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

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Thread Pools in Java (1)

- Java allows the creation of thread pools as shown next.
- Java classes to support thread pools:

```
public interface Executor {
   // executes the given thread
   // at some time in the future
   void execute(Runnable t);
}
```

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Thread Pools in Java (2)

- Class **Executors** - provides a set of useful methods to create objects that are relevant to thread management in JVM. One static method creates a pool of a given number of threads. Such pool is created as an object of type **ExecutorService** .

```
public static ExecutorService
       newFixedThreadPool(int maxNoThreads)
```

Interface **ExecutorService**

```
  public interface ExecutorService extends Executor {
    … several methods + execute …
}
```

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Thread Pools in Java (2)

- Example of a Java thread pool:
- Assume that class Worker is as follows:

```
public class Worker implements Runnable {
   private static int NT = 0;
   public void run() {
     System.out.println("Thread number " + (++NT));
   }
}
```

- The following creates a thread pool:

```
Runnable r1 = new Worker();
Runnable r2 = new Worker();
Runnable r3 = new Worker();
ExecutorService pool = Executors.newFixedThreadPool(3);
pool.execute(r1);
pool.execute(r2);
pool.execute(r3);
```

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Thread Specific Data

- Allows each thread to have its own copy of data
  - Transaction processing system (each thread handle separate transaction)
- Useful when you do not have control over the thread creation process (i.e., when using thread pools)

Transaction	Thread
new_order()	trans_T1
payment()	trans_T3
order_status()	trans_T5
delivery()	trans_T2
stock_value()	trans_T4

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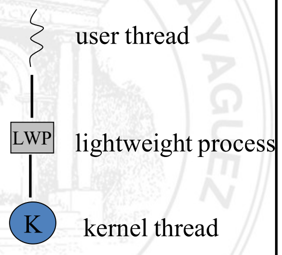
Scheduler Activations

- Both M:M and Two-level models require communication to dynamically maintain the appropriate number of kernel threads allocated to the application
- Place a data structure between user and kernel threads (lightweight process)
- 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



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Windows XP Threads (1)

- Implements the one-to-one mapping, kernel-level
- Each thread contains
  - A thread id
  - Register set
  - Separate user and kernel stacks
  - Private data storage area

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Windows XP Threads (2)

- The register set, stacks, and private storage area are known as the context of the threads
- The primary data structures of a thread include:
  - ETHREAD (executive thread block)
  - KTHREAD (kernel thread block)
  - TEB (thread environment block)

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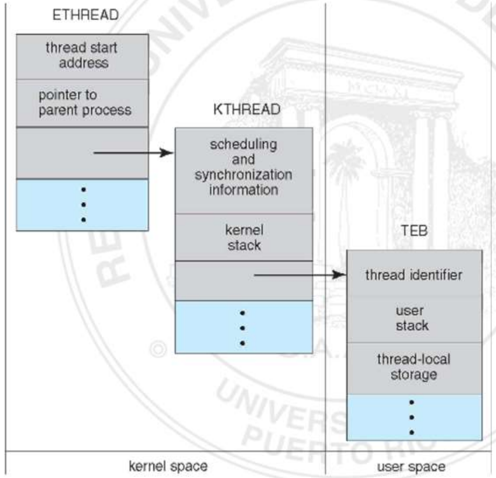
Windows XP Threads



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Linux Threads (1)

- Linux refers to them as *tasks* rather than *threads or processes*
- Thread creation is done through **clone()** system call
- **clone()** allows a child task to share the address space of the parent task (process), several flags control amount of sharing between parent-child, if no flags are set:
- **clone() = fork()**

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Linux Threads (2)

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.

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