Chapter 4: Threads – Outline

- What are threads ? How do they compare with processes ?
- Why are threads important ?
- What are the common multithreading models ?
- What are the common multithreading libraries ?
- Discussion on threading issues.
- Examples of threads in contemporary OSes.

Process Overview

- The basic unit of CPU utilization is a process.
- To run a program (a sequence of instructions), create a process.
- Process properties
  - `fork()` → `exec()` can be used to start new program execution
  - processes are well protected from each other
  - context-switching between processes is fairly expensive
  - inter-process communication used for information sharing and co-ordination between processes
    - shared memory
    - message passing

Is the Process Abstraction Always Suitable ?

- Consider characteristics for a game software
  - different code sequences for different game objects
    - soldiers, cities, airplanes, cannons, user-controlled heroes, etc.
  - each object is more or less independent
- Problems
  - single monolithic process may not utilize resources optimally
    - can create a process for each object
  - action of an object depends on game state
    - sharing and co-ordination of information necessary
    - IPC is expensive
  - number of objects proceed simultaneously
    - may involve lots of context switches
    - process context switches are expensive

Is the Process Abstraction Always Suitable ? (2)

- Ability to run multiple sequences of code (threads of control) for different object
  - individual process only offers one thread of control
- Way for threads of control to share data effectively
  - processes NOT designed to do this
- Protection between threads of control not very important
  - all in one application, anyway !
  - process is an over-kill
- Switching between threads of control must be efficient
  - context switching involves a lot of overhead
- Different threads of control may share most information
  - processes duplicate entire address space

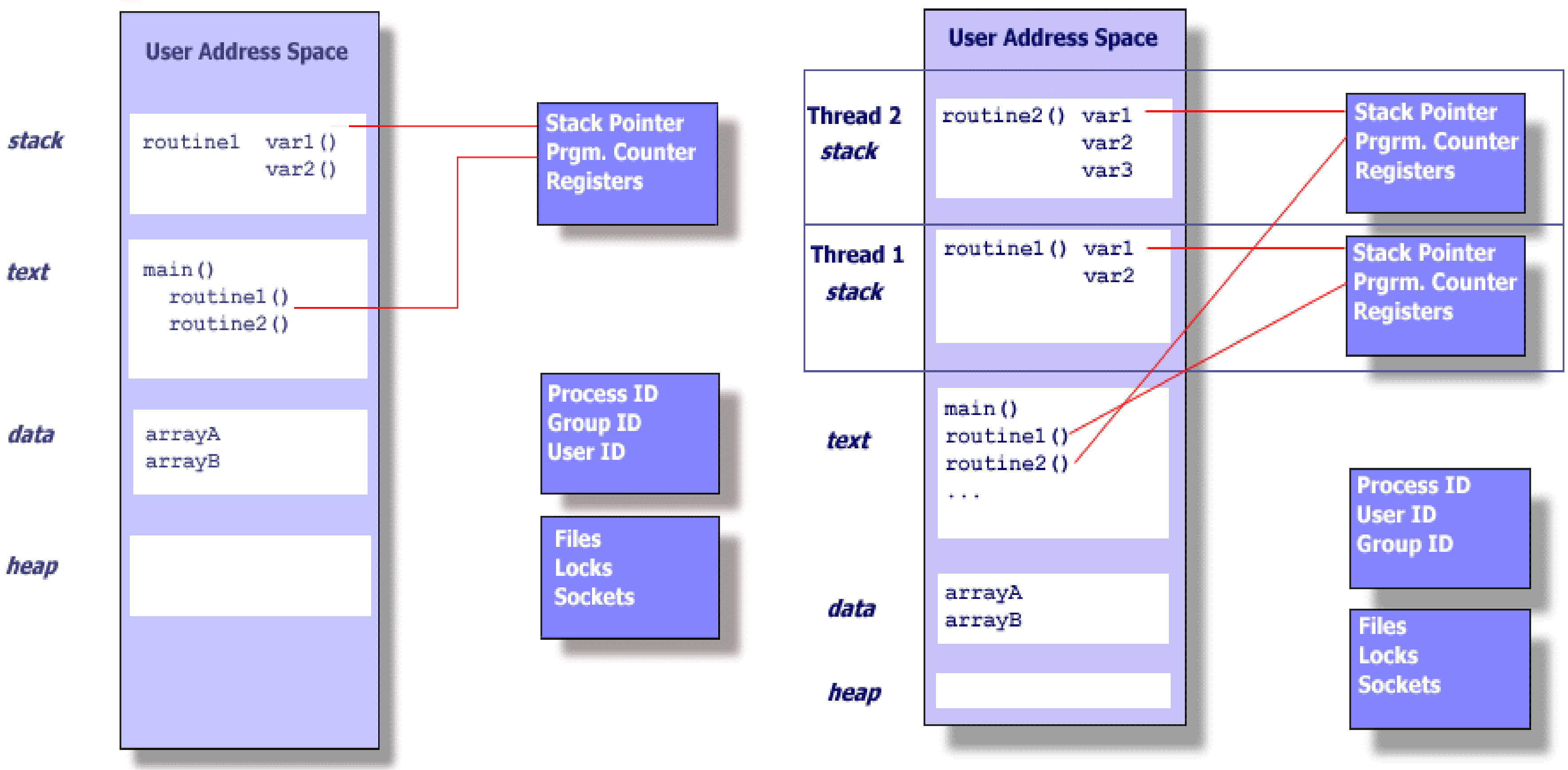
Threads to the Rescue

- *Threads* are designed to achieve all the above requirements !
  - do as little as possible to allow execution of a thread of control
- Thread are known as a *lightweight* process
  - only the necessary context information is re-generated
    - thread-context: PC, registers, stack, other misc. info
    - process-context: also includes data and code regions
  - threads are executed within a process
    - code and data shared among different threads
    - reduced communication overhead
  - smaller context
    - faster context switching
  - a single address space for all threads in a process
    - reduced inter-thread protection

Thread Basics

- Thread – *a lightweight process*
  - have their own independent flow of control
  - share process resources with other sibling threads
  - exist within the context space of the same process
- Threads shared data
  - process instructions
  - most data
  - open files (descriptors)
  - signals and signal handlers
  - current working directory
  - user and group id
- Threads specific data
  - thread id
  - registers, stack pointer
  - thread-specific data
    (stack of activation records)
  - signal mask
  - scheduling properties
  - return value

Single and Multithreaded Process



source: https://computing.llnl.gov/tutorials/pthreads/

Thread Benefits

- Responsiveness
  - for an interactive user, if part of the application is blocked
- Resource Sharing
  - easier, via memory sharing
  - be aware of synchronization issues
- Economy
  - sharing reduces creation, context-switching, and space overhead
- Scalability
  - can exploit computational resources of a multicore CPU

Thread Programming In Linux

- Threads can be created using the *Pthreads* library
  - IEEE POSIX C language thread programming interface
  - may be provided either as user-level or kernel-level

- Pthreads API
  - *Thread management* – functions to create, destroy, detach, join, set/query thread attributes
  - *Mutexes* – functions to enforce synchronization. Create, destroy, lock, unlock mutexes
  - *Condition variables* – functions to manage thread communication. Create, destroy, wait and signal based on specified variable values

Pthreads Example

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

int sum; /* data shared by all threads */
void runner(void param); /* thread function prototype */

int main (int argc, char *argv[])
{
    pthread_t tid; /* thread identifier */
    pthread_attr_t attr /* set of thread attributes */

    if(atoi(argv[1]) < 0) {
        fprintf(stderr, “%d must be >=0\n”, atoi(argv[1]));
        return -1;
    }
    /* get the default thread attributes */
    pthread_attr_init(&attr);
    /* create the thread */
    pthread_create(&tid, &attr, runner, argv[1]);
    /* wait for the thread to exit */
    pthread_join(tid, NULL);
    fprintf(stdout, “sum = %d\n”, sum);
}
```

Pthreads Example (2)

```
.... (cont. from previous page...)

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

    for(i=1 ; i<=upper ; i++)
        sum += i;

    pthread_exit(0);
}
```

Pthread Example – API Calls

- pthread_attr_init – initialize the thread attributes object
  - `int pthread_attr_init(pthread_attr_t *attr);`
  - defines the attributes of the thread created
- pthread_create – create a new thread
  - `int pthread_create(pthread_t *restrict thread, const pthread_attr_t *restrict attr, void *(*start_routine)(void*), void *restrict arg);`
  - upon success, a new thread id is returned in `thread`
- pthread_join – wait for thread to exit
  - `int pthread_join(pthread_t thread, void **value_ptr);`
  - calling process blocks until thread exits
- pthread_exit – terminate the calling thread
  - `void pthread_exit(void *value_ptr);`
  - make return value available to the joining thread

User Vs. Kernel Level Threads

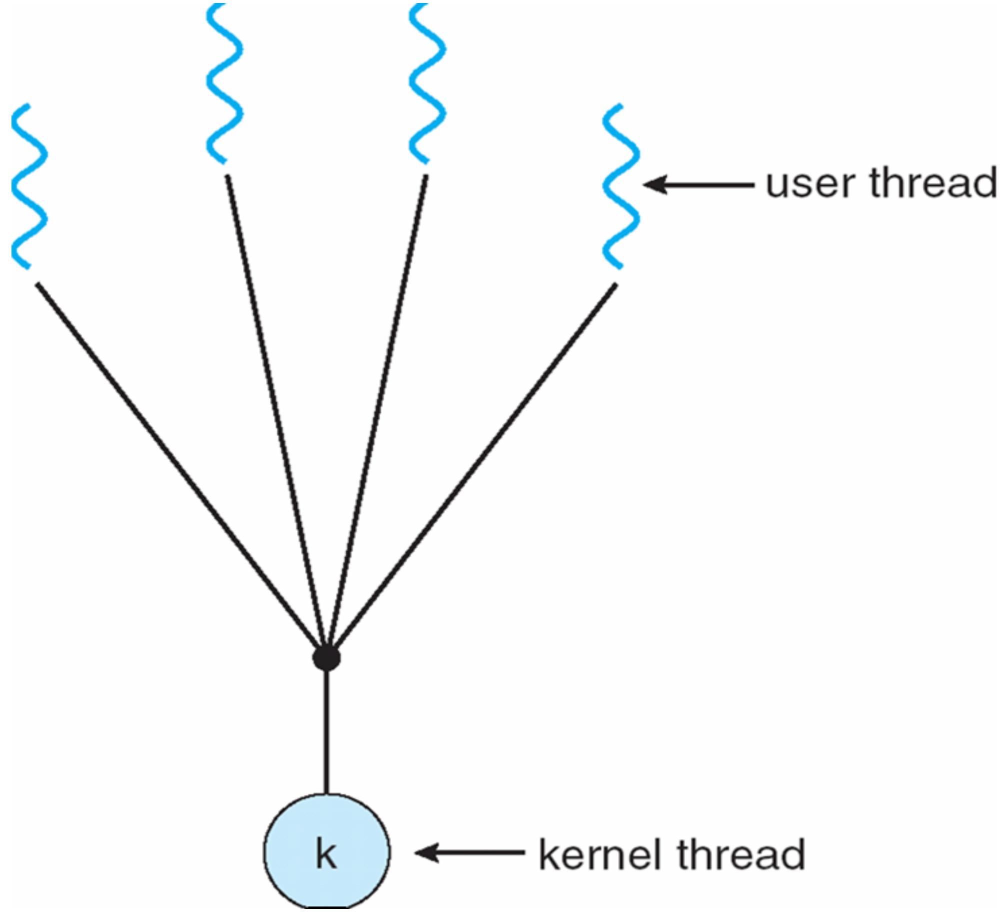
- User-level threads – manage threads in user code
  - advantages – efficient and flexible in space, speed, switching, and scheduling
  - disadvantages – one thread blocked on I/O can block all threads, difficult to automatically take advantage of SMP
  - examples of thread libraries – POSIX Pthreads, Windows threads, Java Threads, GNU portable Threads
- Kernel-level threads – kernel manages the threads
  - Advantages – removes disadvantages of user-level threads
  - Disadvantages – greater overhead due to kernel involvement
  - Examples – provided by almost all GP OS
    - Windows, Solaris, Linux, Mac OS, etc.

Multithreading Models

- Relationships between user and kernel threads
  - Many-to-One
  - One-to-One
  - Many-to-Many

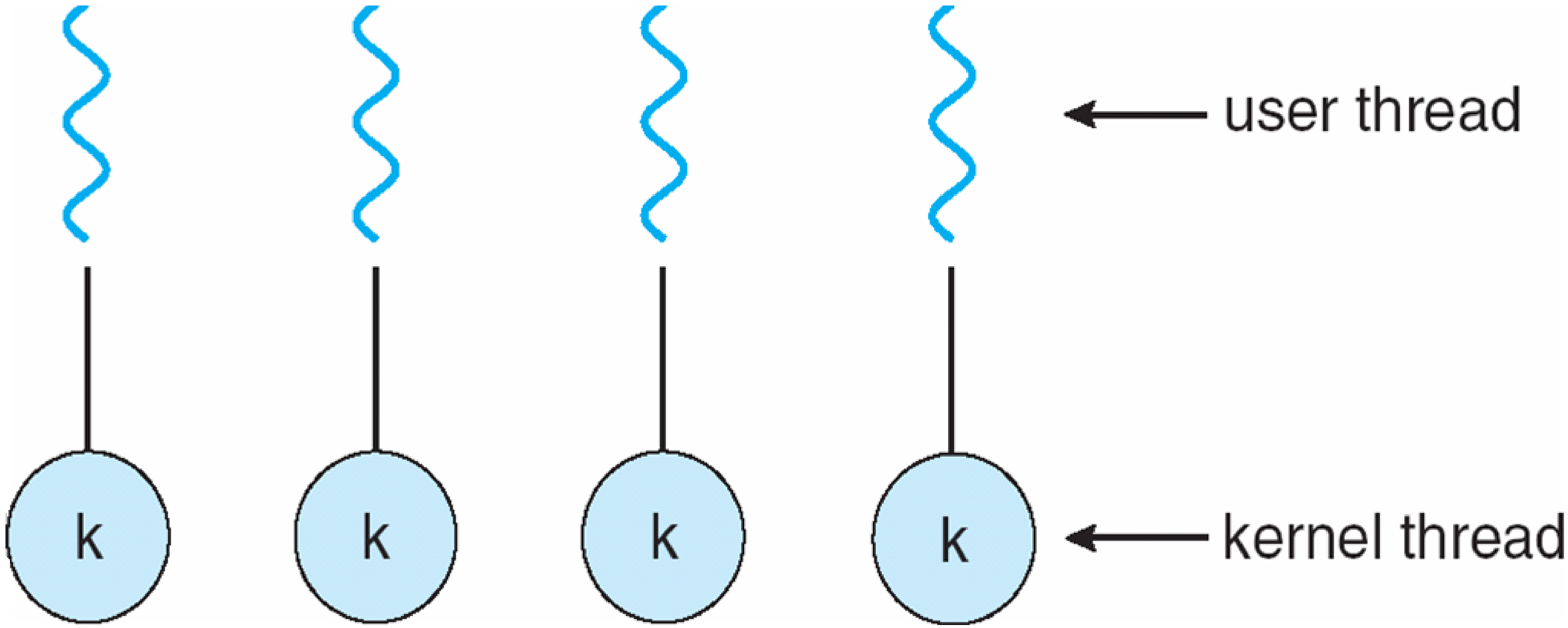
Many–to–One Multithreading Model

- Many user-level threads mapped to single kernel thread
  - examples – Solaris Green Threads, GNU Portable Threads



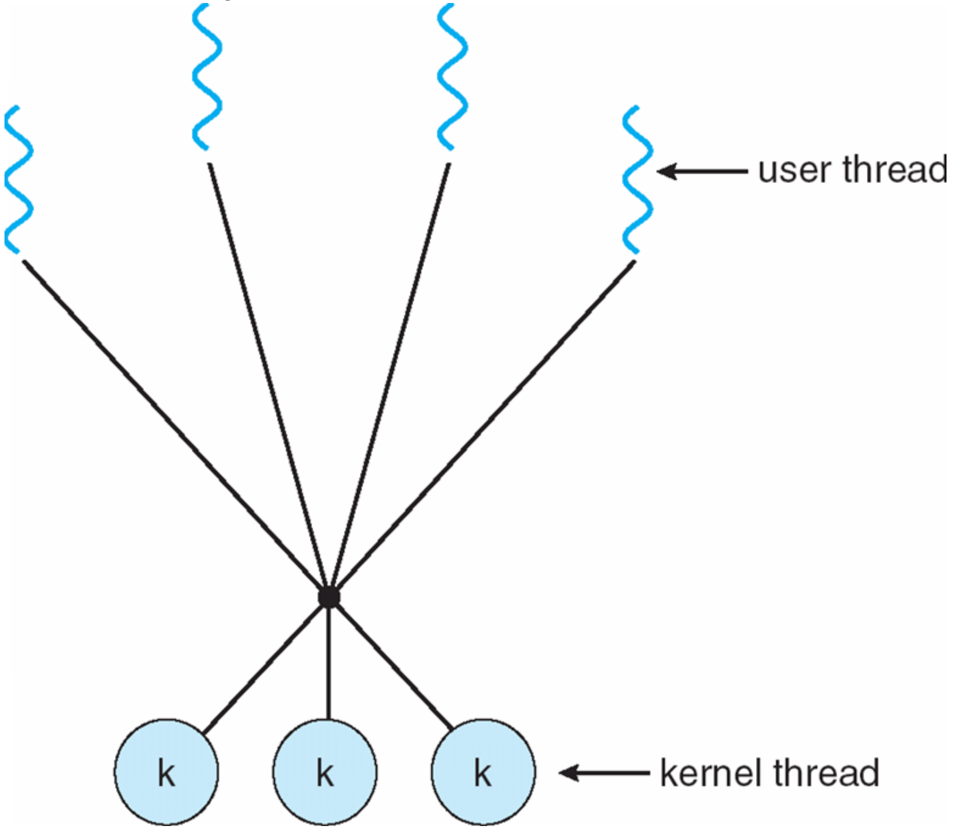
One–to–One Multithreading Model

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



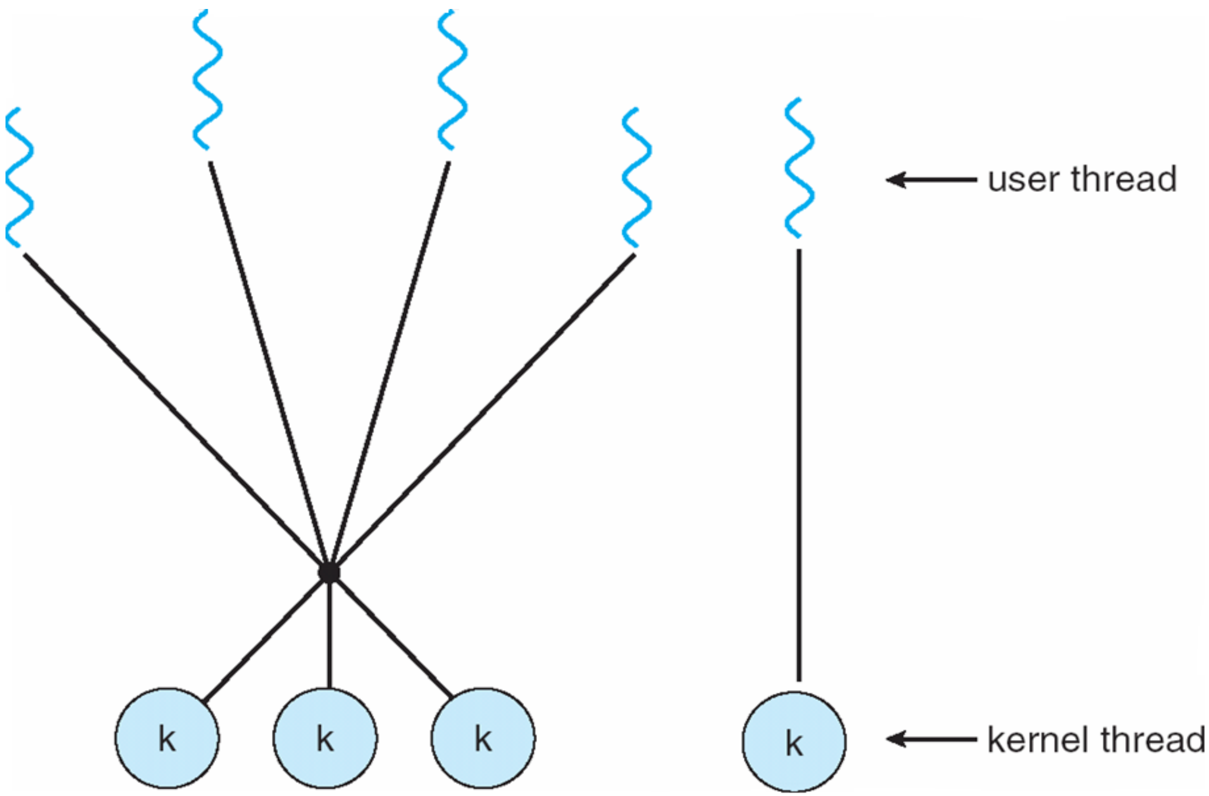
Many–to–Many Multithreading Model

- *m* user level threads mapped to *n* kernel threads
  - operating system can create a sufficient number of kernel threads
  - examples – Solaris prior to v9, Windows NT/2000 *ThreadFiber* package



Two-level Multithreading Model

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



Threading Issues

- Semantics of **fork()** and **exec()** system calls
- Thread cancellation of target thread
- Signal handling
- Implicit Threading
- Thread-specific data
- Scheduler activations

Semantics of fork() and exec()

- Does fork() duplicate only the calling thread or all threads ?
  - some systems provide two versions of fork()
- How about exec() ?
  - most systems maintain the semantics of exec()
- Observations
  - exec() called immediately after fork
    - duplicating all threads is unnecessary
  - exec() not called after fork
    - new process should duplicate all threads

Thread Cancellation

- Terminating a thread before it has finished
- Asynchronous cancellation
  - terminates the target thread immediately
  - allocated resources may not all be freed easily
  - status of shared data may remain ill-defined
- Deferred cancellation
  - target thread terminates itself
  - orderly cancellation can be easily achieved
  - failure to check cancellation status may cause issues

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
  - OS may deliver the signal to the appropriate process
  - OS or process handles the signal
- Types of signals
  - synchronous – generated by some event in the process
  - asynchronous – generated by an event outside the process
- Where to deliver a signal 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

Implicit Threading

- Writing correct multi-threaded programs is more difficult for programmers
  - use compilers and run-time libraries to create and manage threads automatically
- Some example methods include
  - Thread pools
  - OpenMP
  - Grand central dispatch, MS Thread building blocks (TBB), java.util.concurrent package

Thread Pools

- Concerns with multithreaded applications
  - continuously creating and destroying threads is expensive
  - overshooting the bound on concurrently active threads
- Thread Pools
  - create a number of threads in a pool where they await work
  - number of threads can be proportional to the number of processors
- Advantages
  - faster to service a request with an existing thread than create a new thread every time
  - allows the number of threads in the application(s) to be bound to the size of the pool

OpenMP

- Compiler directives and an API for C, C++, FORTRAN
- Supports parallel programming in shared-memory environments
- *User* identifies parallel region
- Create as many threads as there are cores

  ```
  #pragma omp parallel
  ```

- Run for loop in parallel

  ```
  #pragma omp parallel for
  for(i=0 ; i<N ; i++)
      c[i] = a[i] + b[i];
  ```

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

int main(int argc, char *argv[])
{
   /* sequential code */

   #pragma omp parallel
   {
      printf("I am a parallel region.");
   }

   /* sequential code */

   return 0;
}
```

Linux Thread Implementation

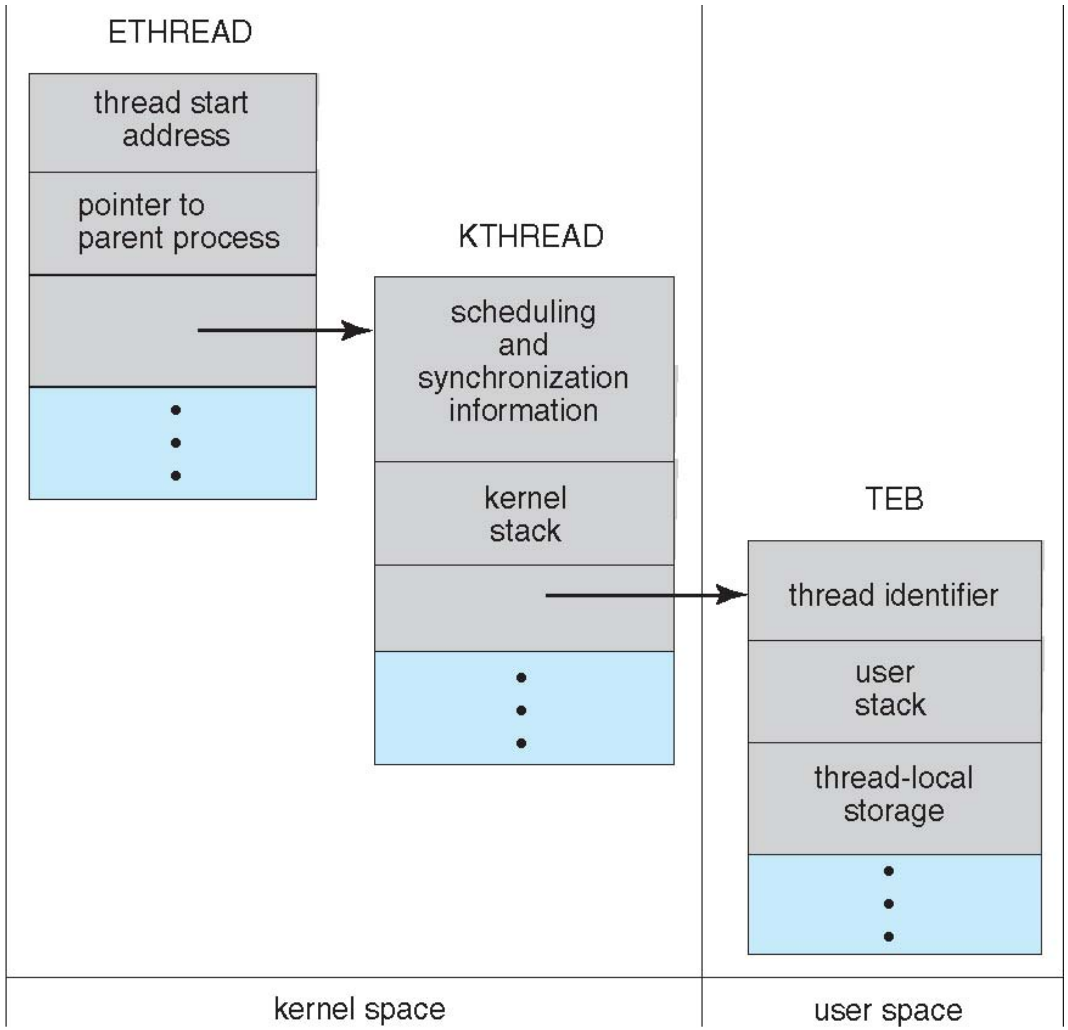
- Linux refers to them as *tasks* rather than *threads*
- Thread creation is done through **clone()** system call
- **clone()** allows a child task to share the address space of the parent task (process)

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.

Windows XP Thread Implementation

- 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
- 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)

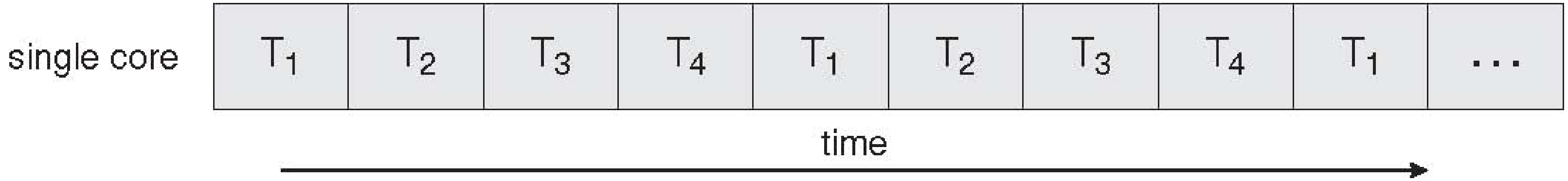
Windows XP Threads



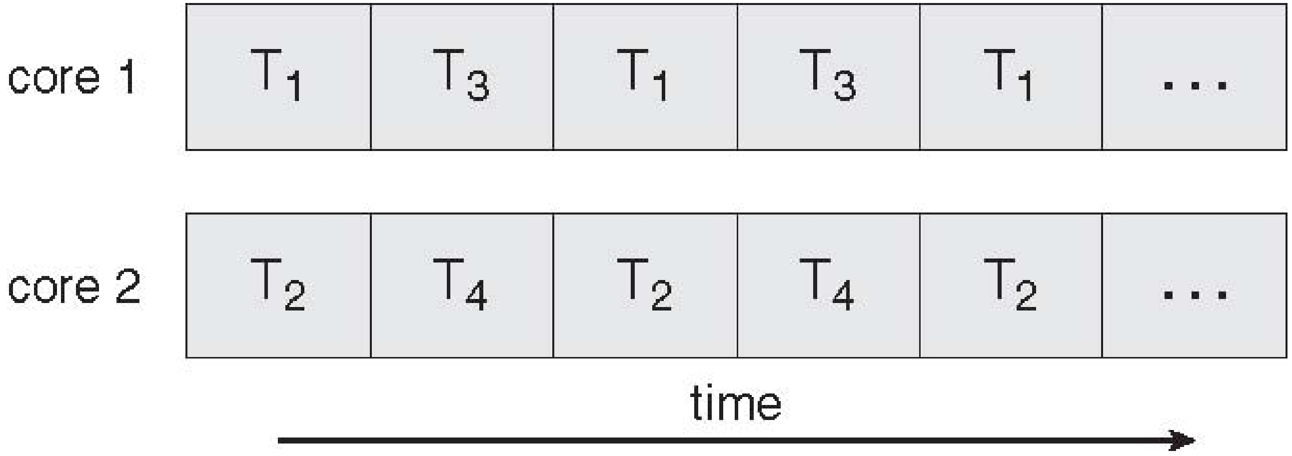
Multicore Processors

- Multiple processing cores on a single chip.
- Reasons for a shift to multicore processors
  - power wall
  - limits to frequency scaling
  - transistor scaling still a reality
- Multicore programming Vs. multicomputer programming
  - same-chip communication is faster
  - memory sharing is easier and faster

Single Core Vs. Multicore Execution



Single core execution



Multiple core execution

Challenges for Multicore Programming

- Dividing activities
- Balance
- Data splitting
- Data dependency
- Testing and debugging