Operating System: Chap4 Multithreaded Programming

National Tsing Hua University

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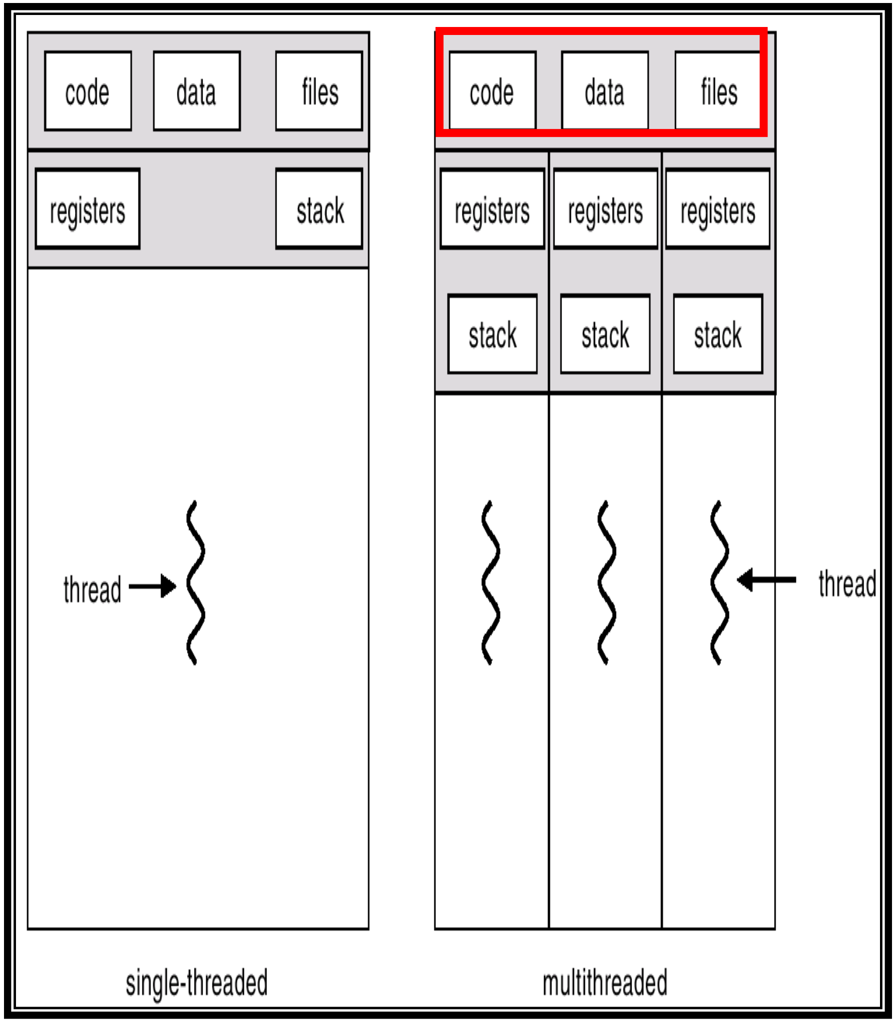
Overview

- Thread Introduction
- Multithreading Models
- Threaded Case Study
- Threading Issues

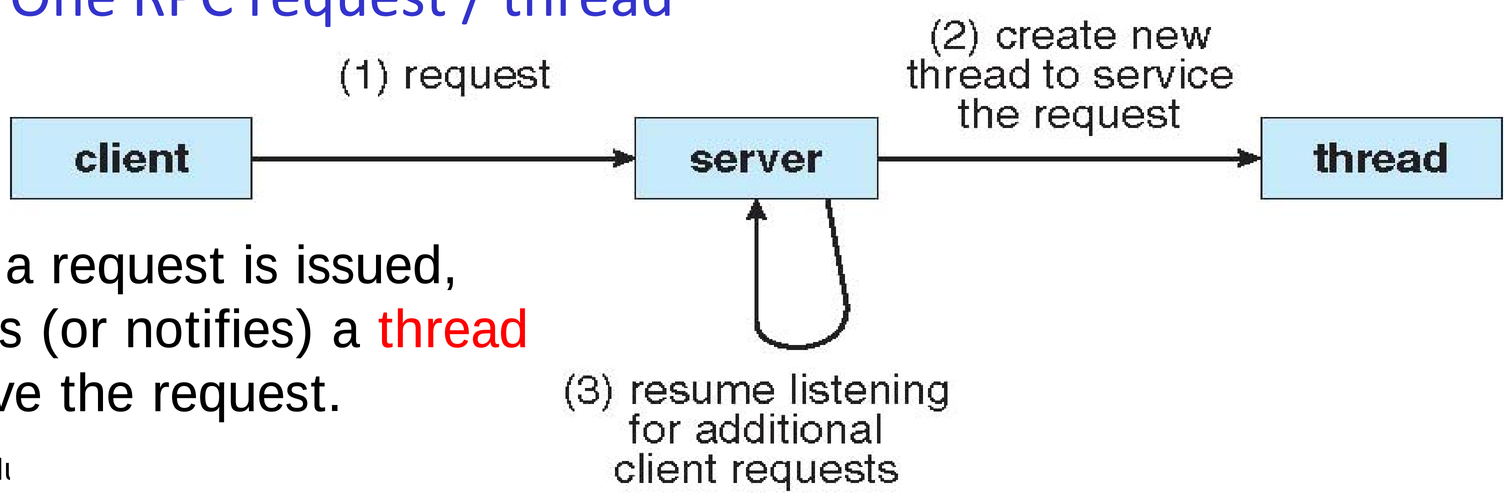
Threads

- A.k.a lightweight process: basic unit of CPU utilization
- All threads belonging to the same process share
  - code section, data section, and OS resources (e.g. open files and signals)
- But each thread has its own (**thread control block**)
  - thread ID, program counter, register set, and a stack



Motivation

- Example: a web browser
  - One thread displays contents while the other thread receives data from network
- Example: a web server
  - One request / process: poor performance
  - One request / thread: better performance as code and resource sharing
- Example: RPC server
  - One RPC request / thread



When a request is issued, creates (or notifies) a thread to serve the request.

Benefits of Multithreading

- **Responsiveness**: allow a program to continue running even if part of it is blocked or is performing a lengthy operation
- **Resource sharing**: several different threads of activity all within the same address space
- **Utilization of MP arch.**: Several thread may be running in parallel on different processors
- **Economy**: Allocating memory and resources for process creation is costly. In Solaris, creating a process is about 30 times slower than is creating a thread, and context switching is about five times slower. A register set switch is still required, but no memory-management related work is needed

Why Thread?

- Lower creation/management cost vs. Process

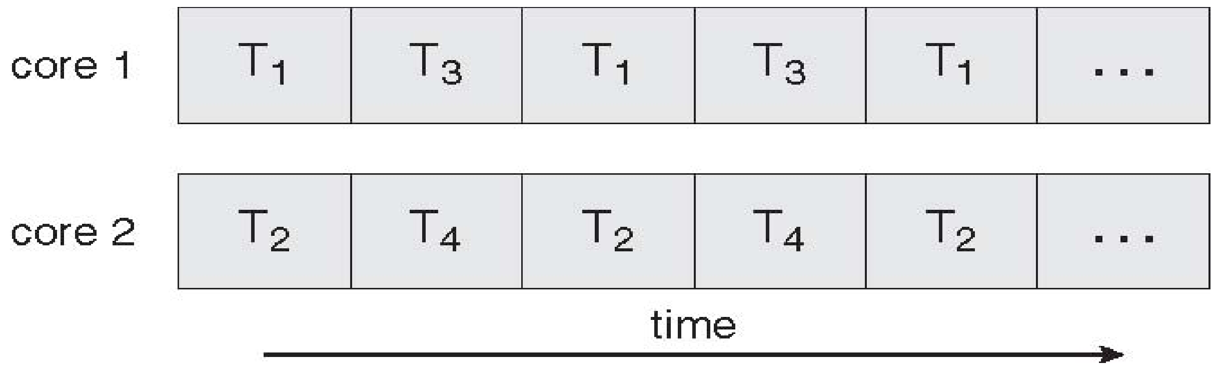
platform	fork()	pthread_create()	speedup
AMD 2.4 GHz Opteron	17.6	1.4	15.6x
IBM 1.5 GHz POWER4	104.5	2.1	49.8x
INTEL 2.4 GHz Xeon	54.9	1.6	34.3x
INTEL 1.4 GHz Itanium2	54.5	2.0	27.3x

- Faster inter-process communication vs. MPI

platform	MPI Shared Memory BW (GB/sec)	Pthreads Worst Case Memory-to-CPU BW (GB/sec)	speedup
AMD 2.4 GHz Opteron	1.2	5.3	4.4x
IBM 1.5 GHz POWER4	2.1	4	1.9x
INTEL 2.4 GHz Xeon	0.3	4.3	14.3x
INTEL 1.4 GHz Itanium2	1.8	6.4	3.6x

Parallel Programming

- Multithreaded programming provides a mechanism for more efficient use of multiple cores and improved concurrency (threads can run in parallel)
- Multicore systems putting pressure on system designers and application programmers
  - OS designers: scheduling algorithms use cores to allow the parallel execution



Challenges in Parallel Programming

- **Dividing activities:** divide program into concurrent tasks
- **Data splitting:** divide data accessed and manipulated by the tasks
- **Data dependency:** synchronize data access
- **Balance:** evenly distribute tasks to cores
- **Testing and debugging**

User vs. Kernel Threads

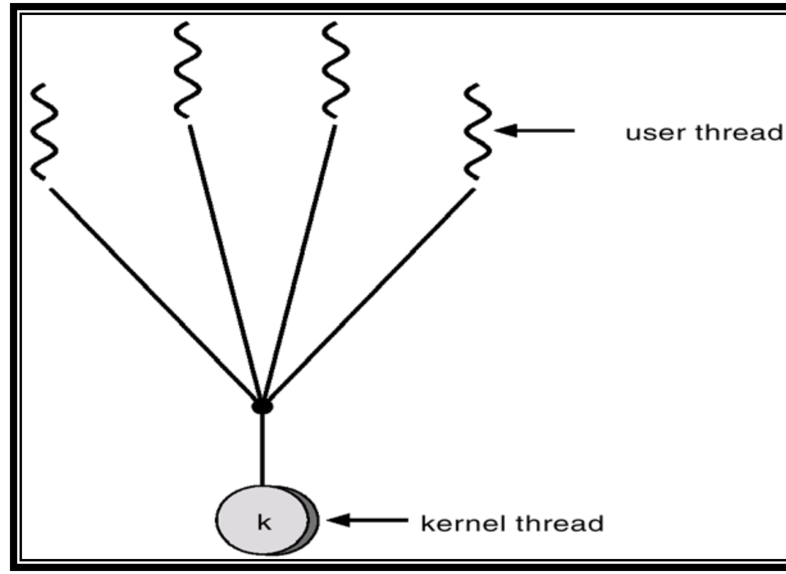
- User threads – thread management done by **user-level** threads library
  - POSIX Pthreads
  - Win32 threads
  - Java threads
- Kernel threads – supported by the kernel (OS) directly
  - Windows 2000 (NT)
  - Solaris
  - Linux
  - Tru64 UNIX

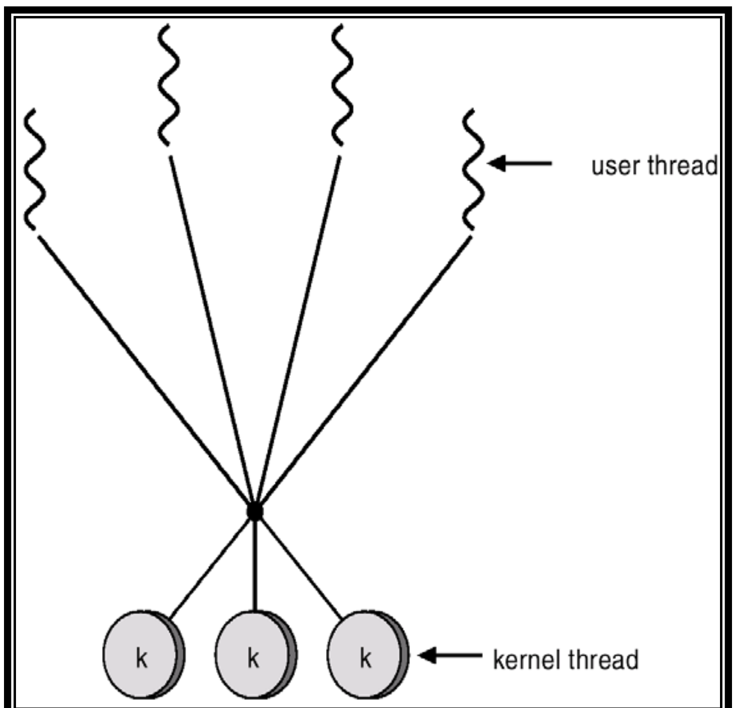
User vs. Kernel Threads

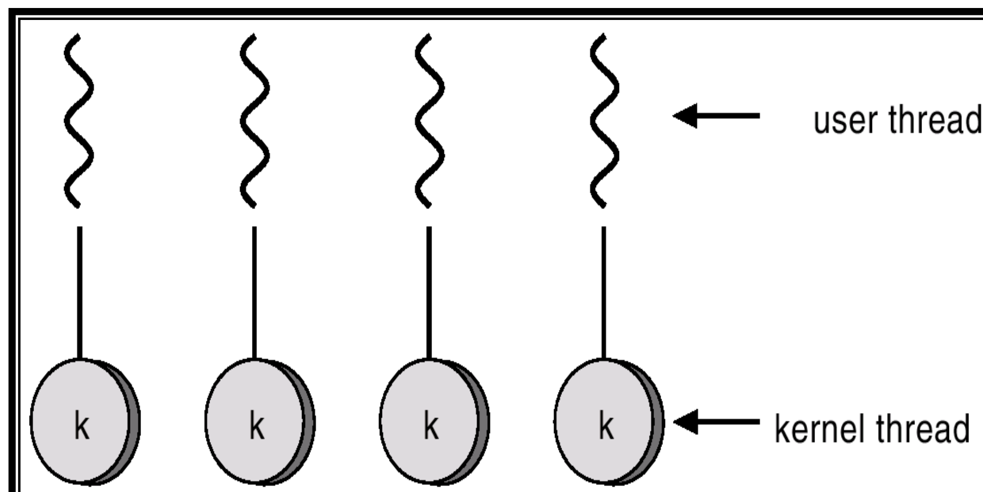
- User threads
  - Thread library provides support for thread creation, scheduling, and deletion
  - Generally fast to create and manage
  - If the kernel is single-threaded, a user-thread blocks → entire process blocks even if other threads are ready to run
- Kernel threads
  - The kernel performs thread creation, scheduling, etc.
  - Generally slower to create and manage
  - If a thread is blocked, the kernel can schedule another thread for execution

Multithreading Models

- Many-to-One
- One-to-One
- Many-to-Many







Many-to-One

- Many user-level threads mapped to single kernel thread
- Used on systems that do not support kernel threads
- Thread management is done in user space, so it is efficient

☹ The entire process will block if a thread makes a blocking system call

☹ Only one thread can access the kernel at a time, multiple threads are unable to run in parallel on multiprocessors

One-to-one

- Each user-level thread maps to a kernel thread
  - There could be a limit on number of kernel threads

☺More concurrency

☹Overhead: Creating a thread requires creating the corresponding kernel thread

- Examples
  - Windows XP/NT/2000
  - Linux
  - Solaris 9 and later

Many-to-Many

- **Multiplexes** many user-level threads to a smaller or equal number of kernel threads
- Allows the developer to create as many **user threads** as wished

☺The corresponding kernel threads can run in parallel on a multiprocessor

☺When a thread performs a blocking call, the kernel can **schedule** another thread for execution.

Review Slides (I)

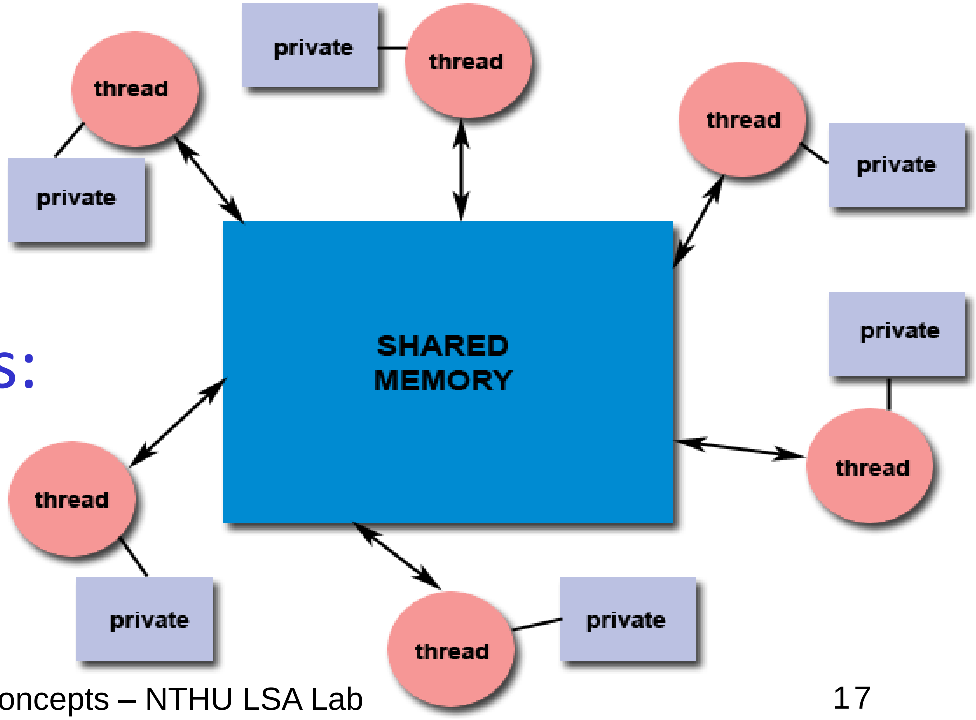
- Process context swap? Thread context swap?
- Benefit of multithreading?
  - Responsive, Economy, resource utilization, resource sharing
- Challenges of multithreading programming?
- User threads & kernel threads? Differences?
- Threading model?
  - Many-to-one
  - One-to-one
  - Many-to-many

Case Study

- Thread libraries
  - Pthreads
  - Java threads
- OS examples
  - WinXP
  - Linux

Shared-Memory Programming

- **Definition**: Processes communicate or work together with each other through a shared memory space which can be accessed by all processes
  - Faster & more efficient than message passing
- Many issues as well:
  - Synchronization
  - Deadlock
  - Cache coherence
- Programming techniques:
  - Parallelizing compiler
  - Unix processes
  - Threads (**Pthread**, Java)

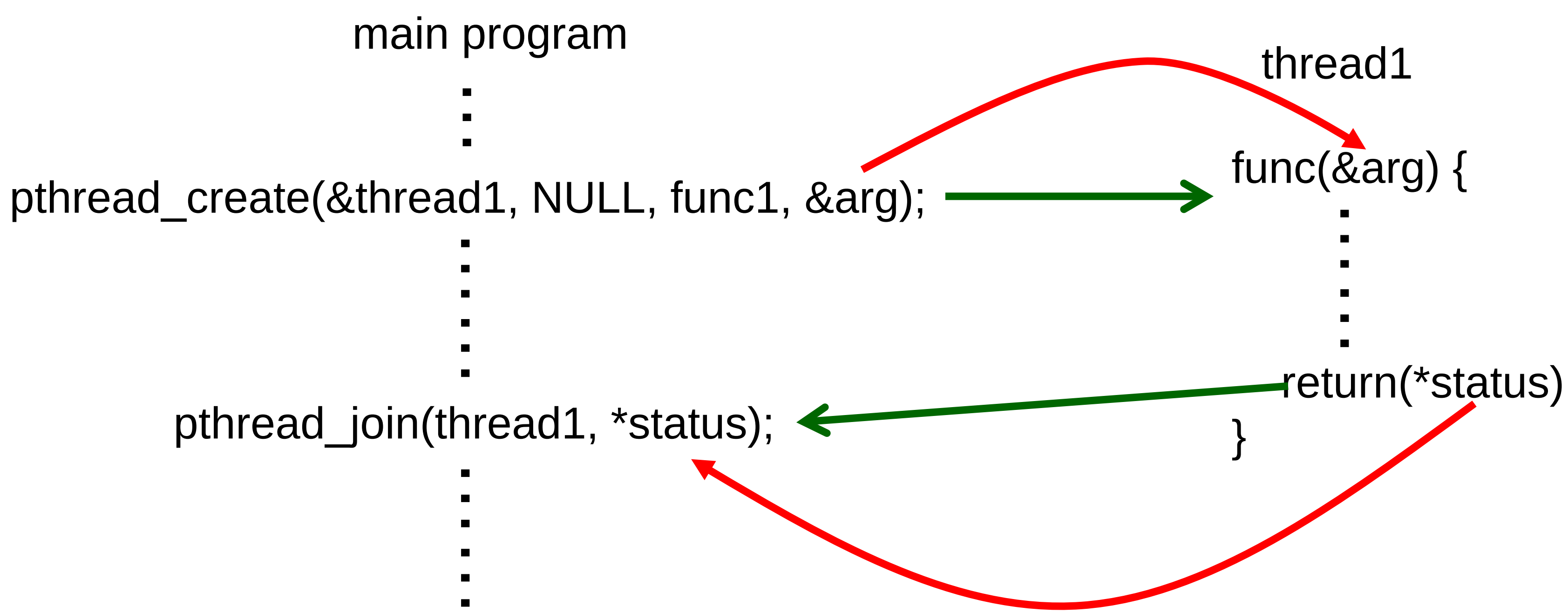


What is Pthread?

- Historically, hardware vendors have implemented their own proprietary versions of threads
- POSIX (Potable Operating System Interface) standard is specified for portability across Unix-like systems
  - Similar concept as MPI for message passing libraries
- Pthread is the implementation of POSIX standard for thread

Pthread Creation

- pthread_create(thread,attr,routine,arg)
  - **thread**: An unique identifier (token) for the new thread
  - **attr**: It is used to set thread attributes. NULL for the default values
  - **routine**: The routine that the thread will execute once it is created
  - **arg**: A single argument that may be passed to *routine*



Example

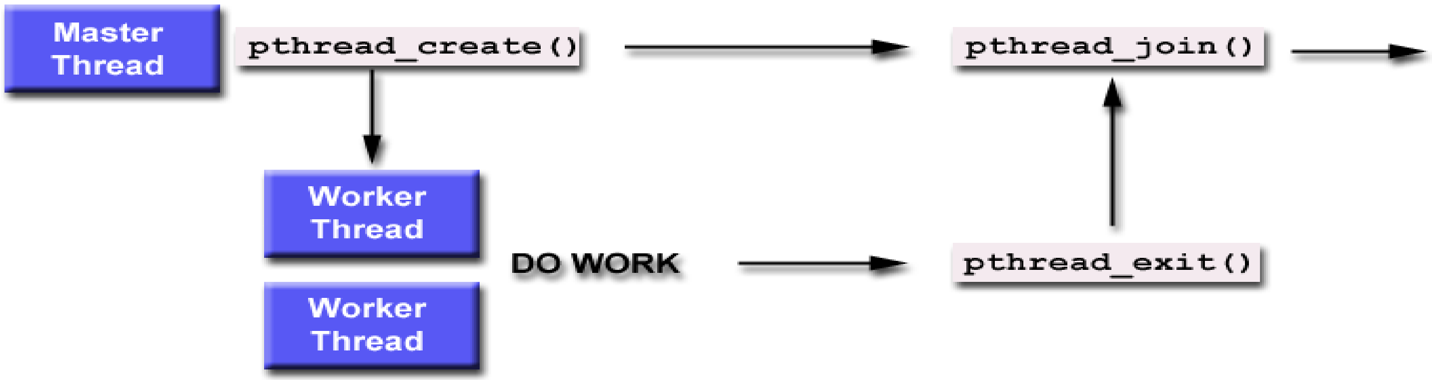
```
#include <pthread.h>
#include <stdio.h>
#define NUM_THREADS 5

void *PrintHello(void *threadId) {
  long* data = static_cast <long*> threadId;
  printf("Hello World! It's me, thread #%ld!\n", *data);
   pthread_exit(NULL);
}
int main (int argc, char *argv[]) {
   pthread_t threads[NUM_THREADS];
   for(long tid=0; tid<NUM_THREADS; tid++){
           pthread_create(&threads[tid], NULL, PrintHello, (void *)&tid);
   }
   /* Last thing that main() should do */
   pthread_exit(NULL);
}
```

Pthread Joining & Detaching

- pthread_join(threadId, status)
  - Blocks until the specified ***threadId*** thread terminates
  - One way to accomplish synchronization between threads
  - Example: to create a pthread barrier

```
for (int i=0; i<n; i++)  pthread_join(thread[i], NULL);
```

- pthread_detach(threadId)
  - Once a thread is **detached**, it can **never** be joined
  - Detach a thread could free some system resources



Java Threads

- Thread is created by
  - Extending Thread class
  - Implementing the Runnable interface
- Java threads are implemented using a thread library on the host system
  - Win32 threads on Windows
  - Pthreads on UNIX-like system
- Thread mapping depends on implementation of the JVM
  - Windows 98/NT: one-on-one model
  - Solaris 2: many-to-many model

Linux Threads

- Linux does ***not*** support multithreading
- Vrious Pthreads implementation are available for **user-level**
- The fork system call – create a new process and a copy of the associated data of the parent process
- The clone system call – create a new process and a link that points to the associated data of the parent process

Linux Threads

- A set of flags is used in the clone call for indication of the level of the sharing
  - None of the flags is set → clone = fork
  - All flags are set → parent and child share everything

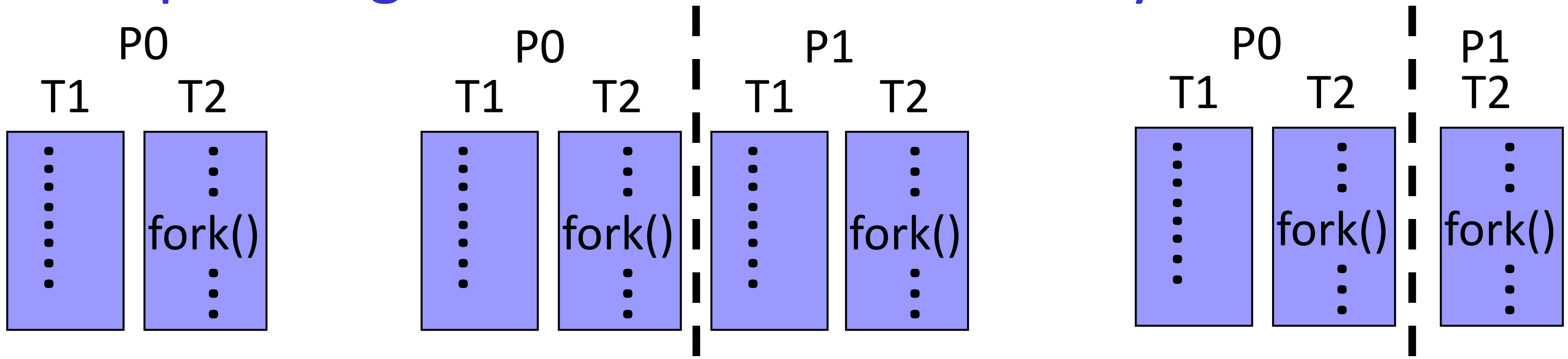
flag	meaning
CLONE_FS	File-system information is shared.
CLONE_VM	The same memory space is shared.
CLONE_SIGHAND	Signal handlers are shared.
CLONE_FILES	The set of open files is shared.

Threading Issues

- Semantics of fork() and exec() system calls. Duplicate all the threads or not?
- Thread cancellation: Asynchronous or deferred
- Signal handling: Where then should a signal be delivered?
- Thread pools: Create a number of threads at process startup.
- Thread specific data: Each thread might need its own copy of certain data.
- Scheduler activations

Semantics of fork() and exec()

- Does **fork()** duplicate only the calling thread or all threads?
  - Some UNIX system support two versions of fork()
- **execlp()** works the same; replace the entire process
  - If exec() is called immediately after forking, then duplicating all threads is unnecessary



Thread Cancellation

- What happen if a thread determinates before it has completed?
  - E.g, terminate web page loading
- **Target thread**: a thread that is to be cancelled
- Two general approaches:
  - **Asynchronous cancellation**
    - One thread terminates the target thread immediately
  - **Deferred cancellation (default option)**
    - The target thread periodically checks whether it should be terminated, allowing it an opportunity to terminate itself in an orderly fashion (canceled safely).
    - Check at Cancellation points

Signal Handling

- Signals (synchronous or asynchronous) are used in UNIX systems to notify a process that an event has occurred
  - Synchronous: illegal memory access
  - Asynchronous: <control-C>
- A **signal handler** is used to process signals
  1. Signal is generated by particular event
  2. Signal is delivered to a process
  3. Signal is handled
- 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

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
- # of threads: # of CPUs, expected # of requests, amount of physical memory

Reading Material

- Chap 4
- Problems
  - 4.2: Under what circumstances does a multithreaded solution using multiple kernel threads provide better performance than a single-threaded solution on a single-processor system?
  - 4.3: Which of the following components of program state are shared across threads in a multithreaded process?

    a. Register values; b. Heap memory; c. Global variables;

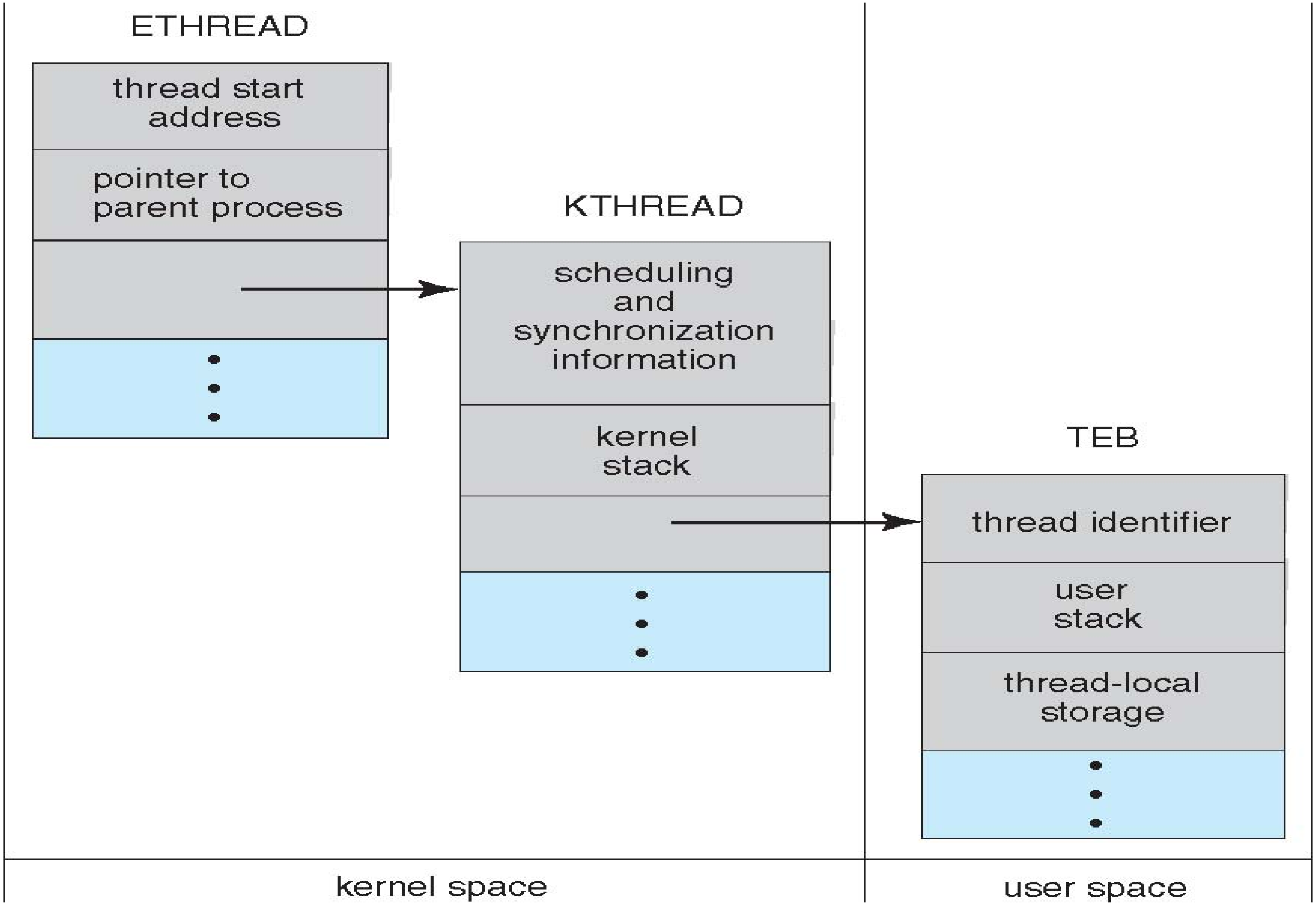
    d. Stack memory

Backup

Windows XP Threads

- Implement the one-to-one mapping
- Each thread contains
  - A thread ID
  - Register set
  - Separate user and kernel stacks
  - Private data storage area
- The primary data structures of a thread include:
  - ETHREAD (executive thread block)
  - KTHREAD (kernel thread block)
  - TEB (thread environment block)
- Also provide support for a **fiber** library, that provides the functionality of the many-to-many model

Windows XP Threads



Thread Specific Data

- Allows each thread to have its own copy of data
  - Each transaction assigned a unique number in the transaction-processing system
- Useful when you do not have control over the thread creation process (i.e., when using a thread pool)

Scheduler Activations

- Both M: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 correct number kernel threads