

CSE 421/521 - Operating Systems
Fall 2012

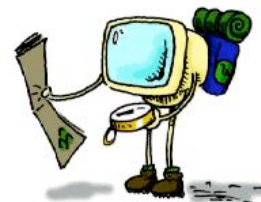
LECTURE - IV
THREADS

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September 6th, 2012

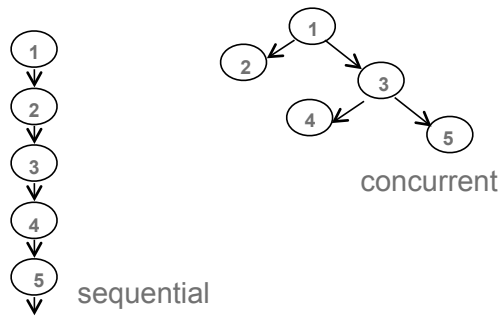
Roadmap

- Threads
 - Why do we need them?
 - Threads vs Processes
 - Threading Examples
 - Threading Implementation & Multi-threading Models
 - Other Threading Issues
 - Thread cancellation
 - Signal handling
 - Thread pools
 - Thread specific data



Concurrent Programming

- In certain cases, a single application may need to run several tasks at the same time



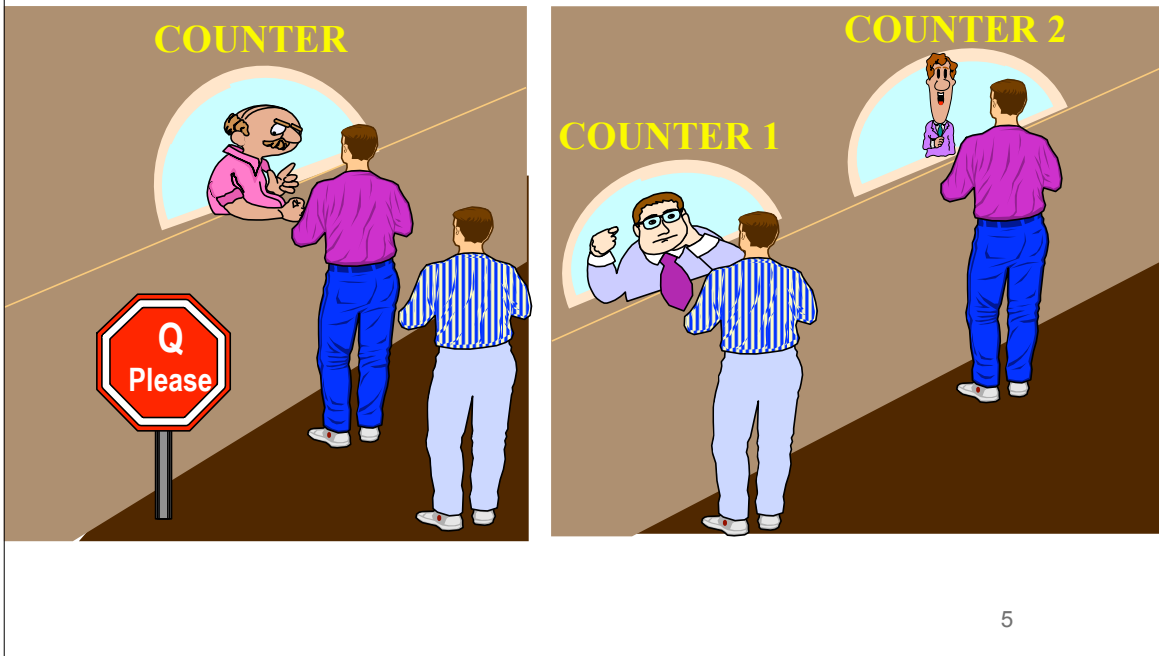
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Motivation

- Increase the performance by running more than one tasks at a time.
 - divide the program to n smaller pieces, and run it n times faster using n processors
- To cope with independent physical devices.
 - do not wait for a blocked device, perform other operations at the background

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Serial vs Parallel



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Divide and Compute

$$x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8$$

How many operations with sequential programming?

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Step 1: $x_1 + x_2$

Step 2: $x_1 + x_2 + x_3$

Step 3: $x_1 + x_2 + x_3 + x_4$

Step 4: $x_1 + x_2 + x_3 + x_4 + x_5$

Step 5: $x_1 + x_2 + x_3 + x_4 + x_5 + x_6$

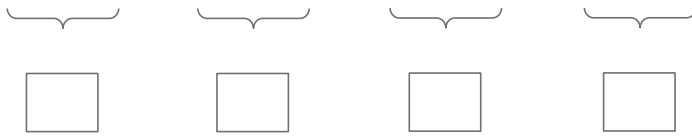
Step 6: $x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7$

Step 7: $x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8$

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Divide and Compute

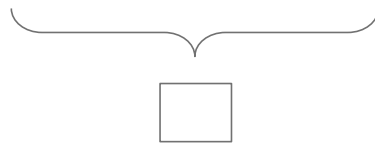
$$x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8$$



Step 1: parallelism = 4



Step 2: parallelism = 2



Step 3: parallelism = 1

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Gain from parallelism

In theory:

- dividing a program into n smaller parts and running on n processors results in n time speedup

In practice:

- This is not true, due to
 - Communication costs
 - Dependencies between different program parts
 - Eg. the addition example can run only in $\log(n)$ time not $1/n$

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Concurrent Programming

- Implementation of concurrent tasks:
 - as separate programs
 - as a set of processes or threads created by a single program
- Execution of concurrent tasks:
 - on a single processor (can be multiple cores)
 - Multithreaded programming
 - on several processors in close proximity
 - Parallel computing
 - on several processors distributed across a network
 - Distributed computing

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Why Threads?

- In certain cases, a single application may need to run several tasks at the same time
 - Creating a new process for each task is **time consuming**
 - Use a single process with multiple threads
 - faster
 - less overhead for creation, switching, and termination
 - share the same address space

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Ownership vs Execution

➤ A process embodies two independent concepts:

1. resource ownership
2. execution & scheduling

1. Resource ownership

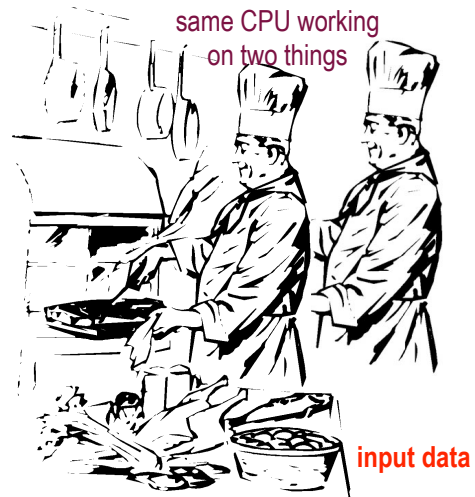
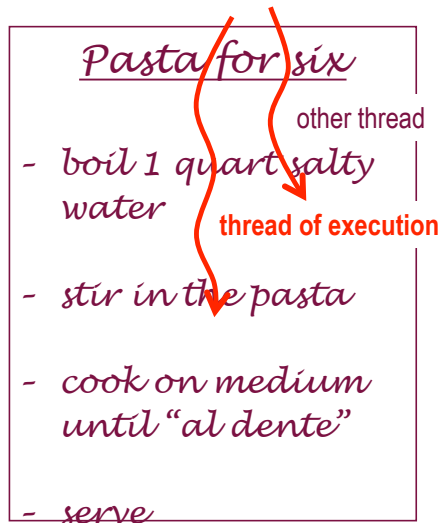
- ✓ a process is allocated address space to hold the image, and is granted control of I/O devices and files
- ✓ the O/S prevents interference among processes while they make use of resources (multiplexing)

2. Execution & scheduling

- ✓ a process follows an execution path through a program --> Thread
- ✓ it has an execution state and is scheduled for dispatching

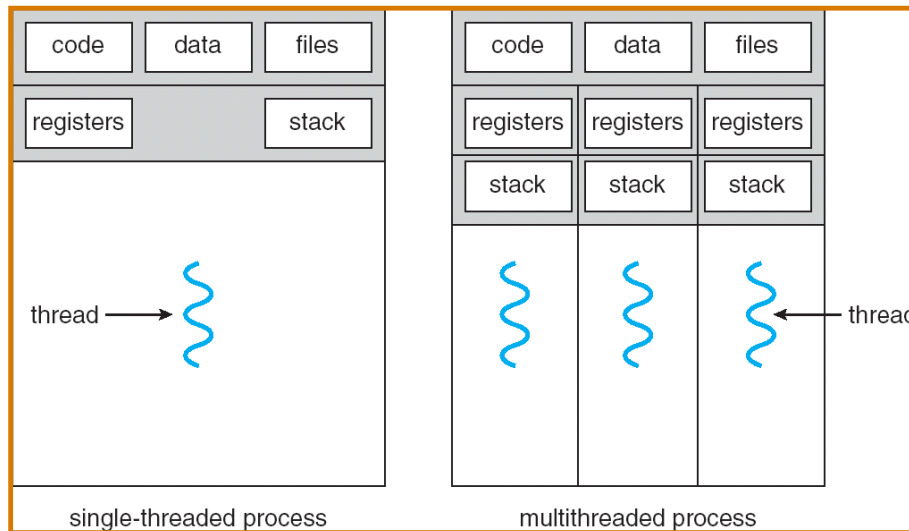
Multi-threading

➤ The execution part is a “thread” that can be multiplied



Process

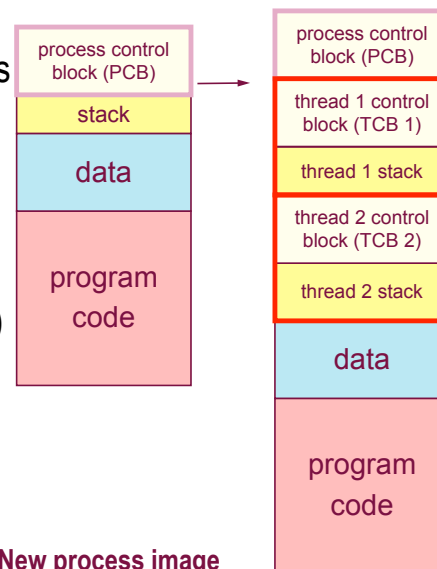
Single and Multithreaded Processes



New Process Description Model

➤ Multithreading requires changes in the process description model

- ✓ each thread of execution receives its own control block and stack
 - own execution state (“Running”, “Blocked”, etc.)
 - own copy of CPU registers
 - own execution history (stack)
- ✓ the process keeps a global control block listing resources currently used



New process image

Per-process vs per-thread items

- Per-process items and per-thread items in the control block structures
 - ✓ process identification data + thread identifiers
 - numeric identifiers of the process, the parent process, the user, etc.
 - ✓ CPU state information
 - user-visible, control & status registers
 - stack pointers
 - ✓ process control information
 - scheduling: state, priority, awaited event
 - used memory and I/O, opened files, etc.
 - pointer to next PCB

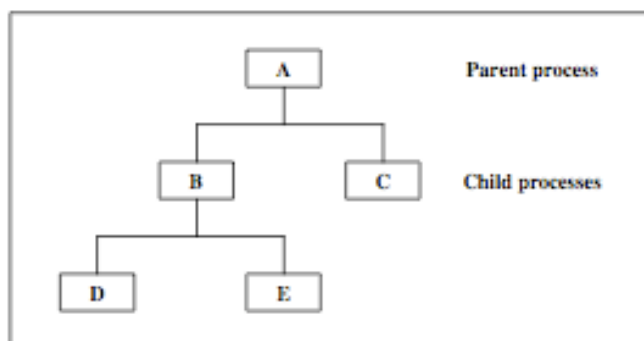
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Multi-process model

Process Spawning:

Process creation involves the following four main actions:

- setting up the process control block,
- allocation of an address space and
- loading the program into the allocated address space and
- passing on the process control block to the scheduler

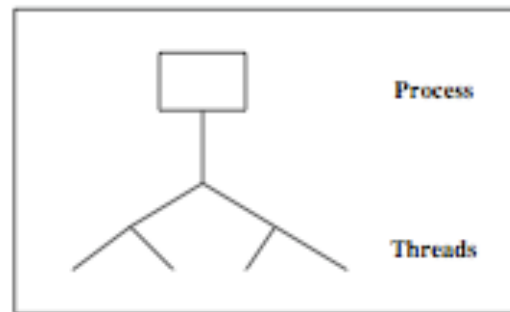


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Multi-thread model

Thread Spawning:

- Threads are created *within and belonging to* processes
- All the threads created within one process share the resources of the process including the address space
- Scheduling is performed on a per-thread basis.
- The thread model is a *finer grain scheduling model* than the process model
- Threads have a similar *lifecycle* as the processes and will be managed mainly in the same way as processes are



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Threads vs Processes

- A common terminology:
 - Heavyweight Process = Process
 - Lightweight Process = Thread

Advantages (Thread vs. Process):

- Much quicker to create a thread than a process
 - spawning a new thread only involves allocating a new stack and a new CPU state block
- Much quicker to switch between threads than to switch between processes
- Threads share data easily

Disadvantages (Thread vs. Process):

- Processes are more flexible
 - They don't have to run on the same processor
- No security between threads: One thread can stomp on another thread's data
- For threads which are supported by user thread package instead of the kernel:
 - If one thread blocks, all threads in task block.

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Thread Creation

- **pthread_create**

```
// creates a new thread executing start_routine
int pthread_create(pthread_t *thread,
                  const pthread_attr_t *attr,
                  void *(*start_routine)(void*), void *arg);
```

- **pthread_join**

```
// suspends execution of the calling thread until the target
// thread terminates
int pthread_join(pthread_t thread, void **value_ptr);
```

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Thread Example

```
int main()
{
    pthread_t thread1, thread2; /* thread variables */

    pthread_create (&thread1, NULL, (void *) &print_message_function,
                  (void*)"hello ");
    pthread_create (&thread2, NULL, (void *) &print_message_function,
                  (void*)"world!\n");

    pthread_join(thread1, NULL);
    pthread_join(thread2, NULL);

    exit(0);
}
```

Why use pthread_join?

To force main block to wait for both threads to terminate, before it exits.
If main block exits, both threads exit, even if the threads have not finished their work.

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Exercise

Consider a process with two concurrent threads T1 and T2. The code being executed by T1 and T2 is as follows:

Shared Data:
X:= 5; Y:=10;

T1:
Y = X+1;
X = Y;
Write X;

T2:
U = Y-1;
Y = U;
Write Y;

Assume that each assignment statement on its own is executed as an atomic operation. What are the possible outputs of this process?

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Solution

All six statements can be executed in any order. Possible outputs are:

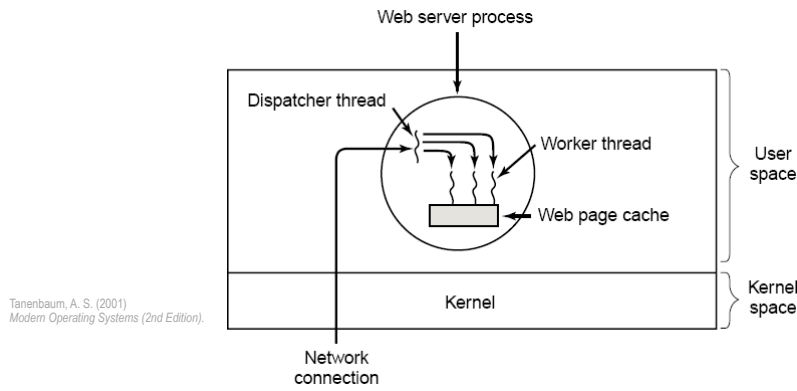
- 1) 65
- 2) 56
- 3) 55
- 4) 99
- 5) 66
- 6) 69
- 7) 96

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Threading Examples

➤ Web server

- ✓ as each new request comes in, a “dispatcher thread” spawns a new “worker thread” to read the requested file (worker threads may be discarded or recycled in a “thread pool”)



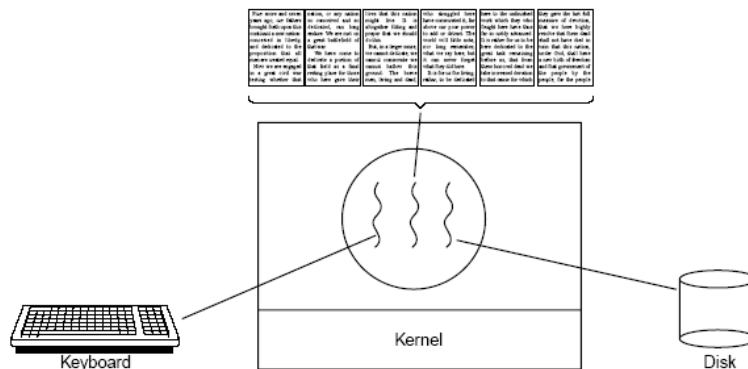
Tanenbaum, A. S. (2001) *Modern Operating Systems (2nd Edition)*.

A multithreaded Web server

Threading Examples

➤ Word processor

- ✓ one thread listens continuously to keyboard and mouse events to refresh the GUI; a second thread reformats the document (to prepare page 600); a third thread writes to disk periodically



Tanenbaum, A. S. (2001) *Modern Operating Systems (2nd Edition)*.

A word processor with three threads

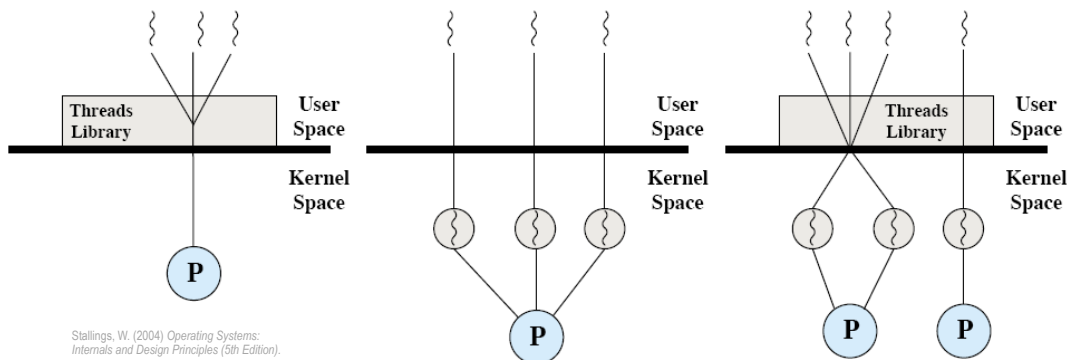
Threading Benefits

- Patterns of multithreading usage across applications
 - ✓ perform foreground and background work in parallel
 - illusion of full-time interactivity toward the user while performing other tasks (same principle as time-sharing)
 - ✓ allow asynchronous processing
 - separate and desynchronize the execution streams of independent tasks that don't need to communicate
 - handle external, surprise events such as client requests
 - ✓ increase speed of execution
 - "stagger" and overlap CPU execution time and I/O wait time (same principle as multiprogramming)

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Thread Implementation

- Two broad categories of thread implementation
 - ✓ User-Level Threads (ULTs)
 - ✓ Kernel-Level Threads (KLTs)



Stallings, W. (2004) Operating Systems: Internals and Design Principles (5th Edition).

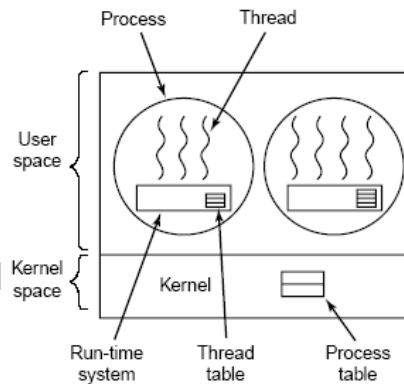
Pure user-level (ULT), pure kernel-level (KLT) and combined-level (ULT/KLT) threads

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Thread Implementation

➤ User-Level Threads (ULTs)

- ✓ the kernel is not aware of the existence of threads, it knows only processes with one thread of execution (one PC)
- ✓ each user process manages its own private thread table
- 👉 light thread switching: does not need kernel mode privileges
- 👉 cross-platform: ULTs can run on any underlying O/S
- 👉 if a thread blocks, the entire process is blocked, including all other threads in it



Tanenbaum, A. S. (2001)
Modern Operating Systems (2nd Edition).

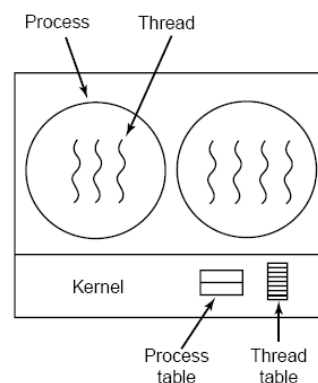
A user-level thread package

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Thread Implementation

➤ Kernel-Level Threads

- ✓ the kernel knows about and manages the threads: creating and destroying threads are system calls
- 👉 fine-grain scheduling, done on a thread basis
- 👉 if a thread blocks, another one can be scheduled without blocking the whole process
- 👉 heavy thread switching involving mode switch



Tanenbaum, A. S. (2001)
Modern Operating Systems (2nd Edition).

A kernel-level thread package

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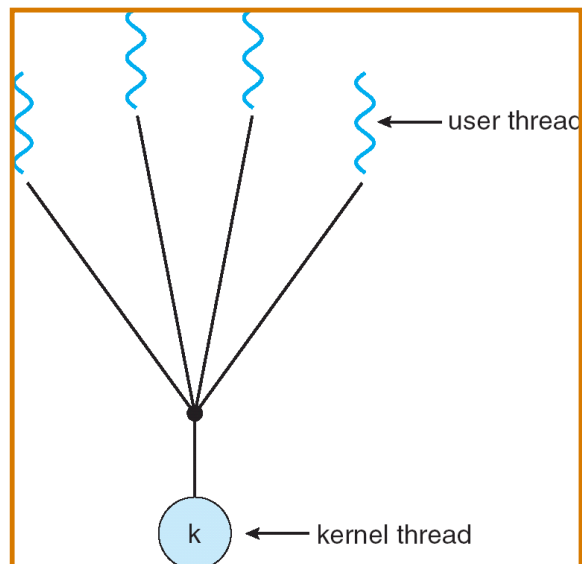
Different Multi-threading Models

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

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Many-to-One Model

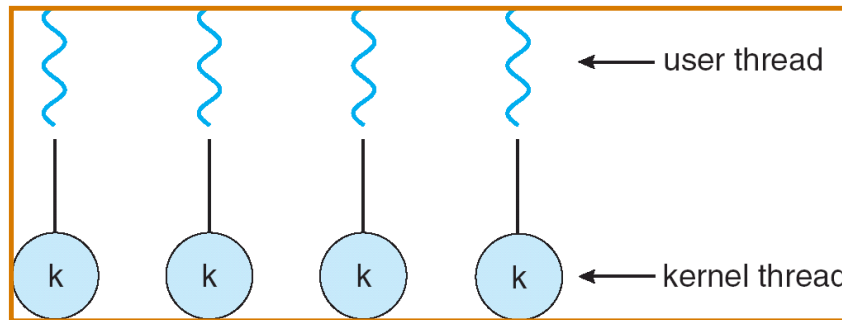
- Several user-level threads mapped to single kernel thread
- Thread management in user space → efficient
- If a thread blocks, entire process blocks
- One thread can access the kernel at a time → limits parallelism
- Examples:
 - Solaris Green Threads
 - GNU Portable Threads



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One-to-One Model

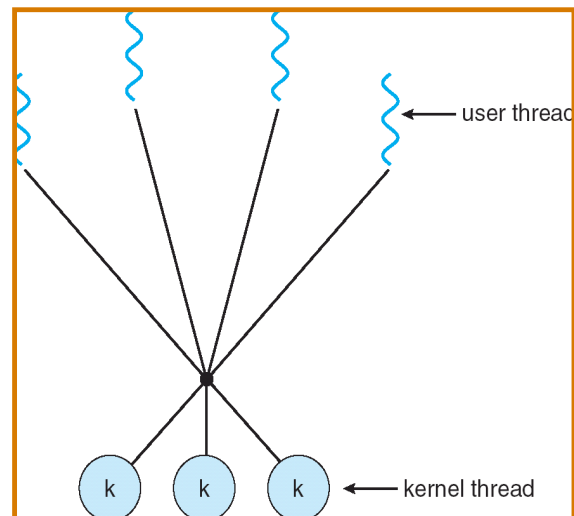
- Each user-level thread maps to a kernel thread
- A blocking thread does not block other threads
- Multiple threads can access kernel concurrently → increased parallelism
- Drawback: Creating a user level thread requires creating a kernel level thread → increased overhead and limited number of threads
- Examples: Windows NT/XP/2000, Linux, Solaris 9 and later



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Many-to-Many Model

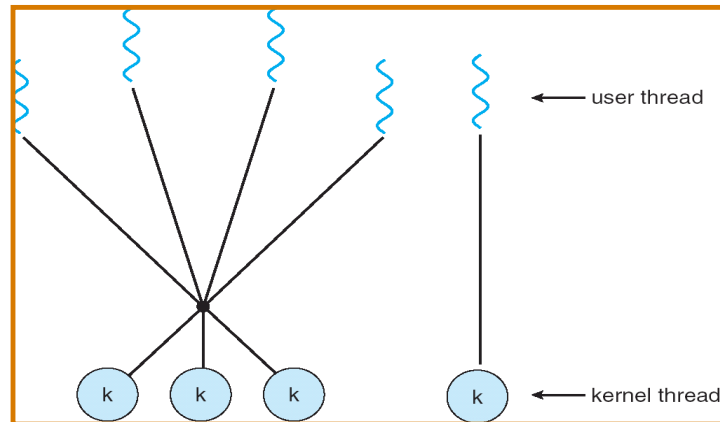
- Allows many user level threads to be mapped to a smaller number of kernel threads
- Allows the operating system to create a sufficient number of kernel threads
- Increased parallelism as well as efficiency
- Solaris prior to version 9
- Windows NT/2000 with the *ThreadFiber* package



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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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Threading Issues

- Thread pools
- Thread specific data
- Semantics of `fork()` and `exec()` system calls
- Thread cancellation
- Signal handling

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Thread Pools

- Threads come with some overhead as well
- Unlimited threads can exhaust system resources, such as CPU or memory
- Create a number of threads at process startup) and put them in a pool, where they await work
- When a server receives a request, it awakens a thread from this pool
- Advantages:
 - Usually 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
- Number of threads in the pool can be setup according to:
 - Number of CPUs, memory, expected number of concurrent requests

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Thread Specific Data

- Threads belonging to the same process share the data of the process
- In some cases, each thread needs to have its own copy of data → **thread specific**
- Useful when you do not have control over the thread creation process (i.e., when using a thread pool)

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Semantics of fork() and exec()

- Semantics of **fork()** and **exec()** system calls change in a multithreaded program
 - Eg. if one thread in a multithreaded program calls fork()
 - Should the new process duplicate all threads?
 - Or should it be single-threaded?
 - Some UNIX systems implement two versions of fork()
 - If a thread executes exec() system call
 - Entire process will be replaced, including all threads

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Thread Cancellation

- Terminating a thread before it has finished
 - If one thread finishes searching a database, others may be terminated
 - If user presses a button on a web browser, web page can be stopped from loading further
- Two approaches to cancel the target thread
 - **Asynchronous cancellation** terminates the target thread immediately
 - **Deferred cancellation** allows the target thread to periodically check if it should be cancelled
 - More controlled and safe

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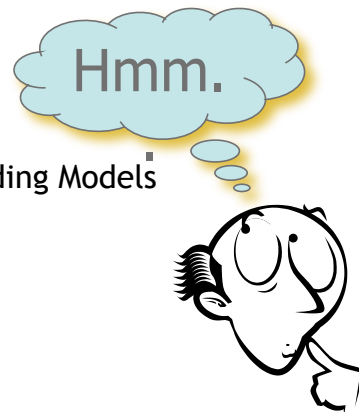
Signal Handling

- Signals are used in UNIX systems to notify a process that a particular event has occurred
- All signals follow this pattern:
 1. Signal is generated by particular event
 2. Signal is delivered to a process
 3. Once delivered, a signal must be handled
- In **multithreaded systems**, there are 4 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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Summary

- Why do we need them?
- Threads vs Processes
- Threading Examples
- Threading Implementation & Multi-threading Models
- Other Threading Issues
 - Thread cancellation
 - Signal handling
 - Thread pools
 - Thread specific data



- **HW1 out today; due next Thursday, Sept 13th!**
- **Next Lecture: CPU Scheduling**
- **Reading Assignment: Chapter 4 from Silberschatz.**

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Acknowledgements

- “Operating Systems Concepts” book and supplementary material by A. Silberschatz, P. Galvin and G. Gagne
- “Operating Systems: Internals and Design Principles” book and supplementary material by W. Stallings
- “Modern Operating Systems” book and supplementary material by A. Tanenbaum
- R. Doursat and M. Yuksel from UNR