Threads Implementation

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Today's Topics

- **How to implement threads?**
  - User-level threads
  - Kernel-level threads
- **Threading models**

Kernel/User-level Threads

- **Who is responsible for creating/managing threads?**
  - The OS (kernel threads)
    - Thread creation and management requires system calls
  - The user-level process (user-level threads)
    - A library linked into the program manages the threads

- **Why is user-level thread management possible?**
  - Threads share the same address space
    - The thread manager doesn't need to manipulate address spaces
  - Threads only differ in hardware contexts (roughly)
    - PC, SP, registers
    - These can be manipulated by the user-level process itself.

Kernel-level Threads (1)

- **OS-managed threads**
  - The OS manages threads and processes.
  - All thread operations are implemented in the kernel.
  - The OS schedules all of the threads in a system.
    - If one thread in a process blocks (e.g., on I/O), the OS knows about it, and can run other threads from that process.
    - Possible to overlap I/O and computation inside a process.
  - Kernel threads are cheaper than processes.
    - Less state to allocate and initialize
  - Windows 98/NT/2000/XP/Vista/7

    Solaris

    Tru64 Unix

    Linux

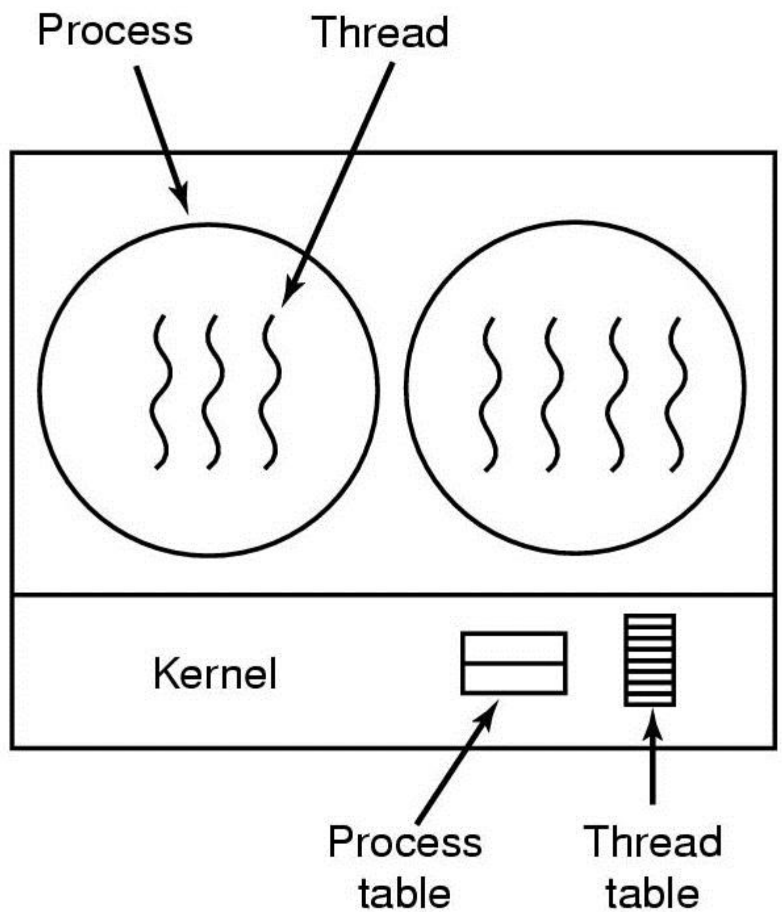
    Mac OS X

Kernel-level Threads (2)

- **Limitations**
  - They can still be too expensive.
    - For fine-grained concurrency, we need even cheaper threads.
    - Ideally, we want thread operations as fast as a procedure call.
  - Thread operations are all system calls.
    - The program must cross an extra protection boundary on every thread operation, even when the processor is being switched between threads in the same address space.
    - The OS must perform all of the usual argument checks.
  - Must maintain kernel state for each thread.
    - Can place limit on the number of simultaneous threads. (typically ~1000)
  - Kernel-level threads have to be general to support the needs of all programmers, languages, runtime systems, etc.

Implementing Kernel-level Threads

- **Kernel-level threads**
  - Kernel-level threads are similar to original process management and implementation.



User-level Threads (1)

- **Motivation**
  - To make threads cheap and fast, they need to be implemented at the user level.
  - Portable: User-level threads are managed entirely by the runtime system (user-level library).

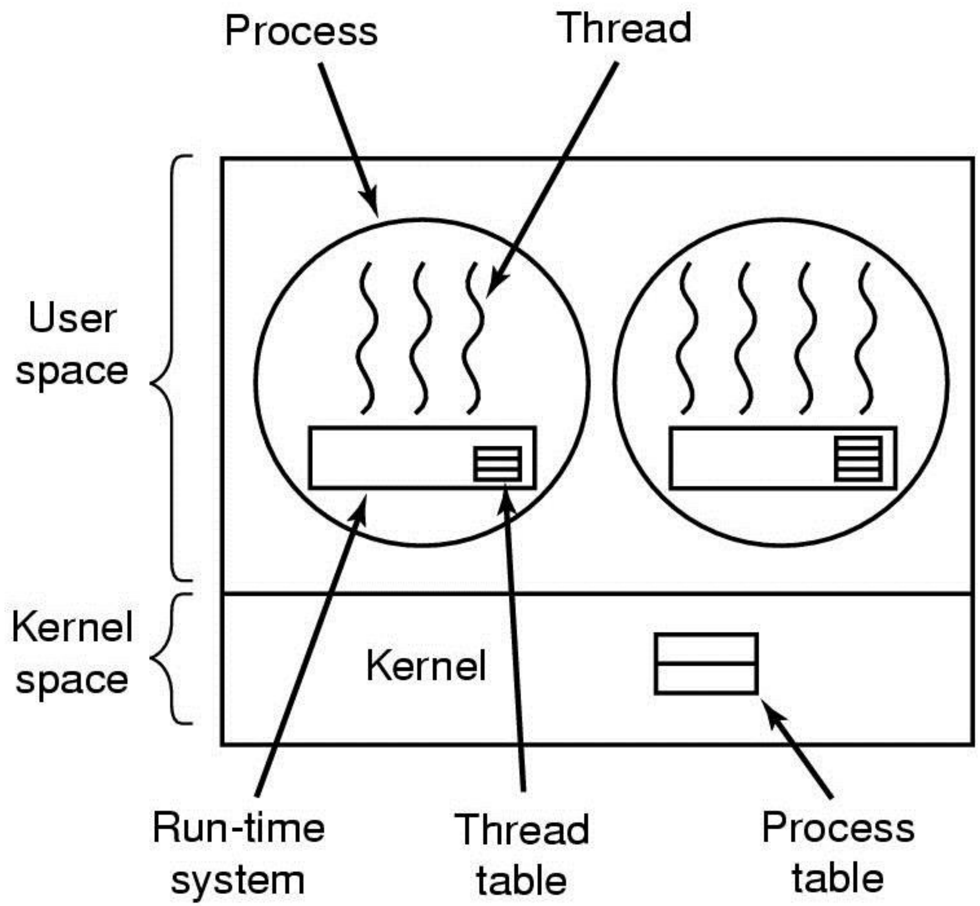
- **User-level threads are small and fast**
  - Each thread is represented simply by a PC, registers, a stack, and a small thread control block (TCB).
  - Creating a thread, switching between threads, and synchronizing threads are done via procedure calls (No kernel involvement).
  - User-level thread operations can be 10-100x faster than kernel-level threads.

User-level Threads (2)

- **Limitations**
  - User-level threads are invisible to the OS.
    - They are not well integrated with the OS
  - As a result, the OS can make poor decisions.
    - Scheduling a process with only idle threads
    - Blocking a process whose thread initiated I/O, even though the process has other threads that are ready to run.
    - Unscheduling a process with a thread holding a lock.
  - Solving this requires coordination between the kernel and the user-level thread manager.
    - e.g., all blocking system calls should be emulated in the library via non-blocking calls to the kernel.

Implementing User-level Threads (1)

- **User-level threads**



Implementing User-level Threads (2)

- **Thread context switch**
  - Very simple for user-level threads
    - Save context of currently running thread
      : push all machine state onto its stack
    - restore context of the next thread
      : pop machine state from next thread's stack
    - the next thread becomes the current thread
    - return to caller as the new thread
      : execution resumes at PC of next thread
  - All done by assembly languages
    - It works at the level of the procedure calling convention, so it cannot be implemented using procedure calls.

Implementing User-level Threads (3)

- **Thread scheduling**
  - A thread scheduler determines when a thread runs.
    - Just like the OS and processes
    - But implemented at user-level as a library
  - It uses queues to keep track of what threads are doing.
    - Run queue: threads currently running
    - Ready queue: threads ready to run
    - Wait queue: threads blocked for some reason (maybe blocked on I/O or a lock)
  - How can we prevent a thread from hogging the CPU?

Implementing User-level Threads (4)

- **Non-preemptive scheduling**
  - Force everybody to cooperate
    - Threads willingly give up the CPU by calling `yield()`.
  - `yield()` calls into the scheduler, which context switches to another ready thread.

```
Thread ping ()
{
  while (1) {
    printf ("ping\n");
    yield();
  }
}
```

```
Thread pong ()
{
  while (1) {
    printf ("pong\n");
    yield();
  }
}
```

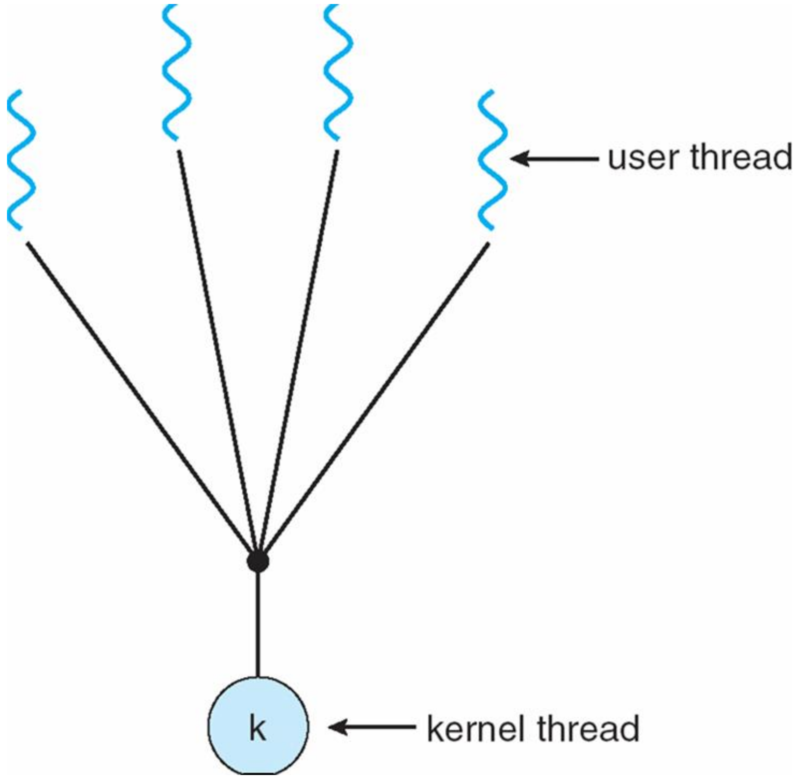
  - What happens if a thread never calls `yield()`?

Implementing User-level Threads (5)

- **Preemptive scheduling**
  - Need to regain control of processor asynchronously.
  - Scheduler requests that a timer interrupt be delivered by the OS periodically.
    - Usually delivered as a UNIX signal
    - Signals are just like software interrupts, but delivered to user-level by the OS instead of delivered to OS by hardware
  - At each timer interrupt, scheduler gains control and context switches as appropriate.

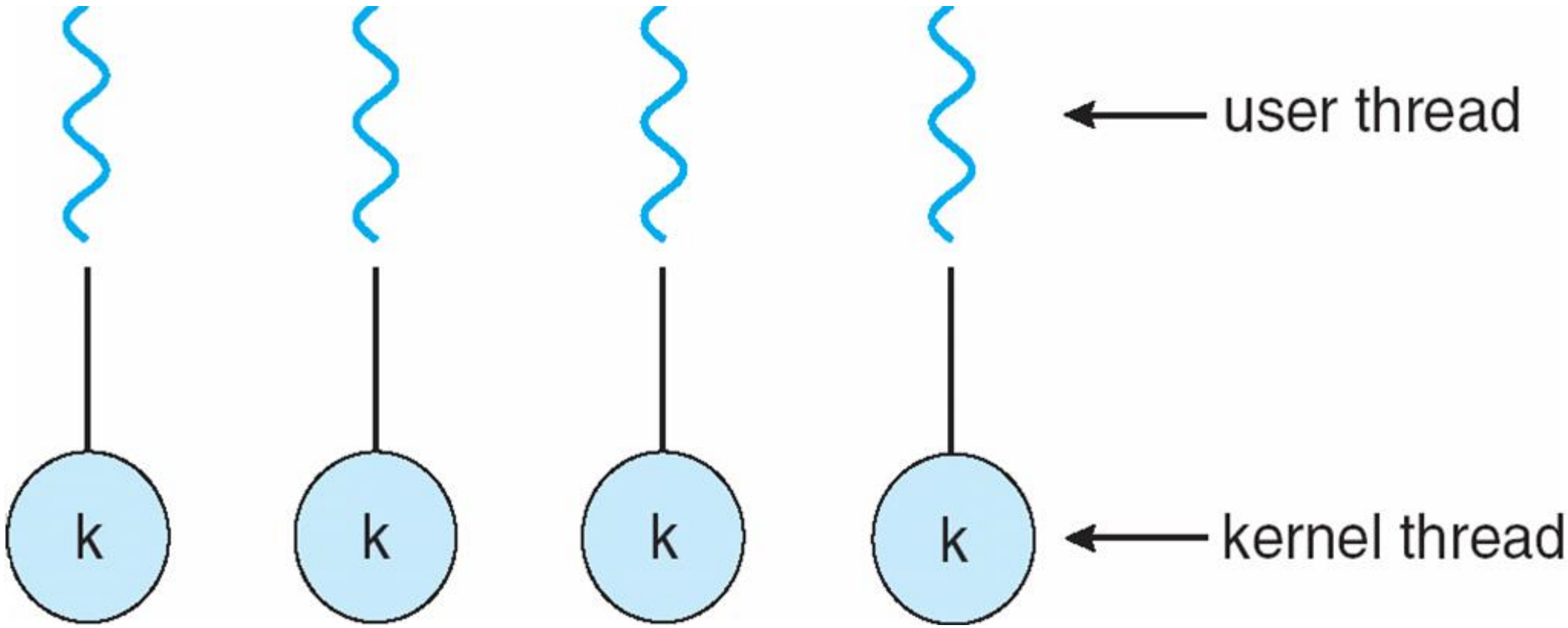
Threading Models (1)

- **Many-to-One (N:1)**
  - Many user-level threads mapped to a single kernel thread
  - Used on systems that do not support kernel threads.
  - Solaris Green Threads GNU Portable Threads



Threading Models (2)

- **One-to-One (1:1)**
  - Each user-level thread maps to a kernel thread.
  - Windows 98/NT/2000/XP, OS/2, Linux, Solaris 9+



Threading Models (3)

- **Many-to-Many (M:N)**
  - Allows many user-level threads to be mapped to many kernel threads.
  - Allows the OS to create a sufficient number of kernel threads.
  - Solaris prior to v9,
    IRIX,
    HP-UX,
    Tru64