ECE30021/ITP30002 Operating System

Multithreaded Programming

(OSC: Ch. 4)

This lecture note is taken from the instructor's resource of Operating System Concept, 9/e and then partly edited/revised by Shin Hong.

Motivation

- Threads run within an application
- Most modern applications are multithreaded to run multiple tasks within an application
  - Update display
  - Fetch data
  - Spell checking
  - Answer a network request
- Thread creation is light-weight compared to process
  - Can simplify code, increase efficiency
  - Kernels are generally multithreaded

Benefits

- **Responsiveness –** may allow continued execution if part of process is blocked, especially important for user interfaces
- **Resource Sharing –** threads share resources of process, easier than shared memory or message passing
- **Efficiency –** cheaper than process creation, thread switching lower overhead than context switching
- **Scalability –** process can take advantage of multiprocessor architectures

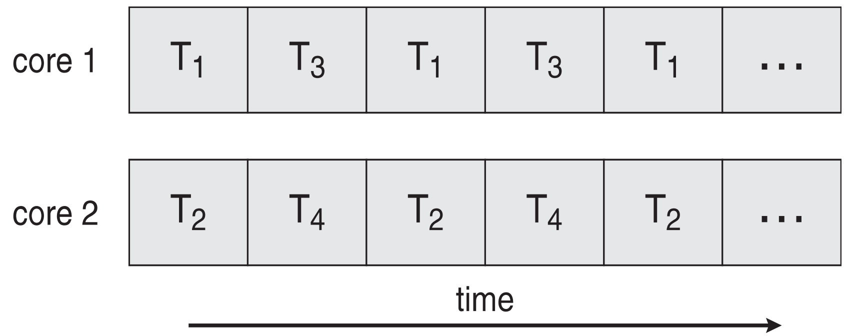
Multicore Programming

- Multicore or multiprocessor systems putting pressure on programmers, challenges include:
  - Dividing activities
  - Balance
  - Data splitting
  - Data dependency
  - Testing and debugging
- *Parallelism* implies a system can perform more than one task simultaneously
- *Concurrency* supports more than one task making progress
  - Single processor / core, scheduler providing concurrency

Concurrency vs. Parallelism

Concurrent execution on single-core system:

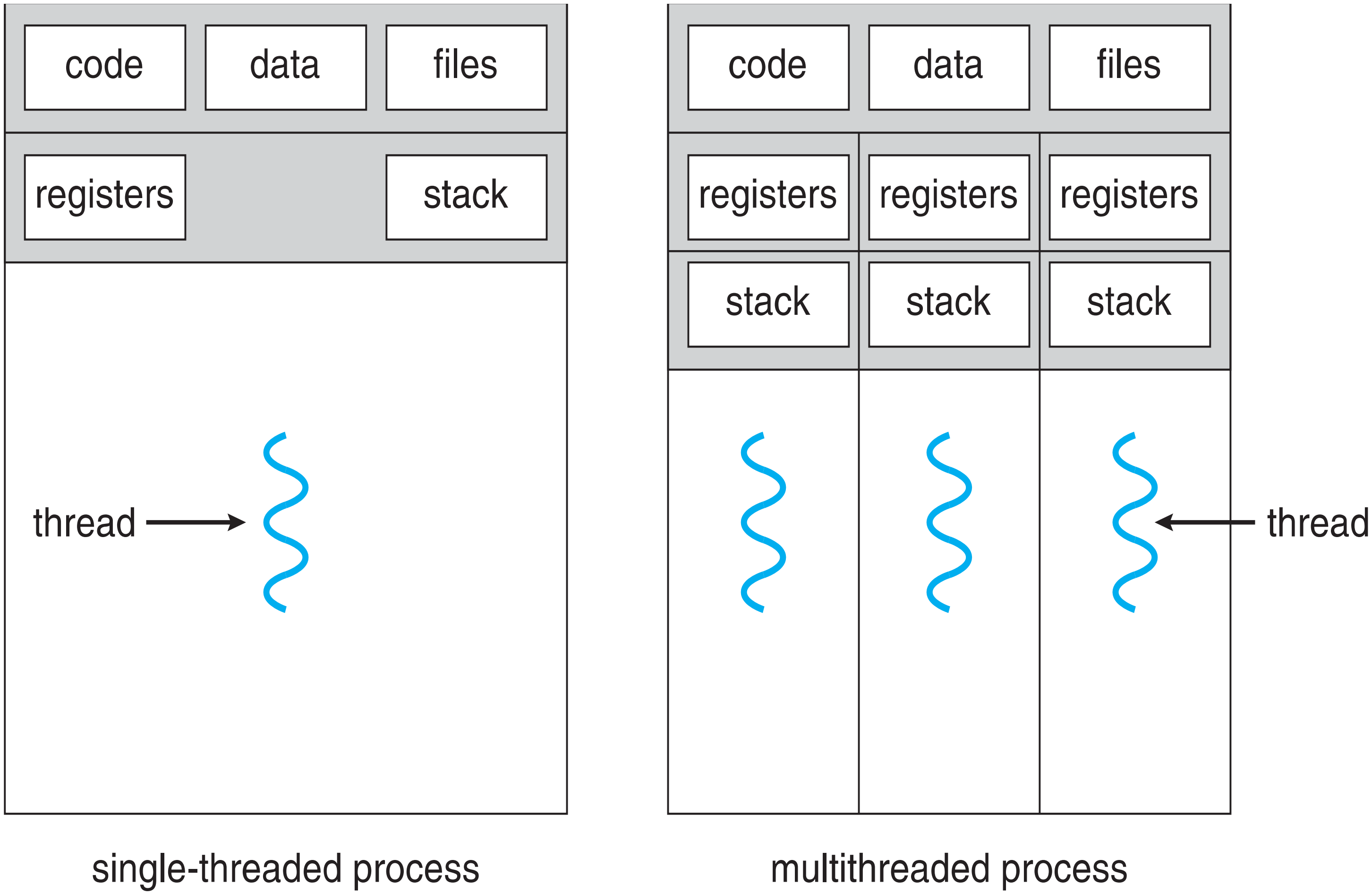
Parallelism on a multi-core system:



Multicore Programming (Cont.)

- Types of parallelism
  - Data parallelism – distributes subsets of the same data across multiple cores, same operation on each
  - Task parallelism – distributing threads across cores, each thread performing unique operation
- As the number of threads grows in programs, so does architectural support for threading
  - CPUs have cores as well as *hardware threads*

Single and Multithreaded Processes



Amdahl's Law

- Upper bound of performance gains by adding additional cores to an application that has both serial and parallel components
  - *S* is serial portion
  - *N* processing cores

$$speedup \le \frac{1}{S + \frac{(1-S)}{N}}$$

  - That is, if application is 75% parallel / 25% serial, moving from 1 to 2 cores results in speedup of 1.6 times
  - As *N* approaches infinity, speedup approaches 1 / *S*

- Serial portion of an application has disproportionate effect on performance gained by adding additional cores

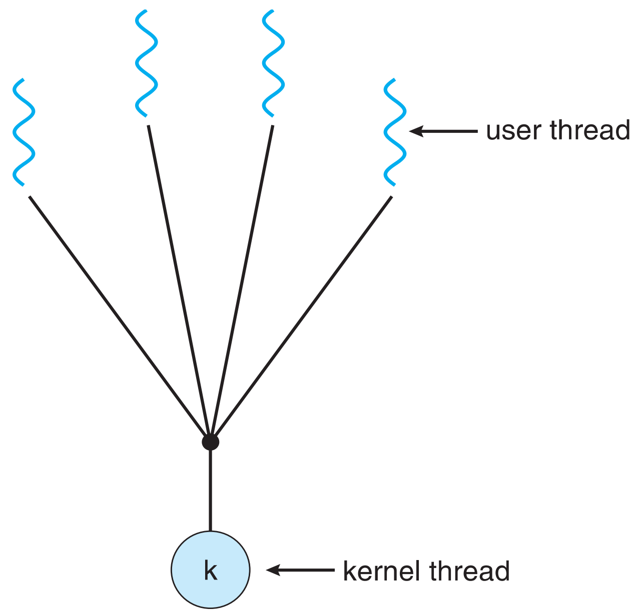
- But does the law take into account contemporary multicore systems?

User Threads and Kernel Threads

- User threads - management done by user-level threads library
  - POSIX Pthreads
  - Windows threads
  - Java threads
- Kernel threads - Supported by the Kernel
  - Windows
  - Solaris
  - Linux
  - Tru64 UNIX
  - Mac OS X

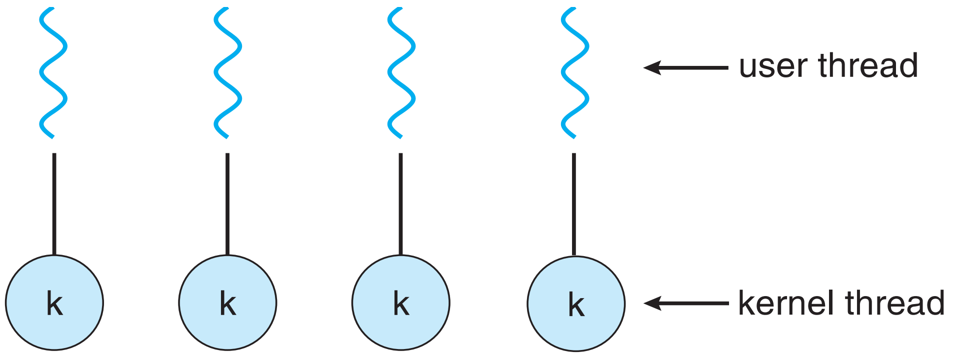
Many-to-One

- Many user-level threads mapped to single kernel thread
- One thread blocking causes all to block
- Multiple threads may not run in parallel on muticore system because only one may be in kernel at a time
- Few systems currently use this model
  - Solaris Green Threads
  - GNU Portable Threads



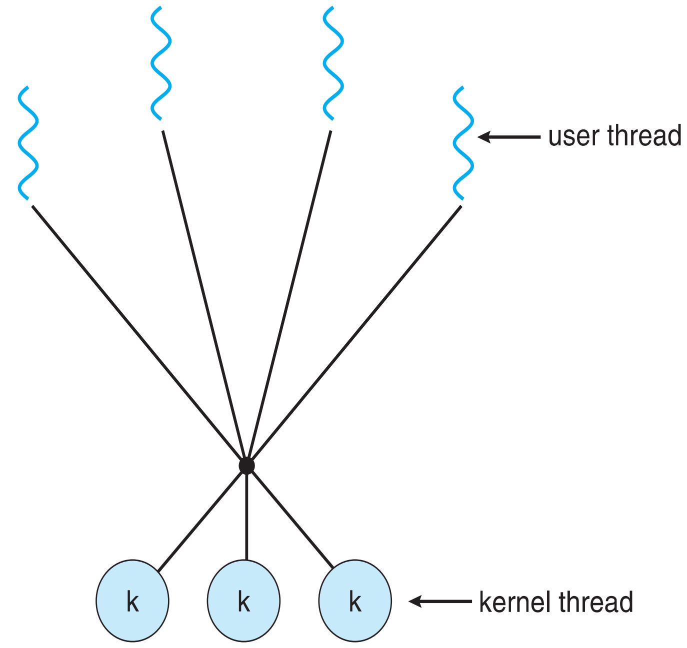
One-to-One

- Each user-level thread maps to kernel thread
- Creating a user-level thread creates a kernel thread
- More concurrency than many-to-one
- Number of threads per process sometimes restricted due to overhead
  - Windows
  - Linux
  - Solaris 9 and later



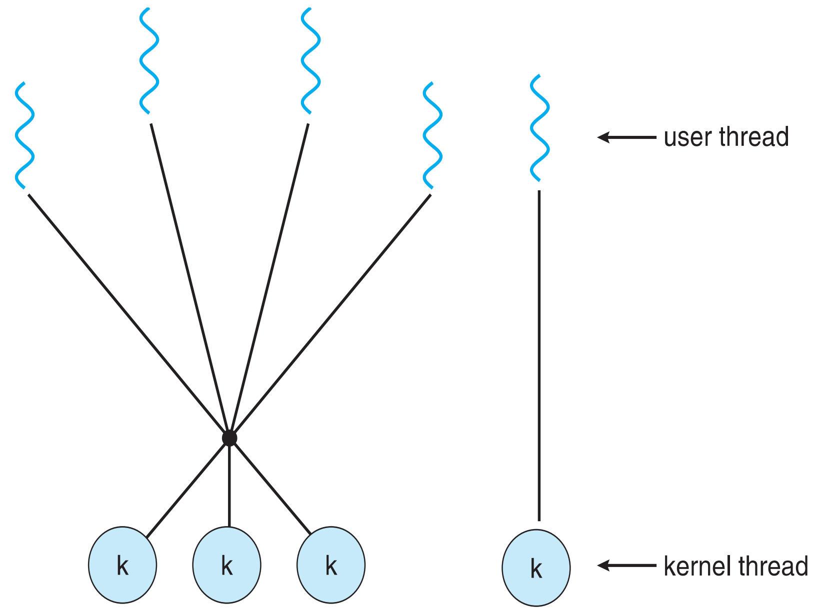
Many-to-Many Model

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



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



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

Pthreads

- May be provided either as user-level or kernel-level
- A POSIX standard (IEEE 1003.1c) API for thread creation and synchronization
  - *Specification*, not *implementation*
- API specifies behavior of the thread library, implementation is up to development of the library
- Common in UNIX operating systems

Pthreads Example

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

int sum; /* this data is shared by the thread(s) */
void *runner(void *param); /* threads call this function */

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

   if (argc != 2) {
      fprintf(stderr,"usage: a.out <integer value>\n");
      return -1;
   }
   if (atoi(argv[1]) < 0) {
      fprintf(stderr,"%d must be >= 0\n",atoi(argv[1]));
      return -1;
   }
```

Pthreads Example (Cont.)

```
   /* get the default 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);

   printf("sum = %d\n",sum);
}

/* 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);
}
```

Pthreads Code for Joining 10 Threads

```
#define NUM_THREADS 10

/* an array of threads to be joined upon */
pthread_t workers[NUM_THREADS];

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

Implicit Threading

- Growing in popularity as numbers of threads increase, program correctness more difficult with explicit threads
- Creation and management of threads done by compilers and run-time libraries rather than programmers
- Three methods explored
  - Thread Pools
  - OpenMP
  - Grand Central Dispatch
- Other methods include Microsoft Threading Building Blocks (TBB), **`java.util.concurrent`** package

Thread Pools

- Create a number of threads in a pool where they await work
- Advantages
  - 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
  - Separating parallel tasks from threading mechanisms

OpenMP

- Set of compiler directives and an API for C, C++, FORTRAN
- Provides support for parallel programming in shared-memory environments
- Identifies **parallel regions** – blocks of code that can run in parallel

```
#pragma omp parallel
```

Create as many threads as there are cores

```
#pragma omp parallel for
  for(i=0;i<N;i++) {

     c[i] = a[i] + b[i];

}
```

Run for loop in parallel

```
#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;
}
```

Threading Design Issue: Fork & Exec

- Does **`fork()`** duplicate only the calling thread or all threads?
  - Some UNIXes have two versions of fork
- **`exec()`** usually works as to replace the running process including all threads

Threading Design Issue: Signal

- Signals are used in UNIX systems to notify a process that a particular event has occurred
  - A signal handler is used to response to signals
    - Signal is generated by particular event
    - Signal is delivered to a process
  - Every signal has default handler that kernel runs when handling signal
    - User-defined signal handler can override default
    - For single-threaded, signal delivered to process

- Where should a signal be delivered for multi-threaded?
  - 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

Threading Design Issue: Thread Cancellation

- Terminating a thread before it has finished
- Thread to be canceled is target thread
- Two general approaches
  - Asynchronous cancellation terminates the target thread immediately
  - Deferred cancellation allows the target thread to periodically check if it should be cancelled

Threading Design Issue: Thread-Local Storage

- Thread-local storage (TLS) allows each thread to have its own copy of data
- Useful when you do not have control over the thread creation process (i.e., when using a thread pool)
- Different from local variables
  - Local variables visible only during single function invocation
  - TLS visible across function invocations
- Similar to `static` data
  - TLS is unique to each thread

Threading Design Issue: Scheduler Activations

- Problem: Both M:M and Two-level models require communication to maintain the appropriate number of kernel threads allocated to the application
- Solution: use Light Weight Process (LWP), an intermediate data structure between user and kernel threads
  - Appears to be a virtual processor on which process can schedule user thread to run
  - Each LWP attached to kernel thread
  - Kernel raises upcalls to user-level threading library to give the information on kernel threads for the threading library to maintain the correct number kernel threads