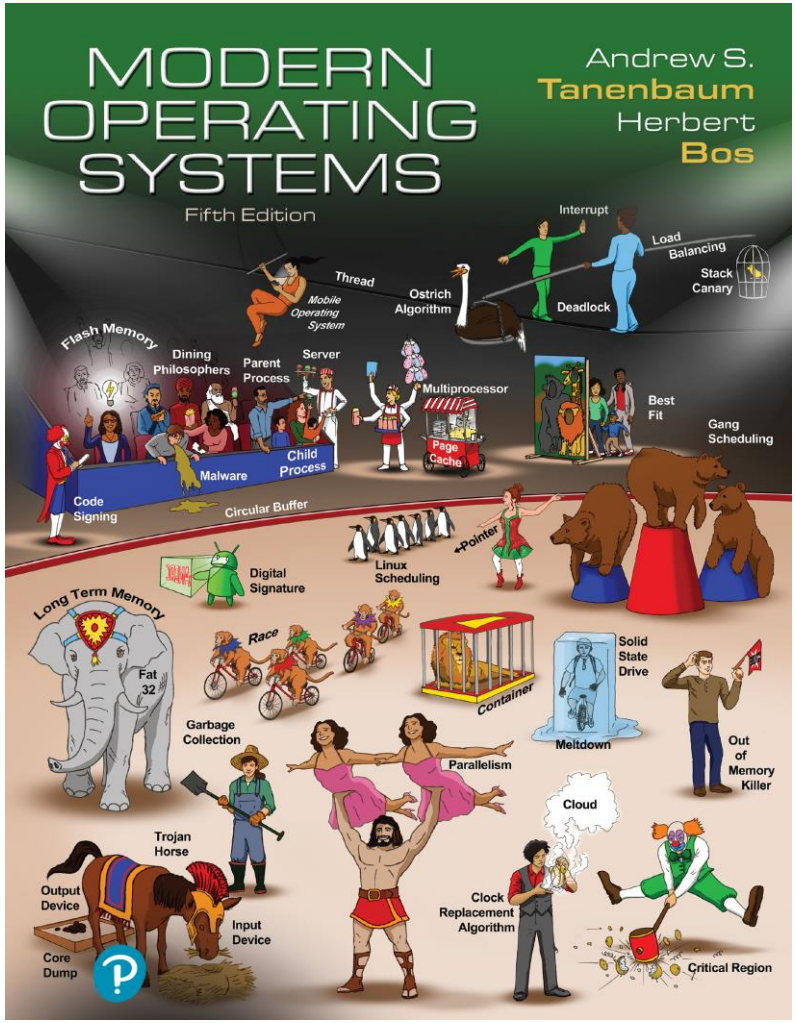
Modern Operating Systems

Fifth Edition



Chapter 2

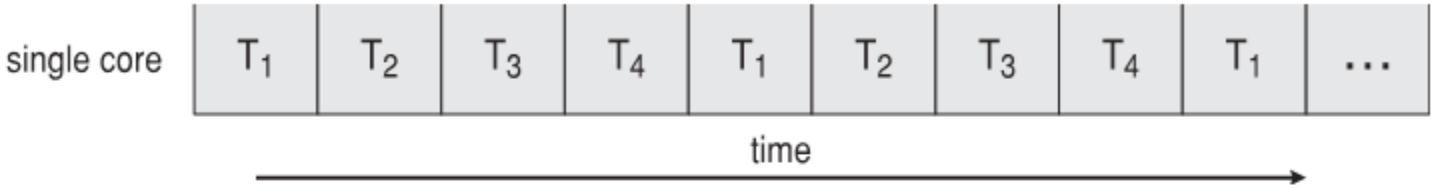
Threads

Threads

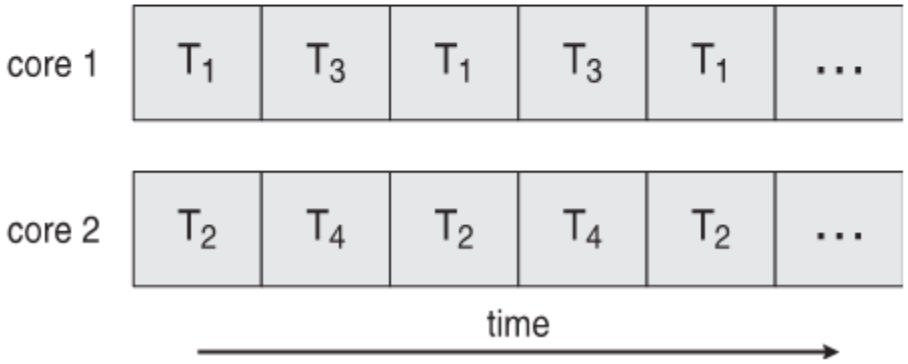
- Implicit assumption so far:
  - 1 process $\rightarrow$ 1 thread of execution
- Multithreaded execution:
  - 1 process $\rightarrow$ N threads of execution
- Why allow multiple **threads** per process?
  - Lightweight processes
    - Allow space- and time- efficient parallelism
  - Organized in thread groups
    - Allow simple communication and synchronization

Concurrency vs. Parallelism

- **Concurrent execution on single-core system:**



- **Parallelism on a multi-core system:**

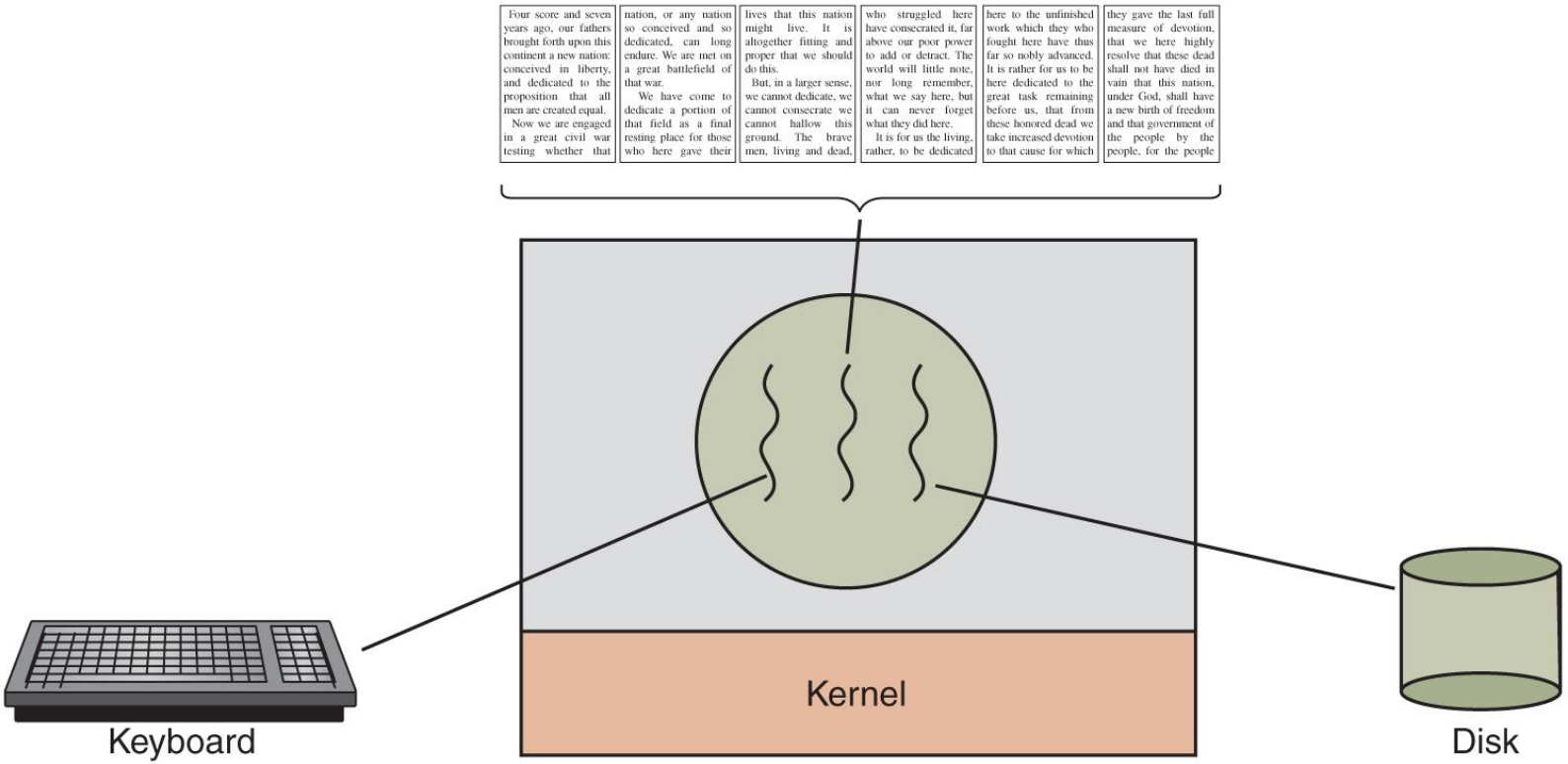


Threads Usage

- Many web browsers ran as single process (some still do)
  - If one web site causes trouble, entire browser can hang or crash
- Google Chrome Browser is multiprocess with 3 different types of processes:
  - **Browser** process manages user interface, disk and network I/O
  - **Renderer** process renders web pages, deals with HTML, Javascript. A new renderer created for each website opened
    - Runs in **sandbox** restricting disk and network I/O, minimizing effect of security exploits
  - **Plug-in** process for each type of plug-in

Thread Usage

A word processor with three threads.

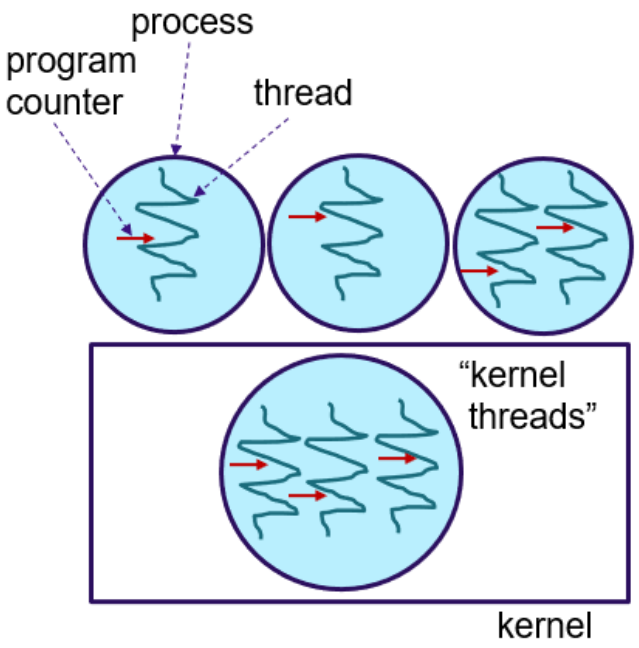


Thread Benefits

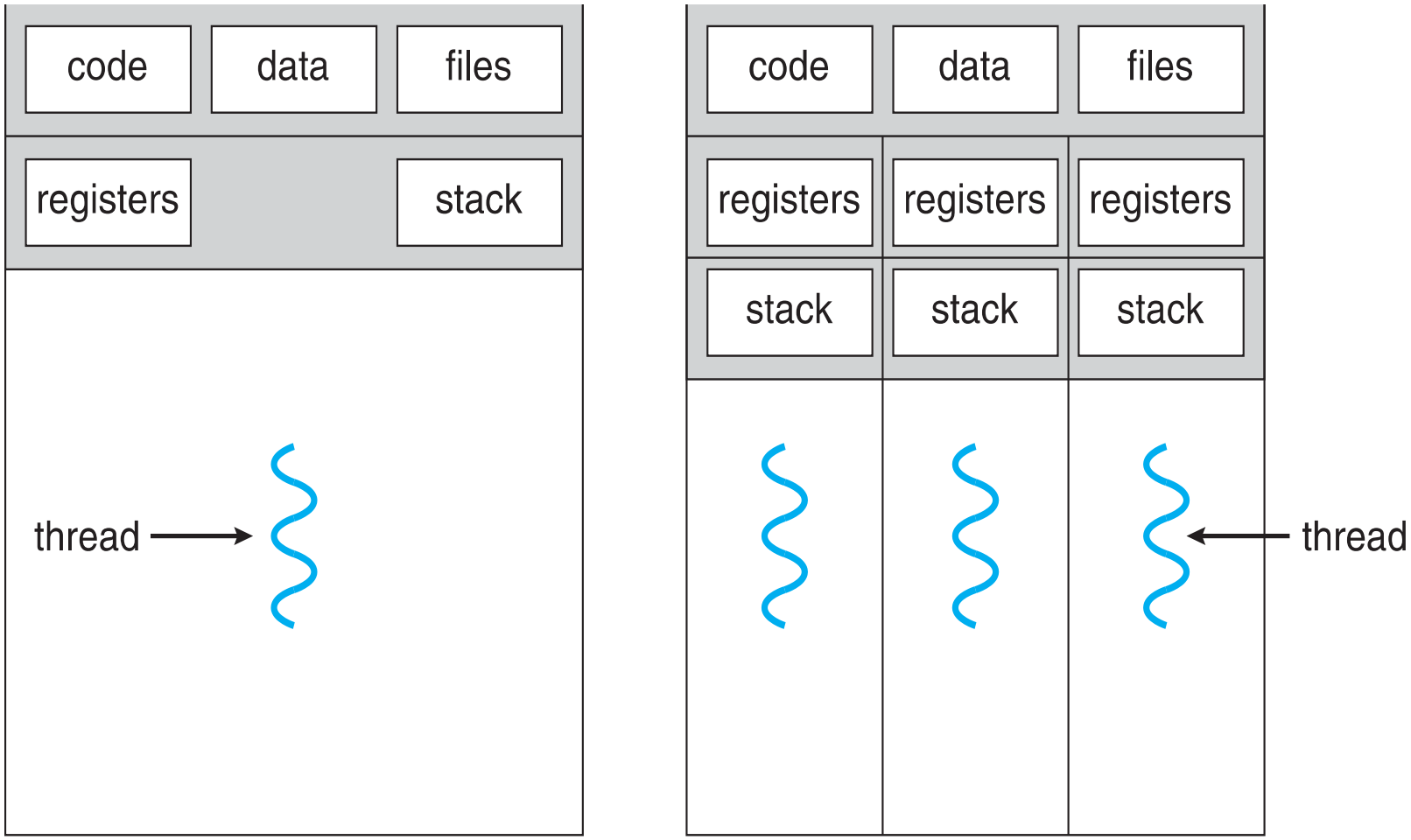
- **Responsiveness –** may allow continued execution if part of process is blocked, especially important for user interfaces
- **Resource Sharing –** threads share resources of process, easier than shared memory or message passing
- **Economy –** cheaper than process creation, thread switching lower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

Threads and Processes

- Threads reside in the same address space of a single process
- All information exchange is via data shared between the threads
- Threads synchronize via simple primitives
- Each thread has its own stack, hardware registers, and state
- Thread table/switch: a lighter process table/switch
- Each thread may call any OS-supported system call on behalf of the process to which it belongs



Single and Multithreaded Processes



POSIX Threads

Thread call	Description
Pthread_create	Create a new thread
pthread_exit	Terminate the calling thread
pthread_join	Wait for a specific thread to exit
pthread_yield	Release the CPU to let another thread run
pthread_attr_init	Create and initialize a thread's attribute structure
pthread_attr_destroy	Remove a thread's attribute structure

Some of the P threads function calls.

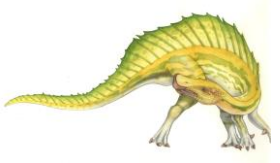
Pthreads Example

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

#define NUMBER_OF_THREADS  10
void * print_hello_world(void * tid)
{
  printf("Hello World. Greetings from thread %d\n", tid);
  pthread_exit(NULL);
}
int main(int argc, char * argv[])
{
  pthread_t threads[NUMBER_OF_THREADS];
  int status, i;
  for(i=0; i < NUMBER_OF_THREADS; i++) {
    status = pthread_create(&threads[i], NULL, print_hello_world, (void * )i);
    if (status != 0) {
      exit(-1);
    }
  }
  return 0;
}
```

What will the output be?

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);
```

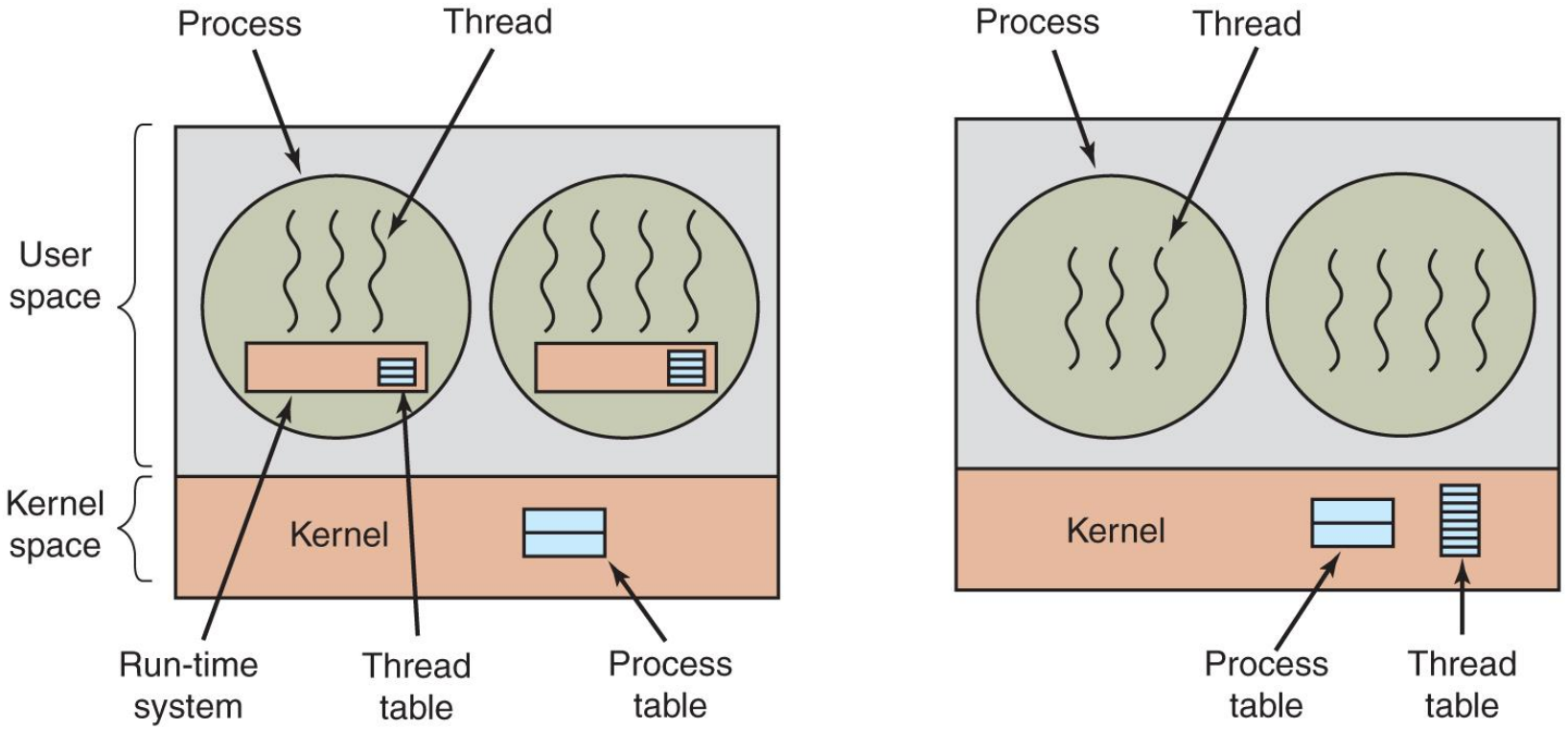


User Threads and Kernel Threads

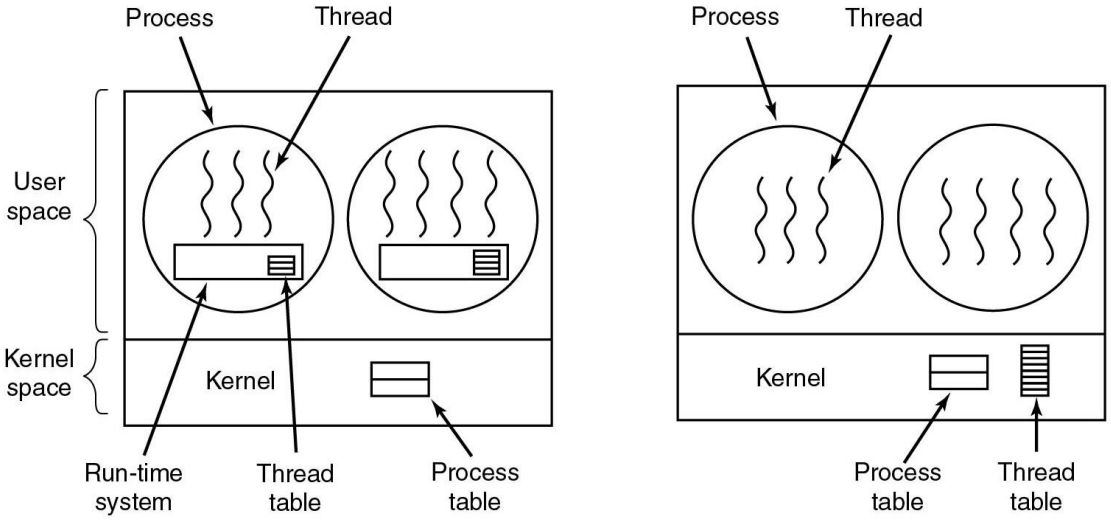
- **User threads** - management done by user-level threads library
- Three primary thread libraries:
  - POSIX **Pthreads**
  - Windows threads
  - Java threads
- **Kernel threads** - Supported by the Kernel
- Examples – virtually all general-purpose operating systems, including:
  - Windows
  - Solaris
  - Linux
  - Tru64 UNIX
  - Mac OS X

User and Kernel Level Threads

(a) A user-level threads package. (b) A threads package managed by the kernel.



User Threads: Pros and Cons



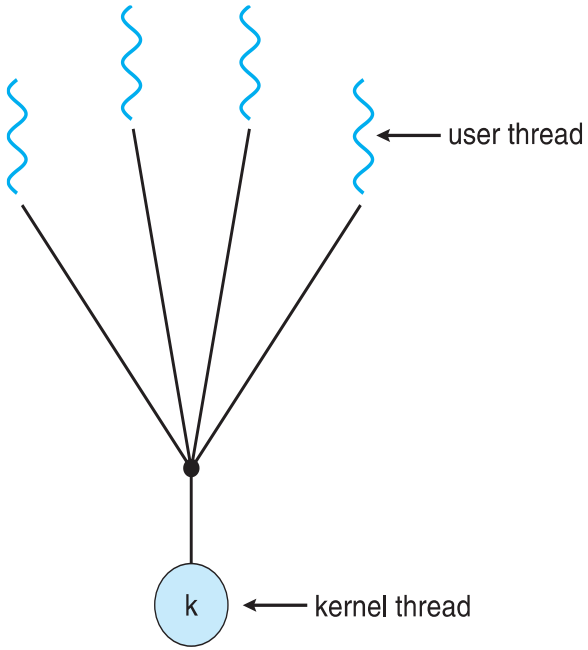
+ Thread switching time (no mode switch)
+ Scalability, customizability (no in-kernel management)
- Transparency (typically requires app cooperation)
- Parallelism (blocking syscalls are problematic)

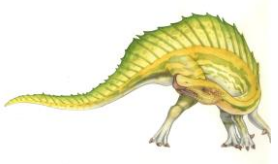
Multithreading Models

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

Many-to-One

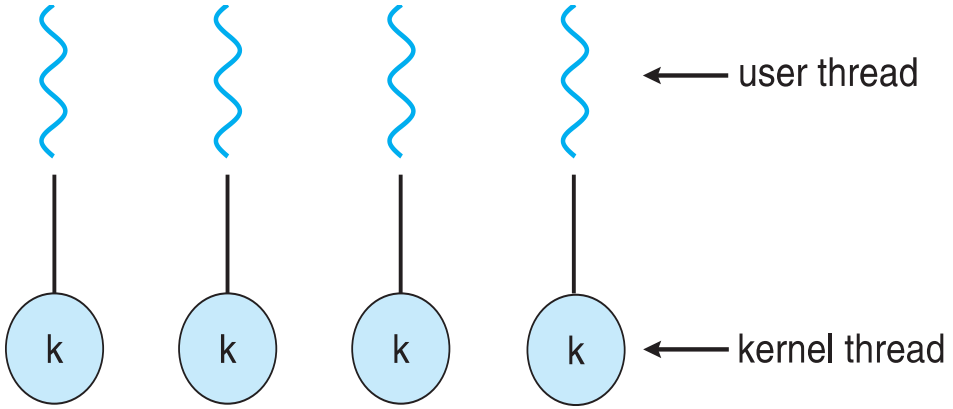
- Many user-level threads mapped to single kernel thread
- One thread blocking causes all to block
- Multiple threads may not run in parallel on muticore system because only one may be in kernel at a time
- Few systems currently use this model
- Examples:
  - **Solaris Green Threads**
  - **GNU Portable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





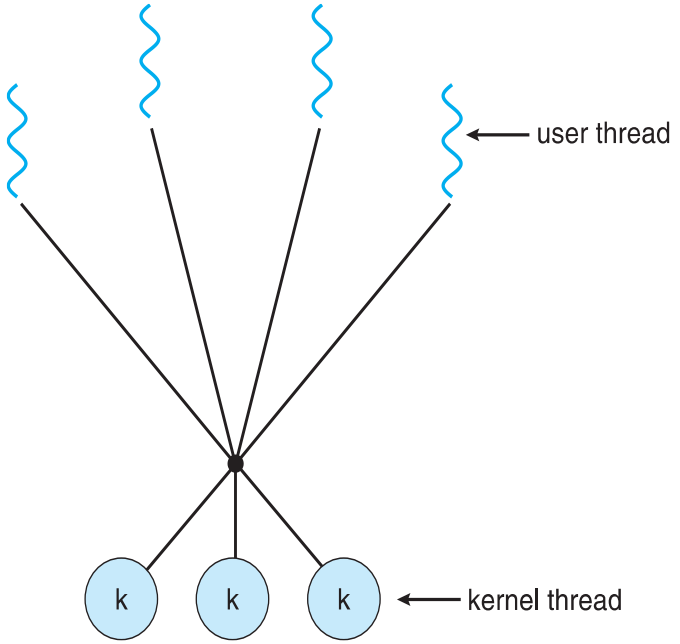
One-to-One

- 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
- Examples
  - Windows
  - Linux
  - Solaris 9 and later



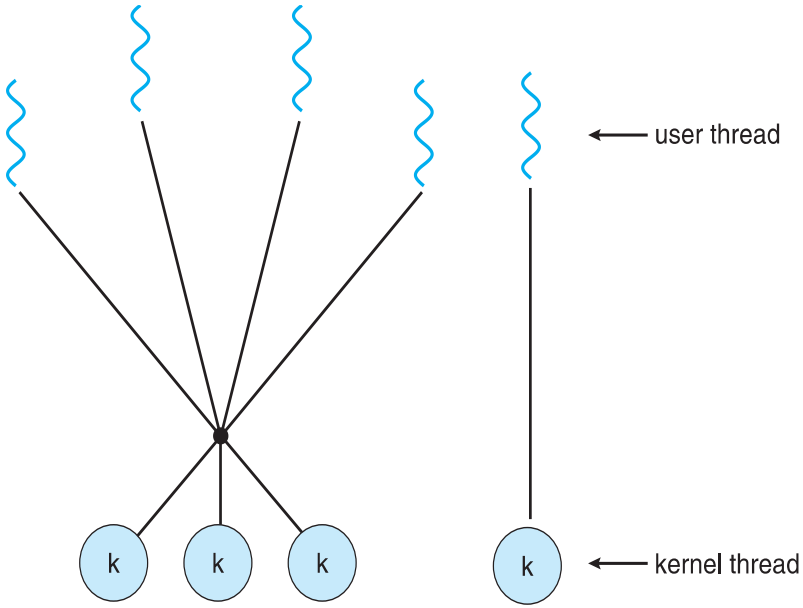
Many-to-Many Model

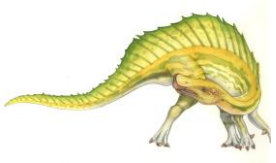
- Allows many user level threads to be mapped to many kernel threads
- Allows the operating system to create a sufficient number of kernel threads
- Solaris prior to version 9
- Windows with the *ThreadFiber* package



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





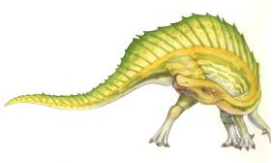
Implicit Threading

- 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:
  - 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
  - Separating task to be performed from mechanics of creating task allows different strategies for running task
    - i.e.Tasks could be scheduled to run periodically
- Windows API supports thread pools:

```
DWORD WINAPI PoolFunction(AVOID Param) {
    /*
    * this function runs as a separate thread.
    */
}
```



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

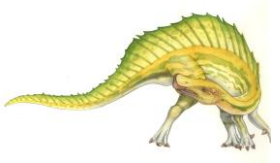
```
#pragma omp parallel
```

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;
}
```



Grand Central Dispatch

- Apple technology for Mac OS X and iOS operating systems
- Extensions to C, C++ languages, API, and run-time library
- Allows identification of parallel sections
- Manages most of the details of threading
- Block is in "^{ }" - `^{ printf("I am a block"); }`
- Blocks placed in dispatch queue
  - Assigned to available thread in thread pool when removed from queue

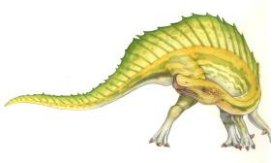
Threads: Issues

- Does the OS keep track of threads?
  - Kernel threads vs. user threads
- What to do on fork?
  - Clone all threads vs. calling thread
  - What if a thread is currently blocking on a systems call?
- What to do with signals?
  - Send signal to all threads vs. single thread
  - Per-process or per-thread signal handlers
- Where to store per-thread variables?
- Does sharing come at a cost?
- Are threads required inside an operating system?

Thread Cancellation

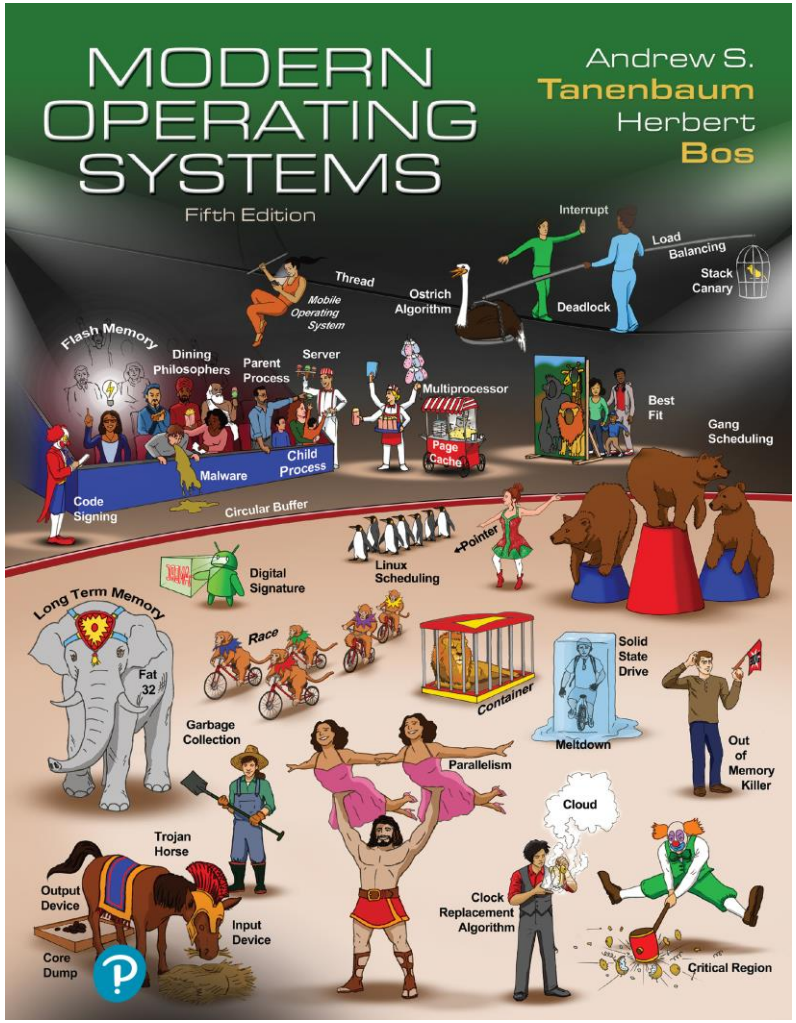
- Terminating a thread before it has finished
- Thread to be canceled is **target thread**
- Two general approaches:
  - **Asynchronous cancellation** terminates the target thread immediately
  - **Deferred cancellation** allows the target thread to periodically check if it should be cancelled
- Pthread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

```
pthread_t tid;

/* create the thread */
pthread_create(&tid, 0, worker, NULL);

. . .

/* cancel the thread */
pthread_cancel(tid);
```



Modern Operating Systems

Fifth Edition



End of Threads Lecture