Chapter 4: Threads

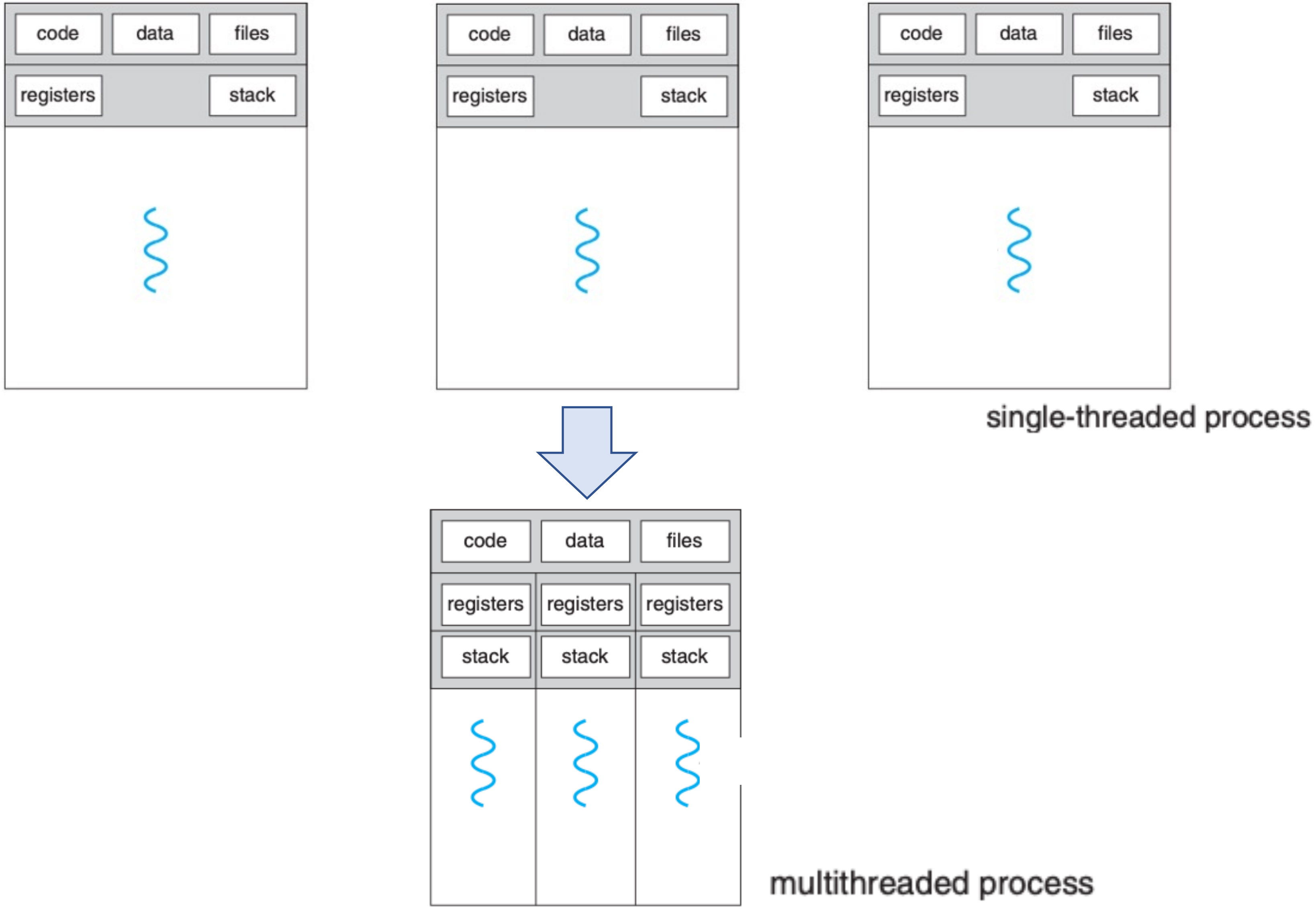
Notion of thread

APIs for the Pthread, Windows, and Java thread libraries

Issues related to multithreaded programming

Contents

4.1 Overview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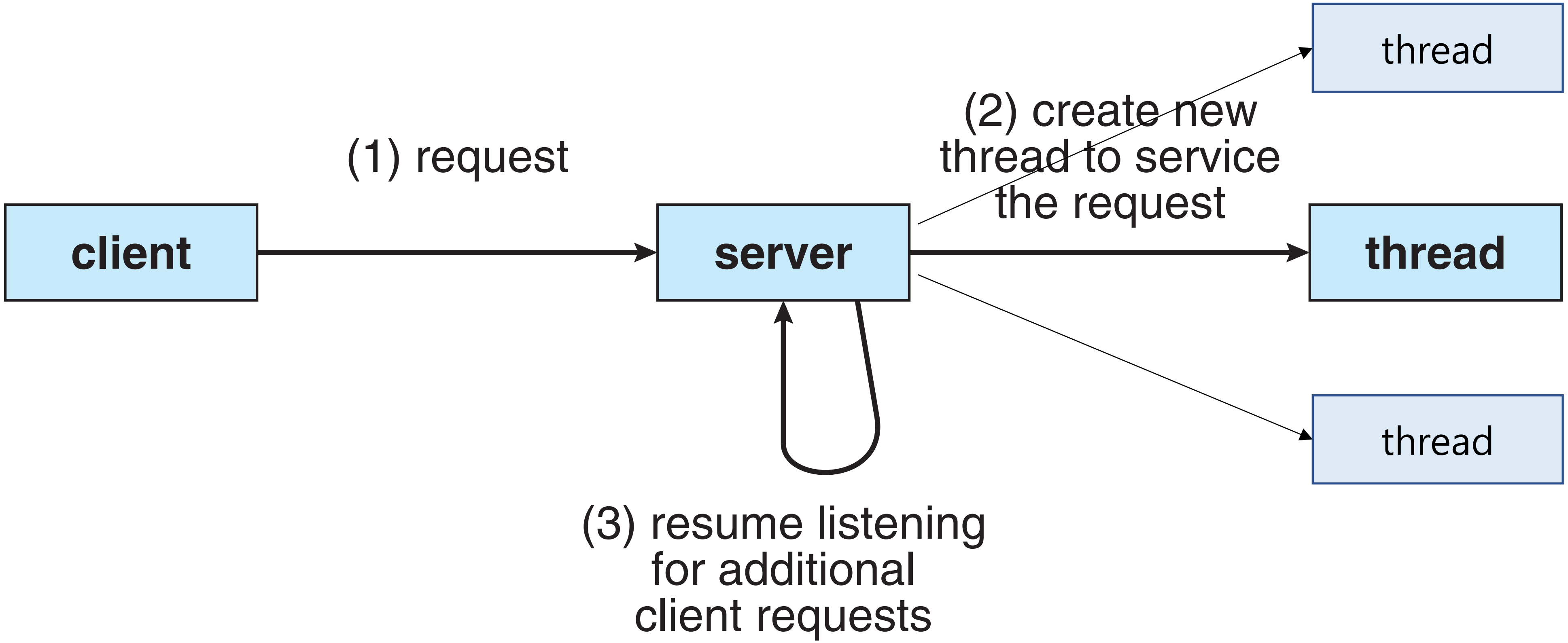
multithreaded process

Motivation

- Most modern applications are multithreaded
- Threads run within application
- Multiple tasks with the application can be implemented by separat e threads
  - Update display
  - Fetch data
  - Spell checking
  - Answer a network request
- Process creation is heavy-weight while thread creation is light-weig ht
- Can simplify code, increase efficiency
- Kernels are generally multithreaded

Multithreaded Server Architecture

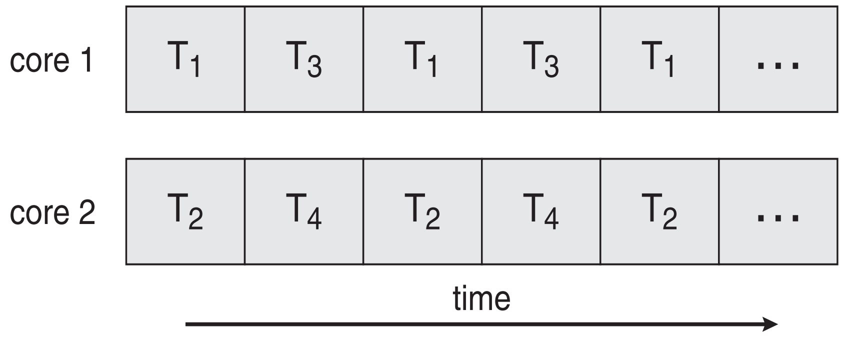


Benefits

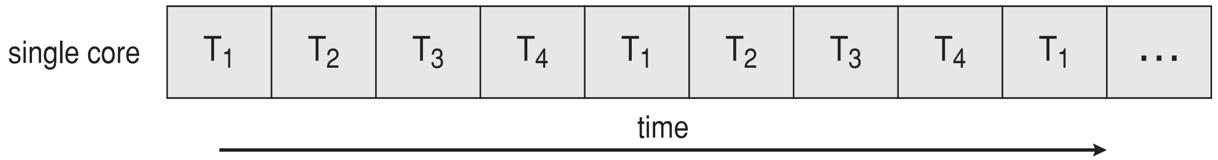
- **Responsiveness –** may allow continued execution if part of p rocess is blocked, especially important for user interfaces
- **Resource Sharing –** threads share resources of process, easie r than shared memory or message passing
- **Economy –** cheaper than process creation, thread switching l ower overhead than context switching
- **Scalability –** process can take advantage of multiprocessor ar chitectures

4.2 Multicore Programming

- **Multicore** or **multiprocessor** systems
- ***Parallelism*** implies a system can perform more than one task simultaneously
- ***Concurrency*** supports more than one task making progre ss
    - Single processor / core, sched uler providing concurrency



Parallelism on a multi-core system



Concurrent execution on single-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
- **Multicore** or **multiprocessor** systems putting pressure on programmers, challenges include:
  - **Dividing activities**
  - **Balance**
  - **Data splitting**
  - **Data dependency**
  - **Testing and debugging**

Amdahl's Law

- Identifies performance gains from adding additional cores to an application that has both serial and parallel components
- S is serial portion and 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?

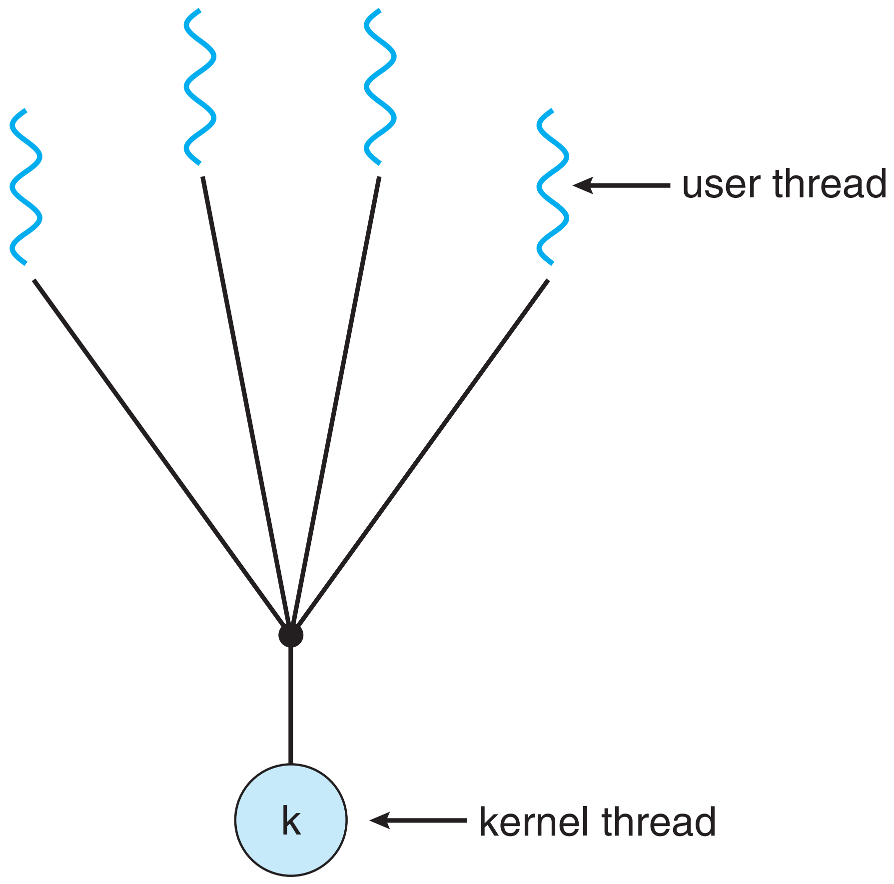
4.3 Multithreading models

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

- Multithreading models
  - Many-to-One
  - One-to-One
  - Many-to-Many

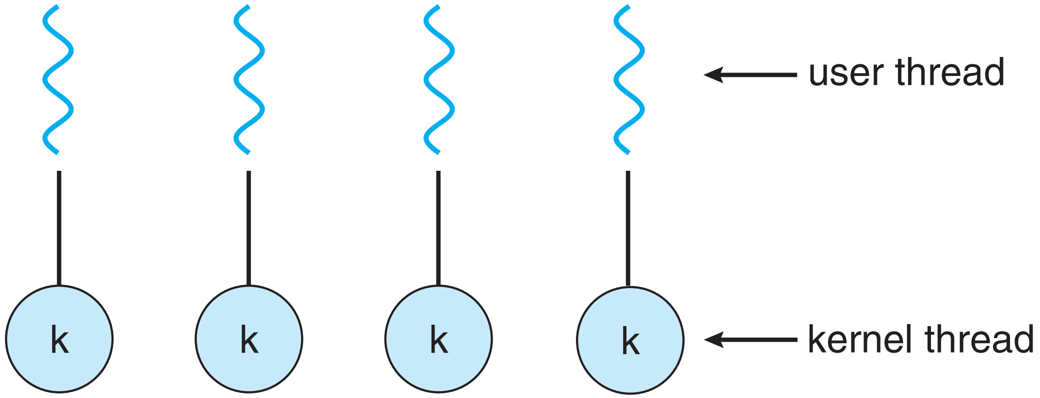
Many-to-One

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



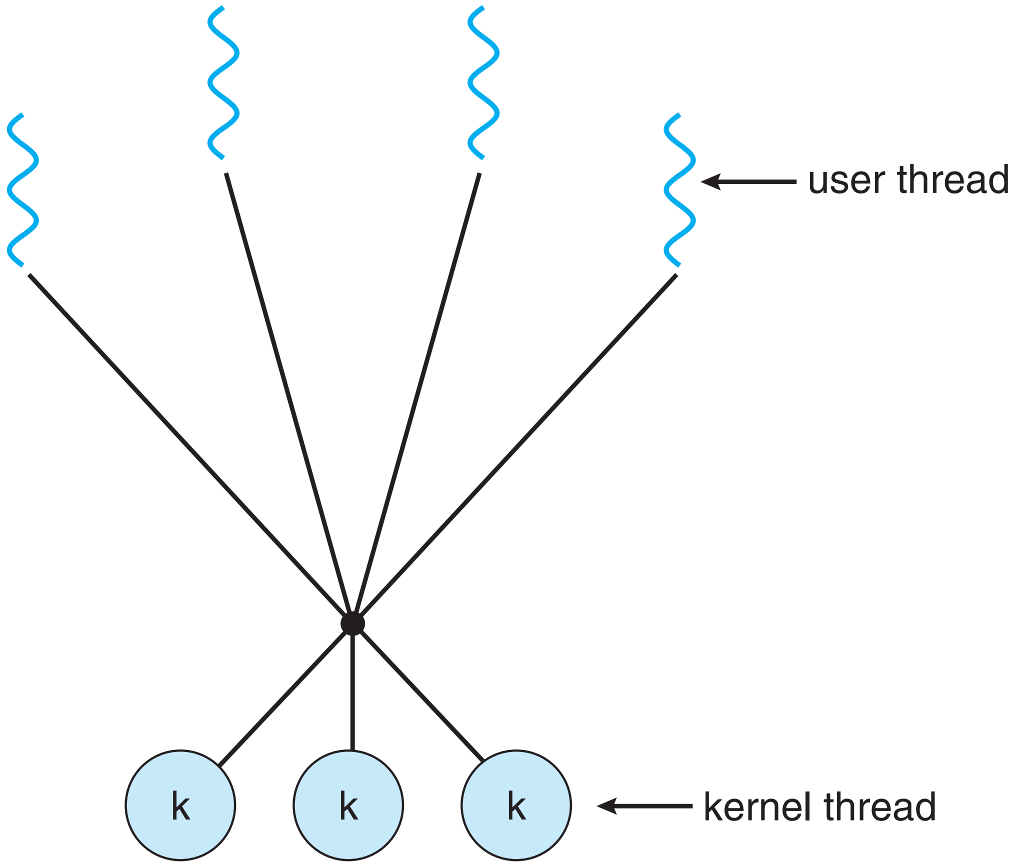
One-to-One

- 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



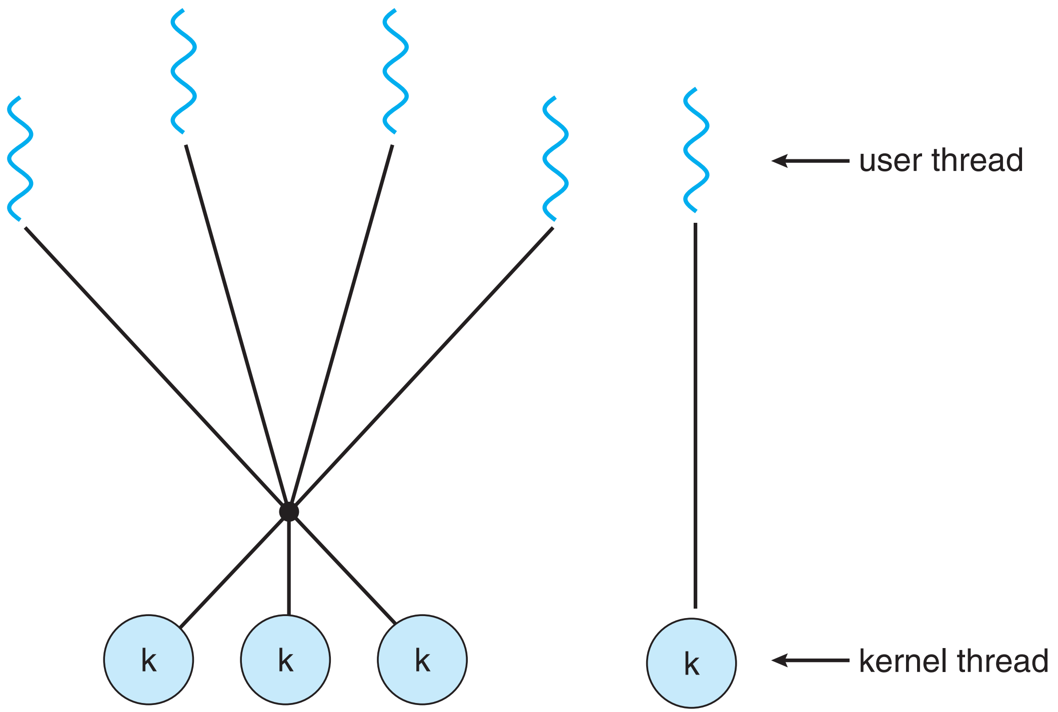
Many-to-Many Model

- Allows many user level threa ds to be mapped to many ke rnel threads
- Allows the operating system to create a sufficient number of kernel threads
- Solaris prior to version 9 / W indows with the *ThreadFiber* package



Two-level Model

- Similar to M:M, except that it allows a user thread to be **b ound** to kernel thread
- Examples
  - IRIX
  - HP-UX
  - Tru64 UNIX
  - Solaris 8 and earlier



4.4 Thread Libraries

- **Thread library** provides programmer with API for creating an d managing threads
- Two primary ways of implementing
  - Library entirely in user space
  - Kernel-level library supported by the OS
- POSIX Pthreads / Windows Threads / Java Thread

Pthreads

- May be provided either as user-level or kernel-level
- A POSIX standard (IEEE 1003.1c) API for thread creation and s ynchronization
- ***Specification***, not ***implementation.*** API specifies behavior of the thread library, implementation is up to development of th e library
- Common in UNIX operating systems (Solaris, Linux, Mac OS X)

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;
   }
```

```
   /* 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);
}
```

Windows Multithreaded C Program

(1)
```c
#include <windows.h>
#include <stdio.h>
```
(2)
```c
DWORD Sum; /* data is shared by the thread(s) */

/* the thread runs in this separate function */
```
(3)
```c
DWORD WINAPI Summation(LPVOID Param)
{
   DWORD Upper = *(DWORD*)Param;
   for (DWORD i = 0; i <= Upper; i++)
      Sum += i;
   return 0;
}
```
(4)
```c
int main(int argc, char *argv[])
{
   DWORD ThreadId;
   HANDLE ThreadHandle;
   int Param;

   if (argc != 2) {
      fprintf(stderr,"An integer parameter is required\n");
      return -1;
   }
   Param = atoi(argv[1]);
   if (Param < 0) {
      fprintf(stderr,"An integer >= 0 is required\n");
      return -1;
   }

   /* create the thread */
   ThreadHandle = CreateThread(
      NULL, /* default security attributes */
      0, /* default stack size */
      Summation, /* thread function */
      &Param, /* parameter to thread function */
      0, /* default creation flags */
      &ThreadId); /* returns the thread identifier */

   if (ThreadHandle != NULL) {
      /* now wait for the thread to finish */
      WaitForSingleObject(ThreadHandle,INFINITE);

      /* close the thread handle */
      CloseHandle(ThreadHandle);

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

4.5 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

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 ne w 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 s trategies 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++, F ORTRAN
- Provides support for parallel programming in share d-memory environments. dentifies **parallel regions** – blocks of code that can run in parallel

- Create as many threads as there are cores

```
#pragma omp parallel
```

- Run for loop in parallel

```
#pragma omp parallel for for(i=0;i<N;i++
  ) {
    c[i] = a[i] + b[i];
}
```

```
#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
- Block is in "^{ }" - **`^{ printf("I am a block"); }`**
- Blocks placed in dispatch queue
  - Assigned to available thread in thread pool when removed from queue

- Allows identification of parallel sections
- Manages most of the details of threading

Grand Central Dispatch

- Two types of dispatch queues:
  - serial – blocks removed in FIFO order, queue is per process , called **main queue**
    - Programmers can create additional serial queues within program
  - concurrent – removed in FIFO order but several may be re moved at a time
    - Three system wide queues with priorities low, default, high

```
dispatch_queue_t queue = dispatch_get_global_queue
   (DISPATCH_QUEUE_PRIORITY_DEFAULT, 0);

dispatch_async(queue, ^{ printf("I am a block."); });
```

Threading Issues

- Semantics of **fork()** and **exec()** system calls
- Signal handling
  - Synchronous and asynchronous
- Thread cancellation of target thread
  - Asynchronous or deferred
- Thread-local storage
- Scheduler Activations