東南大學
SOUTHEAST UNIVERSITY

OPERATING SYSTEM CONCEPTS

Chapter 4. Threads

A/Prof. Kai Dong

Warm-up

Thread — A New Abstraction

- Why we need this abstraction?
- Think of: Some programs have more than one point of execution (i.e., multiple PCs).

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  - Example #1: adding two large arrays together
  - How to speed up execution?
  - Example #2: some elements need input
  - How to speed up execution?
- Why multiple threads, not multiple processes?
  - We are now detailing the reasons.

Objectives

- To introduce the notion of a thread — a fundamental unit of CPU utilization that forms the basis of multithreaded computer systems
- To discuss the APIs for the Pthreads, Windows, and Java thread libraries
- To explore several strategies that provide implicit threading
- To examine issues related to multithreaded programming
- To cover operating system support for threads in Windows and Linux

Contents

Contents

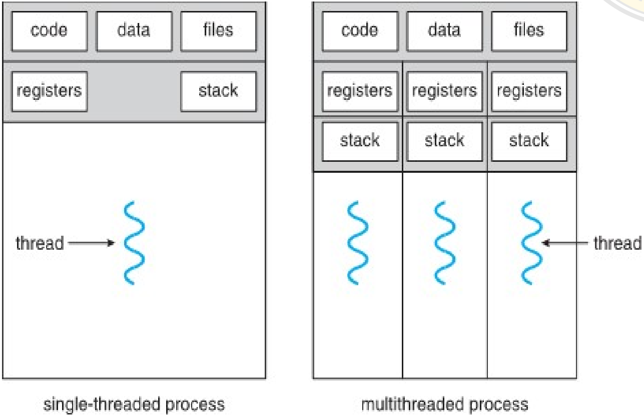
Overview

Motivation

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

Overview

Single and Multithreaded Processes



Overview

Benefits

- Responsiveness — may allow continued execution if part of process is blocked, especially important for user interfaces

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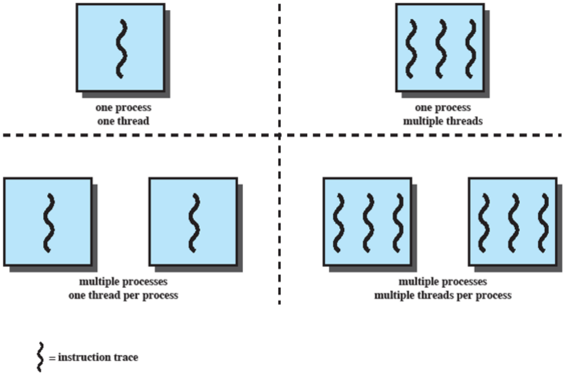
- Economy — cheaper than process creation, thread switching lower overhead than context switching
- Scalability — process can take advantage of multiprocessor architectures

Overview

Multithreading

MS-DOS	JRE
UNIX	most OS



Contents

Multicore Programming

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

Multicore Programming

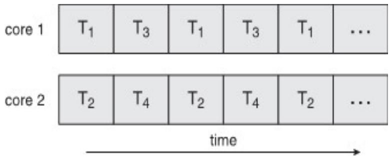
- **Multicore** or **multiprocessor** systems putting pressure on programmers, challenges include:
  - Dividing activities
  - Balance
  - Data splitting
  - Data dependency
  - Testing and debugging
- **Parallelism** implies a system can perform more than one task simultaneously
- **Concurrency** supports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

Multicore Programming

Concurrency Vs. Parallelism

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

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



Multicore Programming

- 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

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  - CPUs have cores as well as hardware threads
  - Consider Oracle SPARC T4 with 8 cores, and 8 hardware threads per core

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- As ♯ of threads grows, so does architectural support for threading
  - CPUs have cores as well as hardware threads
  - Consider Oracle SPARC T4 with 8 cores, and 8 hardware threads per core
- How much performance can we gain from adding additional cores? Suppose we have N processing cores.

Multicore Programming

Amdahl's Law

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- N processing cores

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- 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

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Multithreading Models

User Threads and Kernel Threads

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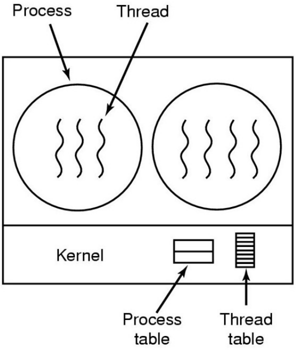
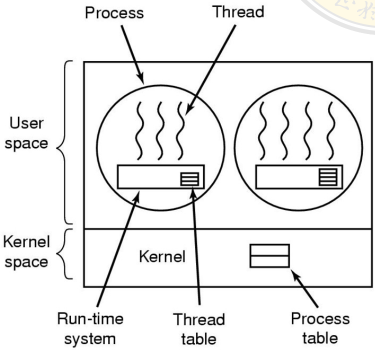
- Three primary thread libraries:
  - POSIX **Pthreads**
  - Windows threads
  - Java threads
- **Kernel threads** - Supported by the Kernel
- Examples — virtually all general purpose operating systems, including:
  - Windows
  - Solaris
  - Linux
  - Tru64 UNIX
  - Mac OS X

Multithreading Models

Implementing Threads in Kernel/User Space



Kernel Threads



User Threads

Multithreading Models

Motivating Kernel/User Threads

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Multithreading Models

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  - However, blocking one thread will not cause other threads of the same process to block. The kernel simply runs other threads.

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  - In a multiprocessor environment, the kernel can schedule threads on different processors
- Why kernel threads are not enough?
  - Kernel threads are usually slower than the user threads.

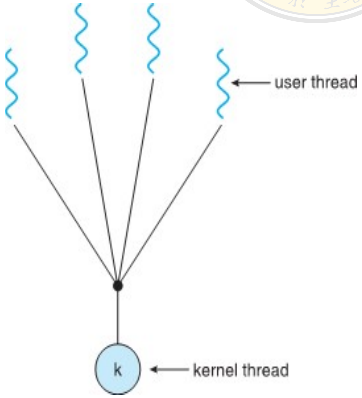
Multithreading Models

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

Multithreading Models

Many-to-One

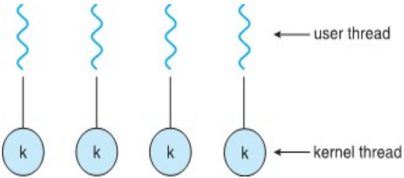
- Many user-level threads mapped to single kernel thread
- One thread blocking causes all to block
- Multiple threads may not run in parallel on multicore system
- Used on systems that do not support kernel threads.
- Few systems currently use this model



Multithreading Models

One-to-One

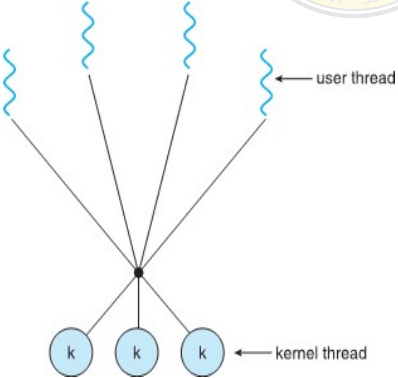
- Each user-level thread maps to kernel thread
- Creating a user-level thread creates a kernel thread
- More concurrency than many-to-one
- Number of threads per process sometimes restricted due to overhead



Multithreading Models

Many-to-Many

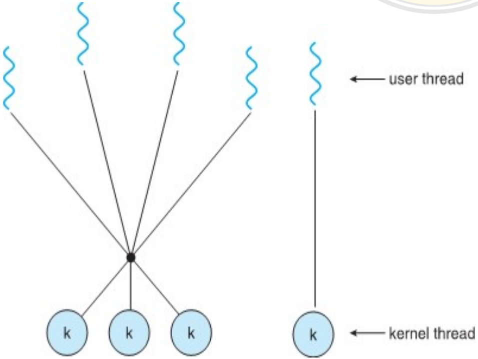
- Allows many user level threads to be mapped to many kernel threads
- Allows the operating system to create a sufficient number of kernel threads



Multithreading Models

Two-Level Model

- Similar to M:M, except that it allows a user thread to be bound to kernel thread



Multithreading Models

Aside

- Among the three models, which model(s) are general in modern systems?
  - M:M for server
  - 1:1 for PC
    - To improve LinuxThreads, two competing projects were started to develop a replacement; NGPT (Next Generation POSIX Threads from IBM) and NPTL (Native POSIX Thread Library from Red Hat). NPTL won out and is today shipped with the vast majority of Linux systems
    - NGPT M:M
    - NPTL 1:1

Contents

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
- Three main thread libraries
  - **POSIX Pthreads**
  - Windows
  - Java

Thread Libraries

Pthreads

- May be provided either as user-level or kernel-level
- A POSIX standard (IEEE 1003.1c) API for thread creation and synchronization

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Thread Libraries

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 (Solaris, Linux, Mac OS X)

Thread Libraries

Pthread Creation

```c
#include <pthread.h>
int
pthread_create( pthread_t *       thread,
         const   pthread_attr_t  *attr,
                 void *           (*start_routine) (void*),
                 void *           arg);
```

1. Which thread is to be created?
   - A pointer to structure of this thread.
2. What kind of thread is it?
   - The stack size and priority information, etc.
3. How to run the thread?
   - The thread entry function (function pointer in C).
4. With what arguments?
   - arg.

Thread Libraries

Pthread Creation — What is the Output?

```
#include <pthread.h>

typedef struct __myarg_t {
        int a;
        int b;
} myarg_t;

void *mythread(void *arg) {
        myarg_t *m = (myarg_t *) arg;
        printf("%d %d\n", m->a, m->b);
        return NULL;
}

int main(int argc, char *argv[]) {
        pthread_t p;
        int rc;
        myarg_t args;
        args.a = 10;
        args.b = 20;
        rc = pthread_create(&p, NULL, mythread, &args);
        ...
}
```

Thread Libraries

Pthread Completion

```
#include <pthread.h>
int
pthread_join(    pthread_t *      thread,
                 void **          value_ptr);
```

1. Which thread is to be completed?
   - A pointer to structure of this thread.
2. What is the return value?
   - void **value_ptr.

Thread Libraries

Pthread Completion — What is the Output?

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

typedef strct __myarg_t {
  int a;
  int b;
} myarg_t;

typedef struct __myret_t {
  int x;
  int y;
} myret_t;

void *mythread(void *arg) {
  myarg_t *m = (myarg_t *) arg;
  printf("%d %d\n", m->a, m->b);
  myret_t *r = Malloc(sizeof(
        myret_t));
  r->x = 1;
  r->y = 2;
  return (void *) r;
}
```

```c
int main(int argc, char *argv[]) {
  int rc;
  pthread_t p;
  myret_t *m;
  myarg_t args;
  args->a = 10;
  args->b = 20;
  Pthread_create(&p, NULL,
        mythread, &args);
  Pthread_join(p, (void **) &m);
  printf("returned %d %d\n", m->x,
        m->y);
  return 0;
}
```

Thread Libraries

Windows Multithreaded C Program

```c
#include <windows.h>
#include <stdio.h>
DWORD Sum;
DWORD WINAPI Summation(LPVOID Param) {
  DWORD Upper = *(DWORD *) Param;
  for (DWORD i = 0; i <= Upper; i++)
    Sum+=i;
  return 0;
}

int main(int argc, char *argv[]) {
  DWORD ThreadId;
  HANDLE ThreadHandle;
  int Param;
  if (argc != 2) {
    fprintf(stderr, "argc!=2\n");
    return -1;
  }
  Param = atoi(argv[1]);
  if (Param < 0) {
    fprintf(stderr, "Param<0\n");
    return -1;
  }
```

```c
/* 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);
  }
}
```

Thread Libraries

Java Threads

- Java threads are managed by the JVM
- Typically implemented using the threads model provided by underlying OS
- Java threads may be created by:

```
public interface Runnable {
        public abstract void run();
}
```

- Extending Thread class
- Implementing the Runnable interface

Thread Libraries

Java Multithreaded Program

```
class Sum {
  private int sum;
  public int getSum() {
    return sum;
  }
  public void setSum(int sum) {
    this.sum = sum;
  }
}
class Summation implements Runnable {
  private int upper;
  private Sum sumValue;
  public Summation(int upper, Sum sumValue) {
    this.upper = upper;
    this.sumValue = sumValue;
  }
  public void run() {
    int sum = 0;
    for (int i = 0; i <= upper; i ++)
      sum += i;
    sumValue.setSum(sum);
  }
}
```

Thread Libraries

Java Multithreaded Program (contd.)

```java
public class Driver {
  public static void main(String[] args) {
    if (args.length > 0) {
      if (Integer.parseInt(args[0]) < 0)
        System.err.println(args[0] + "must be >= 0.");
      else {
        Sum sumObject = new Sum();
        int upper = Integer.parseInt(args[0]);
        Thread thrd = new Thread(new Summation(upper, sumObject));
        thrd.start();
        try {
          thrd.join();
          System.out.println("The sum of " + upper + " is " + sumObject.getSum());
        } catch (InterruptedException ie) {}
      }
    }
    else
      System.err.println("Usage: Summation <integer value>");
  }
}
```

In Class Exercise

What are Possible Outputs?

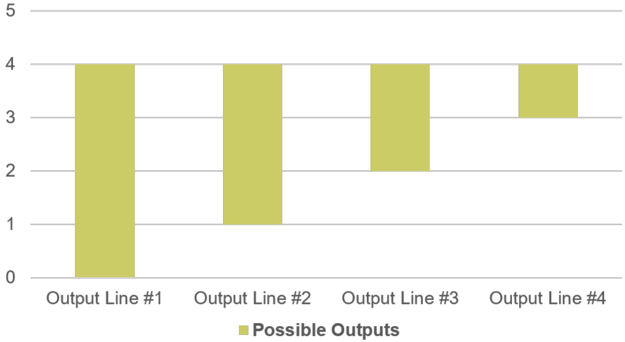
```
void *helloFunc(void *ptr) {
        int *data;
        data = (int *) ptr;
        printf("I'm Thread %d\n", *data);
}

int main(int argc, char *argv[]) {
        pthread_t hThread[4];
        for (int i = 0; i < 4; i ++)
                pthread_create(&hThread[i], NULL, helloFunc, (void *) &i);
        for (int i = 0; i < 4; i ++)
                pthread_join(hThread[i], NULL);
        return 0;
}
```

In Class Exercise

Key

Non-decreasing sequence satisfying ...



Contents

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

Implicit Threading

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.
         */
}
```

Contents

Threading Issues

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

Threading Issues

Semantics of fork() and exec()

- If one thread in a program calls *fork*(), does the new process duplicate all threads, or is the new process single-threaded?
  - Two versions of *fork*().

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- Discussion: If *exec*() is called immediately after forking, which version of *fork*() do you prefer?

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  - Two versions of *fork*().
- What about *exec*()?
  - Replace the entire process, including all thread.
- Discussion: If *exec*() is called immediately after forking, which version of *fork*() do you prefer?
  - If *exec*() is called immediately after forking, then duplicating all threads is unnecessary

Threading Issues

Thread Cancellation

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- 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 canceled
- 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);
```

Threading Issues

Thread Cancellation (contd.)

- Invoking thread cancellation requests cancellation, but actual cancellation depends on thread state

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- Default type is deferred
  - Cancellation only occurs when thread reaches cancellation point
    - i.e., *pthread_testcancel*()
    - Then cleanup handler is invoked

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    - i.e., *pthread_testcancel*()
    - Then cleanup handler is invoked
- On Linux systems, thread cancellation is handled through signals

Threading Issues

Signal Handling

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- A signal handler is used to process signals
  - Signal is generated by particular event
  - Signal is delivered to a process
  - Signal is handled by one of two signal handlers:
    - default
    - user-defined

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- A signal handler is used to process signals
  - Signal is generated by particular event
  - Signal is delivered to a process
  - Signal is handled by one of two signal handlers:
    - default
    - user-defined
- 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

Threading Issues

Signal Handling (contd.)

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- Discussion: Can a thread have its own handler?
  - All threads in a process share a same signal handler, which can be either a default one or a user-defined one (overridden).

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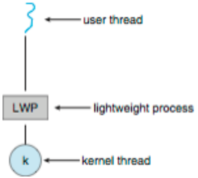

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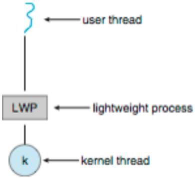

- Scheduler activations provide upcalls - a communication mechanism from the kernel to the upcall handler in the thread library. (vs. downcalls)
- This communication allows an application to maintain the correct number kernel threads

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Scheduler Activations (contd.)

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- After returning from upcall handling, how many LWPs now?
- If we wish to run this application efficiently, how many LWPs are needed for this application.