



Operating System Concepts

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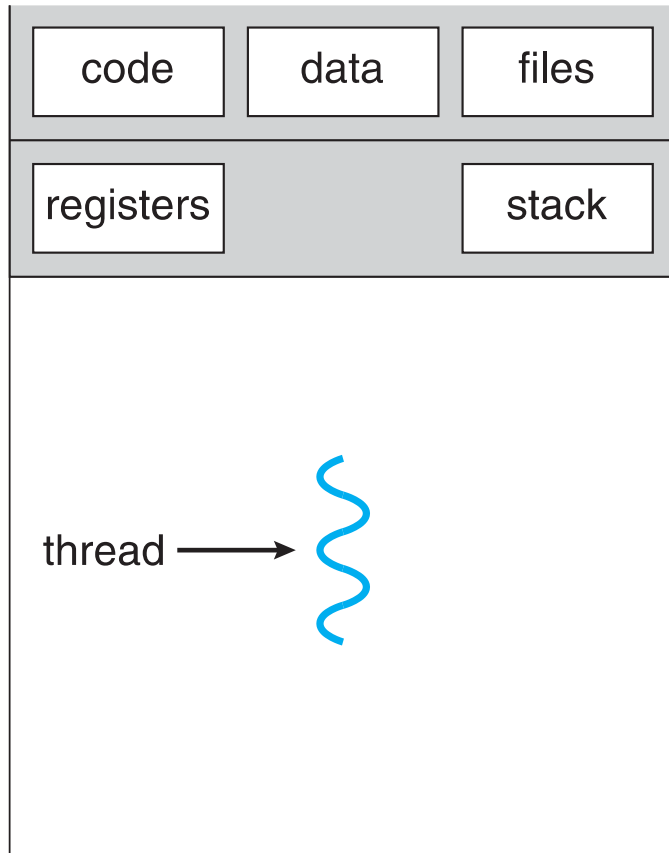
Chapter 4. Multithreaded Programming

Objectives

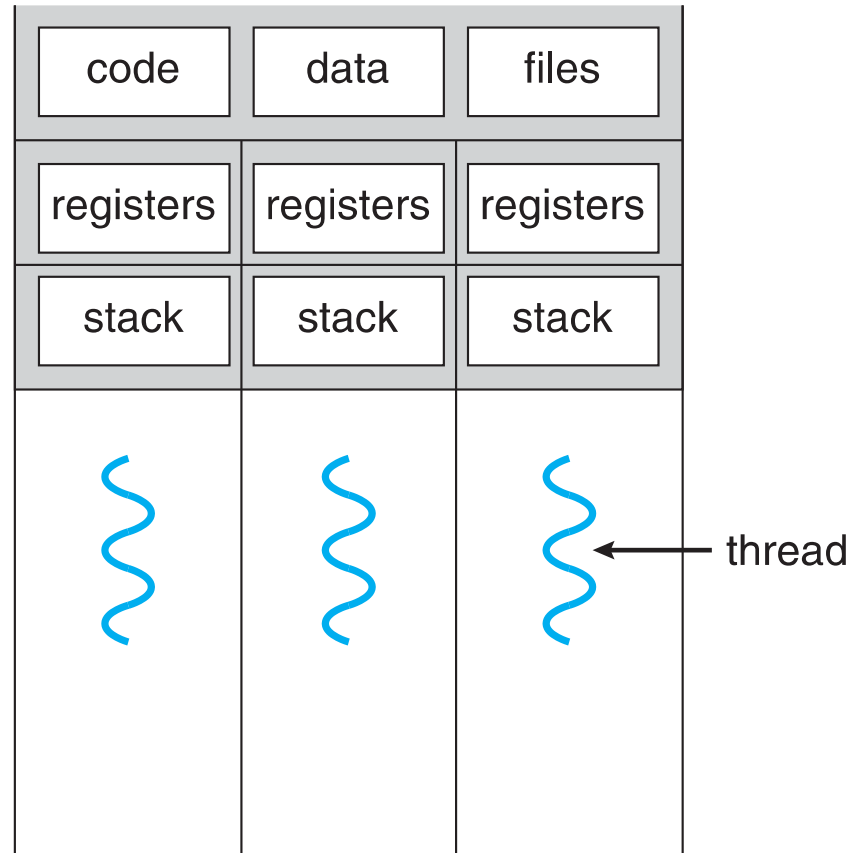
- ▶ To introduce the notion of a thread
- ▶ To discuss the APIs for the Pthreads, Windows, and Java thread libraries
- ▶ To explore several strategies that provide implicit threading
- ▶ To examine issues related to multithreaded programming



Single and Multithreaded Processes



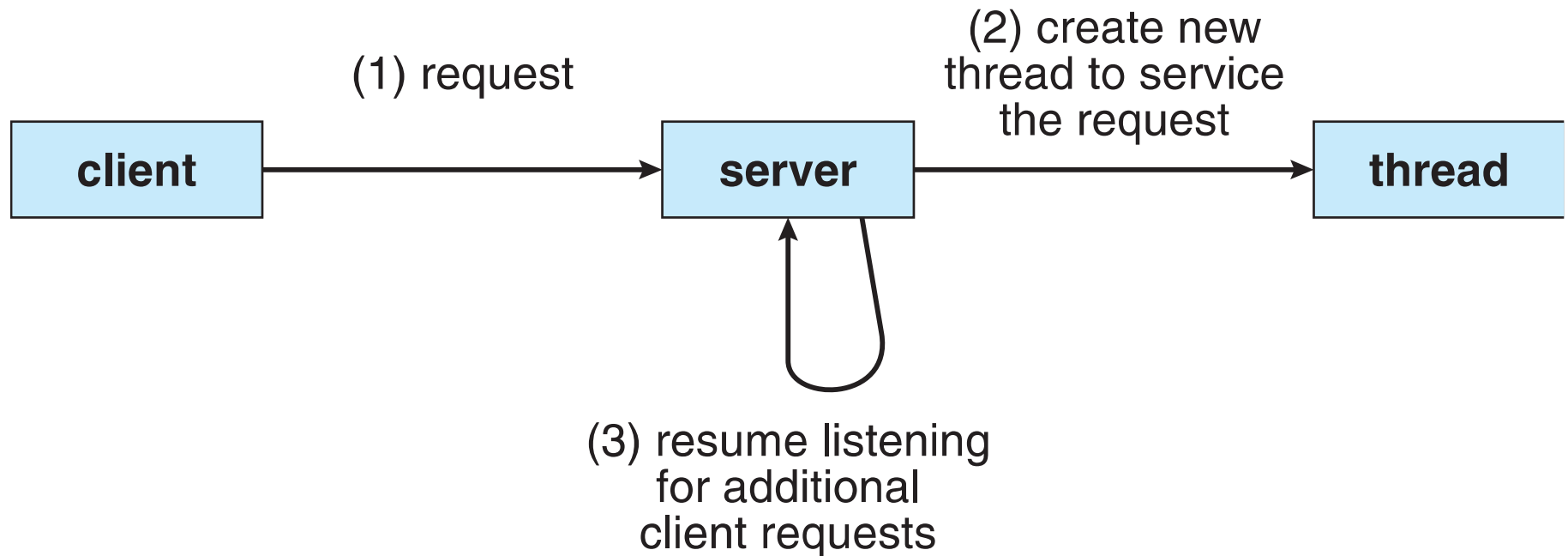
single-threaded process



multithreaded process



Multithreaded Server Architecture



Motivation

- ▶ Most modern applications are multithreaded
- ▶ Multiple tasks with the application can be implemented by separate threads
 - Update display
 - Fetch data
 - Spell checking
- ▶ Process creation is heavy-weight while thread creation is light-weight
- ▶ Kernels are generally multithreaded



Benefits

▶ Responsiveness

- It allows a program to continue running even if part of it is blocked or is performing a lengthy operation

▶ Resource Sharing

- Threads share resources of process, easier than shared memory or message passing

▶ Economy

- Thread creation is cheaper than process creation
- Thread switching overhead is lower than context switching

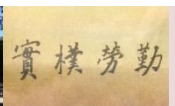
▶ Scalability

- Threads can efficiently use multiprocessor architectures



Multicore Programming

- ▶ Motivation: the popularity of multiple computing cores per system
 - Multithreaded Programming
- ▶ Challenges in Programming
 - Dividing Activities
 - Load Balancing
 - Data Splitting
 - Data Dependency
 - Testing and Debugging



User Threads and Kernel Threads

▶ User threads

- Management done by user-level threads library
- Three primary thread libraries:
 - POSIX Pthreads
 - Win32 threads
 - Java threads

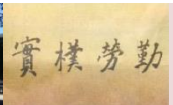
▶ Kernel threads

- Supported by the Kernel
- Examples – virtually all general purpose operating systems, including:
 - Windows, Solaris, Linux, Tru64 UNIX, Mac OS X



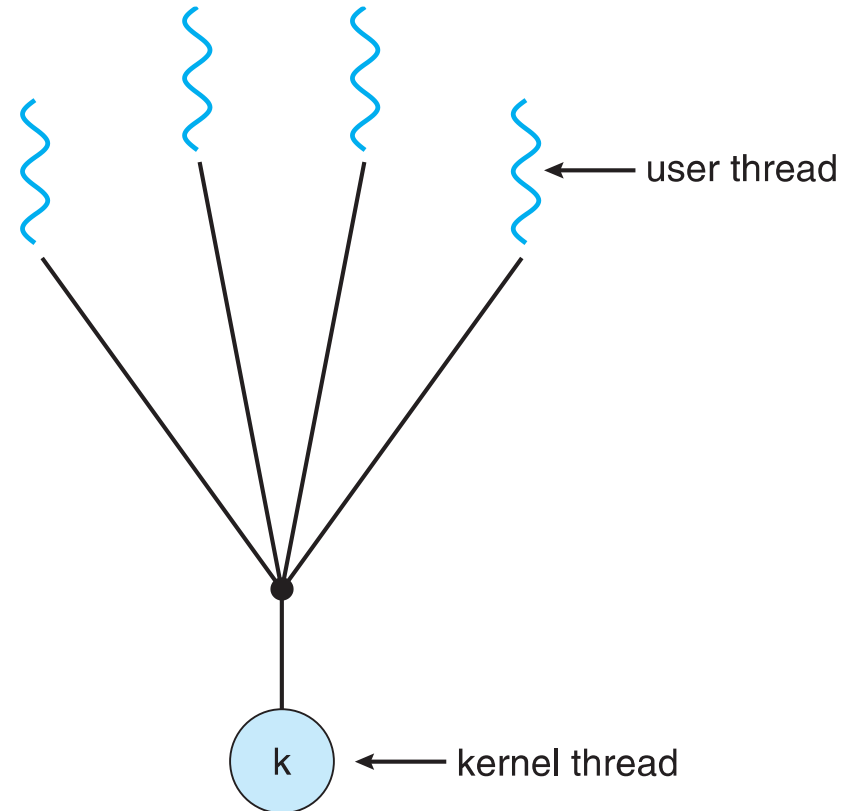
Multithreading Models

- ▶ Relationship between user threads and kernel threads
 - Many-to-One
 - One-to-One
 - Many-to-Many



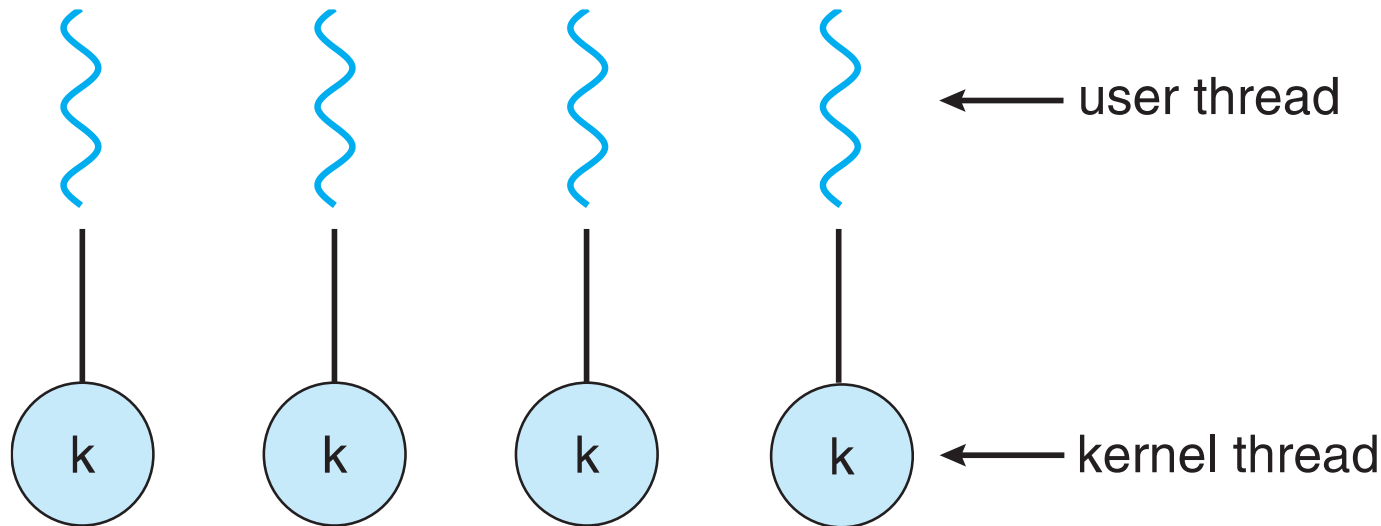
Many-to-One Model

- ▶ Many user threads to one kernel thread
- ▶ Advantage:
 - Efficiency
- ▶ Disadvantage:
 - One blocking system call blocks all
 - No parallelism for multiple processors
- ▶ Example:
 - Solaris Green Threads
 - GNU Portable Threads



One-to-One Model

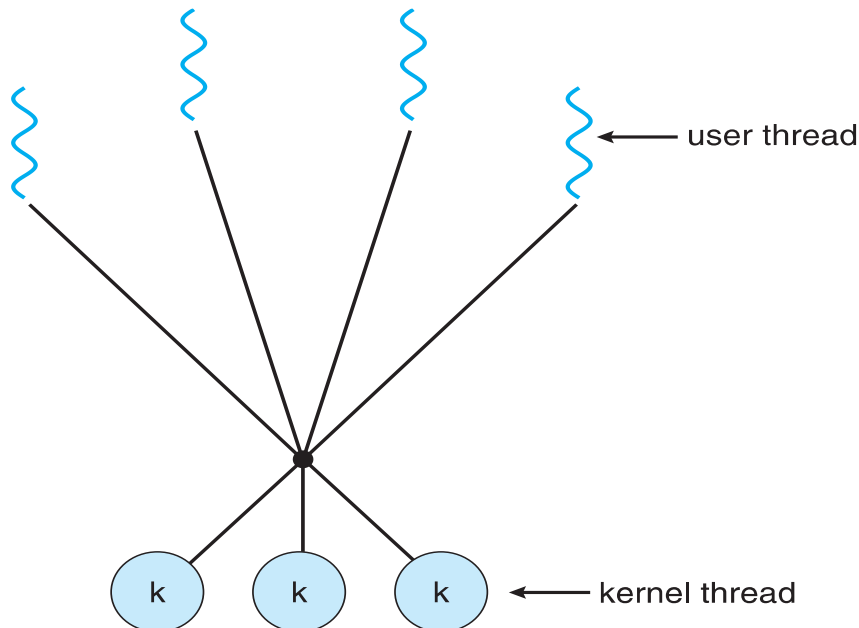
- ▶ One user-level thread to one kernel thread
- ▶ Advantage: One system call blocks one thread
- ▶ Disadvantage: Overheads in creating a kernel thread
- ▶ Example: Windows NT/2000/XP, Linux, Solaris 9



Many-to-Many Model

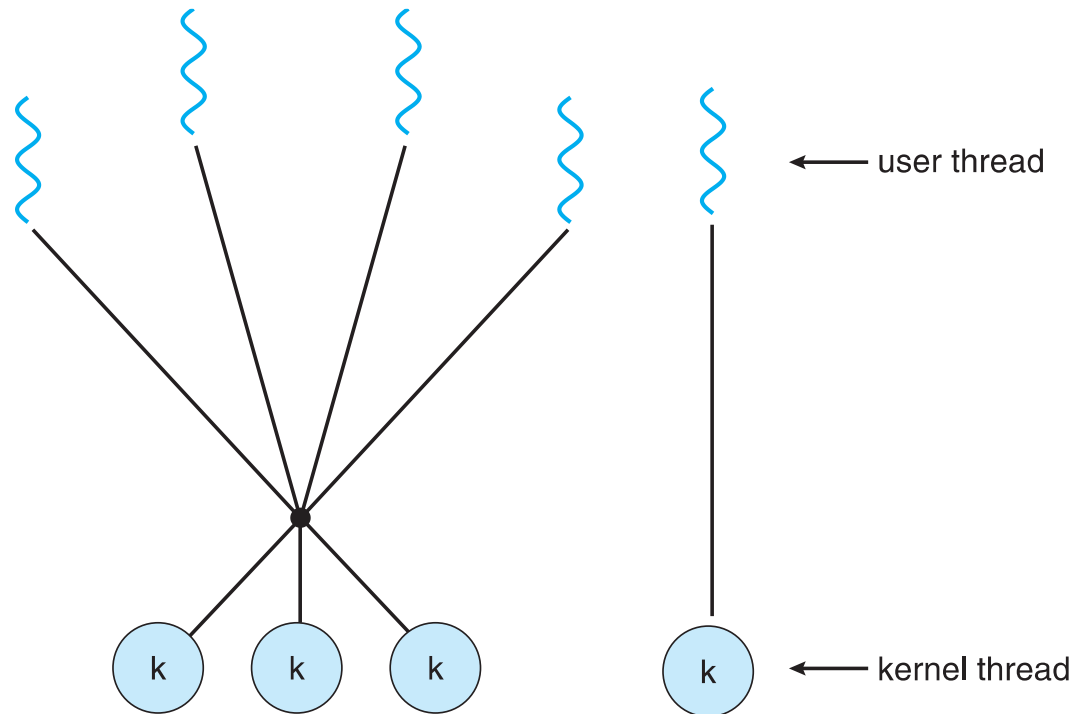
► Many-to-Many Model

- Many user-level threads to many kernel threads
- Advantage: A combination of parallelism and efficiency
- Example: Solaris prior to version 9



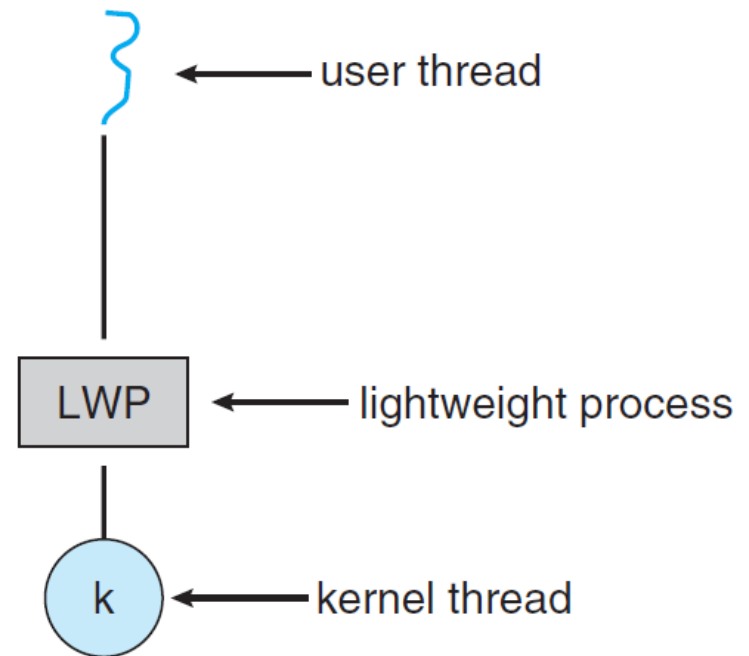
Two-Level Model

- ▶ Similar to the many-to-many model, except that it allows a user thread to be bound to a kernel thread
- ▶ Examples
 - IRIX
 - HP-UX
 - Tru64 UNIX
 - Solaris 8 and earlier



Scheduler Activations

- ▶ Definition: A scheme for the communication between the user-thread library and the kernel
 - The kernel provides a set of virtual processors, i.e., light weight processes (LWP)
 - User threads on a LWP are blocked if any of the user threads is blocked!



Thread Libraries

- ▶ The goal thread libraries is to provide an API for creating and managing threads
- ▶ Two Approaches
 - User Thread Library
 - Kernel-Level Thread Library
- ▶ Well-Known Examples
 - POSIX Pthread – User or Kernel Level
 - Win32 thread – Kernel Level
 - Java thread – Level Depending on the Thread Library on the Host System



A Pthread Example (1 / 3)

- ▶ The specification of the example program
 - Read an input integer N
 - Create a thread to calculate the summation from 1 to N
 - Wait for the completion of the thread
 - Print the result from the thread
- ▶ Now, let's use the Pthread library to implement the program



A Pthread Example (2 / 3)

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

Include the header file of pthread

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

```
int main(int argc, char *argv[])
{
```

Declare the function to be executed by the thread

```
    pthread_t tid; /* the thread identifier */
    pthread_attr_t attr; /* set of thread attributes */
```

Create the data-structure to be used by the thread

```
    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;
    }
}
```



A Pthread Example (3 / 3)

```
/* 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);
}
```

Initialize the data-structure to be used by the thread

Create the thread

Wait for the completion of the thread

Define the function to be executed by the thread



Compiling POSIX-Thread Programs

Compiler / Platform	Compiler Command	Description
INTEL	icc -pthread	C
Linux	icpc -pthread	C++
PGI	pgcc -lpthread	C
Linux	pgCC -lpthread	C++
GNU	gcc -lpthread	GNU C
Linux, Blue Gene	g++ -lpthread	GNU C++
IBM	bgxlc_r / bgcc_r	C (ANSI / non-ANSI)
Blue Gene	bgxlC_r, bgxlc++_r	C++



Implicit Threading

- ▶ Implicit threading is growing in popularity as numbers of threads increase
- ▶ Program correctness is more difficult with explicit threads
- ▶ Creation and management of threads done by compilers and run-time libraries rather than programmers
- ▶ Examples
 - OpenMP on Linux, Windows and Mac OS X
 - Grand Central Dispatch on Mac OS X



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



Fork and Exec System Calls

- ▶ When a process consists of multiple threads, does **fork()** duplicate only the calling thread or all threads?
 - Some UNIX systems have two versions of fork()
- ▶ **exec()** usually works as normal— replaces the running process including all threads



Signal Handling

► Two Types of Signals

- Synchronous signal– should be delivered to the same process that performed the operation causing the signal
 - e.g., illegal memory access or division by zero
- Asynchronous signal– can happen at any time point
 - e.g., ^C or timer expiration

► Delivery of a Signal

- To the thread to which the signal applies
 - e.g., division-by-zero
- To every threads in the process
 - e.g., ^C
- To certain threads in the process
- Assign a specific thread to receive all signals for the process



Thread Cancellation

- ▶ A cancellation signal is sent to the target thread
- ▶ Two scenarios for the cancellation:
 - Asynchronous cancellation
 - Immediate cancel the thread
 - Deferred cancellation
 - Wait until some special point of the thread, e.g., cancellation points in Pthread
- ▶ Difficulty
 - Resources have been allocated to a cancelled thread
 - A thread is cancelled while it is updating data



Thread-Local Storage

- ▶ Thread-local storage (TLS) allows each thread to have its own copy of data
- ▶ 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



Windows Threads

- ▶ Windows implements the Windows API— primary API for Win 98, Win NT, Win 2000, Win XP, Win 7, Win 8, and Win 10
- ▶ It implements the one-to-one mapping
- ▶ Each thread contains
 - A thread id
 - Register set representing state of processor
 - Separate user and kernel stacks for when thread runs in user mode or kernel mode
 - Private data storage area used by run-time libraries and dynamic link libraries (DLLs)
- ▶ The register set, stacks, and private storage area are known as the **context** of a thread



Linux Threads

- ▶ The concepts of threads was introduced in version 2.2
- ▶ In Linux
 - Processes and threads are called tasks
 - Any task has a PID (process identifier)
 - If two tasks do not share any data-structure, they are two processes
 - If two tasks share some data-structure, they just like two threads in the same process
 - `fork()` is used to create a new process
 - `clone()` is used to create a new thread
 - Flag setting in `clone()` invocation: `CLONE_FS`, `CLONE_VM`, `CLONE_SIGHAND`, `CLONE_FILES`

