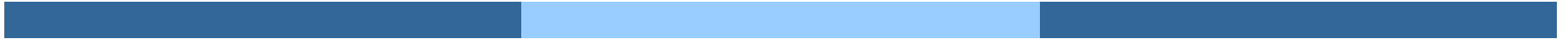


Threads Part 2



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 (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;
    }
}
```

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);
```

Windows Multithreaded C Program

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

/* the thread runs in this separate function */
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, "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;
    }
}
```

Windows Multithreaded C Program (Cont.)

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


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

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);
    }
}
```

Java Multithreaded Program (Cont.)

```
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>"); }
}
```

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

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 removed 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

Semantics of `fork()` and `exec()`

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

Signal Handling

- n **Signals** are used in UNIX systems to notify a process that a particular event has occurred.
- n A **signal handler** is used to process signals
 1. Signal is generated by particular event
 2. Signal is delivered to a process
 3. Signal is handled by one of two signal handlers:
 1. default
 2. user-defined
- n 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

Signal Handling (Cont.)

- n 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

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);
```

Thread Cancellation (Cont.)

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

| Mode | State | Type |
|--------------|----------|--------------|
| Off | Disabled | – |
| Deferred | Enabled | Deferred |
| Asynchronous | Enabled | Asynchronous |

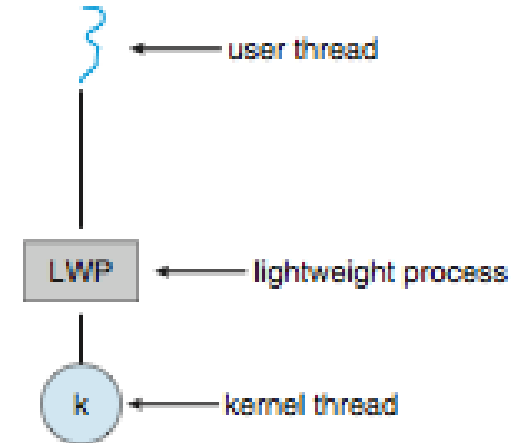
- If thread has cancellation disabled, cancellation remains pending until thread enables it
- Default type is deferred
 - Cancellation only occurs when thread reaches **cancellation point**
 - ▶ I.e. `pthread_testcancel()`
 - ▶ Then **cleanup handler** is invoked
- On Linux systems, thread cancellation is handled through signals

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

Scheduler Activations

- Both M:M and Two-level models require communication to maintain the appropriate number of kernel threads allocated to the application
- Typically use an intermediate data structure between user and kernel threads – **lightweight process (LWP)**
 - Appears to be a virtual processor on which process can schedule user thread to run
 - Each LWP attached to kernel thread
 - How many LWPs to create?
- Scheduler activations provide **upcalls** - a communication mechanism from the kernel to the **upcall handler** in the thread library
- This communication allows an application to maintain the correct number kernel threads



Operating System Examples

- Windows Threads
- Linux Threads

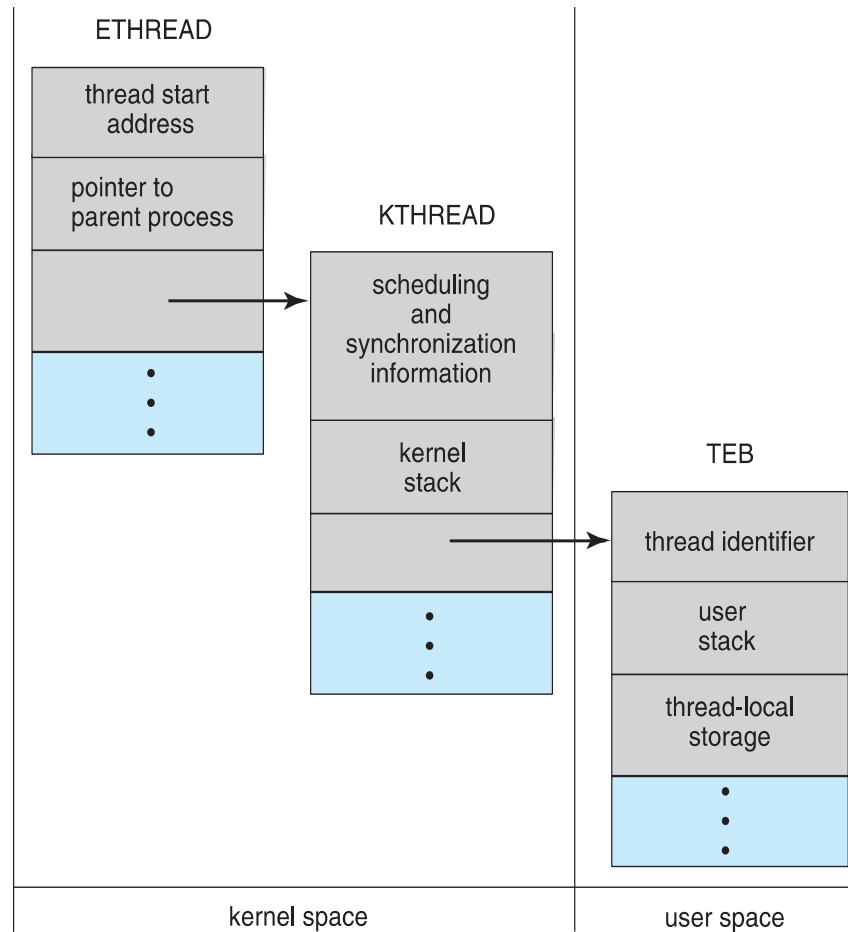
Windows Threads

- ❑ Windows implements the Windows API – primary API for Win 98, Win NT, Win 2000, Win XP, and Win 7
- ❑ Implements the one-to-one mapping, kernel-level
- ❑ 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 the thread

Windows Threads (Cont.)

- The primary data structures of a thread include:
 - ETHREAD (executive thread block) – includes pointer to process to which thread belongs and to KTHREAD, in kernel space
 - KTHREAD (kernel thread block) – scheduling and synchronization info, kernel-mode stack, pointer to TEB, in kernel space
 - TEB (thread environment block) – thread id, user-mode stack, thread-local storage, in user space

Windows Threads Data Structures



Linux Threads

- ❑ Linux refers to them as **tasks** rather than **threads**
- ❑ Thread creation is done through `clone()` system call
- ❑ `clone()` allows a child task to share the address space of the parent task (process)
 - ❑ Flags control behavior

| flag | meaning |
|---------------|------------------------------------|
| CLONE_FS | File-system information is shared. |
| CLONE_VM | The same memory space is shared. |
| CLONE_SIGHAND | Signal handlers are shared. |
| CLONE_FILES | The set of open files is shared. |

- ❑ `struct task_struct` points to process data structures (shared or unique)