CS370 Operating Systems

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Slides based on

- **Text by Silberschatz, Galvin, Gagne**
- **Various sources**

Common Questions

Investigate and see if you can find the answer.

- How many threads can a process spawn?
- If a thread is blocked what happens to the calling process?
- Are they scheduled like processes?
- Why is context switching faster in threads?
- Is the kernel one thread or process?
- Can threads have threads?

Pthreads Example (next 2 slides)

- This process will have two threads
  - Initial/main thread to execute the main ( ) function. It crates a new thread and waits for it to finish.
  - A new thread that runs function runner ( )
    - It will get a parameter, an integer, and will compute the sum of all integers from 1 to that number.
    - New thread leaves the result in a global variable **sum**.
  - The main thread prints the result.

Pthreads Example Pt 1

```
#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);
}
```

Compile using
gcc thrd.c –lpthread

Execution:
%./thrd 4
sum = 10

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);
```

Java Threads

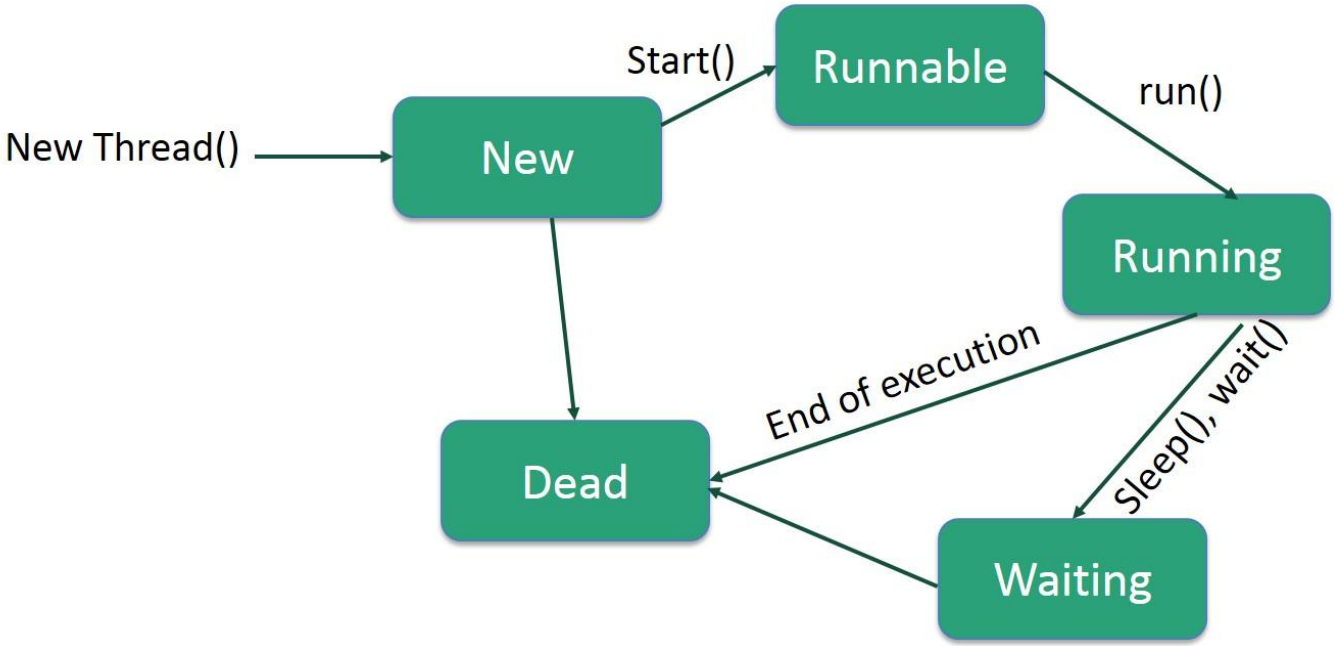
- Java threads are managed by the JVM
- Typically implemented using the threads model provided by underlying OS
- Java threads may be created by:

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

  - Extending Thread class
    - Override its run() method
  - More commonly, implementing the Runnable interface

    1. Has 1 method run()
    2. Create new Thread class by passing a Runnable object to its constructor
    3. start( ) method creates a new thread by calling the run( ) method.

Java Thread States



Ex: Using Java Threads (1)

Java version of a multithreaded program that computes summation of a non-negative integer.

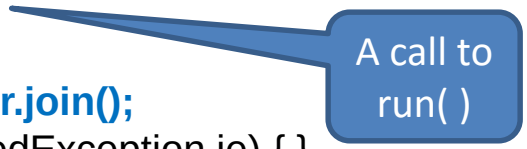
```
class Sum
{
        private int sum;

        public int get() {
                return sum;
        }

        public void set(int sum) {
                this.sum = sum;
        }
}
```

Ex: Using Java Threads (2)

```
class Summation implements Runnable
{
        private int upper;
        private Sum sumValue;

        public Summation(int upper, Sum sumValue) {
                if (upper < 0)
                        throw new IllegalArgumentException();

                this.upper = upper;
                this.sumValue = sumValue;
        }

        public void run() {
                int sum = 0;

                for (int i = 0; i <= upper; i++)
                        sum += i;

                sumValue.set(sum);
        }
}
```

Ex: Using Java Threads (3)

```
public class Driver
{
        public static void main(String[] args) {
                if (args.length != 1) {
                        System.err.println("Usage Driver <integer>");
                        System.exit(0);
                }

                Sum sumObject = new Sum();
                int upper = Integer.parseInt(args[0]);

                Thread worker = new Thread(new Summation(upper, sumObject));
                worker.start();
                try {
                        worker.join();
                } catch (InterruptedException ie) { }
                System.out.println("The sum of " + upper + " is " + sumObject.get());
        }
}
```



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.

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;
}
```

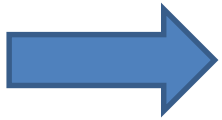
Compile using
gcc -fopenmp openmp.c

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

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



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

- **Signals** are used in UNIX systems to notify a process that a particular event has occurred.
- 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
- 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.)

- 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)
  - Ex: Each transaction has a thread and a transaction identifier is needed.
- 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