

CSE201: Monsoon 2020

Advanced Programming

Lecture 19: Thread Pool

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Last Lecture

- There are two ways to create your own **Thread** object
 - Implementing the **Runnable** interface
 - Subclassing the **Thread** class and instantiating a new object of that class

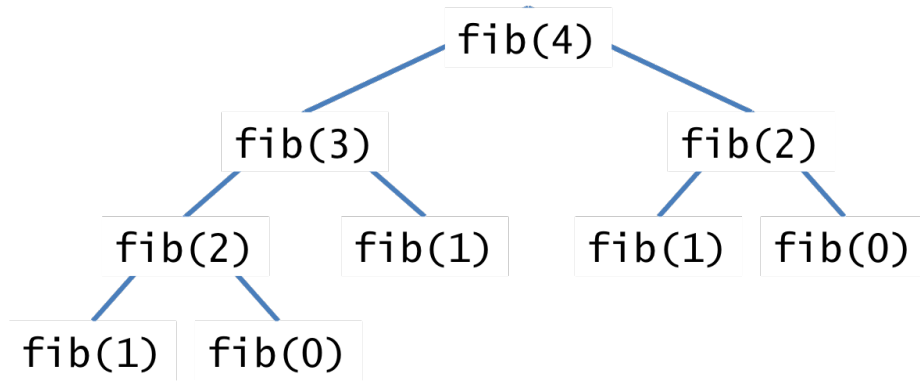
```
public class ArraySum extends Thread {  
    int[] array;  
    int sum, low, high;  
    public ArraySum(int[] arr, int l, int h) {  
        array=arr; sum=0; low=l; high=h;  
    }  
    //assume array.length%2=0  
    @Override  
    public void run() {  
        for(int i=low; i<high; i++)  
            sum += array[i];  
    }  
    public int getResult() { return sum; }  
    public static void main(String[] args)  
        throws InterruptedException {  
        int size; int[] array; //allocated (size) & initialized  
        ArraySum t1 = new ArraySum(array, 0, size/2);  
        ArraySum t2 = new ArraySum(array, size/2, size);  
        t1.start(); t2.start();  
        t1.join(); t2.join();  
        int result = t1.getResult() + t2.getResult();  
    }  
}
```

```
public class ArraySum implements Runnable {  
    int[] array;  
    int sum, low, high;  
    public ArraySum(int[] arr, int l, int h) {  
        array=arr; sum=0; low=l; high=h;  
    }  
    //assume array.length%2=0  
    public void run() {  
        for(int i=low; i<high; i++)  
            sum += array[i];  
    }  
    public int getResult() { return sum; }  
    public static void main(String[] args)  
        throws InterruptedException {  
        int size; int[] array; //allocated (size) & initialized  
        ArraySum left = new ArraySum(array, 0, size/2);  
        ArraySum right = new ArraySum(array, size/2, size);  
        Thread t1 = new Thread(left);  
        Thread t2 = new Thread(right);  
        t1.start(); t2.start(); right.run();  
        t1.join(); t2.join();  
        int result = left.getResult() + right.getResult();  
    }  
}
```

Changes for using only one thread along with the main thread

- **Multiple inheritance is not allowed in Java** hence if our ArraySum class extends Thread then it cannot extend any other class. By implementing Runnable our ArraySum can easily extend any other class
- **Subclassing is used in OOP to add additional feature**, modifying or improving behavior. If no modifications are being made to Thread class then use Runnable interface
- **Thread can only be started once**. Runnable is better as same object could be passed to different threads
- If just run() method has to be provided then **extending Thread class is an overhead for JVM**

Think Tasks, not Threads



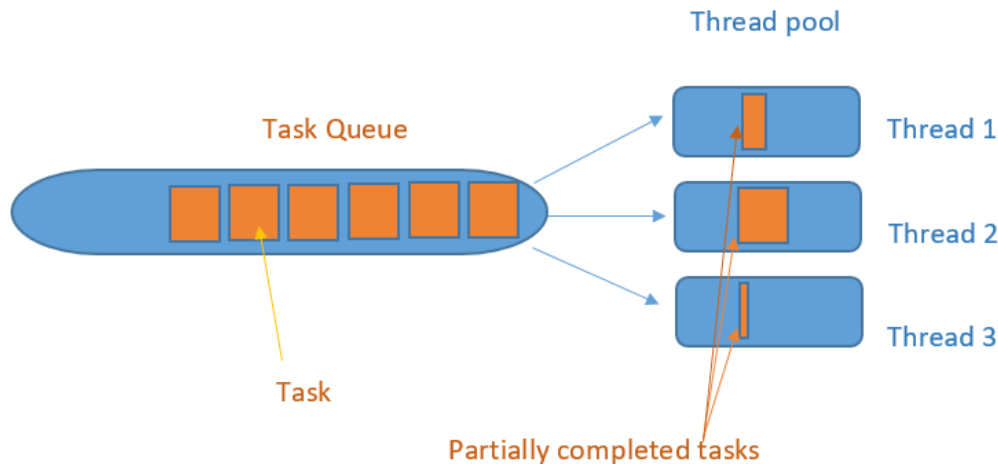
- Tasks are logic unit of work
- Threads are mechanism by which tasks can run asynchronously
- E.g., for calculating Fibonacci number (Lecture 18), each node in this tree represents one task
- Tasks are lightweight than a thread !
 - Why ?

Mapping Tasks to Cores

- Generally

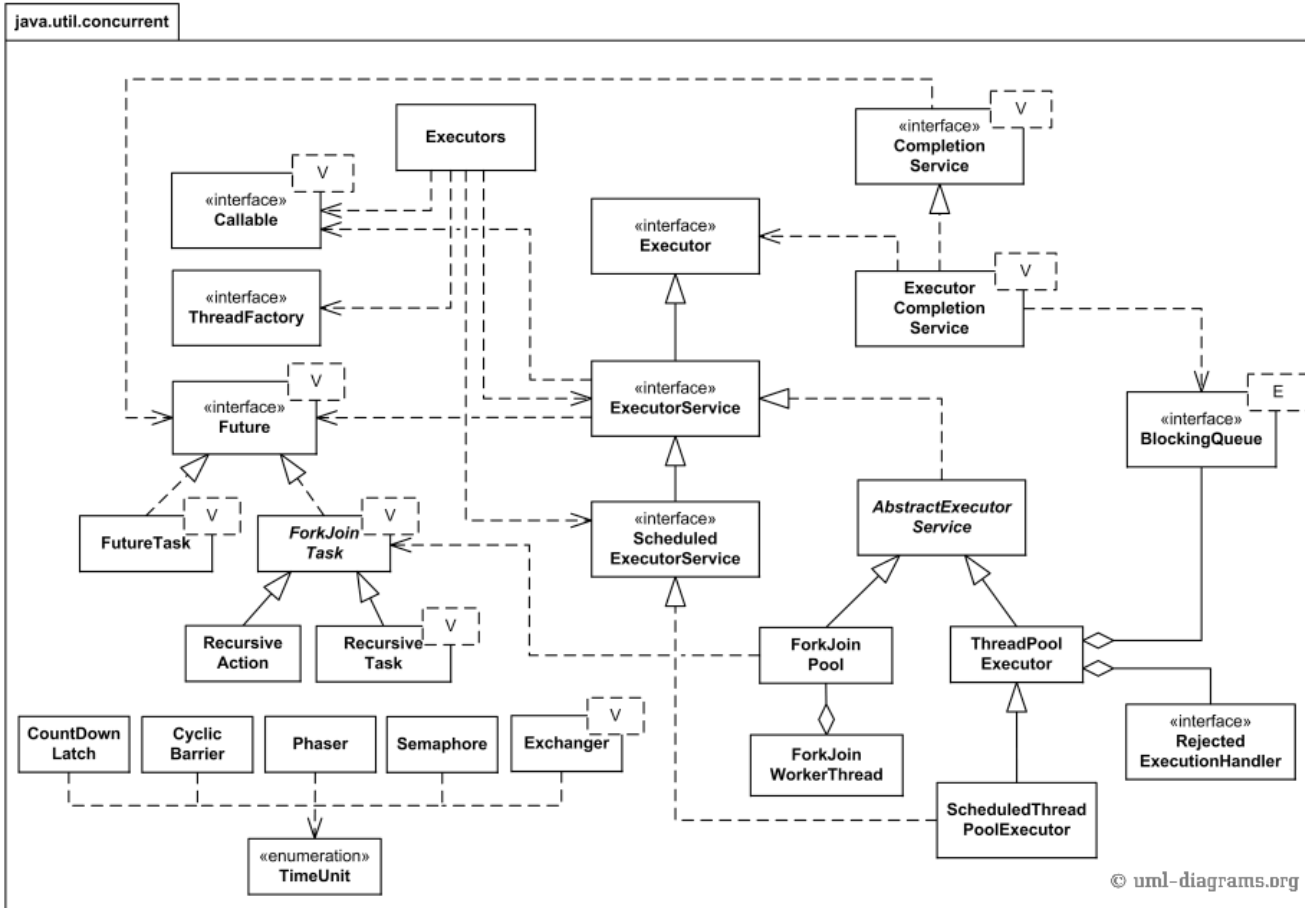
- # of tasks \geq threads available
- parallel algorithm must map tasks to threads
- schedule independent tasks on separate threads (consider computation graph)
- threads should have minimum interaction with one another

Thread Pool



- Thread-pool consists of a fixed number of threads
 - Provided by the Java runtime
- User application creates “task” rather than threads
- These tasks are added to a task-pool
- Free threads from thread-pool takes out a task from task-pool and execute it

Package java.util.concurrent



- Framework for concurrent programming
- In this course we will only introduce a few basic features of this framework

ExecutorService Interface

- An ExecutorService is a group of thread objects (thread pool), each running some variant of the following
 - `while (....) { get work and run it; }`
- ExecutorService take responsibility for the threads they create
 - User starts and shuts down ExecutorService
 - ExecutorService starts and shut down threads
- Method `execute(Runnable object)`
 - Accepts task as a Runnable type object that is executed by a thread in thread pool
- Method `shutdown()`
 - Thread pool terminates once all pre-submitted tasks are executed

Executors Class

- Provides factory and utility methods for `ExecutorService`
- Static method `newFixedThreadPool(int num_threads)`
 - Creates a thread pool that reuses a fixed number of threads for task execution

Let's Revisit Our Parallel Array Sum

```
public class ArraySum implements Runnable {
    int[] array;
    int sum, low, high;
    public ArraySum(int[] arr, int l, int h) {
        array=arr; sum=0; low=l; high=h;
    }
    //assume array.length%2=0
    public void run() {
        for(int i=low; i<high; i++)
            sum += array[i];
    }
    public int getResult() { return sum; }
    public static void main(String[] args)
        throws InterruptedException {
        int size; int[] array; //allocated (size) & initialized
        ExecutorService exec =
Executors.newFixedThreadPool(2);
        ArraySum left = new ArraySum(array, 0, size/2);
        ArraySum right = new ArraySum(array, size/2, size);
exec.execute(left); exec.execute(right);
if(!exec.isTerminated()) {
    exec.shutdown();
    exec.awaitTermination(5L, TimeUnit.SECONDS);
}
        int result = left.getResult() + right.getResult();
    } }
}
```

● ExecutorService methods:

- `isTerminated()`
 - Returns true if all tasks are terminated following the shutdown
- `awaitTermination(long timeout, TimeUnit unit)` throws `InterruptedException`
 - Blocks until all tasks have completed execution after a shutdown request

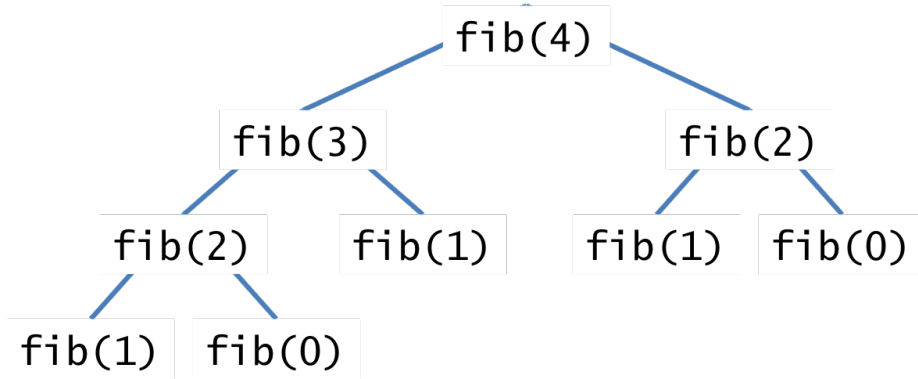
● Important that you wait for all tasks to terminate after a shutdown request

Let's Revisit Our Multithreaded Server

```
import java.io.*; import java.net.*;
import java.util.concurrent.*;
public class Server {
    public static void main(String args[ ])
        throws IOException {
        /* create a server socket
           bound to the specified port 1234 */
        ServerSocket me = new ServerSocket(1234);
        /* Server is now listening
           for incoming client's request */
        ExecutorService exec =
        Executors.newFixedThreadPool(2);
        while (true) {
            /* Connection is established */
            Socket connection = me.accept();
            System.out.println("Connected");
            Runnable task = new
            ConnectionHandler(connection);
            /* new Thread(task).start(); */
            exec.execute(task);
        }
    }
}
```

- Rather than creating a new thread for every incoming client connection, we will instead create a new task and submit it to thread pool
 - No other changes to Server.java or Client.java
- Now our server will not go crazy even if several clients are lined up simultaneously

How to Improve Parallel Fibonacci?



- We know that there is a lot of parallelism and hence its not efficient to just create two tasks, i.e., one task for `fib(n-1)` and another task for `fib(n-2)`
- Every node in this tree can be computed in parallel
- Recursive divide and conquer application!

ForkJoinPool

- Designed to support a common need
 - Recursive divide and conquer pattern
 - For small problems (below cutoff threshold), execute sequentially
 - For larger problems
 - Define a task for each subproblem
 - Library provides
 - A Thread manager, called a ForkJoinPool
 - Methods to send your subtask objects to the pool to be run, and your call waits until they are done
 - The pool handles the multithreading well
- The “thread manager”
 - Used when calls are made to RecursiveTask’s methods fork(), invokeAll(), etc.

Parallel Fibonacci Using ForkJoinPool

```
import java.util.concurrent.*;  
  
public class Fibonacci extends RecursiveAction {  
    int n, result;  
    public Fibonacci(int _n, int _r) { n=_n; result=_r; }  
  
}
```

● Step-1

- o Fibonacci class should extend the class RecursiveAction
- o RecursiveAction represents a task that doesn't return any result

Parallel Fibonacci Using ForkJoinPool

```
import java.util.concurrent.*;

public class Fibonacci extends RecursiveAction {
    int n, result;
    public Fibonacci(int _n, int _r) { n=_n; result=_r; }

    public void compute() {
        if(n<2) {
            this.result = n;
            return;
        }
        Fibonacci left = new Fibonacci(this.n-1);
        Fibonacci right = new Fibonacci(this.n-2);

    }
}
```

● Step-2

- Implement the method “public void compute()”
 - Similar to run() method
- Computes the recursive divide and conquer task
- Similar to Runnable implementation of Fibonacci, create the two tasks. One for calculating fib(n-1) while the other for calculating fib(n-2)

Parallel Fibonacci Using ForkJoinPool

```
import java.util.concurrent.*;

public class Fibonacci extends RecursiveAction {
    int n, result;
    public Fibonacci(int _n, int _r) { n=_n; result=_r; }

    public void compute() {
        if(n<2) {
            this.result = n;
            return;
        }
        Fibonacci left = new Fibonacci(this.n-1);
        Fibonacci right = new Fibonacci(this.n-2);
        left.fork();

    }
}
```

● Step-3

- Start the first task (“left”) **asynchronously**
- Calling the fork() method on one of the task is similar to calling start() on a thread.
- However, fork() does not start any new thread but rather adds this task to the task pool
 - Similar to calling execute() from ExecutorService

Parallel Fibonacci Using ForkJoinPool

```
import java.util.concurrent.*;

public class Fibonacci extends RecursiveAction {
    int n, result;
    public Fibonacci(int _n, int _r) { n=_n; result=_r; }

    public void compute() {
        if(n<2) {
            this.result = n;
            return;
        }
        Fibonacci left = new Fibonacci(this.n-1);
        Fibonacci right = new Fibonacci(this.n-2);
        left.fork();
        right.compute();

    }
}
```

● Step-4

- Start the second task (“right”) **sequentially**, i.e. on the current thread
- Why not start this also with fork() ?
 - Not an error and you can definitely do so
 - However, the current thread is already done with current task (the compute() method) hence it can be reused to directly compute the “right” task

Parallel Fibonacci Using ForkJoinPool

```
import java.util.concurrent.*;

public class Fibonacci extends RecursiveAction {
    int n, result;
    public Fibonacci(int _n, int _r) { n=_n; result=_r; }

    public void compute() {
        if(n<2) {
            this.result = n;
            return;
        }
        Fibonacci left = new Fibonacci(this.n-1);
        Fibonacci right = new Fibonacci(this.n-2);
        left.fork();
        right.compute();
        left.join();
        this.result = left.result + right.result;
    }
}
```

● Step-5

- Once the “right” task completes, compute method should wait for all the asynchronous tasks spawned inside it (i.e. “left” task)
- `left.join()` is a blocking operation and will return only when “left” has terminated
 - Similar to `thread.join()` but this waits for a “task” to terminate rather than a “thread”
- Sum the partial results

Parallel Fibonacci Using ForkJoinPool

```
import java.util.concurrent.*;

public class Fibonacci extends RecursiveAction {
    int n, result;
    public Fibonacci(int _n, int _r) { n=_n; result=_r; }

    public void compute() {
        if(n<2) {
            this.result = n;
            return;
        }
        Fibonacci left = new Fibonacci(this.n-1);
        Fibonacci right = new Fibonacci(this.n-2);
        left.fork();
        right.compute();
        left.join();
        this.result = left.result + right.result;
    }
    public static void main(String[] args) {
        ForkJoinPool pool = new ForkJoinPool(2);
        Fibonacci task = new Fibonacci(40);
        pool.invoke(task);
        int result = task.result;
    }
}
```

● Step-6

- Create a ForkJoinPool type thread pool with fixed number of threads
- Create the root task (see the binary tree representation for Fibonacci)
- Add this root task in the **task pool**
 - `pool.invoke`
 - Blocking operation and doesn't return until all tasks are terminated
- A free thread from thread pool will execute this task and recursively create new tasks that will in turn be added to the task pool

Using RecursiveTask<T> to Return Value

```
import java.util.concurrent.*;

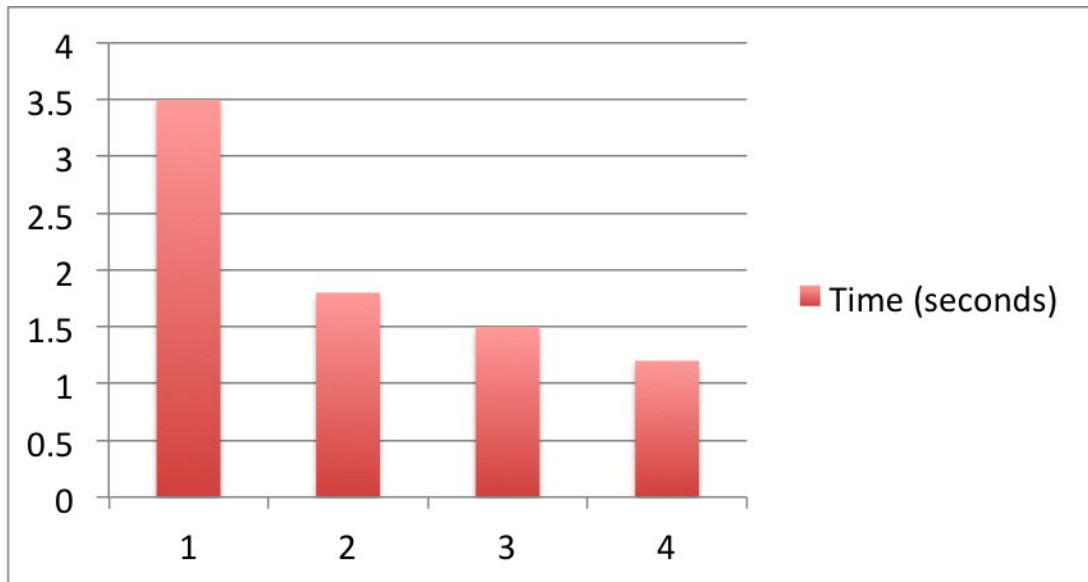
public class Fibonacci extends RecursiveTask<Integer> {
    int n;
    public Fibonacci(int _n) { n=_n; }

    public Integer compute() {
        if(n<2) return n;

        Fibonacci left = new Fibonacci(this.n-1);
        Fibonacci right = new Fibonacci(this.n-2);
        left.fork();
        return right.compute() + left.join();
    }
    public static void main(String[] args) {
        ForkJoinPool pool = new ForkJoinPool(2);
        Fibonacci task = new Fibonacci(40);
        int result = pool.invoke(task);
    }
}
```

- RecursiveTask<T> is better suited in scenarios where there is a need to return results from each task (same return type for all tasks)
- Very minimal changes required to our Fibonacci program to use this feature

Performance of Our Parallel Fibonacci



Total Threads in ForkJoinPool

- Increasing the thread pool size decreases the execution time
- 0 4 core processor

Too Many Tasks Hamper Performance

```
import java.util.concurrent.*;

public class Fibonacci extends RecursiveTask<Integer> {
    int n;
    static int threshold = 10;
    public Fibonacci(int _n) { n=_n; }
    private int sequential(int n) {
        if(n<2) return n;
        else return sequential(n-1) + sequential(n-2);
    }
    public Integer compute() {
        if(n<threshold) return sequential(n);

        Fibonacci left = new Fibonacci(this.n-1);
        Fibonacci right = new Fibonacci(this.n-2);
        left.fork();
        return right.compute() + left.join();
    }
    public static void main(String[] args) {
        ForkJoinPool pool = new ForkJoinPool(2);
        Fibonacci task = new Fibonacci(40);
        int result = pool.invoke(task);
    }
}
```

- Although, tasks are lightweight than threads, too many tasks can also hamper the performance
- Use some cut off in your application to stop creation of tasks beyond certain threshold
 - When computation become too small, stop creation of any new task
- Fibonacci on left even with a single thread will run significantly faster than the Fibonacci shown on slide-16

Thread Pool Shutdown

```
import java.util.concurrent.*;

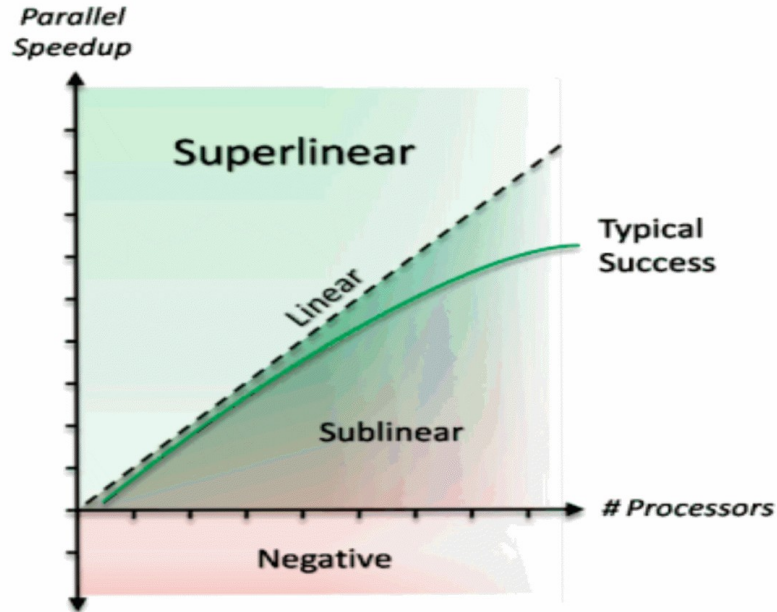
public class Search extends RecursiveAction<...> {
    .....
    public void compute() {
        if(this.searchItemIsFound()) {
            pool.shutdownNow();
        }

        Search left = new Search(...);
        Search right = new Search(...);
        left.fork();
        return right.compute() + left.join();
    }
    public static void main(String[] args) {
        ForkJoinPool pool = new ForkJoinPool(2);
        Search task = new Search(..., pool);
        try {
            pool.invoke(task);
        }
        catch(CancellationException e) {
            System.out.println("Goal is found, pool
aborted");
        }
    }
}
```

- For some type of parallel applications (e.g., searching element in a huge array) you would like to stop creating tasks once the goal is found
 - **Speculative parallelism**
- *public void shutdownNow()*
 - Stops everything, i.e., creation of new tasks, all running tasks and previously submitted tasks
 - Throws an unchecked exception CancellationException upon cancellation

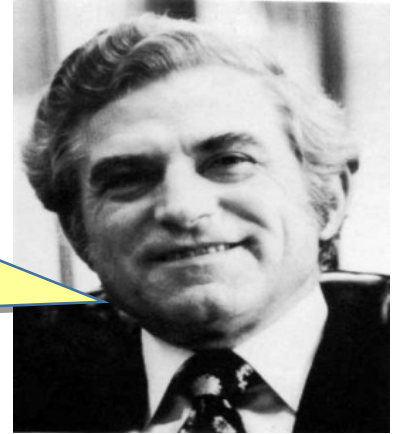
Measures of parallel performance

- Speedup = $T_{\text{serial}}/T_{\text{parallel}}$
- Parallel efficiency = $T_{\text{serial}}/(pT_{\text{parallel}})$



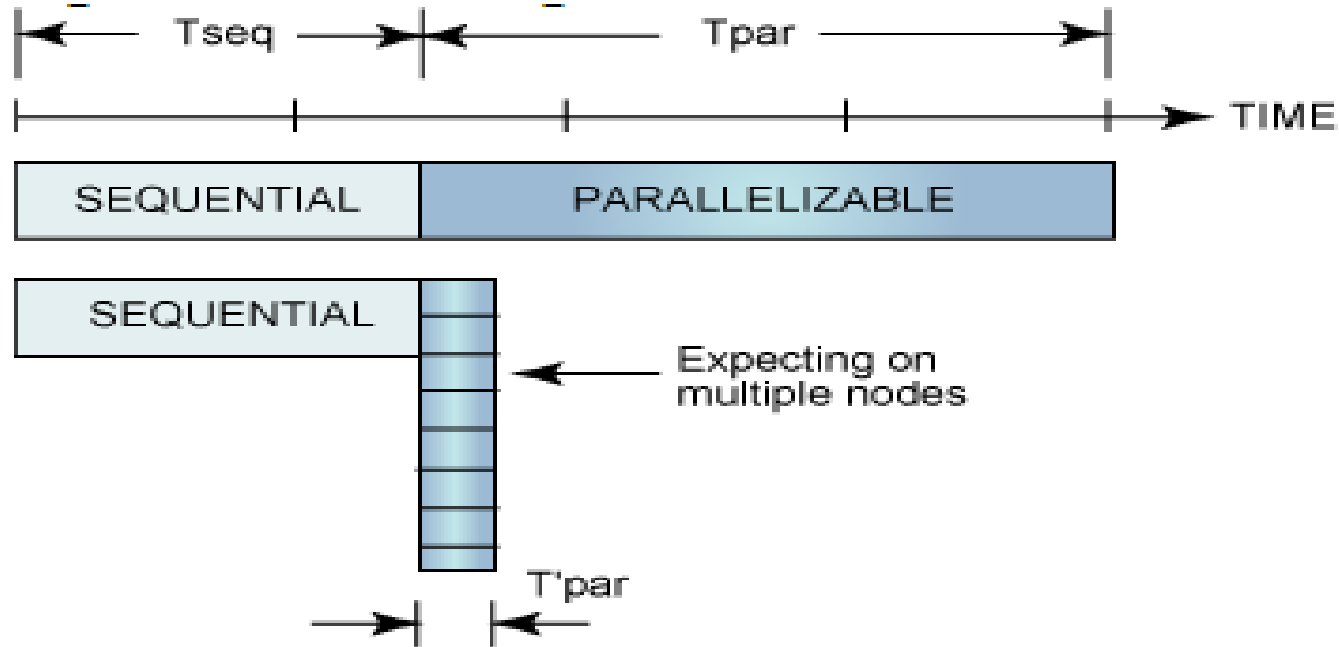
Amdahl's Law

If 50% of your application is parallel and 50% is serial, you can't get more than a factor of 2 speedup, no matter how many processors it runs on.



Gene M. Amdahl

Amdahl's Law



$$T_{Parallel} = T_{seq} + T'_{par}$$

With infinite processors, $T'_{par} \sim 0$ (theoretically) $\Rightarrow T_{Parallel} = T_{seq}$

Next Lecture

- Mutual exclusion