Parallel Computing

CSCI 201

Principles of Software Development

Jeffrey Miller, Ph.D.
jeffrey.miller@usc.edu

Outline

- Parallel Computing
- Program

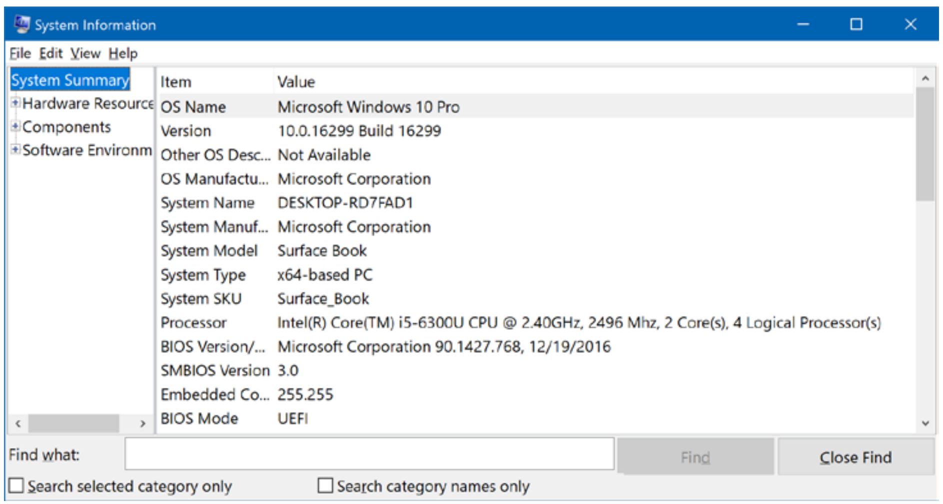
Parallel Computing

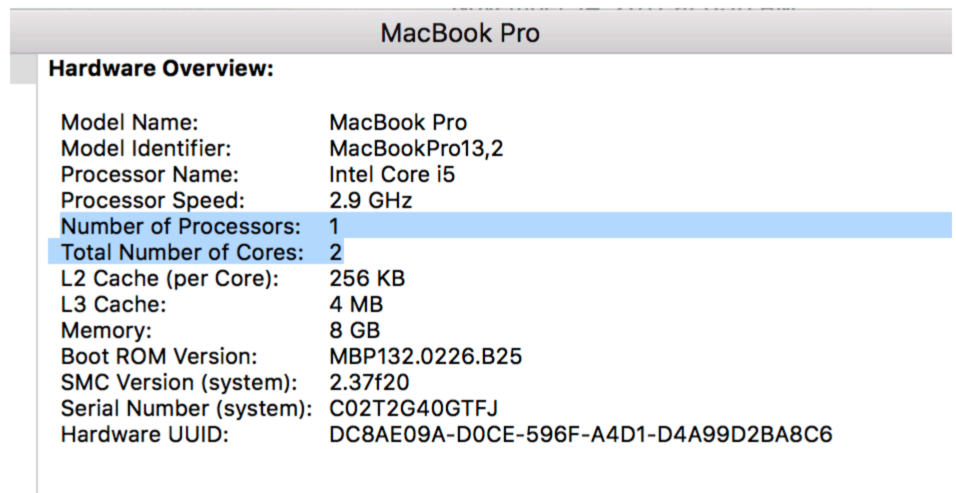
- Parallel computing studies software systems where components located on connected components communicate through message passing
  - Individual threads have only a partial knowledge of the problem
  - Parallel computing is a term used for programs that operate within a shared memory space with multiple processors or cores

USC Viterbi School of Engineering

Redundant Hardware Determination

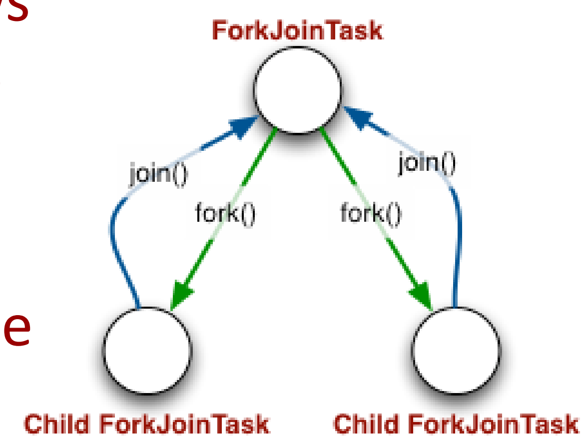
- To determine what CPU or CPUs you have in your computer
  - On Windows, Run (+ R) and type `msinfo32`
  - On Mac, go to ->About this Mac -> System Report



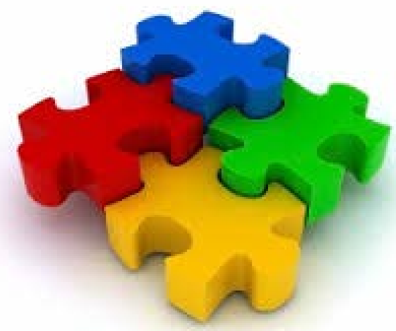


Fork/Join Framework

- The fork/join framework is an implementation of the `ExecutorService` interface that allows taking advantage of multiple cores or multiple processors
- It is designed for work that can be broken into smaller pieces recursively, allowing all available processing power
- We can create threads and add them to a thread pool
- The `ForkJoinPool` class implements the core algorithm for parallel computing in Java and can execute `ForkJoinTask` processes



Fork/Join Framework Structure



- Pseudocode for the fork/join framework is:

```
if (condition)
    do the work directly
else
    split work into multiple pieces
    invoke the pieces and wait for results
```

- The above code should be inside a child of `ForkJoinTask`
  - `RecursiveTask` can return a result
  - `RecursiveAction` does not return a result
- Create the object that represents the work to be done and pass it to the `invoke(…)` or `execute(…)` method of a `ForkJoinPool`

`ForkJoinTask` Class

- The `ForkJoinTask` class has a method `compute()` that should be overridden
- The `compute()` method will contain the main computation performed by the task
- The `fork()` method allows asynchronous execution (starts the thread and calls `compute()`)
- The `join()` method will not proceed until the task's `compute()` method has completed as a result of the call to `fork()`
- The `invoke()` method on a `ForkJoinPool` will execute the `compute()` method asynchronously and return the value (through a `fork()` then a `join()` call)
- The `execute()` method on a `ForkJoinPool` will execute the `compute()` method asynchronously but will not return any value (through a `fork()` call with no `join()`)

Multi-Threading vs Parallel Comparison

	Multi-Threading	Parallel
Class/Interface from which to inherit	`Thread/Runnable`	`RecursiveAction` or `RecursiveTask`
Method to override	`void run()`	`protected abstract void compute()` (*`RecursiveAction`*) `protected abstract V compute()` (*`RecursiveTask`*)
Method called to start thread	`public void start()`	`public final ForkJoinTask<V> fork()`
Managing class	`ExecutorService`	`ForkJoinPool`
Method to call on managing class to start thread	`void execute(Runnable)`	`public void execute(ForkJoinTask<?>)` (*`RecursiveAction`*) `public T invoke(ForkJoinTask<T>)` (*`RecursiveTask`*)
Method to stop current thread from continuing until another thread completes	`public final void join()`	`public final V join()`

Running Time

- Any time you fork a task, there is overhead in moving that to a new CPU, executing it, and getting the response
- Just because you are parallelizing code *does not mean* that you will have an improvement in execution speed
- If you fork more threads than you have CPUs, the threads will execute in a concurrent manner (time-slicing similar to multi-threading) in each CPU

USC Viterbi School of Engineering

Not Parallel Sum

```
public class SumNoParallel {
  public static void main(String [] args) {
    long maxNumber = 1_000_000_000;
    long before = System.currentTimeMillis();
    Sum sum = new Sum(maxNumber);
    long num = sum.compute();
    long after = System.currentTimeMillis();
    System.out.println("time without parallelism = " + (after - before));
    System.out.println("SUM(0.." + maxNumber + ") = " + num);
  }
}
class Sum {
  private long maxNum;
  Sum(long maxNum) {
    this.maxNum = maxNum;
  }
  protected Long compute() {
    long sum = 0;
    for (int i=0; i <= maxNum; i++) {
      sum += i;
    }
    return sum;
  }
}
```

```
time without parallelism = 902
SUM(0..1000000000) = 500000000500000000
```

```
time without parallelism = 928
SUM(0..1000000000) = 500000000500000000
```

```
time without parallelism = 812
SUM(0..1000000000) = 500000000500000000
```

Parallel Sum

```java
import java.util.concurrent.ForkJoinPool;
import java.util.concurrent.RecursiveTask;

public class SumParallel {
  public static void main(String [] args) {
    long minNumber = 0;
    long maxNumber = 1_000_000_000;
    long numElements = 1000;
    int numThreads = (int)((maxNumber - minNumber) / numElements);
    long before = System.currentTimeMillis();

    ForkJoinPool pool = new ForkJoinPool();
    SumP sum[] = new SumP[numThreads];
    long start = minNumber;
    long end = numElements;
    for (int i=0; i < numThreads; i++) {
      sum[i] = new SumP(start, end);
      start = end + 1;
      end = start + numElements - 1;
      pool.execute(sum[i]); // no return value, so we will join later
    }
    long num = 0;
    for (int i=0; i < numThreads; i++) {
      num += sum[i].join();
    }
    long after = System.currentTimeMillis();
    System.out.println("time with parallelism = " + (after-before));
    System.out.print("SUM(" + minNumber + ".." + maxNumber + ") = ");
    System.out.println(num);
  }
}
```

```java
class SumP extends RecursiveTask<Long> {
  private long minNum;
  private long maxNum;
  public static final long serialVersionUID = 1;
  public SumP(long minNum, long maxNum) {
    this.minNum = minNum;
    this.maxNum = maxNum;
  }
  protected Long compute() {
    long sum = 0;
    for (long i=minNum; i <= maxNum; i++) {
      sum += i;
    }
    return sum;
  }
}
```

```
time with parallelism = 457
SUM(0..1000000000) = 500000000500000000
```

```
time with parallelism = 436
SUM(0..1000000000) = 500000000500000000
```

```
time with parallelism = 433
SUM(0..1000000000) = 500000000500000000
```

Not Parallel Mergesort

```java
public class NonParallelMergeSort {
  public static void main(String[] args) {
    int SIZE = 2_000_000;
    int[] list = new int[SIZE];
    for (int i = 0; i < SIZE; i++) {
      list[i] = (int)(Math.random() * Integer.MAX_VALUE);
    }
    long timing = 0;
    long sum = 0;
    // run it 8 times to see if there are variations
    for (int i=0; i < 8; i++) {
      timing = nonParallelMergeSort((int[])list.clone());
      System.out.println(timing + " ms");
      sum += timing;
    }
    System.out.println("average = " + (sum / 8) + " ms");
  }

  public static long nonParallelMergeSort(int[] list) {
    long before = System.currentTimeMillis();
    new SortTask(list).compute();
    long after = System.currentTimeMillis();
    long time = after - before;
    return time;
  }
  private static class SortTask {
    private int[] list;
    SortTask(int[] list) {
      this.list = list;
    }
    protected void compute() {
      if (list.length < 2) return; // base case
        // split into halves
        int[] firstHalf = new int[list.length / 2];
        System.arraycopy(list, 0, firstHalf, 0, list.length / 2);
        int secondLength = list.length - list.length / 2;
        int[] secondHalf = new int[secondLength];
        System.arraycopy(list, list.length / 2, secondHalf, 0, secondLength);

        // recursively sort the two halves
        new SortTask(firstHalf).compute();
        new SortTask(secondHalf).compute();
        // merge halves together
        merge(firstHalf, secondHalf, list);
      }
    }

    public static void merge(int[] list1, int[] list2, int[] merged) {
      int i1 = 0, i2 = 0, i3 = 0; // index in list1, list2, out
      while (i1 < list1.length && i2 < list2.length) {
        merged[i3++] = (list1[i1] < list2[i2]) ? list1[i1++] : list2[i2++];
      }
      // any trailing ends
      while (i1 < list1.length) {
        merged[i3++] = list1[i1++];
      }
      while (i2 < list2.length) {
        merged[i3++] = list2[i2++];
      }
    }
}
```

```
458 ms
416 ms
412 ms
451 ms
401 ms
378 ms
417 ms
397 ms
average = 416 ms
```

Parallel Merge Sort Example

```java
import java.util.concurrent.ForkJoinPool;
import java.util.concurrent.RecursiveAction;
public class ParallelMergeSort {
  public static void main(String[] args) {
    int SIZE = 2_000_000;
    int[] list = new int[SIZE];

    for (int i = 0; i < SIZE; i++) {
      list[i] = (int)(Math.random() * Integer.MAX_VALUE);
    }
    int numProcessors = Runtime.getRuntime().availableProcessors();
    System.out.println("num processors: " + numProcessors);

    // timing[i] : time to sort on i processors
    long[] timing = new long[numProcessors*2+1];

    for (int i=1; i <= numProcessors * 2; i++) {
      timing[i] = parallelMergeSort((int[])list.clone(), i);
      System.out.println(i + " processors=" + timing[i] + " ms");
    }
  }

  public static long parallelMergeSort(int[] list, int proc) {
    long before = System.currentTimeMillis();
    ForkJoinPool pool = new ForkJoinPool(proc);
    pool.invoke(new SortTask(list));
    pool.shutdown();
    while (!pool.isTerminated()) {
      Thread.yield();
    }
    long after = System.currentTimeMillis();
    long time = after - before;
    return time;
  }
```

```
num processors: 4
1 processors=902 ms
2 processors=704 ms
3 processors=269 ms
4 processors=257 ms
5 processors=214 ms
6 processors=240 ms
7 processors=249 ms
8 processors=236 ms
```

```java
  private static class SortTask extends RecursiveAction {
    public static final long serialVersionUID = 1;
    private int[] list;
    SortTask(int[] list) {
      this.list = list;
    }

    protected void compute() {
      if (list.length < 2) return; // base case
      // split into halves
      int[] firstHalf = new int[list.length / 2];
      System.arraycopy(list, 0, firstHalf, 0, list.length / 2);
      int secondLength = list.length - list.length / 2;
      int[] secondHalf = new int[secondLength];
      System.arraycopy(list, list.length / 2, secondHalf, 0, secondLength);

      // recursively sort the two halves
      SortTask st1 = new SortTask(firstHalf);
      SortTask st2 = new SortTask(secondHalf);
      st1.fork();
      st2.fork();
      st1.join();
      st2.join();
    }
  }

  public static void merge(int[] list1, int[] list2, int[] merged) {
    int i1 = 0, i2 = 0, i3 = 0; // index in list1, list2, out
    while (i1 < list1.length && i2 < list2.length) {
      merged[i3++] = (list1[i1] < list2[i2]) ? list1[i1++] : list2[i2++];
    }
    // any trailing ends
    while (i1 < list1.length) {
      merged[i3++] = list1[i1++];
    }
    while (i2 < list2.length) {
      merged[i3++] = list2[i2++];
    }
  }
}
```

```
num processors: 4
1 processors=912 ms
2 processors=732 ms
3 processors=273 ms
4 processors=255 ms
5 processors=228 ms
6 processors=224 ms
7 processors=261 ms
8 processors=235 ms
```

Outline

- Parallel Computing
- Program

Program

- Modify the `ParallelMergeSort` code to split the array into the same number of sub-arrays as processors/cores on your computer. Does that provide a lower execution time than splitting the array into two sub-arrays? Why or why not?