**Comparing Parallel and Distributed Programming Models:**

**Coursework Stage 1: Performance and Programmability of Shared-memory Parallel Models**

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**Section 1 Comparative Sequential Performance**

Sequential

|  |  |  |
| --- | --- | --- |
| Data Set | Go Runtimes (s) | C Runtimes (s) |
| DS1 | 15.91639141 | 15.21514 |
| DS2 | 15.95532 | 65.28168 |

**Section 2 Comparative Parallel Performance Measurements**

**Section 2.1 Runtimes**

Dataset 1

|  |  |  |
| --- | --- | --- |
| Threads | Go | OpenMP |
| 1 | 16.2292 | 15.18 |
| 2 | 12.44243 | 11.668 |
| 4 | 7.478488 | 7.022 |
| 8 | 4.147318 | 3.9 |
| 12 | 2.887657 | 2.7 |
| 16 | 2.201418 | 2.279 |
| 24 | 1.628665 | 1.432 |
| 32 | 1.270825 | 1.11 |
| 48 | 0.982692 | 0.898 |
| 64 | 0.878035 | 0.822 |

Dataset 2

|  |  |  |
| --- | --- | --- |
| Threads | Go | OpenMP |
| 1 | 69.29402 | 71.705 |
| 2 | 53.03127 | 55.978 |
| 4 | 31.78972 | 31.284 |
| 8 | 17.68323 | 16.716 |
| 12 | 12.31131 | 11.547 |
| 16 | 9.407323 | 8.822 |
| 24 | 6.699683 | 6.185 |
| 32 | 5.323557 | 4.855 |
| 48 | 4.30356 | 3.837 |
| 64 | 3.81732 | 3.429 |

Dataset 3

|  |  |  |
| --- | --- | --- |
| Threads | Go | OpenMP |
| 8 | 74.89538 | 70.478 |
| 16 | 39.81903 | 37.504 |
| 32 | 22.33225 | 20.811 |
| 64 | 15.64302 | 14.783 |

**Section 2.2 Speedups**

**Section 2.3**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Language | Sequential Runtime (s) | Best Parallel Runtime (s) | Best Speedup | No. Threads |
| Go | 15.91639 | 0.878035 | 18.12729 | 64 |
| C+OpenMP | 15.22271 | 0.822 | 18.51912 | 64 |

**Section 2.4**

The runtimes for both Go and C+OpenMP are very similar, with C+OpenMP being slightly faster on average in all cases.

Looking at the numbers for speedups, the results for DS1, DS2 and DS3 are very similar, with 64 threads providing 18-19 times speedup on average for all three. However, C+OpenMP consistently shows a significantly higher speedup than Go. The graph is also mostly linear, which suggests the parallelism is ideal, until it plateaus at around 32 threads. This suggests that this is the fastest the program can run, irregardless of an increase in threads/cores.

**Section 3 Programming Model Comparison**

TODO: finish this section (compare models)

The biggest challenge I had was deciding how to split the dataset into correctly sized chunks for the Go program. This was especially difficult as the count of goroutines would often not be a factor of the dataset (e.g. 60000 / 64) and due to Go’s integer division always rounding down this could cause some numbers to be skipped/processed twice. I first experimented with converting the integers to floats and rounding explicitly, but this was messy and didn’t guarantee the final upper number would be correct (e.g. could be rounded up to 60001). I finally decided to stick with the current functionality, which uses integer division to divide the dataset into a variable called chunk (threads\*chunk\_size < dataset because integer division rounds down). Each goroutine would process work of chunk\_size, and the last goroutine would handle whatever was remaining. This guarantees that every number is processed and splits the data into almost even chunks.

However, I ultimately changed this to a round-robin style where goroutines are spawned and only deal with one value from a channel containing all numbers to be processed. This proved to be significantly faster than the original method (as seen below).

**Appendix A C+OpenMP TotientRange Program**

**Code:**

// TotientRangePar.c - Parallel Euler Totient Function (C Version)

// compile: gcc -Wall -O -o TotientRangePar TotientRangePar.c

// run:     ./TotientRangePar lower\_num upper\_num num\_threads(optional)

// Author: Max Kirker Burton 2260452b     13/11/19

// This program calculates the sum of the totients between a lower and an

// upper limit using C longs, and can be run with several Goroutines either set as an argument or

// as an environment variable

// It is based on earlier work by:

// Phil Trinder, Nathan Charles, Hans-Wolfgang Loidl and Colin Runciman

// The comments provide (executable) Haskell specifications of the functions

#include <stdio.h>

#include <omp.h>

#include <sys/time.h>

// hcf x 0 = x

// hcf x y = hcf y (rem x y)

long hcf(long x, long y)

{

  long t;

  while (y != 0) {

    t = x % y;

    x = y;

    y = t;

  }

  return x;

}

// relprime x y = hcf x y == 1

int relprime(long x, long y)

{

  return hcf(x, y) == 1;

}

// euler n = length (filter (relprime n) [1 .. n-1])

long euler(long n)

{

  long length, i;

  length = 0;

  for (i = 1; i < n; i++)

    if (relprime(n, i))

      length += 1;

  return length;

}

// sumTotient lower upper = sum (map euler [lower, lower+1 .. upper])

long sumTotient(long lower, long upper, int n\_threads)

{

  long sum, i;

  sum = 0;

  #pragma omp parallel for schedule(guided) reduction(+: sum) num\_threads(n\_threads)

    for (i = lower; i <= upper; i++)

      sum += euler(i);

  return sum;

}

int main(int argc, char \*\* argv)

{

  long lower, upper;

  int num\_threads = omp\_get\_num\_threads();

  float msec;

  struct timeval start, stop;

  if (argc < 3) {

    printf("fewer than 2 arguments\n");

    return 1;

  }

  sscanf(argv[1], "%ld", &lower);

  sscanf(argv[2], "%ld", &upper);

  if (argc == 4){

    sscanf(argv[3], "%d", &num\_threads);

  }

  gettimeofday(&start, NULL);

  printf("C: Sum of Totients  between [%ld..%ld] is %ld\n",

         lower, upper, sumTotient(lower, upper, num\_threads));

  gettimeofday(&stop, NULL);

  if (stop.tv\_usec < start.tv\_usec) {

    stop.tv\_usec += 1000000;

    stop.tv\_sec--;

  }

  msec = 1000 \* (stop.tv\_sec - start.tv\_sec) +

                (stop.tv\_usec - start.tv\_usec) / 1000;

  printf("%f\n", msec);  // Rename to elapsed time:

  return 0;

}

Uses a Pragma-based Shared Memory paradigm (e.g. using shared variables).

I used only one pragma in the final code, but I experimented with using nested pragmas, with another pragma inside of the euler function. I thought that I could parallelise the calculations of relprimes and tried assigning threads in different ways (e.g. 2 threads for the euler function, and all other threads for the sumTotient function) but all these methods resulted in slower runtimes than simply using one pragma.

What did improve runtimes noticeably was changing the schedule parameter of the pragma. By default, it takes the “static” argument, which splits chunks into even sizes. Because my original Go program did something similar, I tried to find a way to improve the runtimes in OpenMP. I found that setting schedule to “guided” which starts chunk\_size high then decreases it for later threads. This reduces runtime since higher numbers take longer to compute (explained further in Appendix B).

**Appendix B Go TotientRange Program**

**Code:**

// totientRangePar.go - Parallel Euler Totient Function (Go Version)

// compile: go build

// run:     totientRangePar lower\_num upper\_num num\_threads

// Author: Max Kirker Burton 2260452b   07/11/2019

// This program calculates the sum of the totients between a lower and an

// upper limit, and can be run with several Goroutines

//

// Each function has an executable Haskell specification

//

// It is based on earlier work by: Greg Michaelson, Patrick Maier, Phil Trinder,

// Nathan Charles, Hans-Wolfgang Loidl and Colin Runciman

package main

import (

    "fmt"

    "os"

    "runtime"

    "strconv"

    "sync"

    "time"

)

// Compute the Highest Common Factor, hcf of two numbers x and y

//

// hcf x 0 = x

// hcf x y = hcf y (rem x y)

func hcf(x, y int64) int64 {

    var t int64

    for y != 0 {

        t = x % y

        x = y

        y = t

    }

    return x

}

// relprime determines whether two numbers x and y are relatively prime

//

// relprime x y = hcf x y == 1

func relprime(x, y int64) bool {

    return hcf(x, y) == 1

}

// sequential euler function

func euler\_seq(n int64) int64 {

    var length, i int64

    length = 0

    for i = 1; i < n; i++ {

        if relprime(n, i) {

            length++

        }

    }

    return length

}

// euler(n) computes the Euler totient function, i.e. counts the number of

// positive integers up to n that are relatively prime to n

//

// euler n = length (filter (relprime n) [1 .. n-1])

func euler(value int64, ch chan int64, wg \*sync.WaitGroup) {

    var length, i int64

    length = 0

    for i = 1; i < value; i++ {

        if relprime(i, value) {

            length++

        }

    }

    ch <- length

    wg.Done()

}

// sumTotient lower upper sums the Euler totient values for all numbers

// between "lower" and "upper".

//

// sumTotient lower upper = sum (map euler [lower, lower+1 .. upper])

func sumTotient(lower, upper, cores int64) int64 {

    var sum, i int64

    sum = 0

    // If more than 1 core is being used, utilise parallelism, otherwise run sequentially (with 1 core in this program, sequential is faster)

    if cores > 1 {

        chIn := make(chan int64, 100000)

        chSum := make(chan int64, 100000)

        var goroutines int64 = cores

        runtime.GOMAXPROCS(int(goroutines))

        var wg sync.WaitGroup // using a waitgroup to close the channel after all threads are completed

        // add all numbers in range of lower and upper to a channel

        for i = lower; i <= upper; i++ {

            chIn <- i

        }

        close(chIn)

        // repeatedly spawn goroutines to take 1 entry in chIn and calculate its totient, which is then sent onto channel chSum

        for value := range chIn {

            wg.Add(1)

            go euler(value, chSum, &wg)

        }

        wg.Wait()

        close(chSum)

        // sum all values in channel chSum

        for value := range chSum {

            sum += value

        }

    } else {

        for i = lower; i <= upper; i++ {

            sum = sum + euler\_seq(i)

        }

    }

    return sum

}

func main() {

    var lower, upper, cores int64

    var err error

    // Read and validate lower and upper arguments

    if len(os.Args) < 3 {

        panic(fmt.Sprintf("Usage: must provide lower and upper range limits and number of cores as arguments"))

    }

    if lower, err = strconv.ParseInt(os.Args[1], 10, 64); err != nil {

        panic(fmt.Sprintf("Can't parse first argument"))

    }

    if upper, err = strconv.ParseInt(os.Args[2], 10, 64); err != nil {

        panic(fmt.Sprintf("Can't parse second argument"))

    }

    if cores, err = strconv.ParseInt(os.Args[3], 10, 64); err != nil {

        panic(fmt.Sprintf("Can't parse third argument"))

    }

    // Record start time

    start := time.Now()

    // Compute and output sum of totients

    fmt.Println("Sum of Totients between", lower, "and", upper, "is", sumTotient(lower, upper, cores))

    // Record the elapsed time

    t := time.Now()

    elapsed := t.Sub(start)

    fmt.Println("Elapsed time", elapsed)

}

Uses a Message Passing paradigm (e.g. creating a channel with send and receives).

The reason why low number of goroutines (e.g. 2) don’t provide a huge reduction in runtime is likely because of how the program separates work into chunks. My program splits work into mostly even chunks and calculating the sum of totients in a range 1-1000 would take much less time than 1000-2000, as more relative primes need to be calculated. Since I used a waitgroup to ensure all goroutines are completed before the sum of the channel is calculated, the program runtime will be the runtime of the slowest goroutine. This becomes less of a problem at higher counts of goroutines as the chunks are smaller. I thought of ways to have different sized chunks, with larger sized chunks for the earlier numbers (e.g. for a range of 2000 and 2 threads, split into chunks of 1-1500 and 1500-2000), but this proved difficult to implement, and would require heavy tuning to be optimal.

Instead, I changed my program to disregard chunk\_size and instead spawn an arbitrary number of goroutines that only compute 1 number. This works as at the start of the program, all numbers are sent to a channel, and the goroutines receive one number from the channel to compute. This significantly improved runtimes compared to my original method.

However, as you can see from the graph, this also increased the runtime for 1 thread. To improve that, I added an if statement that would run the program sequentially if only 1 core was set by runtime.GOMAXPROCS. The result is my final Go program.