CP 431/631 Assignment 1

By group 2 (Omer Tal, Elizabeth Gorbonos, Tianran Wang, Ryan Kazmerik)

1. Assignment description:

The PrimeGaps program (appendix 1) is responsible for finding the maximum gap between prime numbers from 0 up to a given number "range".
This program is written using MPI library in C. It breaks the range of potential prime numbers into $\frac{n}{P}$ fractions using the following formula:

$$n_p = \left\lfloor \frac{n}{P} \right\rfloor + \begin{cases} 1 & \text{if } p < \text{mod}(n, P), \\ 0 & \text{else,} \end{cases}$$

Each processor computes the largest gap for the range from $i_{start,p}$ to $i_{start,p} + n_P$ where:

$$i_{\text{start},p} = p \left\lfloor \frac{n}{P} \right\rfloor + \min(p, \text{mod}(n, P)).$$

The program is using mpz_nextprime function provided by the GMP library in order to find all the prime numbers in a "local range" and the smallest prime bigger than $i_{start,p} + n_P$ (the upper bound of a local range).
The program was tested on Sharcnet's Orca cluster using 1 to 8 processors for an input of 10^9.
We were able to scale the code up to an input of 10^{12} by increasing the number of processors to 32 and 64, and by replacing the variables from "int" data type to "unsigned long long".

2. Results:

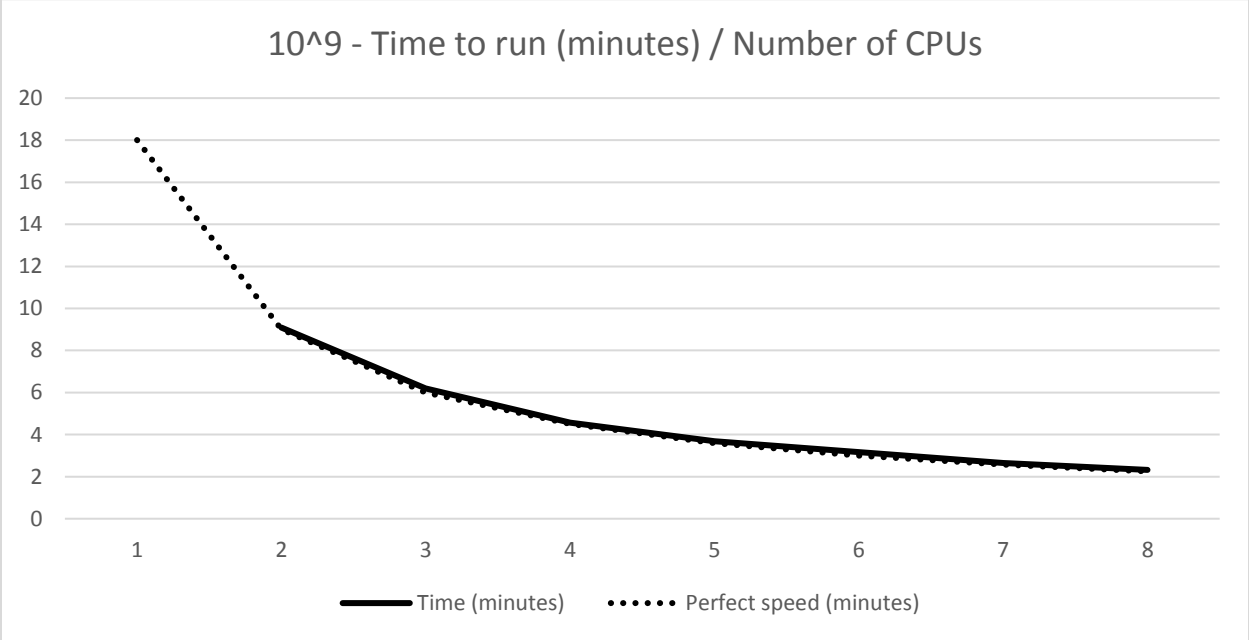
The program output for 10^9 is:

Largest gap found: 282, between 436273009 and 436273291 (appendix 2).

The program output for 10^{12} is:

Largest gap found: 540, between 738832927927 and 738832928467 (appendix 3).

3. Benchmarks:



Data size (n)	Number of CPUs	Time (seconds)	Time (minutes)	Perfect speed (minutes)
10^9	1	1080.357769	18.0	18.0
	2	545.334086	9.1	9.0
	3	371.728151	6.2	6.0
	4	273.814905	4.6	4.5
	5	221.334371	3.7	3.6
	6	189.839989	3.2	3.0
	7	159.134436	2.7	2.6
	8	139.303029	2.3	2.3
10^{12}	32	33723.28674	562.1	
	64	17065.50847	284.4	

Appendix 1 : Program code

```
/*
 ============================================================================
 Name        : PrimeGaps.h
 Author      : Omer Tal, Elizabeth Gorbonos, Tianran Wang, Ryan Kazmerik
 Version     : 1.1
 Description : Finds the largest gap between consecutive primes using
               parallel approach
 ============================================================================
 */


#include <stdio.h>
#include <stdlib.h>
#include <stdarg.h>
#include <string.h>
#include <time.h>
#include <mpi.h>
#include <gmp.h>


void setup();
void max_gap();
void reduce_gaps();
void p_printf(const char* msg, ...);
unsigned long long mpz_get_ull(mpz_t t);
void mpz_set_ull(mpz_t t, unsigned long long l);


const int MASTER_RANK   = 0;
const int DEFAULT_RANGE = 1000000000;


int                         p_num, rank, p_max_gap;
unsigned long long          p_prime;
mpz_t                       range, p_range, p_start, p_end;
double                      start_time, end_time;
time_t                      t;
```

```
/*
 ============================================================================
 Name        : PrimeGaps.c
 Author      : Omer Tal, Elizabeth Gorbonos, Tianran Wang, Ryan Kazmerik
 Version     : 1.1
 Description : Finds the largest gap between consecutive primes using
               parallel approach
 ============================================================================
 */


#include "primegaps.h"


int main(int argc,char**argv) {
	MPI_Init(&argc,&argv);
	MPI_Comm_size(MPI_COMM_WORLD, &p_num);
	MPI_Comm_rank(MPI_COMM_WORLD, &rank);


	if( argc == 2 ) {
		mpz_set_ull(range, atoll(argv[1]));
	}
	else {
		 mpz_set_ull(range, DEFAULT_RANGE); /* default is 10^9 */
	}

	MPI_Barrier(MPI_COMM_WORLD);
	if (rank == MASTER_RANK){
		start_time = MPI_Wtime();
		p_printf("Starting");
	}

	setup();  /* calculate the work-range */

	max_gap();  /* find max gap */

	reduce_gaps();  /* send all gaps to master and find the largest */

	if(rank == MASTER_RANK){
		p_printf("Largest gap found: %d, between %lli and %lli.", p_max_gap,
				p_prime, p_prime + p_max_gap);
```

```
                end_time = MPI_Wtime();
                p_printf("Run time was %f seconds", end_time-start_time);
                p_printf("End");
        }

        MPI_Finalize();

        return EXIT_SUCCESS;
}

/*
 * Function: setup
 * ----------------------------
 *   Calculate the range (start and end values) for the current process to work on
 *   Using: n(p)       = floor(n/P) ( +1 if p < mod(n,P)) = p_range
 *            start(p) = p*floor(n/P) + min(p, mod(n,P))  = p_start
 *            where p is rank
 */
void setup(){
        mpz_t rem;


        mpz_init(p_start);
        mpz_init(p_end);
        mpz_init(p_range);
        mpz_init(rem);

        mpz_fdiv_q_ui(p_range, range, p_num);       /* p_range = floor(n/P) */
        mpz_fdiv_r_ui(rem, range, p_num);           /* rem = mod(n,P) */

        mpz_mul_ui(p_start, p_range, rank);  /* p_start = p*floor(n/P) */

        if(mpz_cmp_ui(rem, rank) > 0){                    /* if mod(n,P) > p */
                mpz_add_ui(p_start, p_start, rank); /* p_start += p */
                mpz_add_ui(p_range, p_range, 1);    /* increase p_range by 1 */
        }
        else{
                mpz_add(p_start, p_start, rem);     /* p_start += mod(n,P) */
        }

        mpz_add(p_end, p_start, p_range);           /* end(p) = start(p) + n(p) */
```

```
        p_printf("Working on range: %lli to %lli", mpz_get_ull(p_start),
                 mpz_get_ull(p_end));
}


/*
 * Function: max_gap
 * ----------------------------
 *   Finds and sets p_max_gap and p_prime for the process work-range
 */
void max_gap()
{
        mpz_t curr_prime, next_prime, gap, max_gap;
        mpz_init(curr_prime);
        mpz_init(next_prime);
        mpz_init(gap);
        mpz_init(max_gap);

        /* start from the first prime in the process work-range */
        mpz_nextprime(curr_prime, p_start);

        while(mpz_cmp(p_end, curr_prime) > 0){
                mpz_nextprime(next_prime, curr_prime);
                mpz_sub(gap, next_prime, curr_prime);

        /* if the gap is the largest so far and it's not outside our entire
           range */
                if (mpz_cmp(gap, max_gap) > 0 && mpz_cmp(next_prime, range) <= 0){
                        mpz_set(max_gap, gap); /* update the max */
                        p_prime = mpz_get_ull(curr_prime);
                }

                mpz_set(curr_prime, next_prime); /* move on to the next prime */
        }

        p_max_gap = mpz_get_ull(max_gap); /* set the max gap found */
}

/*
 * Function: reduce_gaps
 * ----------------------------
 *   Sends all max gaps found by all non-MASTER processes to MASTER.
 *   Stores the largest gap and it's first occurrence in the MASTER process.
```

```
 */
void reduce_gaps(){
	unsigned long long data[2];

	if (rank != MASTER_RANK)
	{
		data[0] = p_max_gap;
		data[1] = p_prime;
		MPI_Send(&data, 2, MPI_LONG_LONG, MASTER_RANK, 0, MPI_COMM_WORLD);
	}
	else{
		p_printf("Found gap - %d, low prime - %lli.", p_max_gap, p_prime);

		MPI_Status status;
		int i;
		for (i = 0; i < p_num - 1; i++){
			MPI_Recv(&data, 2, MPI_LONG_LONG, MPI_ANY_SOURCE, 0,
				 MPI_COMM_WORLD, &status);
			p_printf("Received from process %d: max gap - %d, low prime –
				 %lli.", status.MPI_SOURCE, data[0], data[1]);

			if( data[0] > p_max_gap){
				p_max_gap =  data[0]; /* update max gap */
				p_prime =  data[1];
			}
		}
	}
}


/*
 * Function: p_printf
 * ----------------------------
 *   Similar to printf, adds the process identifier and a timestamp.
 */
void p_printf(const char* format, ...){
	t = time(NULL);
	printf("%s Process %d / %d: ", strtok(ctime(&t), "\n"), rank, p_num);

	va_list arg;
	va_start(arg, format);
	vfprintf (stdout, format, arg);
	va_end(arg);
```

```
        printf("\n");
}

/*
 * Function: mpz_get_ull
 * ----------------------------
 *   Converts the value of a mpz_t variable to unsigned long long
 *   t: the mpz_t variable
 *
 *   returns: the value of t as unsigned long long
 */
unsigned long long mpz_get_ull(mpz_t t)
{
    unsigned long long val = 0;
    mpz_export(&val, 0, -1, sizeof val, 0, 0, t);
    return val;
}

/*
 * Function: mpz_set_ull
 * ----------------------------
 *   Sets the value of a mpz_t variable from unsigned long long variable
 *   t: the mpz_t variable to set
 *   l: the value to set in t
 */
void mpz_set_ull(mpz_t t, unsigned long long l)
{
    mpz_import(t, 1, -1, sizeof l, 0, 0, &l);
}
```

Appendix 2 : Program output for 10^9

Serial output (p = 1)

```
Mon Oct  2 12:57:35 2017 Process 0 / 1: Starting
Mon Oct  2 12:57:35 2017 Process 0 / 1: Working on range: 0 to 1000000000
Mon Oct  2 13:15:36 2017 Process 0 / 1: Found gap - 282, low prime - 436273009.
Mon Oct  2 13:15:36 2017 Process 0 / 1: Largest gap found: 282, between 436273009 and
436273291.
Mon Oct  2 13:15:36 2017 Process 0 / 1: Run time was 1080.357769 seconds
Mon Oct  2 13:15:36 2017 Process 0 / 1: End
--- SharcNET Job Epilogue ---
           job id: 10860608
      exit status: 0
         cpu time: 1080s / 3.0h (10 %)
     elapsed time: 1081s / 3.0h (10 %)
   virtual memory: 339.6M / 1.0G (33 %)

Job completed successfully
WARNING: Job only used 10 % of its requested walltime.
WARNING: Job only used 10 % of its requested cpu time.
WARNING: Job only used 33% of its requested memory.
```

2 processor output

Mon Oct 2 12:23:20 2017 Process 0 / 2: Starting
Mon Oct 2 12:23:20 2017 Process 0 / 2: Working on range: 0 to 500000000
Mon Oct 2 12:23:20 2017 Process 1 / 2: Working on range: 500000000 to 1000000000
Mon Oct 2 12:32:25 2017 Process 0 / 2: Found gap - 282, low prime - 436273009.
Mon Oct 2 12:32:25 2017 Process 0 / 2: Received from process 1: max gap - 276, low prime - 649580171.
Mon Oct 2 12:32:25 2017 Process 0 / 2: Largest gap found: 282, between 436273009 and 436273291.
Mon Oct 2 12:32:25 2017 Process 0 / 2: Run time was 545.334086 seconds
Mon Oct 2 12:32:25 2017 Process 0 / 2: End
--- SharcNET Job Epilogue ---
           job id: 10860531
       exit status: 0
         cpu time: 1078s / 2.0h (14 %)
      elapsed time: 579s / 1.0h (16 %)
    virtual memory: 320.2M / 1.0G (31 %)

Job completed successfully
WARNING: Job only used 16 % of its requested walltime.
WARNING: Job only used 14 % of its requested cpu time.
WARNING: Job only used 31% of its requested memory.

3 processor output

Mon Oct 2 12:23:49 2017 Process 1 / 3: Working on range: 333333334 to 666666667
Mon Oct 2 12:23:49 2017 Process 0 / 3: Starting
Mon Oct 2 12:23:49 2017 Process 0 / 3: Working on range: 0 to 333333334
Mon Oct 2 12:23:49 2017 Process 2 / 3: Working on range: 666666667 to 1000000000
Mon Oct 2 12:30:01 2017 Process 0 / 3: Found gap - 248, low prime - 191912783.
Mon Oct 2 12:30:01 2017 Process 0 / 3: Received from process 1: max gap - 282, low prime - 436273009.
Mon Oct 2 12:30:01 2017 Process 0 / 3: Received from process 2: max gap - 260, low prime - 944192807.
Mon Oct 2 12:30:01 2017 Process 0 / 3: Largest gap found: 282, between 436273009 and 436273291.
Mon Oct 2 12:30:01 2017 Process 0 / 3: Run time was 371.728151 seconds
Mon Oct 2 12:30:01 2017 Process 0 / 3: End
--- SharcNET Job Epilogue ---
           job id: 10860532
       exit status: 0
         cpu time: 1087s / 3.0h (10 %)
      elapsed time: 434s / 1.0h (12 %)
    virtual memory: 301.5M / 1.0G (29 %)

Job completed successfully
WARNING: Job only used 12 % of its requested walltime.
WARNING: Job only used 10 % of its requested cpu time.
WARNING: Job only used 29% of its requested memory.

4 processor output

Mon Oct 2 12:23:48 2017 Process 0 / 4: Starting
Mon Oct 2 12:23:48 2017 Process 0 / 4: Working on range: 0 to 250000000
Mon Oct 2 12:23:48 2017 Process 2 / 4: Working on range: 500000000 to 750000000
Mon Oct 2 12:23:48 2017 Process 3 / 4: Working on range: 750000000 to 1000000000
Mon Oct 2 12:23:48 2017 Process 1 / 4: Working on range: 250000000 to 500000000
Mon Oct 2 12:28:22 2017 Process 0 / 4: Found gap - 248, low prime - 191912783.
Mon Oct 2 12:28:22 2017 Process 0 / 4: Received from process 1: max gap - 282, low prime - 436273009.
Mon Oct 2 12:28:22 2017 Process 0 / 4: Received from process 3: max gap - 260, low prime - 944192807.
Mon Oct 2 12:28:22 2017 Process 0 / 4: Received from process 2: max gap - 276, low prime - 649580171.
Mon Oct 2 12:28:22 2017 Process 0 / 4: Largest gap found: 282, between 436273009 and 436273291.
Mon Oct 2 12:28:22 2017 Process 0 / 4: Run time was 273.814905 seconds
Mon Oct 2 12:28:22 2017 Process 0 / 4: End
--- SharcNET Job Epilogue ---
           job id: 10860533
      exit status: 0
         cpu time: 1088s / 4.0h (7 %)
     elapsed time: 335s / 1.0h (9 %)
   virtual memory: 262.0M / 1.0G (25 %)

Job completed successfully
WARNING: Job only used 9 % of its requested walltime.
WARNING: Job only used 7 % of its requested cpu time.
WARNING: Job only used 25% of its requested memory.

5 processor output

Mon Oct 2 12:23:49 2017 Process 3 / 5: Working on range: 600000000 to 800000000
Mon Oct 2 12:23:49 2017 Process 0 / 5: Starting
Mon Oct 2 12:23:49 2017 Process 0 / 5: Working on range: 0 to 200000000
Mon Oct 2 12:23:49 2017 Process 4 / 5: Working on range: 800000000 to 1000000000
Mon Oct 2 12:23:49 2017 Process 1 / 5: Working on range: 200000000 to 400000000
Mon Oct 2 12:23:49 2017 Process 2 / 5: Working on range: 400000000 to 600000000
Mon Oct 2 12:27:31 2017 Process 0 / 5: Found gap - 248, low prime - 191912783.
Mon Oct 2 12:27:31 2017 Process 0 / 5: Received from process 4: max gap - 260, low prime - 944192807.
Mon Oct 2 12:27:31 2017 Process 0 / 5: Received from process 1: max gap - 250, low prime - 387096133.
Mon Oct 2 12:27:31 2017 Process 0 / 5: Received from process 2: max gap - 282, low prime - 436273009.
Mon Oct 2 12:27:31 2017 Process 0 / 5: Received from process 3: max gap - 276, low prime - 649580171.
Mon Oct 2 12:27:31 2017 Process 0 / 5: Largest gap found: 282, between 436273009 and 436273291.
Mon Oct 2 12:27:31 2017 Process 0 / 5: Run time was 221.334371 seconds
Mon Oct 2 12:27:31 2017 Process 0 / 5: End
--- SharcNET Job Epilogue ---
           job id: 10860534
        exit status: 0
          cpu time: 1085s / 5.0h (6 %)
       elapsed time: 284s / 1.0h (7 %)
     virtual memory: 261.7M / 1.0G (25 %)

Job completed successfully
WARNING: Job only used 7 % of its requested walltime.
WARNING: Job only used 6 % of its requested cpu time.
WARNING: Job only used 76 % of allocated cpu time.
WARNING: Job only used 25% of its requested memory.

6 processor output

Mon Oct 2 12:23:17 2017 Process 0 / 6: Starting
Mon Oct 2 12:23:17 2017 Process 0 / 6: Working on range: 0 to 166666667
Mon Oct 2 12:23:17 2017 Process 2 / 6: Working on range: 333333334 to 500000001
Mon Oct 2 12:23:17 2017 Process 4 / 6: Working on range: 666666668 to 833333334
Mon Oct 2 12:23:17 2017 Process 5 / 6: Working on range: 833333334 to 1000000000
Mon Oct 2 12:23:17 2017 Process 3 / 6: Working on range: 500000001 to 666666668
Mon Oct 2 12:23:17 2017 Process 1 / 6: Working on range: 166666667 to 333333334
Mon Oct 2 12:26:27 2017 Process 0 / 6: Found gap - 222, low prime - 122164747.
Mon Oct 2 12:26:27 2017 Process 0 / 6: Received from process 5: max gap - 260, low prime - 944192807.
Mon Oct 2 12:26:27 2017 Process 0 / 6: Received from process 1: max gap - 248, low prime - 191912783.
Mon Oct 2 12:26:27 2017 Process 0 / 6: Received from process 2: max gap - 282, low prime - 436273009.
Mon Oct 2 12:26:27 2017 Process 0 / 6: Received from process 4: max gap - 250, low prime - 708730291.
Mon Oct 2 12:26:27 2017 Process 0 / 6: Received from process 3: max gap - 276, low prime - 649580171.
Mon Oct 2 12:26:27 2017 Process 0 / 6: Largest gap found: 282, between 436273009 and 436273291.
Mon Oct 2 12:26:27 2017 Process 0 / 6: Run time was 189.839989 seconds
Mon Oct 2 12:26:27 2017 Process 0 / 6: End
--- SharcNET Job Epilogue ---
           job id: 10860535
      exit status: 0
         cpu time: 1094s / 6.0h (5 %)
     elapsed time: 220s / 1.0h (6 %)
   virtual memory: 263.2M / 1.0G (25 %)

Job completed successfully
WARNING: Job only used 6 % of its requested walltime.
WARNING: Job only used 5 % of its requested cpu time.
WARNING: Job only used 25% of its requested memory.

7 processor output

Fri Sep 29 23:36:34 2017 Process 1 / 7: Working on range: 142857143 to 285714286
Fri Sep 29 23:36:34 2017 Process 0 / 7: Starting
Fri Sep 29 23:36:34 2017 Process 0 / 7: Working on range: 0 to 142857143
Fri Sep 29 23:36:34 2017 Process 5 / 7: Working on range: 714285715 to 857142858
Fri Sep 29 23:36:34 2017 Process 4 / 7: Working on range: 571428572 to 714285715
Fri Sep 29 23:36:34 2017 Process 3 / 7: Working on range: 428571429 to 571428572
Fri Sep 29 23:36:34 2017 Process 6 / 7: Working on range: 857142858 to 1000000000
Fri Sep 29 23:36:34 2017 Process 2 / 7: Working on range: 285714286 to 428571429
Fri Sep 29 23:39:13 2017 Process 0 / 7: Found gap - 222, low prime - 122164747.
Fri Sep 29 23:39:13 2017 Process 0 / 7: Received from process 6: max gap - 260, low prime - 944192807.
Fri Sep 29 23:39:13 2017 Process 0 / 7: Received from process 2: max gap - 250, low prime - 387096133.
Fri Sep 29 23:39:13 2017 Process 0 / 7: Received from process 3: max gap - 282, low prime - 436273009.
Fri Sep 29 23:39:13 2017 Process 0 / 7: Received from process 4: max gap - 276, low prime - 649580171.
Fri Sep 29 23:39:13 2017 Process 0 / 7: Received from process 5: max gap - 246, low prime - 848758531.
Fri Sep 29 23:39:13 2017 Process 0 / 7: Received from process 1: max gap - 248, low prime - 191912783.
Fri Sep 29 23:39:13 2017 Process 0 / 7: Largest gap found: 282, between 436273009 and 436273291.
Fri Sep 29 23:39:13 2017 Process 0 / 7: Run time was 159.134436 seconds
Fri Sep 29 23:39:13 2017 Process 0 / 7: End
--- SharcNET Job Epilogue ---
job id: 10859727
exit status: 0
cpu time: 1086s / 7.0h (4 %)
elapsed time: 190s / 1.0h (5 %)
virtual memory: 246.7M / 1.0G (24 %)

Job completed successfully
WARNING: Job only used 5 % of its requested walltime.
WARNING: Job only used 4 % of its requested cpu time.
WARNING: Job only used 24% of its requested memory.

8 processor output

Fri Sep 29 23:36:35 2017 Process 0 / 8: Starting
Fri Sep 29 23:36:35 2017 Process 0 / 8: Working on range: 0 to 125000000
Fri Sep 29 23:36:35 2017 Process 4 / 8: Working on range: 500000000 to 625000000
Fri Sep 29 23:36:35 2017 Process 6 / 8: Working on range: 750000000 to 875000000
Fri Sep 29 23:36:35 2017 Process 5 / 8: Working on range: 625000000 to 750000000
Fri Sep 29 23:36:35 2017 Process 1 / 8: Working on range: 125000000 to 250000000
Fri Sep 29 23:36:35 2017 Process 3 / 8: Working on range: 375000000 to 500000000
Fri Sep 29 23:36:35 2017 Process 2 / 8: Working on range: 250000000 to 375000000
Fri Sep 29 23:36:35 2017 Process 7 / 8: Working on range: 875000000 to 1000000000
Fri Sep 29 23:38:54 2017 Process 0 / 8: Found gap - 222, low prime - 122164747.
Fri Sep 29 23:38:54 2017 Process 0 / 8: Received from process 1: max gap - 248, low prime - 191912783.
Fri Sep 29 23:38:54 2017 Process 0 / 8: Received from process 2: max gap - 242, low prime - 367876529.
Fri Sep 29 23:38:54 2017 Process 0 / 8: Received from process 3: max gap - 282, low prime - 436273009.
Fri Sep 29 23:38:54 2017 Process 0 / 8: Received from process 4: max gap - 250, low prime - 516540163.
Fri Sep 29 23:38:54 2017 Process 0 / 8: Received from process 6: max gap - 246, low prime - 848758531.
Fri Sep 29 23:38:54 2017 Process 0 / 8: Received from process 7: max gap - 260, low prime - 944192807.
Fri Sep 29 23:38:54 2017 Process 0 / 8: Received from process 5: max gap - 276, low prime - 649580171.
Fri Sep 29 23:38:54 2017 Process 0 / 8: Largest gap found: 282, between 436273009 and 436273291.
Fri Sep 29 23:38:54 2017 Process 0 / 8: Run time was 139.303029 seconds
Fri Sep 29 23:38:54 2017 Process 0 / 8: End
--- SharcNET Job Epilogue ---
job id: 10859728
exit status: 0
cpu time: 1100s / 8.0h (3 %)
elapsed time: 170s / 1.0h (4 %)
virtual memory: 240.6M / 1.0G (23 %)

Job completed successfully
WARNING: Job only used 4 % of its requested walltime.
WARNING: Job only used 3 % of its requested cpu time.
WARNING: Job only used 23% of its requested memory.

Appendix 3 : Program output for 10^{12}

32 processor output

Tue Sep 26 13:35:35 2017 Process 12 / 32: Working on range: 375000000000 t
Mon Oct 2 12:44:56 2017 Process 1 / 32: Working on range: 31250000000 to 62500000000
Mon Oct 2 12:44:56 2017 Process 9 / 32: Working on range: 281250000000 to 312500000000
Mon Oct 2 12:44:56 2017 Process 0 / 32: Starting
Mon Oct 2 12:44:56 2017 Process 0 / 32: Working on range: 0 to 31250000000
Mon Oct 2 12:44:56 2017 Process 29 / 32: Working on range: 906250000000 to 937500000000
Mon Oct 2 12:44:56 2017 Process 31 / 32: Working on range: 968750000000 to 1000000000000
Mon Oct 2 12:44:56 2017 Process 26 / 32: Working on range: 812500000000 to 843750000000
Mon Oct 2 12:44:56 2017 Process 25 / 32: Working on range: 781250000000 to 812500000000
Mon Oct 2 12:44:56 2017 Process 10 / 32: Working on range: 312500000000 to 343750000000
Mon Oct 2 12:44:56 2017 Process 15 / 32: Working on range: 468750000000 to 500000000000
Mon Oct 2 12:44:56 2017 Process 22 / 32: Working on range: 687500000000 to 718750000000
Mon Oct 2 12:44:56 2017 Process 27 / 32: Working on range: 843750000000 to 875000000000
Mon Oct 2 12:44:56 2017 Process 13 / 32: Working on range: 406250000000 to 437500000000
Mon Oct 2 12:44:56 2017 Process 16 / 32: Working on range: 500000000000 to 531250000000
Mon Oct 2 12:44:56 2017 Process 6 / 32: Working on range: 187500000000 to 218750000000
Mon Oct 2 12:44:56 2017 Process 17 / 32: Working on range: 531250000000 to 562500000000
Mon Oct 2 12:44:56 2017 Process 11 / 32: Working on range: 343750000000 to 375000000000
Mon Oct 2 12:44:56 2017 Process 2 / 32: Working on range: 62500000000 to 93750000000
Mon Oct 2 12:44:56 2017 Process 3 / 32: Working on range: 93750000000 to 125000000000
Mon Oct 2 12:44:56 2017 Process 4 / 32: Working on range: 125000000000 to 156250000000
Mon Oct 2 12:44:56 2017 Process 5 / 32: Working on range: 156250000000 to 187500000000
Mon Oct 2 12:44:56 2017 Process 18 / 32: Working on range: 562500000000 to 593750000000
Mon Oct 2 12:44:56 2017 Process 19 / 32: Working on range: 593750000000 to 625000000000
Mon Oct 2 12:44:56 2017 Process 20 / 32: Working on range: 625000000000 to 656250000000
Mon Oct 2 12:44:56 2017 Process 21 / 32: Working on range: 656250000000 to 687500000000
Mon Oct 2 12:44:56 2017 Process 12 / 32: Working on range: 375000000000 to 406250000000
Mon Oct 2 12:44:56 2017 Process 28 / 32: Working on range: 875000000000 to 906250000000
Mon Oct 2 12:44:56 2017 Process 23 / 32: Working on range: 718750000000 to 750000000000
Mon Oct 2 12:44:56 2017 Process 7 / 32: Working on range: 218750000000 to 250000000000
Mon Oct 2 12:44:56 2017 Process 8 / 32: Working on range: 250000000000 to 281250000000
Mon Oct 2 12:44:56 2017 Process 24 / 32: Working on range: 750000000000 to 781250000000
Mon Oct 2 12:44:56 2017 Process 30 / 32: Working on range: 937500000000 to 968750000000
Mon Oct 2 12:44:56 2017 Process 14 / 32: Working on range: 437500000000 to 468750000000
Mon Oct 2 22:06:59 2017 Process 0 / 32: Found gap - 456, low prime - 25056082087.
Mon Oct 2 22:06:59 2017 Process 0 / 32: Received from process 1: max gap - 464, low prime - 42652618343.
Mon Oct 2 22:06:59 2017 Process 0 / 32: Received from process 2: max gap - 450, low prime - 63816175447.
Mon Oct 2 22:06:59 2017 Process 0 / 32: Received from process 4: max gap - 468, low prime - 127976334671.
Mon Oct 2 22:06:59 2017 Process 0 / 32: Received from process 7: max gap - 486, low prime - 241160624143.
Mon Oct 2 22:06:59 2017 Process 0 / 32: Received from process 8: max gap - 444, low prime - 274905296293.
Mon Oct 2 22:06:59 2017 Process 0 / 32: Received from process 11: max gap - 478, low prime - 367766547571.
Mon Oct 2 22:06:59 2017 Process 0 / 32: Received from process 15: max gap - 500, low prime - 487286789723.
Mon Oct 2 22:06:59 2017 Process 0 / 32: Received from process 16: max gap - 450, low prime - 531060842243.
Mon Oct 2 22:06:59 2017 Process 0 / 32: Received from process 29: max gap - 500, low prime - 929156727137.
Mon Oct 2 22:06:59 2017 Process 0 / 32: Received from process 30: max gap - 484, low prime - 942509706043.
Mon Oct 2 22:06:59 2017 Process 0 / 32: Received from process 31: max gap - 494, low prime - 993878218139.
Mon Oct 2 22:06:59 2017 Process 0 / 32: Received from process 12: max gap - 478, low prime - 389353209841.
Mon Oct 2 22:06:59 2017 Process 0 / 32: Received from process 3: max gap - 438, low prime - 101328529441.
Mon Oct 2 22:06:59 2017 Process 0 / 32: Received from process 6: max gap - 454, low prime - 202530831163.
Mon Oct 2 22:06:59 2017 Process 0 / 32: Received from process 13: max gap - 516, low prime - 416608695821.
Mon Oct 2 22:06:59 2017 Process 0 / 32: Received from process 14: max gap - 532, low prime - 461690510011.
Mon Oct 2 22:06:59 2017 Process 0 / 32: Received from process 17: max gap - 462, low prime - 532857173801.
Mon Oct 2 22:06:59 2017 Process 0 / 32: Received from process 22: max gap - 466, low prime - 703718206123.
Mon Oct 2 22:06:59 2017 Process 0 / 32: Received from process 23: max gap - 540, low prime - 738832927927.

Mon Oct 2 22:06:59 2017 Process 0 / 32: Received from process 24: max gap - 484, low prime - 767644374817.
Mon Oct 2 22:06:59 2017 Process 0 / 32: Received from process 28: max gap - 516, low prime - 893531612273.
Mon Oct 2 22:06:59 2017 Process 0 / 32: Received from process 5: max gap - 474, low prime - 182226896239.
Mon Oct 2 22:06:59 2017 Process 0 / 32: Received from process 9: max gap - 514, low prime - 304599508537.
Mon Oct 2 22:06:59 2017 Process 0 / 32: Received from process 10: max gap - 454, low prime - 337737093847.
Mon Oct 2 22:06:59 2017 Process 0 / 32: Received from process 18: max gap - 480, low prime - 589097679491.
Mon Oct 2 22:06:59 2017 Process 0 / 32: Received from process 19: max gap - 534, low prime - 614487453523.
Mon Oct 2 22:06:59 2017 Process 0 / 32: Received from process 20: max gap - 474, low prime - 634213178969.
Mon Oct 2 22:06:59 2017 Process 0 / 32: Received from process 21: max gap - 474, low prime - 673420121333.
Mon Oct 2 22:06:59 2017 Process 0 / 32: Received from process 25: max gap - 504, low prime - 789448506659.
Mon Oct 2 22:06:59 2017 Process 0 / 32: Received from process 26: max gap - 474, low prime - 813942473723.
Mon Oct 2 22:06:59 2017 Process 0 / 32: Received from process 27: max gap - 474, low prime - 846399952577.
Mon Oct 2 22:06:59 2017 Process 0 / 32: Largest gap found: 540, between 738832927927 and 738832928467.
Mon Oct 2 22:06:59 2017 Process 0 / 32: Run time was 33723.286738 seconds
Mon Oct 2 22:06:59 2017 Process 0 / 32: End
--- SharcNET Job Epilogue ---
           job id: 10860530
      exit status: 0
         cpu time: 12.4d / 16.0d (77 %)
     elapsed time: 9.4h / 12.0h (78 %)
   virtual memory: 223.2M / 1.0G (21 %)

Job completed successfully
WARNING: Job only used 78 % of its requested walltime.
WARNING: Job only used 77 % of its requested cpu time.
WARNING: Job only used 21% of its requested memory.

64 processor output

Mon Oct 2 12:23:20 2017 Process 62 / 64: Working on range: 968750000000 to 984375000000
Mon Oct 2 12:23:20 2017 Process 12 / 64: Working on range: 187500000000 to 203125000000
Mon Oct 2 12:23:20 2017 Process 63 / 64: Working on range: 984375000000 to 1000000000000
Mon Oct 2 12:23:20 2017 Process 45 / 64: Working on range: 703125000000 to 718750000000
Mon Oct 2 12:23:20 2017 Process 44 / 64: Working on range: 687500000000 to 703125000000
Mon Oct 2 12:23:20 2017 Process 46 / 64: Working on range: 718750000000 to 734375000000
Mon Oct 2 12:23:20 2017 Process 19 / 64: Working on range: 296875000000 to 312500000000
Mon Oct 2 12:23:20 2017 Process 22 / 64: Working on range: 343750000000 to 359375000000
Mon Oct 2 12:23:20 2017 Process 17 / 64: Working on range: 265625000000 to 281250000000
Mon Oct 2 12:23:20 2017 Process 31 / 64: Working on range: 484375000000 to 500000000000
Mon Oct 2 12:23:20 2017 Process 18 / 64: Working on range: 281250000000 to 296875000000
Mon Oct 2 12:23:20 2017 Process 49 / 64: Working on range: 765625000000 to 781250000000
Mon Oct 2 12:23:20 2017 Process 14 / 64: Working on range: 218750000000 to 234375000000
Mon Oct 2 12:23:20 2017 Process 30 / 64: Working on range: 468750000000 to 484375000000
Mon Oct 2 12:23:20 2017 Process 50 / 64: Working on range: 781250000000 to 796875000000
Mon Oct 2 12:23:20 2017 Process 34 / 64: Working on range: 531250000000 to 546875000000
Mon Oct 2 12:23:20 2017 Process 51 / 64: Working on range: 796875000000 to 812500000000
Mon Oct 2 12:23:20 2017 Process 54 / 64: Working on range: 843750000000 to 859375000000
Mon Oct 2 12:23:20 2017 Process 47 / 64: Working on range: 734375000000 to 750000000000
Mon Oct 2 12:23:20 2017 Process 15 / 64: Working on range: 234375000000 to 250000000000
Mon Oct 2 12:23:20 2017 Process 55 / 64: Working on range: 859375000000 to 875000000000
Mon Oct 2 12:23:20 2017 Process 8 / 64: Working on range: 125000000000 to 140625000000
Mon Oct 2 12:23:20 2017 Process 23 / 64: Working on range: 359375000000 to 375000000000
Mon Oct 2 12:23:20 2017 Process 39 / 64: Working on range: 609375000000 to 625000000000
Mon Oct 2 12:23:20 2017 Process 20 / 64: Working on range: 312500000000 to 328125000000
Mon Oct 2 12:23:20 2017 Process 13 / 64: Working on range: 203125000000 to 218750000000
Mon Oct 2 12:23:20 2017 Process 7 / 64: Working on range: 109375000000 to 125000000000
Mon Oct 2 12:23:20 2017 Process 2 / 64: Working on range: 31250000000 to 46875000000
Mon Oct 2 12:23:20 2017 Process 16 / 64: Working on range: 250000000000 to 265625000000
Mon Oct 2 12:23:20 2017 Process 52 / 64: Working on range: 812500000000 to 828125000000
Mon Oct 2 12:23:20 2017 Process 58 / 64: Working on range: 906250000000 to 921875000000
Mon Oct 2 12:23:20 2017 Process 40 / 64: Working on range: 625000000000 to 640625000000
Mon Oct 2 12:23:20 2017 Process 36 / 64: Working on range: 562500000000 to 578125000000
Mon Oct 2 12:23:20 2017 Process 38 / 64: Working on range: 593750000000 to 609375000000
Mon Oct 2 12:23:20 2017 Process 29 / 64: Working on range: 453125000000 to 468750000000
Mon Oct 2 12:23:20 2017 Process 48 / 64: Working on range: 750000000000 to 765625000000
Mon Oct 2 12:23:20 2017 Process 4 / 64: Working on range: 62500000000 to 78125000000
Mon Oct 2 12:23:20 2017 Process 42 / 64: Working on range: 656250000000 to 671875000000
Mon Oct 2 12:23:20 2017 Process 43 / 64: Working on range: 671875000000 to 687500000000
Mon Oct 2 12:23:20 2017 Process 41 / 64: Working on range: 640625000000 to 656250000000
Mon Oct 2 12:23:20 2017 Process 1 / 64: Working on range: 15625000000 to 31250000000
Mon Oct 2 12:23:20 2017 Process 26 / 64: Working on range: 406250000000 to 421875000000
Mon Oct 2 12:23:20 2017 Process 9 / 64: Working on range: 140625000000 to 156250000000
Mon Oct 2 12:23:20 2017 Process 33 / 64: Working on range: 515625000000 to 531250000000
Mon Oct 2 12:23:20 2017 Process 6 / 64: Working on range: 93750000000 to 109375000000
Mon Oct 2 12:23:20 2017 Process 11 / 64: Working on range: 171875000000 to 187500000000
Mon Oct 2 12:23:20 2017 Process 25 / 64: Working on range: 390625000000 to 406250000000
Mon Oct 2 12:23:20 2017 Process 35 / 64: Working on range: 546875000000 to 562500000000
Mon Oct 2 12:23:20 2017 Process 3 / 64: Working on range: 46875000000 to 62500000000
Mon Oct 2 12:23:20 2017 Process 28 / 64: Working on range: 437500000000 to 453125000000
Mon Oct 2 12:23:20 2017 Process 10 / 64: Working on range: 156250000000 to 171875000000
Mon Oct 2 12:23:20 2017 Process 56 / 64: Working on range: 875000000000 to 890625000000
Mon Oct 2 12:23:20 2017 Process 57 / 64: Working on range: 890625000000 to 906250000000
Mon Oct 2 12:23:20 2017 Process 21 / 64: Working on range: 328125000000 to 343750000000
Mon Oct 2 12:23:20 2017 Process 53 / 64: Working on range: 828125000000 to 843750000000
Mon Oct 2 12:23:20 2017 Process 61 / 64: Working on range: 953125000000 to 968750000000

Mon Oct 2 12:23:20 2017 Process 32 / 64: Working on range: 500000000000 to 515625000000
Mon Oct 2 12:23:20 2017 Process 24 / 64: Working on range: 375000000000 to 390625000000
Mon Oct 2 12:23:20 2017 Process 0 / 64: Starting
Mon Oct 2 12:23:20 2017 Process 0 / 64: Working on range: 0 to 15625000000
Mon Oct 2 12:23:20 2017 Process 37 / 64: Working on range: 578125000000 to 593750000000
Mon Oct 2 12:23:20 2017 Process 5 / 64: Working on range: 78125000000 to 93750000000
Mon Oct 2 12:23:20 2017 Process 59 / 64: Working on range: 921875000000 to 937500000000
Mon Oct 2 12:23:20 2017 Process 60 / 64: Working on range: 937500000000 to 953125000000
Mon Oct 2 12:23:20 2017 Process 27 / 64: Working on range: 421875000000 to 437500000000
Mon Oct 2 17:01:23 2017 Process 0 / 64: Found gap - 382, low prime - 10726904659.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 16: max gap - 440, low prime - 256680893009.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 1: max gap - 456, low prime - 25056082087.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 2: max gap - 464, low prime - 42652618343.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 4: max gap - 450, low prime - 63816175447.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 8: max gap - 468, low prime - 127976334671.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 31: max gap - 500, low prime - 487286789723.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 32: max gap - 440, low prime - 502917163271.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 44: max gap - 452, low prime - 694169425889.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 62: max gap - 470, low prime - 983150214251.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 63: max gap - 494, low prime - 993878218139.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 15: max gap - 486, low prime - 241160624143.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 12: max gap - 454, low prime - 202530831163.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 13: max gap - 438, low prime - 218145699553.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 22: max gap - 420, low prime - 347899961347.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 23: max gap - 478, low prime - 367766547571.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 24: max gap - 478, low prime - 389353209841.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 25: max gap - 462, low prime - 400729567081.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 33: max gap - 450, low prime - 531060842243.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 34: max gap - 462, low prime - 532857173801.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 45: max gap - 466, low prime - 703718206123.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 27: max gap - 498, low prime - 428315806823.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 3: max gap - 414, low prime - 49914935177.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 6: max gap - 438, low prime - 101328529441.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 7: max gap - 438, low prime - 115954395943.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 11: max gap - 474, low prime - 182226896239.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 17: max gap - 444, low prime - 274905296293.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 30: max gap - 480, low prime - 482423533897.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 46: max gap - 480, low prime - 731674970641.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 50: max gap - 504, low prime - 789448506659.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 57: max gap - 516, low prime - 893531612273.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 55: max gap - 472, low prime - 865244709607.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 26: max gap - 516, low prime - 416608695821.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 29: max gap - 532, low prime - 461690510011.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 47: max gap - 540, low prime - 738832927927.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 49: max gap - 484, low prime - 767644374817.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 52: max gap - 474, low prime - 813942473723.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 58: max gap - 492, low prime - 910361180689.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 59: max gap - 500, low prime - 929156727137.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 60: max gap - 484, low prime - 942509706043.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 61: max gap - 456, low prime - 960530371991.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 54: max gap - 474, low prime - 846399952577.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 5: max gap - 432, low prime - 87241770619.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 14: max gap - 432, low prime - 233688424001.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 28: max gap - 454, low prime - 451215196093.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 35: max gap - 450, low prime - 549088570211.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 38: max gap - 448, low prime - 604730989609.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 48: max gap - 444, low prime - 761267254453.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 51: max gap - 494, low prime - 804541404419.

Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 53: max gap - 474, low prime - 835021343713.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 56: max gap - 498, low prime - 878651274181.
Mon Oct 2 17:01:23 2017 Process 0 / 64: Received from process 36: max gap - 466, low prime - 565855695631.
Mon Oct 2 17:01:30 2017 Process 0 / 64: Received from process 37: max gap - 480, low prime - 589097679491.
Mon Oct 2 17:01:33 2017 Process 0 / 64: Received from process 40: max gap - 474, low prime - 634213178969.
Mon Oct 2 17:01:41 2017 Process 0 / 64: Received from process 41: max gap - 464, low prime - 645644546333.
Mon Oct 2 17:01:44 2017 Process 0 / 64: Received from process 19: max gap - 514, low prime - 304599508537.
Mon Oct 2 17:01:53 2017 Process 0 / 64: Received from process 39: max gap - 534, low prime - 614487453523.
Mon Oct 2 17:02:07 2017 Process 0 / 64: Received from process 20: max gap - 444, low prime - 317747523557.
Mon Oct 2 17:02:08 2017 Process 0 / 64: Received from process 21: max gap - 454, low prime - 337737093847.
Mon Oct 2 17:02:16 2017 Process 0 / 64: Received from process 42: max gap - 462, low prime - 670161395489.
Mon Oct 2 17:02:50 2017 Process 0 / 64: Received from process 18: max gap - 460, low prime - 292237633381.
Mon Oct 2 17:04:46 2017 Process 0 / 64: Received from process 43: max gap - 474, low prime - 673420121333.
Mon Oct 2 17:05:28 2017 Process 0 / 64: Received from process 10: max gap - 444, low prime - 164739487597.
Mon Oct 2 17:07:46 2017 Process 0 / 64: Received from process 9: max gap - 460, low prime - 148473908887.
Mon Oct 2 17:07:46 2017 Process 0 / 64: Largest gap found: 540, between 738832927927 and 738832928467.
Mon Oct 2 17:07:46 2017 Process 0 / 64: Run time was 17065.508472 seconds
Mon Oct 2 17:07:46 2017 Process 0 / 64: End
--- SharcNET Job Epilogue ---
           job id: 10860529
        exit status: 0
          cpu time: 12.3d / 32.0d (38 %)
       elapsed time: 4.7h / 12.0h (39 %)
     virtual memory: 222.9M / 1.0G (21 %)

Job completed successfully
WARNING: Job only used 39 % of its requested walltime.
WARNING: Job only used 38 % of its requested cpu time.
WARNING: Job only used 21% of its requested memory.