

CS499 Assignment 7 Report
Caleb Johnson
CJJ226

Question 1:

1. Node Report
 - a. Ran on: cn1
 - b. GPU Installed: Tesla V100-SXM2
2. Compute Compatibility
 - a. The Tesla V100 has version 7.0 compute capability
3. Compile Line
 - a. nvcc -arch=compute_70 -code=sm_70 -lcuda main.cu -o main
 - b. Where main.cu and main are to be replaced with the appropriate file name

Question 2:

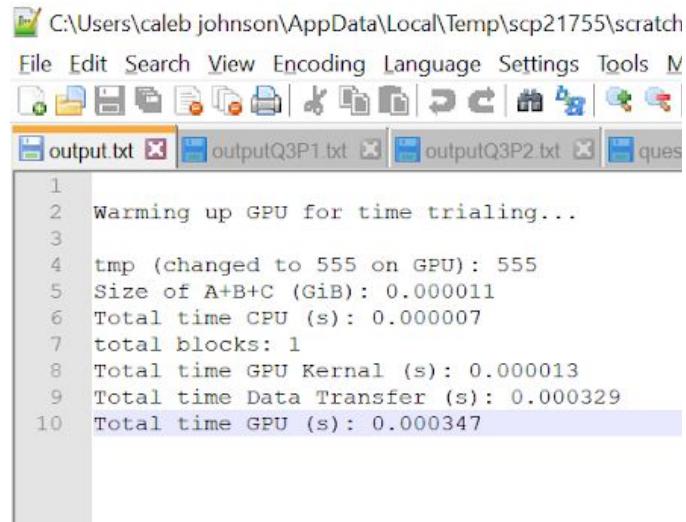
- **Compile Line:** nvcc -Xcompiler -fopenmp -arch=compute_70 -code=sm_70 -lcuda question2_CJJ226.cu -o question2

	CPU Total	GPU Total	GPU Data	GPU Kernel
N = 100	0.000004	0.000348	0.000332	0.000012
N = 1000	0.000007	0.000347	0.000329	0.000013
N = 1000000	0.002652	0.004270	0.004218	0.000045
N = 100000000	0.268526	0.348867	0.347364	0.001488
N = 5000000000	1.342452	1.744342	1.737036	0.007293

- N = 100

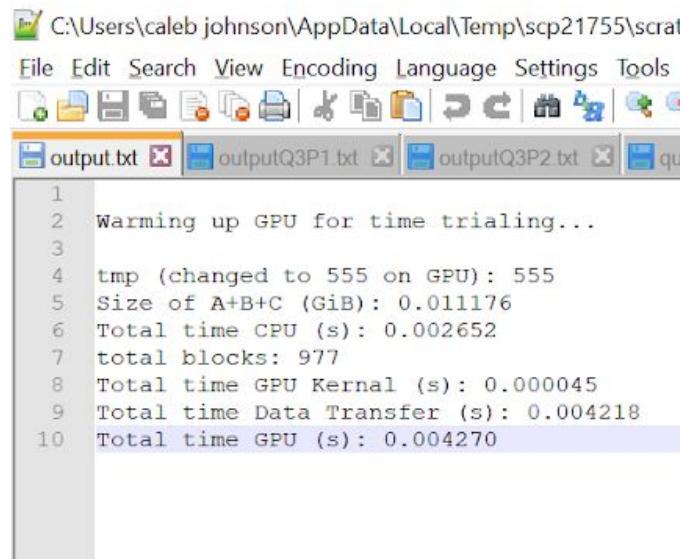
```
C:\Users\caleb.johnson\AppData\Local\Temp\scp21755\scratch>
File Edit Search View Encoding Language Settings Tools Mi
  output.txt  outputQ3P1.txt  outputQ3P2.txt  quest
1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of A+B+C (GiB): 0.000001
6 Total time CPU (s): 0.000004
7 total blocks: 1
8 Total time GPU Kernel (s): 0.000012
9 Total time Data Transfer (s): 0.000332
10 Total time GPU (s): 0.000348
```

- N = 1000



```
C:\Users\caleb johnson\AppData\Local\Temp\scp21755\scratch
File Edit Search View Encoding Language Settings Tools N
output.txt outputQ3P1.txt outputQ3P2.txt ques
1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of A+B+C (GiB): 0.000011
6 Total time CPU (s): 0.000007
7 total blocks: 1
8 Total time GPU Kernel (s): 0.000013
9 Total time Data Transfer (s): 0.000329
10 Total time GPU (s): 0.000347
```

- N = 1000000

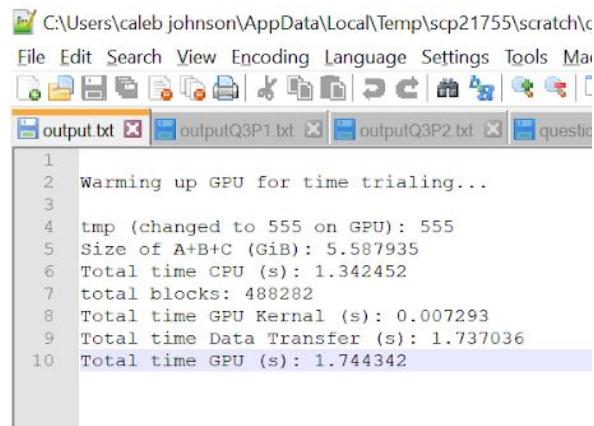


```
C:\Users\caleb johnson\AppData\Local\Temp\scp21755\scrat
File Edit Search View Encoding Language Settings Tools
output.txt outputQ3P1.txt outputQ3P2.txt qu
1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of A+B+C (GiB): 0.011176
6 Total time CPU (s): 0.002652
7 total blocks: 977
8 Total time GPU Kernal (s): 0.000045
9 Total time Data Transfer (s): 0.004218
10 Total time GPU (s): 0.004270
```

- N = 100000000

```
1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of A+B+C (GiB): 1.117587
6 Total time CPU (s): 0.268526
7 total blocks: 97657
8 Total time GPU Kernel (s): 0.001488
9 Total time Data Transfer (s): 0.347364
10 Total time GPU (s): 0.348867
```

- N = 500000000



```
1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of A+B+C (GiB): 5.587935
6 Total time CPU (s): 1.342452
7 total blocks: 488282
8 Total time GPU Kernel (s): 0.007293
9 Total time Data Transfer (s): 1.737036
10 Total time GPU (s): 1.744342
```

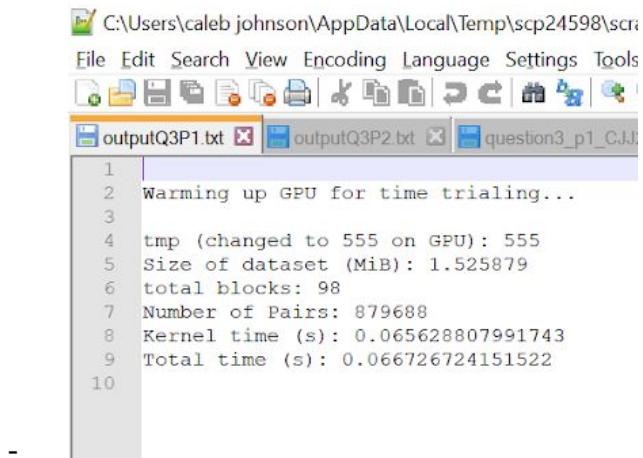
- **Performance Analysis:**

- The performance of the GPU vector addition vs the CPU version increases as N increases. At small N values the CPU runs faster than the GPU due to the extra overhead the GPU has causing a loss in speed. This overhead however is very quickly mitigated as the GPU quickly outspeeds CPU as N gets larger as seen in the N value readings of 1000000 and up. The data transfer does worsen the GPUs overall time resulting in some bad overall speeds even at some high N values. This means that the program for the GPU vector addition does perform very well in computation time compared to the CPU version for the execution of the code, but suffers from the data transfer time making its overall execution time not much better than CPUs overall time.

Question 3:

- **Part 1:** nvcc -Xcompiler -fopenmp -arch=compute_70 -code=sm_70 -lcuda question3_p1_CJJ226.cu -o question3
 - Epsilon = 5

- **N = 100000**

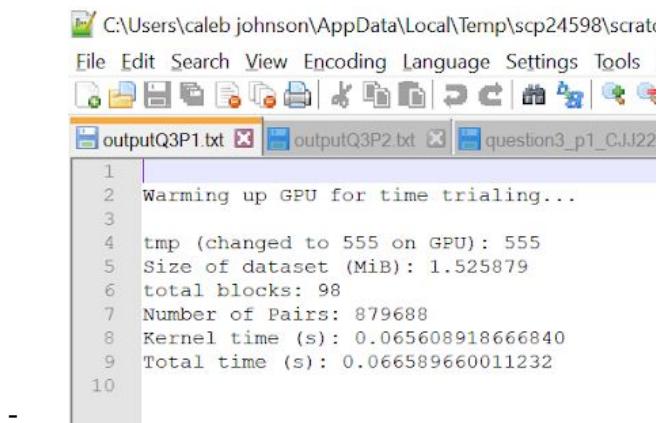


C:\Users\caleb johnson\AppData\Local\Temp\scp24598\scratches

File Edit Search View Encoding Language Settings Tools

outputQ3P1.txt outputQ3P2.txt question3_p1_CJJ

```
1 Warming up GPU for time trialing...
2
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 1.525879
6 total blocks: 98
7 Number of Pairs: 879688
8 Kernel time (s): 0.065628807991743
9 Total time (s): 0.066726724151522
10
```

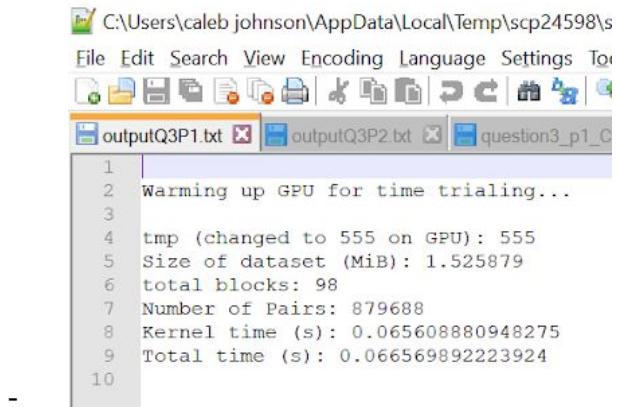


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File Edit Search View Encoding Language Settings Tools

outputQ3P1.txt outputQ3P2.txt question3_p1_CJJ22

```
1 Warming up GPU for time trialing...
2
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 1.525879
6 total blocks: 98
7 Number of Pairs: 879688
8 Kernel time (s): 0.065608918666840
9 Total time (s): 0.066589660011232
10
```



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File Edit Search View Encoding Language Settings Tools

outputQ3P1.txt outputQ3P2.txt question3_p1_CJJ22

```
1 Warming up GPU for time trialing...
2
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 1.525879
6 total blocks: 98
7 Number of Pairs: 879688
8 Kernel time (s): 0.065608880948275
9 Total time (s): 0.066569892223924
10
```

- **N = 10000**

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File Edit Search View Encoding Language Settings Tools Macro

outputQ3P1.txt outputQ3P2.txt question3_p1_CJJ226.cu

```
1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 0.152588
6 total blocks: 10
7 Number of Pairs: 17644
8 Kernel time (s): 0.003358577378094
9 Total time (s): 0.0040133371949|20
10
```

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File Edit Search View Encoding Language Settings Tools Macro

outputQ3P1.txt outputQ3P2.txt question3_p1_CJJ226.cu

```
1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 0.152588
6 total blocks: 10
7 Number of Pairs: 17644
8 Kernel time (s): 0.003357937559485
9 Total time (s): 0.003989554941654
10
```

```
C:\Users\caleb johnson\AppData\Local\Temp\scp41153\scratch\c
File Edit Search View Encoding Language Settings Tools Macro
outputQ3P1.txt outputQ3P2.txt question3_p1_CJJ226.cu
1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 0.152588
6 total blocks: 10
7 Number of Pairs: 17644
8 Kernel time (s): 0.003371859900653
9 Total time (s): 0.0040100943297|15
10
```

- **N = 1000**

```
C:\Users\caleb johnson\AppData\Local\Temp\scp41153\scratch\c
File Edit Search View Encoding Language Settings Tools Macro
outputQ3P1.txt outputQ3P2.txt question3_p1_CJJ226.cu
1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 0.015259
6 total blocks: 1
7 Number of Pairs: 1102
8 Kernel time (s): 0.000347144901752
9 Total time (s): 0.000930155627429
10
```

```
C:\Users\caleb johnson\AppData\Local\Temp\scp41153\scratch\

File Edit Search View Encoding Language Settings Tools Mac
outputQ3P1.txt outputQ3P2.txt question3_p1_CJJ226.cu

1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 0.015259
6 total blocks: 1
7 Number of Pairs: 1102
8 Kernel time (s): 0.000347144901752
9 Total time (s): 0.000930155627429
10
```

```
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File Edit Search View Encoding Language Settings Tools Mac
outputQ3P1.txt outputQ3P2.txt question3_p1_CJJ226.cu

1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 0.015259
6 total blocks: 1
7 Number of Pairs: 1102
8 Kernel time (s): 0.000347696244717
9 Total time (s): 0.000950300134718
10
```

- **N = 100**

```
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File Edit Search View Encoding Language Settings Tools Mac
outputQ3P1.txt outputQ3P2.txt question3_p1_CJJ226.cu

1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 0.001526
6 total blocks: 1
7 Number of Pairs: 100
8 Kernel time (s): 0.000031956471503
9 Total time (s): 0.000601344741881
10
```

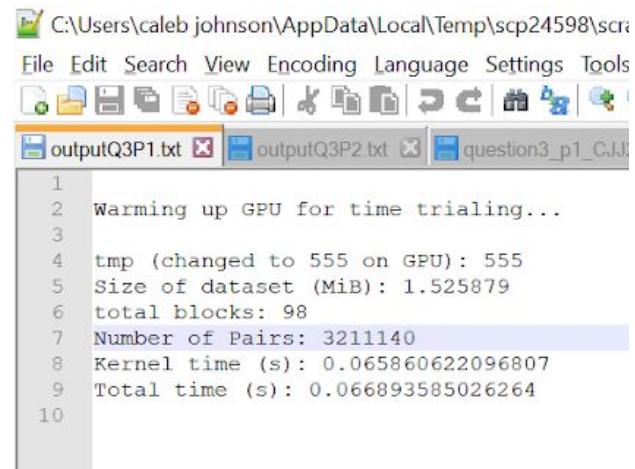
```
C:\Users\caleb johnson\AppData\Local\Temp\scp41153\scratch>
File Edit Search View Encoding Language Settings Tools Mac
outputQ3P1.txt outputQ3P2.txt question3_p1_CJJ226.c
1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 0.001526
6 total blocks: 1
7 Number of Pairs: 100
8 Kernel time (s): 0.000032477080822
9 Total time (s): 0.000600410625339
10
```

```
C:\Users\caleb johnson\AppData\Local\Temp\scp41153\scratch>
File Edit Search View Encoding Language Settings Tools Mac
outputQ3P1.txt outputQ3P2.txt question3_p1_CJJ226.c
1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 0.001526
6 total blocks: 1
7 Number of Pairs: 100
8 Kernel time (s): 0.000032309442759
9 Total time (s): 0.000599347054958
10
```

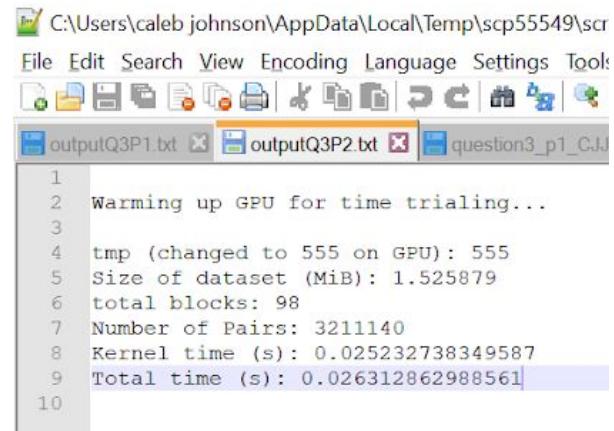
- **Epsilon = 10**

- **N = 100000**

```
C:\Users\caleb johnson\AppData\Local\Temp\scp24598\sc
File Edit Search View Encoding Language Settings Too
outputQ3P1.txt outputQ3P2.txt question3_p1_CJ
1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 1.525879
6 total blocks: 98
7 Number of Pairs: 3211140
8 Kernel time (s): 0.065860622096807
9 Total time (s): 0.066893585026264
10
```



```
C:\Users\caleb johnson\AppData\Local\Temp\scp24598\scr
File Edit Search View Encoding Language Settings Tools
outputQ3P1.txt outputQ3P2.txt question3_p1_CJJ
1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 1.525879
6 total blocks: 98
7 Number of Pairs: 3211140
8 Kernel time (s): 0.065860622096807
9 Total time (s): 0.066893585026264
10
```



```
C:\Users\caleb johnson\AppData\Local\Temp\scp55549\scr
File Edit Search View Encoding Language Settings Tools
outputQ3P1.txt outputQ3P2.txt question3_p1_CJJ
1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 1.525879
6 total blocks: 98
7 Number of Pairs: 3211140
8 Kernel time (s): 0.025232738349587
9 Total time (s): 0.026312862988561
10
```

- **N = 10000**

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```
File Edit Search View Encoding Language Settings Tools Mac
outputQ3P1.txt outputQ3P2.txt question3_p1_CJJ226.c

1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 0.152588
6 total blocks: 10
7 Number of Pairs: 41116
8 Kernel time (s): 0.003359735943377
9 Total time (s): 0.003982611000538
10
```

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```
File Edit Search View Encoding Language Settings Tools Mac
outputQ3P1.txt outputQ3P2.txt question3_p1_CJJ226.c

1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 0.152588
6 total blocks: 10
7 Number of Pairs: 41116
8 Kernel time (s): 0.003377032466233
9 Total time (s): 0.004002605564892
10
```

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```
File Edit Search View Encoding Language Settings Tools Mac
outputQ3P1.txt outputQ3P2.txt question3_p1_CJJ226.c

1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 0.152588
6 total blocks: 10
7 Number of Pairs: 41116
8 Kernel time (s): 0.003357707522810
9 Total time (s): 0.003981850109994
10
```

- **N = 1000**

```
C:\Users\caleb johnson\AppData\Local\Temp\scp41153\scratch\c
File Edit Search Encoding Language Settings Tools Mac
outputQ3P1.txt outputQ3P2.txt question3_p1_CJJ226.cu
1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 0.015259
6 total blocks: 1
7 Number of Pairs: 1356
8 Kernel time (s): 0.000350101850927
9 Total time (s): 0.001781379804015
10
```

```
C:\Users\caleb johnson\AppData\Local\Temp\scp41153\scratc
File Edit Search Encoding Language Settings Tools M
outputQ3P1.txt outputQ3P2.txt question3_p1_CJJ226.
1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 0.015259
6 total blocks: 1
7 Number of Pairs: 1356
8 Kernel time (s): 0.000347306951880
9 Total time (s): 0.000913692638278
10
```

```
C:\Users\caleb johnson\AppData\Local\Temp\scp41153\scratch\
File Edit Search Encoding Language Settings Tools Mac
outputQ3P1.txt outputQ3P2.txt question3_p1_CJJ226.cu
1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 0.015259
6 total blocks: 1
7 Number of Pairs: 1356
8 Kernel time (s): 0.000348986126482
9 Total time (s): 0.000953077338636
10
```

- **N = 100**

```
C:\Users\caleb johnson\AppData\Local\Temp\scp41153\scratch\

File Edit Search View Encoding Language Settings Tools Mac
outputQ3P1.txt outputQ3P2.txt question3_p1_CJJ226.cu

1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 0.001526
6 total blocks: 1
7 Number of Pairs: 100
8 Kernel time (s): 0.000031383708119
9 Total time (s): 0.000590467825532
10
```

```
C:\Users\caleb johnson\AppData\Local\Temp\scp41153\scratch\

File Edit Search View Encoding Language Settings Tools Mac
outputQ3P1.txt outputQ3P2.txt question3_p1_CJJ226.cu

1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 0.001526
6 total blocks: 1
7 Number of Pairs: 100
8 Kernel time (s): 0.000030951574445
9 Total time (s): 0.000610336661339
10
```

```
C:\Users\caleb johnson\AppData\Local\Temp\scp41153\scratch\

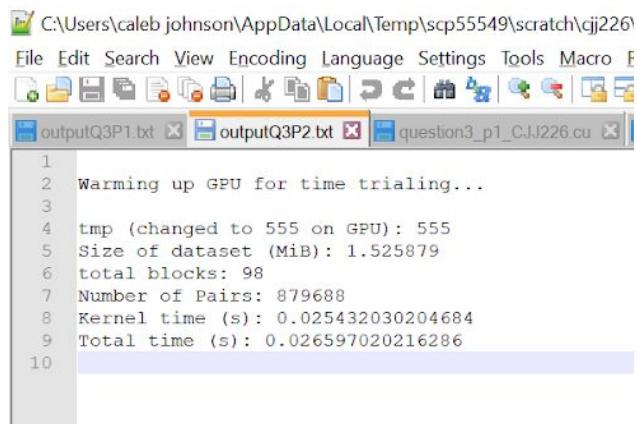
File Edit Search View Encoding Language Settings Tools Mac
outputQ3P1.txt outputQ3P2.txt question3_p1_CJJ226.cu

1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 0.001526
6 total blocks: 1
7 Number of Pairs: 100
8 Kernel time (s): 0.000031539238989
9 Total time (s): 0.000600883737206
10
```

- For assignment 6 the improved algorithm with -O3 ran on 4 cores/threads and at N = 100000 got an average total time of around 2 seconds. The GPU brute force beats the assignment 6 algorithm by a huge margin for N of 10000. For a smaller

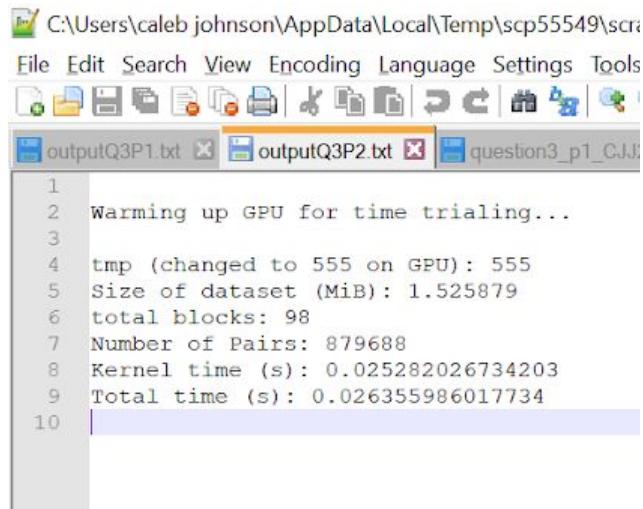
N of 100 the assignment 6 algorithm got an average time of about 0.0001 which is faster than the GPU brute force's total time, but slower than the time for kernel execution. The GPUs response time gets better as N increases and soon begins to allow the GPU to run much faster than the CPU. This is because while the GPUs computation time is faster than the CPUs the time it takes to transfer data hinders the GPU at smaller N values where the CPU is able to run immediately and finish before the GPU can finish transferring data. What this means is that overall performance for GPU increase as N increases when compared to times on CPU.

- **Part 2:** nvcc -Xcompiler -fopenmp -arch=compute_70 -code=sm_70 -lcuda question3_p2_CJJ226.cu -o question3P2
 - Epsilon = 5
 - **N = 100000**



```
C:\Users\caleb johnson\AppData\Local\Temp\scp55549\scratch\cj226
File Edit Search View Encoding Language Settings Tools Macro
outputQ3P1.txt outputQ3P2.txt question3_p1_CJJ226.cu

1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 1.525879
6 total blocks: 98
7 Number of Pairs: 879688
8 Kernel time (s): 0.025432030204684
9 Total time (s): 0.026597020216286
10
```



```
C:\Users\caleb johnson\AppData\Local\Temp\scp55549\scr
File Edit Search View Encoding Language Settings Tools
outputQ3P1.txt outputQ3P2.txt question3_p1_CJJ226.cu

1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 1.525879
6 total blocks: 98
7 Number of Pairs: 879688
8 Kernel time (s): 0.025282026734203
9 Total time (s): 0.026355986017734
10
```

```
C:\Users\caleb johnson\AppData\Local\Temp\scp55549\scratch\cj2.
File Edit Search View Encoding Language Settings Tools Macro
outputQ3P1.txt outputQ3P2.txt question3_p1_CJJ226.cu
1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 1.525879
6 total blocks: 98
7 Number of Pairs: 879688
8 Kernel time (s): 0.025961531791836
9 Total time (s): 0.027842545881867
10
```

- **N = 10000**

```
C:\Users\caleb johnson\AppData\Local\Temp\scp41193\scratch\
File Edit Search View Encoding Language Settings Tools Mac
outputQ3P1.txt outputQ3P2.txt question3_p1_CJJ226.cu
1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 0.152588
6 total blocks: 10
7 Number of Pairs: 17644
8 Kernel time (s): 0.002107883803546
9 Total time (s): 0.002730508334935
10
```

```
C:\Users\caleb johnson\AppData\Local\Temp\scp41193\scratch\c
File Edit Search View Encoding Language Settings Tools Mac
outputQ3P1.txt outputQ3P2.txt question3_p1_CJJ226.cu
1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 0.152588
6 total blocks: 10
7 Number of Pairs: 17644
8 Kernel time (s): 0.002121551893651
9 Total time (s): 0.002753138542175
10
```

```
C:\Users\caleb johnson\AppData\Local\Temp\scp41193\scratch
File Edit Search View Encoding Language Settings Tools Mac
outputQ3P1.txt outputQ3P2.txt question3_p1_CJJ226.c
1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 0.152588
6 total blocks: 10
7 Number of Pairs: 17644
8 Kernel time (s): 0.002108671702445
9 Total time (s): 0.002716528251767
10
```

- **N = 1000**

```
C:\Users\caleb johnson\AppData\Local\Temp\scp41193\scratch
File Edit Search View Encoding Language Settings Tools Mac
outputQ3P1.txt outputQ3P2.txt question3_p1_CJJ226.c
1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 0.015259
6 total blocks: 1
7 Number of Pairs: 1102
8 Kernel time (s): 0.000177664682269
9 Total time (s): 0.000732050277293
10
```

```
C:\Users\caleb johnson\AppData\Local\Temp\scp41193\scratch\c
File Edit Search View Encoding Language Settings Tools Mac
outputQ3P1.txt outputQ3P2.txt question3_p1_CJJ226.cu
1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 0.015259
6 total blocks: 1
7 Number of Pairs: 1102
8 Kernel time (s): 0.000174147076905
9 Total time (s): 0.000726570375264
10
```

```
C:\Users\caleb johnson\AppData\Local\Temp\scp41193\scratch>
File Edit Search View Encoding Language Settings Tools Macro
outputQ3P1.txt outputQ3P2.txt question3_p1_CJJ226.cu
1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 0.015259
6 total blocks: 1
7 Number of Pairs: 1102
8 Kernel time (s): 0.000177799724042
9 Total time (s): 0.002855573780835
10
```

- **N = 100**

```
C:\Users\caleb johnson\AppData\Local\Temp\scp41193\scratch>
File Edit Search View Encoding Language Settings Tools Macro
outputQ3P1.txt outputQ3P2.txt question3_p1_CJJ226.cu
1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 0.001526
6 total blocks: 1
7 Number of Pairs: 100
8 Kernel time (s): 0.000053599476814
9 Total time (s): 0.000593062490225
10
```

```
C:\Users\caleb johnson\AppData\Local\Temp\scp41193\scratch\cj2>
File Edit Search View Encoding Language Settings Tools Macro
outputQ3P1.txt outputQ3P2.txt question3_p1_CJJ226.cu
1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 0.001526
6 total blocks: 1
7 Number of Pairs: 100
8 Kernel time (s): 0.000050211325288
9 Total time (s): 0.000590004026890
10
```

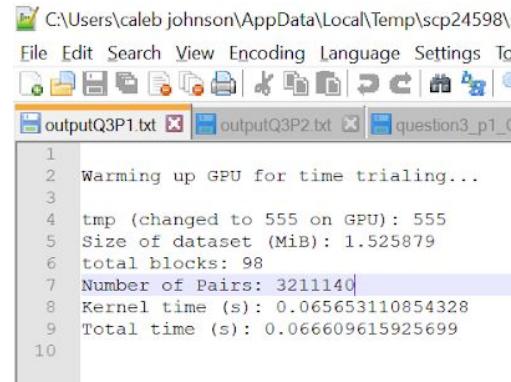
```
C:\Users\caleb johnson\AppData\Local\Temp\scp41193\scratch
File Edit Search View Encoding Language Settings Tools M
outputQ3P1.txt outputQ3P2.txt question3_p1_CJ226.c
1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 0.001526
6 total blocks: 1
7 Number of Pairs: 100
8 Kernel time (s): 0.000049977563322
9 Total time (s): 0.000594664365053
10
```

- **Epsilon = 10**

- **N = 100000**

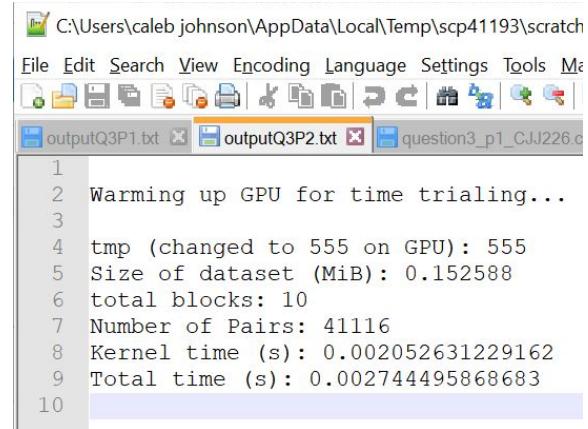
```
C:\Users\caleb johnson\AppData\Local\Temp\scp55549\scr
File Edit Search View Encoding Language Settings Tool
outputQ3P1.txt outputQ3P2.txt question3_p1_CJ226.c
1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 1.525879
6 total blocks: 98
7 Number of Pairs: 3211140
8 Kernel time (s): 0.025376449804753
9 Total time (s): 0.026467834133655
10
```

```
C:\Users\caleb johnson\AppData\Local\Temp\scp55549\scr
File Edit Search View Encoding Language Settings Tool
outputQ3P1.txt outputQ3P2.txt question3_p1_CJ226.c
1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 1.525879
6 total blocks: 98
7 Number of Pairs: 3211140
8 Kernel time (s): 0.025233106222004
9 Total time (s): 0.026298509910703
10
```

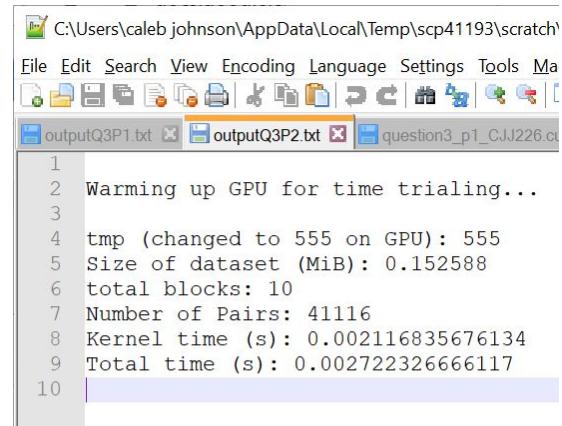


```
C:\Users\caleb johnson\AppData\Local\Temp\scp24598\
File Edit Search View Encoding Language Settings Tools Ma
outputQ3P1.txt outputQ3P2.txt question3_p1_CJJ226.c
1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 1.525879
6 total blocks: 98
7 Number of Pairs: 3211140
8 Kernel time (s): 0.065653110854328
9 Total time (s): 0.066609615925699
10
```

- **N = 10000**



```
C:\Users\caleb johnson\AppData\Local\Temp\scp41193\scratch
File Edit Search View Encoding Language Settings Tools Ma
outputQ3P1.txt outputQ3P2.txt question3_p1_CJJ226.c
1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 0.152588
6 total blocks: 10
7 Number of Pairs: 41116
8 Kernel time (s): 0.002052631229162
9 Total time (s): 0.002744495868683
10
```



```
C:\Users\caleb johnson\AppData\Local\Temp\scp41193\scratch
File Edit Search View Encoding Language Settings Tools Ma
outputQ3P1.txt outputQ3P2.txt question3_p1_CJJ226.c
1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 0.152588
6 total blocks: 10
7 Number of Pairs: 41116
8 Kernel time (s): 0.002116835676134
9 Total time (s): 0.002722326666117
10
```

```
C:\Users\caleb johnson\AppData\Local\Temp\scp41193\scratch\c
File Edit Search View Encoding Language Settings Tools Macro
outputQ3P1.txt outputQ3P2.txt question3_p1_CJJ226.cu
1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 0.152588
6 total blocks: 10
7 Number of Pairs: 41116
8 Kernel time (s): 0.002121448516846
9 Total time (s): 0.002967450767756
10
```

- **N = 1000**

```
C:\Users\caleb johnson\AppData\Local\Temp\scp41193\scratch\cjj
File Edit Search View Encoding Language Settings Tools Macro
outputQ3P1.txt outputQ3P2.txt question3_p1_CJJ226.cu
1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 0.015259
6 total blocks: 1
7 Number of Pairs: 1356
8 Kernel time (s): 0.000180875882506
9 Total time (s): 0.000731313601136
10
```

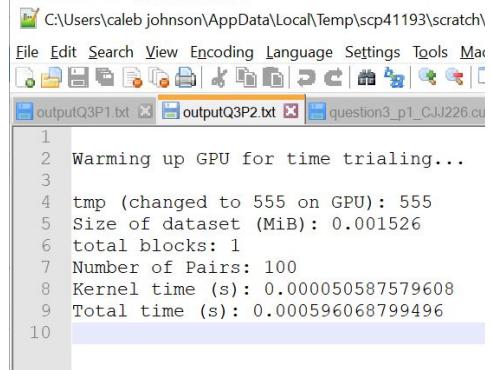
```
C:\Users\caleb johnson\AppData\Local\Temp\scp41193\scratch\
File Edit Search View Encoding Language Settings Tools Ma
outputQ3P1.txt outputQ3P2.txt question3_p1_CJJ226.c
1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 0.015259
6 total blocks: 1
7 Number of Pairs: 1356
8 Kernel time (s): 0.000170182436705
9 Total time (s): 0.000711009837687
10
```

```
C:\Users\caleb johnson\AppData\Local\Temp\scp41193\scratch\cj
File Edit Search View Encoding Language Settings Tools Macro
outputQ3P1.txt outputQ3P2.txt question3_p1_CJJ226.cu
1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 0.015259
6 total blocks: 1
7 Number of Pairs: 1356
8 Kernel time (s): 0.000172556377947
9 Total time (s): 0.000716244801879
10
```

- **N = 100**

```
C:\Users\caleb johnson\AppData\Local\Temp\scp41193\scratch\cj
File Edit Search View Encoding Language Settings Tools Macro
outputQ3P1.txt outputQ3P2.txt question3_p1_CJJ226.cu
1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 0.001526
6 total blocks: 1
7 Number of Pairs: 100
8 Kernel time (s): 0.000050138682127
9 Total time (s): 0.000591217540205
10
```

```
C:\Users\caleb johnson\AppData\Local\Temp\scp41193\scratch\cj
File Edit Search View Encoding Language Settings Tools Macro
outputQ3P1.txt outputQ3P2.txt question3_p1_CJJ226.cu
1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 0.001526
6 total blocks: 1
7 Number of Pairs: 100
8 Kernel time (s): 0.000052387826145
9 Total time (s): 0.000628487206995
10
```



The screenshot shows a terminal window with the following output:

```

C:\Users\caleb johnson\AppData\Local\Temp\scp41193\scratch>
File Edit Search View Encoding Language Settings Tools Mac
outputQ3P1.txt outputQ3P2.txt question3_p1_CJJ226.cu
1
2 Warming up GPU for time trialing...
3
4 tmp (changed to 555 on GPU): 555
5 Size of dataset (MiB): 0.001526
6 total blocks: 1
7 Number of Pairs: 100
8 Kernel time (s): 0.000050587579608
9 Total time (s): 0.000596068799496
10

```

- The new algorithm works by using some elements from assignment 6 in order to reduce the number of total operations and then calculates the final total pairs from the values given back. The adjustments made to this program that are different from assignment 6 are the ways that I set up the kernel to use shared memory as well as avoid the use of atomic. The shared memory simply uses a block size array to hold the threads index value which gets used multiple times to compare to the rest of the data. The function also avoid the bottleneck of atomic by having the threads report their value to an array index based on their ID which allows all the threads to write their pair count down concurrently and without race condition issues. This allows the new algorithm to run much faster than brute force method on GPU especially at higher N values. At N of 100000 the new algorithm runs in 1/3rd of the time of the brute force on average, a 3 times speedup. At N of 100 the new algorithm does become slower likely due to the overhead needed to process the total value of the pairs in epsilon, but this is the only point where the performance is worse and thus still has very good overall performance.

Bonus Question

- Compile: nvcc -Xcompiler -fopenmp -arch=compute_70 -code=sm_70 -lcuda questionBonus_CJJ226.cu -o questionB
- When comparing times between the usage of shared memory vs global memory for brute force I did not observe a speed up. What I found was that the shared memory was actually slightly slower at high N values, but faster at smaller ones. This is likely due to the fact that at large N values the shared memory method loses time when its needs to constantly rewrite the memory in the array, but at smaller N values only needs to write to the shared array once or twice allowing for the system to then have a faster execution.