

## Optimization Discussion

In this project, significant efforts were made to optimize the spatial distance histogram (SDH) algorithm for 3D data on the GPU. The primary focus was to improve performance by reducing global memory contention and exploiting the GPU's fast shared memory. Below, we discuss the key optimization strategies employed:

### 1. Output Privatization Using Shared Memory

In the non-optimized version, each thread directly updated a global histogram using atomic operations, which often became a performance bottleneck due to heavy contention. To alleviate this, we implemented output privatization:

- **Local Accumulation:**  
Each CUDA block allocates a shared memory array (`shared_histogram`) to locally accumulate histogram counts. Threads within the same block update this shared array instead of writing directly to global memory.
- **Reduced Atomic Contention:**  
After local accumulation, the partial results from the shared memory are merged into the global histogram with significantly fewer atomic operations. This two-step reduction minimizes slow global memory accesses, leading to a faster overall execution.

### 2. Efficient Work Distribution and Memory Access Patterns

- **Balanced Workload:**  
Each thread computes its global thread ID and processes a distinct subset of atom pairs. This balanced distribution ensures that all threads are effectively utilized, minimizing idle time.
- **Memory Coalescing:**  
The kernel design encourages threads within a block to access contiguous data. By doing so, memory accesses are coalesced, leading to improved throughput and better utilization of the memory subsystem.

### 3. Accurate Performance Measurement

- **CUDA Event Timing:**  
To ensure the integrity of the performance data, CUDA events were used to measure the kernel execution time accurately. Events are recorded immediately before and after the kernel launch, and the elapsed time is computed with high precision. This method confirms that the reported running time reflects the true kernel performance without any artificial optimizations or timing discrepancies.

### 4. Overall Impact on Performance

The combination of these techniques—shared memory output privatization, balanced workload distribution, optimized memory accesses, and precise kernel timing—resulted in significant

performance improvements. The optimized code achieves lower execution times compared to the non-optimized version by efficiently managing the GPU's memory hierarchy and reducing the overhead associated with atomic operations.

## Experimental Setup & Results

To validate these optimizations, the following experiments were conducted:

### 1. Dataset Size Variation:

- *Small Dataset*: 100,000 points
- *Medium Dataset*: 500,000 points

Fixed bucket width 100 and a block size of 256.

```
/apps/GPU_course/runScript.sh proj2-akmal.cu 100000 100 256
```

```
[akmal@forest.usf.edu@gaivi-login1 project2]$ /apps/GPU_course/runScript.sh proj2-akmal.cu 100000 100 256
----- nvcc Info: -----
nvcc: NVIDIA (R) Cuda compiler driver
Copyright (c) 2005-2021 NVIDIA Corporation
Built on Wed_Jun_2_19:15:15_PDT_2021
Cuda compilation tools, release 11.4, V11.4.48
Build cuda_11.4.r11.4/compiler.30033411_0
----- Compiling -----
ptxas info    : 0 bytes gmem
ptxas info    : Compiling entry function '_Z10PDH_kernelP8atomdescP10hist_entryxdi' for 'sm_52'
ptxas info    : Function properties for _Z10PDH_kernelP8atomdescP10hist_entryxdi
  0 bytes stack frame, 0 bytes spill stores, 0 bytes spill loads
ptxas info    : Used 26 registers, 356 bytes cmem[0], 44 bytes cmem[2]
----- Executing -----
srun: defined options
srun: -----
srun: exclusive      : exclusive
srun: gres           : gres:gpu:TitanX:8
srun: partition       : ClsParSystems
srun: reservation     : Spring2025Class
srun: time            : 01:00:00
srun: verbose          : 1
srun: -----
srun: end of defined options
srun: jobid 224868: nodes(1):'GPU13', cpu counts: 16(x1)
srun: launch/slurm: launch_p_step_launch: CpuBindType=(null type)
srun: launching StepId=224868.0 on host GPU13, 1 tasks: 0
srun: route/default: init: route default plugin loaded
srun: launch/slurm: _task_start: Node GPU13, 1 tasks started

CPU-based version
Running time for CPU version: 98300.47400 ms

***** Total Running Time of Kernel = 1018.97333 ms *****
GPU-based version
```

CPU-based version  
Running time for CPU version: 98300.47400 ms

|      |          |          |          |          |          |
|------|----------|----------|----------|----------|----------|
| 00:  | 1726     | 12084    | 32183    | 62267    | 102025   |
| 05:  | 150903   | 209129   | 277000   | 353639   | 439333   |
| 10:  | 531528   | 634894   | 743396   | 862620   | 988233   |
| 15:  | 1120149  | 1261804  | 1408872  | 1564876  | 1726708  |
| 20:  | 1893736  | 2070286  | 2250538  | 2439201  | 2631292  |
| 25:  | 2832774  | 3036729  | 3246761  | 3463349  | 3679532  |
| 30:  | 3908776  | 4135857  | 4375541  | 4615794  | 4862059  |
| 35:  | 5114919  | 5365363  | 5621203  | 5881228  | 6146076  |
| 40:  | 6411197  | 6686339  | 6960170  | 7242239  | 7520743  |
| 45:  | 7800337  | 8090825  | 8374483  | 8665139  | 8956739  |
| 50:  | 9256989  | 9554754  | 9851306  | 10147565 | 10457237 |
| 55:  | 10758820 | 11061902 | 11369936 | 11676505 | 11986545 |
| 60:  | 12297700 | 12603559 | 12915230 | 13222187 | 13532663 |
| 65:  | 13849303 | 14157374 | 14469180 | 14773823 | 15089613 |
| 70:  | 15403376 | 15709055 | 16020607 | 16328102 | 16634707 |
| 75:  | 16943501 | 17247254 | 17553164 | 17856079 | 18152301 |
| 80:  | 18460144 | 18754760 | 19057797 | 19353488 | 19648414 |
| 85:  | 19934206 | 20236176 | 20525677 | 20804914 | 21093221 |
| 90:  | 21376601 | 21652055 | 21930183 | 22195780 | 22476984 |
| 95:  | 22741305 | 23008249 | 23272087 | 23525390 | 23777162 |
| 100: | 24042946 | 24296767 | 24532429 | 24782914 | 25028572 |
| 105: | 25268878 | 25503537 | 25733764 | 25958802 | 26179891 |
| 110: | 26398836 | 26624190 | 26839134 | 27038659 | 27236838 |
| 115: | 27438519 | 27626672 | 27828462 | 28016824 | 28196027 |
| 120: | 28384625 | 28549269 | 28728313 | 28885766 | 29043345 |
| 125: | 29201866 | 29361085 | 29496466 | 29640995 | 29776749 |
| 130: | 29915049 | 30049094 | 30172425 | 30283845 | 30396883 |
| 135: | 30504873 | 30613171 | 30706955 | 30803699 | 30881911 |
| 140: | 30969651 | 31043633 | 31115975 | 31182179 | 31245424 |
| 145: | 31289098 | 31353311 | 31386314 | 31425679 | 31458811 |
| 150: | 31495306 | 31513776 | 31525248 | 31539977 | 31536211 |
| 155: | 31546704 | 31522600 | 31528794 | 31508146 | 31476655 |
| 160: | 31447727 | 31410173 | 31389803 | 31344052 | 31286065 |
| 165: | 31221440 | 31163800 | 31101112 | 31021603 | 30945615 |
| 170: | 30849748 | 30768215 | 30656579 | 30562757 | 30443120 |
| 175: | 30328536 | 30212123 | 30075917 | 29936772 | 29805822 |
| 180: | 29653939 | 29515489 | 29350654 | 29184997 | 29017251 |
| 185: | 28841989 | 28661137 | 28477064 | 28285708 | 28095952 |
| 190: | 27888280 | 27680056 | 27466778 | 27244918 | 27020071 |
| 195: | 26791869 | 26556987 | 26302139 | 26054810 | 25809283 |
| 200: | 25537693 | 25287294 | 25001582 | 24744651 | 24453088 |
| 205: | 24162759 | 23874926 | 23580600 | 23279620 | 22965526 |
| 210: | 22652193 | 22339603 | 22017119 | 21673648 | 21346940 |
| 215: | 20998282 | 20660710 | 20304107 | 19947068 | 19580013 |
| 220: | 19219581 | 18852523 | 18474612 | 18090457 | 17704531 |
| 225: | 17310859 | 16913626 | 16518880 | 16109264 | 15696995 |
| 230: | 15281001 | 14878741 | 14485621 | 14101955 | 13710932 |
| 235: | 13335315 | 12965855 | 12606294 | 12258051 | 11913136 |
| 240: | 11579784 | 11246584 | 10918511 | 10603114 | 10288712 |
| 245: | 9984617  | 9688445  | 9397492  | 9110351  | 8827069  |
| 250: | 8558773  | 8282274  | 8027875  | 7760549  | 7508100  |
| 255: | 7264262  | 7020351  | 6788131  | 6559952  | 6331780  |
| 260: | 6111531  | 5893676  | 5692702  | 5484714  | 5288549  |
| 265: | 5089950  | 4899835  | 4716860  | 4537131  | 4358321  |
| 270: | 4189129  | 4021072  | 3861826  | 3706294  | 3556448  |
| 275: | 3404058  | 3267089  | 3119986  | 2986570  | 2854061  |
| 280: | 2727343  | 2606183  | 2484200  | 2374265  | 2261546  |
| 285: | 2153631  | 2050550  | 1949454  | 1851997  | 1760401  |
| 290: | 1670764  | 1582297  | 1500317  | 1422724  | 1341610  |
| 295: | 1272718  | 1199521  | 1130957  | 1066826  | 1004900  |
| 300: | 948500   | 890588   | 837621   | 786769   | 737618   |
| 305: | 693309   | 648365   | 606945   | 568159   | 531472   |
| 310: | 495560   | 463096   | 431690   | 401074   | 374276   |
| 315: | 349165   | 325288   | 302002   | 280371   | 261287   |
| 320: | 241826   | 224933   | 208901   | 192590   | 178062   |
| 325: | 165642   | 153587   | 141563   | 131270   | 120954   |
| 330: | 111319   | 103332   | 94843    | 87791    | 80307    |
| 335: | 73833    | 67680    | 61978    | 56468    | 51601    |
| 340: | 47558    | 43008    | 38882    | 35227    | 32327    |
| 345: | 29325    | 26246    | 24213    | 21677    | 19273    |
| 350: | 17377    | 15511    | 14110    | 12534    | 10891    |
| 355: | 9940     | 8672     | 7731     | 6903     | 6025     |
| 360: | 5251     | 4657     | 4056     | 3313     | 2922     |
| 365: | 2626     | 2140     | 1865     | 1592     | 1281     |
| 370: | 1055     | 938      | 741      | 622      | 509      |
| 375: | 433      | 354      | 318      | 220      | 152      |
| 380: | 151      | 97       | 85       | 49       | 27       |
| 385: | 31       | 15       | 15       | 14       | 7        |
| 390: | 0        | 2        | 3        | 0        | 0        |
| 395: | 0        | 0        | 0        | 0        | 0        |

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\*\*\*\*\* Total Running Time of Kernel = 1018.97333 ms \*\*\*\*\*

GPU-based version

\*\*\*\*\* Total Running Time of Kernel = 1018.97333 ms \*\*\*\*\*  
 GPU-based version

|      |          |          |          |          |          |
|------|----------|----------|----------|----------|----------|
| 00:  | 1726     | 12084    | 32183    | 62267    | 102025   |
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| 45:  | 7800337  | 8090825  | 8374483  | 8665139  | 8956739  |
| 50:  | 9256989  | 9554754  | 9851306  | 10147565 | 10457237 |
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| 115: | 27438519 | 27626672 | 27828462 | 28016824 | 28196027 |
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| 125: | 29201866 | 29361085 | 29496466 | 29640995 | 29776749 |
| 130: | 29915049 | 30049094 | 30172425 | 30283845 | 30396883 |
| 135: | 30504873 | 30613171 | 30706955 | 30803699 | 30881911 |
| 140: | 30969651 | 31043633 | 31115975 | 31182179 | 31245424 |
| 145: | 31289098 | 31353311 | 31386314 | 31425679 | 31458811 |
| 150: | 31495306 | 31513776 | 31525248 | 31539977 | 31536211 |
| 155: | 31546704 | 31522600 | 31528794 | 31508146 | 31476655 |
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| 230: | 15281001 | 14878741 | 14485621 | 14101955 | 13710932 |
| 235: | 13335315 | 12965855 | 12606294 | 12258051 | 11913136 |
| 240: | 11579784 | 11246584 | 10918511 | 10603114 | 10288712 |
| 245: | 9984617  | 9688445  | 9397492  | 9110351  | 8827069  |
| 250: | 8558773  | 8282274  | 8027875  | 7760549  | 7508100  |
| 255: | 7264262  | 7020351  | 6788131  | 6559952  | 6331780  |
| 260: | 6111531  | 5893676  | 5692702  | 5484714  | 5288549  |
| 265: | 5089950  | 4899835  | 4716860  | 4537131  | 4358321  |
| 270: | 4189129  | 4021072  | 3861826  | 3706294  | 3556448  |
| 275: | 3404058  | 3267089  | 3119986  | 2986570  | 2854061  |
| 280: | 2727343  | 2606183  | 2484200  | 2374265  | 2261546  |
| 285: | 2153631  | 2050550  | 1949454  | 1851997  | 1760401  |
| 290: | 1670764  | 1582297  | 1500317  | 1422724  | 1341610  |
| 295: | 12727218 | 1199521  | 1130957  | 1066826  | 1004900  |
| 300: | 948500   | 890588   | 837621   | 786769   | 737618   |
| 305: | 693309   | 648365   | 606945   | 568159   | 531472   |
| 310: | 495560   | 463096   | 431690   | 401074   | 374276   |
| 315: | 349165   | 325288   | 302002   | 280371   | 261287   |
| 320: | 241826   | 224933   | 208901   | 192590   | 178062   |
| 325: | 165642   | 153587   | 141563   | 131270   | 120954   |
| 330: | 111319   | 103332   | 94843    | 87791    | 80307    |
| 335: | 73833    | 67680    | 61978    | 56468    | 51601    |
| 340: | 47558    | 43008    | 38882    | 35227    | 32327    |
| 345: | 29325    | 26246    | 24213    | 21677    | 19273    |
| 350: | 17377    | 15511    | 14110    | 12534    | 10891    |
| 355: | 9940     | 8672     | 7731     | 6903     | 6025     |
| 360: | 5251     | 4657     | 4056     | 3313     | 2922     |
| 365: | 2626     | 2140     | 1865     | 1592     | 1281     |
| 370: | 1055     | 938      | 741      | 622      | 509      |
| 375: | 433      | 354      | 318      | 220      | 152      |
| 380: | 151      | 97       | 85       | 49       | 27       |
| 385: | 31       | 15       | 15       | 14       | 7        |
| 390: | 0        | 2        | 3        | 0        | 0        |
| 395: | 0        | 0        | 0        | 0        | 0        |

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Difference between CPU and GPU histograms:

Difference between CPU and GPU histograms:

| 00:  | 0 | 0 | 0 | 0 | 0 | 0 |
|------|---|---|---|---|---|---|
| 05:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 10:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 15:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 20:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 25:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 30:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 35:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 40:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 45:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 50:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 55:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 60:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 65:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 70:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 75:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 80:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 85:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 90:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 95:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 100: | 0 | 0 | 0 | 0 | 0 | 0 |
| 105: | 0 | 0 | 0 | 0 | 0 | 0 |
| 110: | 0 | 0 | 0 | 0 | 0 | 0 |
| 115: | 0 | 0 | 0 | 0 | 0 | 0 |
| 120: | 0 | 0 | 0 | 0 | 0 | 0 |
| 125: | 0 | 0 | 0 | 0 | 0 | 0 |
| 130: | 0 | 0 | 0 | 0 | 0 | 0 |
| 135: | 0 | 0 | 0 | 0 | 0 | 0 |
| 140: | 0 | 0 | 0 | 0 | 0 | 0 |
| 145: | 0 | 0 | 0 | 0 | 0 | 0 |
| 150: | 0 | 0 | 0 | 0 | 0 | 0 |
| 155: | 0 | 0 | 0 | 0 | 0 | 0 |
| 160: | 0 | 0 | 0 | 0 | 0 | 0 |
| 165: | 0 | 0 | 0 | 0 | 0 | 0 |
| 170: | 0 | 0 | 0 | 0 | 0 | 0 |
| 175: | 0 | 0 | 0 | 0 | 0 | 0 |
| 180: | 0 | 0 | 0 | 0 | 0 | 0 |
| 185: | 0 | 0 | 0 | 0 | 0 | 0 |
| 190: | 0 | 0 | 0 | 0 | 0 | 0 |
| 195: | 0 | 0 | 0 | 0 | 0 | 0 |
| 200: | 0 | 0 | 0 | 0 | 0 | 0 |
| 205: | 0 | 0 | 0 | 0 | 0 | 0 |
| 210: | 0 | 0 | 0 | 0 | 0 | 0 |
| 215: | 0 | 0 | 0 | 0 | 0 | 0 |
| 220: | 0 | 0 | 0 | 0 | 0 | 0 |
| 225: | 0 | 0 | 0 | 0 | 0 | 0 |
| 230: | 0 | 0 | 0 | 0 | 0 | 0 |
| 235: | 0 | 0 | 0 | 0 | 0 | 0 |
| 240: | 0 | 0 | 0 | 0 | 0 | 0 |
| 245: | 0 | 0 | 0 | 0 | 0 | 0 |
| 250: | 0 | 0 | 0 | 0 | 0 | 0 |
| 255: | 0 | 0 | 0 | 0 | 0 | 0 |
| 260: | 0 | 0 | 0 | 0 | 0 | 0 |
| 265: | 0 | 0 | 0 | 0 | 0 | 0 |
| 270: | 0 | 0 | 0 | 0 | 0 | 0 |
| 275: | 0 | 0 | 0 | 0 | 0 | 0 |
| 280: | 0 | 0 | 0 | 0 | 0 | 0 |
| 285: | 0 | 0 | 0 | 0 | 0 | 0 |
| 290: | 0 | 0 | 0 | 0 | 0 | 0 |
| 295: | 0 | 0 | 0 | 0 | 0 | 0 |
| 300: | 0 | 0 | 0 | 0 | 0 | 0 |
| 305: | 0 | 0 | 0 | 0 | 0 | 0 |
| 310: | 0 | 0 | 0 | 0 | 0 | 0 |
| 315: | 0 | 0 | 0 | 0 | 0 | 0 |
| 320: | 0 | 0 | 0 | 0 | 0 | 0 |
| 325: | 0 | 0 | 0 | 0 | 0 | 0 |
| 330: | 0 | 0 | 0 | 0 | 0 | 0 |
| 335: | 0 | 0 | 0 | 0 | 0 | 0 |
| 340: | 0 | 0 | 0 | 0 | 0 | 0 |
| 345: | 0 | 0 | 0 | 0 | 0 | 0 |
| 350: | 0 | 0 | 0 | 0 | 0 | 0 |
| 355: | 0 | 0 | 0 | 0 | 0 | 0 |
| 360: | 0 | 0 | 0 | 0 | 0 | 0 |
| 365: | 0 | 0 | 0 | 0 | 0 | 0 |
| 370: | 0 | 0 | 0 | 0 | 0 | 0 |
| 375: | 0 | 0 | 0 | 0 | 0 | 0 |
| 380: | 0 | 0 | 0 | 0 | 0 | 0 |
| 385: | 0 | 0 | 0 | 0 | 0 | 0 |
| 390: | 0 | 0 | 0 | 0 | 0 | 0 |
| 395: | 0 | 0 | 0 | 0 | 0 | 0 |

srn: launch/slurm: \_task\_finish: Received task exit notification for 1 task of StepId=224868.0 (status=0x0000).

srn: launch/slurm: \_task\_finish: GPU13: task 0: Completed



```
/apps/GPU_course/runScript.sh proj2-akmal.cu 500000 100 256
```

```
[akmal@forest.usf.edu@gaivi-login1 project2]$ /apps/GPU_course/runScript.sh proj2-akmal.cu 500000 100 256
----- nvcc Info: -----
nvcc: NVIDIA (R) Cuda compiler driver
Copyright (c) 2005-2021 NVIDIA Corporation
Built on Wed_Jun_2_19:15:15_PDT_2021
Cuda compilation tools, release 11.4, V11.4.48
Build cuda_11.4.r11.4/compiler.30033411_0
----- Compiling -----
ptxas info    : 0 bytes gmem
ptxas info    : Compiling entry function '_Z10PDH_kernelP8atomdescP10hist_entryxdi' for 'sm_52'
ptxas info    : Function properties for _Z10PDH_kernelP8atomdescP10hist_entryxdi
  0 bytes stack frame, 0 bytes spill stores, 0 bytes spill loads
ptxas info    : Used 26 registers, 356 bytes cmem[0], 44 bytes cmem[2]
----- Executing -----
srun: defined options
srun: -----
srun: exclusive      : exclusive
srun: gres           : gres:gpu:TitanX:8
srun: partition       : ClsParSystems
srun: reservation     : Spring2025Class
srun: time            : 01:00:00
srun: verbose          : 1
srun: -----
srun: end of defined options
srun: jobid 224128: nodes(1):`GPU13', cpu counts: 16(x1)
srun: launch/slurm: launch_p_step_launch: CpuBindType=(null type)
srun: launching StepId=224128.0 on host GPU13, 1 tasks: 0
srun: route/default: init: route default plugin loaded
srun: launch/slurm: _task_start: Node GPU13, 1 tasks started
```

## CPU-based version

Running time for CPU version: 2459081.19200 ms

|      |           |           |           |           |           |
|------|-----------|-----------|-----------|-----------|-----------|
| 00:  | 43156     | 297508    | 803510    | 1555008   | 2547646   |
| 05:  | 3778251   | 5230566   | 6923812   | 8826013   | 10951433  |
| 10:  | 13281682  | 15827073  | 18576932  | 21526036  | 24648853  |
| 15:  | 27984373  | 31498939  | 35184089  | 39058471  | 43086875  |
| 20:  | 47293801  | 51663420  | 56196449  | 60860600  | 65710207  |
| 25:  | 70679354  | 75800262  | 81059413  | 86434648  | 91974163  |
| 30:  | 97617577  | 103368734 | 109250682 | 115278095 | 121379103 |
| 35:  | 127594717 | 133899076 | 140295776 | 146797269 | 153405279 |
| 40:  | 160088102 | 166868776 | 173732397 | 180634790 | 187633416 |
| 45:  | 194700675 | 201850913 | 209034539 | 216286883 | 223611218 |
| 50:  | 230932165 | 238362973 | 245824899 | 253333127 | 260848133 |
| 55:  | 268455653 | 276041488 | 283633621 | 291343993 | 299008151 |
| 60:  | 306694785 | 314441257 | 322171810 | 329924298 | 337685652 |
| 65:  | 345436216 | 353196859 | 360997078 | 368738598 | 376502944 |
| 70:  | 384252715 | 391967088 | 399714355 | 407419848 | 415101921 |
| 75:  | 422758335 | 430386847 | 438003506 | 445580673 | 453135876 |
| 80:  | 460649446 | 468136893 | 475589060 | 482998405 | 490328546 |
| 85:  | 497668602 | 504962394 | 512136526 | 519325704 | 526455483 |
| 90:  | 533510418 | 540468354 | 547419731 | 554292324 | 561059173 |
| 95:  | 567812099 | 574467493 | 581057744 | 587599589 | 594026810 |
| 100: | 600410043 | 606725688 | 612888565 | 618969042 | 625092843 |
| 105: | 631016500 | 636866278 | 642650070 | 648337829 | 653909799 |
| 110: | 659445670 | 664800259 | 670101348 | 675344634 | 680454740 |
| 115: | 685433964 | 690314232 | 695153154 | 699830197 | 704379387 |
| 120: | 708794198 | 713210908 | 717375201 | 721544622 | 725569303 |
| 125: | 729471905 | 733252672 | 736929435 | 740438292 | 743861455 |
| 130: | 747188408 | 750364743 | 753416488 | 756289638 | 759147814 |
| 135: | 761825535 | 764343087 | 766820417 | 769099964 | 771202164 |
| 140: | 773288103 | 775190738 | 776958395 | 778676542 | 780114328 |
| 145: | 781491529 | 782751471 | 783867921 | 784789337 | 785616579 |
| 150: | 786342702 | 786906608 | 787327891 | 787601389 | 787761970 |
| 155: | 787780126 | 787645307 | 787332117 | 786926852 | 786324593 |
| 160: | 785624458 | 784808338 | 783829695 | 782690482 | 781400227 |
| 165: | 779975541 | 778428296 | 776764192 | 774892079 | 772883196 |
| 170: | 770739842 | 768482780 | 766002515 | 763498574 | 760789734 |
| 175: | 757933793 | 754920593 | 751776923 | 748513640 | 745041720 |
| 180: | 714185719 | 737763795 | 733902796 | 729822618 | 725636739 |
| 185: | 721356643 | 716853182 | 712307638 | 707509394 | 702656650 |
| 190: | 697643081 | 692463868 | 687097941 | 681611202 | 676021518 |
| 195: | 670305257 | 664331012 | 658321124 | 652180521 | 645821215 |
| 200: | 639387126 | 632765305 | 626072623 | 619259187 | 612208576 |
| 205: | 605079868 | 597812048 | 590411016 | 582825474 | 575129837 |
| 210: | 567305018 | 559295670 | 551236457 | 543032177 | 534665449 |
| 215: | 526162155 | 517478215 | 508757820 | 499853692 | 490857339 |
| 220: | 481708768 | 472451509 | 463026655 | 453463611 | 443875847 |
| 225: | 434043080 | 424179175 | 414112781 | 403941892 | 393671139 |
| 230: | 383366773 | 373126916 | 363228675 | 353462807 | 343919790 |
| 235: | 334525424 | 325371574 | 316368893 | 307596196 | 298931209 |
| 240: | 290498077 | 282221651 | 274030716 | 266067916 | 258279404 |
| 245: | 250649581 | 243129920 | 235810251 | 228618127 | 221576936 |
| 250: | 214704209 | 207923880 | 201374136 | 194897968 | 188555121 |
| 255: | 182403178 | 176339886 | 170453854 | 164708812 | 159073306 |
| 260: | 153575285 | 148187529 | 142954474 | 137840638 | 132850845 |
| 265: | 127957845 | 123233748 | 118619759 | 114102750 | 109717296 |
| 270: | 105448367 | 101296365 | 97264171  | 93341493  | 89512905  |
| 275: | 858235033 | 82210347  | 78713799  | 75309028  | 72021339  |
| 280: | 68841062  | 65758149  | 62765185  | 59889252  | 57069165  |
| 285: | 54361127  | 51761246  | 49232733  | 46807079  | 44467220  |
| 290: | 42203284  | 40025953  | 37948877  | 35929905  | 33992046  |
| 295: | 32150196  | 30366886  | 28667424  | 27044589  | 25481841  |
| 300: | 24015132  | 22586957  | 21235034  | 19941548  | 18729004  |
| 305: | 17553210  | 16448554  | 15401726  | 14401262  | 13468783  |
| 310: | 12577874  | 11740360  | 10952385  | 10202792  | 9506438   |
| 315: | 8851547   | 8233429   | 7653384   | 7118981   | 6617177   |
| 320: | 6142992   | 5700221   | 5288064   | 4903761   | 4550929   |
| 325: | 4216319   | 3905910   | 3611746   | 3344209   | 3090332   |
| 330: | 2855166   | 2632611   | 2427916   | 2238351   | 2056139   |
| 335: | 1888184   | 1736857   | 1592056   | 1457166   | 1331461   |
| 340: | 1219060   | 1109778   | 1010578   | 919469    | 835632    |
| 345: | 758986    | 685512    | 620347    | 558281    | 501304    |
| 350: | 450861    | 403583    | 362261    | 323738    | 286848    |
| 355: | 254485    | 226432    | 199096    | 175797    | 154710    |
| 360: | 135084    | 118155    | 102854    | 88219     | 76474     |
| 365: | 65986     | 56296     | 47879     | 40767     | 34171     |
| 370: | 28644     | 23784     | 19715     | 16163     | 13298     |
| 375: | 10922     | 8645      | 6995      | 5271      | 4188      |
| 380: | 3197      | 2367      | 1841      | 1352      | 928       |
| 385: | 662       | 465       | 308       | 169       | 109       |
| 390: | 59        | 47        | 9         | 3         | 1         |
| 395: | 0         | 0         | 0         | 0         |           |

T:124999750000

\*\*\*\*\* Total Running Time of Kernel = 24569.19531 ms \*\*\*\*\*  
GPU-based version

|      |           |           |           |           |           |
|------|-----------|-----------|-----------|-----------|-----------|
| 00:  | 43156     | 297508    | 803510    | 1555008   | 2547646   |
| 05:  | 3778251   | 5230566   | 6923812   | 8826013   | 10951433  |
| 10:  | 13281682  | 15827073  | 18576932  | 21526036  | 24648853  |
| 15:  | 27984373  | 31498939  | 35184089  | 39058471  | 43086875  |
| 20:  | 47293801  | 51663420  | 56196449  | 60860600  | 65710207  |
| 25:  | 70679354  | 75800262  | 81059413  | 86434648  | 91974163  |
| 30:  | 97617577  | 103368734 | 109250682 | 115278095 | 121379103 |
| 35:  | 127594717 | 133899076 | 140295776 | 146797269 | 153405279 |
| 40:  | 160088102 | 166868776 | 173732397 | 180634790 | 187633416 |
| 45:  | 194700675 | 201850913 | 209034539 | 216286883 | 223611218 |
| 50:  | 230932165 | 238362973 | 245824899 | 253333127 | 260848133 |
| 55:  | 268455653 | 276041488 | 283633621 | 291343993 | 299008151 |
| 60:  | 306694785 | 314441257 | 322171810 | 329924298 | 337685652 |
| 65:  | 345436216 | 353196859 | 360997078 | 368738598 | 376502944 |
| 70:  | 384252715 | 391967088 | 399714355 | 407419848 | 415101921 |
| 75:  | 422758335 | 430386847 | 438003506 | 445580673 | 453135876 |
| 80:  | 460649446 | 468136893 | 475589060 | 482998405 | 490328546 |
| 85:  | 497668602 | 504962394 | 512136526 | 519325704 | 526455483 |
| 90:  | 533510418 | 540468354 | 547419731 | 554292324 | 561059173 |
| 95:  | 567812099 | 574467493 | 581057744 | 587599589 | 594026810 |
| 100: | 600410043 | 606725688 | 612888565 | 618969042 | 625092843 |
| 105: | 631016500 | 636866278 | 642650070 | 648337829 | 653909799 |
| 110: | 659445670 | 664800259 | 670101348 | 675344634 | 680454740 |
| 115: | 685433964 | 690314232 | 695153154 | 699830197 | 704379387 |
| 120: | 708794198 | 713210908 | 717375201 | 721544622 | 725569303 |
| 125: | 729471905 | 733252672 | 736929435 | 740438292 | 743861455 |
| 130: | 747188408 | 750364743 | 753416488 | 756289638 | 759147814 |
| 135: | 761825535 | 764343087 | 766820417 | 769099964 | 771202164 |
| 140: | 773288103 | 775190738 | 776958395 | 778676542 | 780114328 |
| 145: | 781491529 | 782751471 | 783867921 | 784789337 | 785616579 |
| 150: | 786342702 | 786906608 | 787327891 | 787601389 | 787761970 |
| 155: | 787780126 | 787645307 | 787332117 | 786926852 | 786324593 |
| 160: | 785624458 | 784808338 | 783829695 | 782690482 | 781400227 |
| 165: | 779975541 | 778428296 | 776764192 | 774892079 | 772883196 |
| 170: | 770739842 | 768482780 | 766002515 | 763498574 | 760789734 |
| 175: | 757933793 | 754920593 | 751776923 | 748513640 | 745041720 |
| 180: | 741485719 | 737763795 | 733902796 | 729822618 | 725636739 |
| 185: | 721356643 | 716853182 | 712307638 | 707509394 | 702656650 |
| 190: | 697643081 | 692463868 | 687097941 | 681611202 | 676021518 |
| 195: | 670305257 | 664331012 | 658321124 | 652180521 | 645821215 |
| 200: | 639387126 | 632765305 | 626072623 | 619259187 | 612208576 |
| 205: | 605079868 | 597812048 | 590411016 | 582825474 | 575129837 |
| 210: | 567305018 | 559295670 | 551236457 | 543032177 | 534665449 |
| 215: | 526162155 | 517478215 | 508757820 | 499853692 | 490857339 |
| 220: | 481708768 | 472451509 | 463026655 | 453463611 | 443875847 |
| 225: | 434043080 | 424179175 | 414112781 | 403941892 | 393671139 |
| 230: | 383366773 | 373126916 | 363228675 | 353462807 | 343919790 |
| 235: | 334525424 | 325371574 | 316368893 | 307596196 | 298931209 |
| 240: | 290498077 | 282221651 | 274030716 | 266067916 | 258279404 |
| 245: | 250649581 | 243129920 | 235810251 | 228618127 | 221576936 |
| 250: | 214704209 | 207923880 | 201374136 | 194897968 | 188555121 |
| 255: | 182403178 | 176339886 | 170453854 | 164708812 | 159073306 |
| 260: | 153575285 | 148187529 | 142954474 | 137840638 | 132850845 |
| 265: | 127957845 | 123233748 | 118619759 | 114102750 | 109717296 |
| 270: | 105448367 | 101296365 | 97264171  | 93341493  | 89512905  |
| 275: | 85823503  | 82210347  | 78713799  | 75309028  | 72021339  |
| 280: | 68841062  | 65758149  | 62765185  | 59889252  | 57069165  |
| 285: | 54361127  | 51761246  | 49232733  | 46807079  | 44467220  |
| 290: | 42203284  | 40025953  | 37948877  | 35929905  | 33992046  |
| 295: | 32150196  | 30366886  | 28667424  | 27044589  | 25481841  |
| 300: | 24015132  | 22586957  | 21235034  | 19941548  | 18729004  |
| 305: | 17553210  | 16448554  | 15401726  | 14401262  | 13468783  |
| 310: | 12577874  | 11740360  | 10952385  | 10202792  | 9506438   |
| 315: | 8851547   | 8233429   | 7653384   | 7118981   | 6617177   |
| 320: | 6142992   | 5700221   | 5288064   | 4903761   | 4550929   |
| 325: | 4216319   | 3905910   | 3611746   | 3344209   | 3090332   |
| 330: | 2855166   | 2632611   | 2427916   | 2238351   | 2056139   |
| 335: | 1888184   | 1736857   | 1592056   | 1457166   | 1331461   |
| 340: | 1219060   | 1109778   | 1010578   | 919469    | 835632    |
| 345: | 758096    | 685512    | 620347    | 558281    | 501304    |
| 350: | 450861    | 403583    | 362261    | 323738    | 286848    |
| 355: | 254485    | 226432    | 199096    | 175797    | 154710    |
| 360: | 135084    | 118155    | 102854    | 88219     | 76474     |
| 365: | 65986     | 56296     | 47879     | 40767     | 34171     |
| 370: | 28644     | 23784     | 19715     | 16163     | 13298     |
| 375: | 10922     | 8645      | 6995      | 5271      | 4188      |
| 380: | 3197      | 2367      | 1841      | 1352      | 928       |
| 385: | 662       | 465       | 308       | 169       | 109       |
| 390: | 59        | 47        | 9         | 3         | 1         |
| 395: | 0         | 0         | 0         | 0         |           |

T:124999750000

Difference between CPU and GPU histograms:

|      |   |   |   |   |   |   |   |
|------|---|---|---|---|---|---|---|
| 00:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 05:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 15:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 25:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 30:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 35:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 40:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 45:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 50:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 55:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 60:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 65:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 70:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 75:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 80:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 85:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 90:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 95:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 100: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 105: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 110: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 115: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 120: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 125: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 130: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 135: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 140: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 145: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 150: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 155: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 160: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 165: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 170: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 175: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 180: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 185: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 190: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 195: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 200: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 205: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 210: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 215: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 220: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 225: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 230: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 235: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 240: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 245: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 250: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 255: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 260: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 265: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 270: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 275: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 280: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 285: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 290: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 295: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 300: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 305: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 310: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 315: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 320: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 325: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 330: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 335: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 340: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 345: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 350: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 355: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 360: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 365: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 370: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 375: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 380: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 385: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 390: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 395: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

srun: launch/slurm: \_task\_finish: Received task exit notification for 1 task of StepId=224128.0 (status=0x0000).  
srun: launch/slurm: \_task\_finish: GPU13: task 0: Completed

## 2. Block Size Variation:

With a fixed dataset (100,000 points, bucket width = 100), experiments were performed using block sizes of 64, 128, 256, and 512.

```
/apps/GPU_course/runScript.sh proj2-akmal.cu 100000 100 64
[akmal@forest.usf.edu@gaivi-login1 project2]$ /apps/GPU_course/runScript.sh proj2-akmal.cu 100000 100 64
----- nvcc Info: -----
nvcc: NVIDIA (R) Cuda compiler driver
Copyright (c) 2005-2021 NVIDIA Corporation
Built on Wed_Jun_2_19:15:15_PDT_2021
Cuda compilation tools, release 11.4, V11.4.48
Build cuda_11.4.r11.4/compiler.30033411_0
----- Compiling -----
ptxas info    : 0 bytes gmem
ptxas info    : Compiling entry function '_Z10PDH_kernelP8atomdescP10hist_entryxdi' for 'sm_52'
ptxas info    : Function properties for _Z10PDH_kernelP8atomdescP10hist_entryxdi
  0 bytes stack frame, 0 bytes spill stores, 0 bytes spill loads
ptxas info    : Used 26 registers, 356 bytes cmem[0], 44 bytes cmem[2]
----- Executing -----
srun: defined options
srun: -----
srun: exclusive      : exclusive
srun: gres           : gres:gpu:TitanX:8
srun: partition       : ClsParSystems
srun: reservation     : Spring2025Class
srun: time            : 01:00:00
srun: verbose          : 1
srun: -----
srun: end of defined options
srun: jobid 224190: nodes(1):`GPU13', cpu counts: 16(x1)
srun: launch/slurm: launch_p_step_launch: CpuBindType=(null type)
srun: launching StepId=224190.0 on host GPU13, 1 tasks: 0
srun: route/default: init: route default plugin loaded
srun: launch/slurm: _task_start: Node GPU13, 1 tasks started
CPU-based version
Running time for CPU version: 98304.56400 ms

***** Total Running Time of Kernel = 1034.20288 ms *****
GPU-based version
```

## CPU-based version

Running time for CPU version: 98304.56400 ms

|      |          |          |          |          |          |
|------|----------|----------|----------|----------|----------|
| 00:  | 1726     | 12084    | 32183    | 62267    | 102025   |
| 05:  | 150903   | 209129   | 277000   | 353639   | 439333   |
| 10:  | 531528   | 634894   | 743396   | 862620   | 988233   |
| 15:  | 1120149  | 1261804  | 1408872  | 1564876  | 1726708  |
| 20:  | 1893736  | 2070286  | 2250538  | 2439201  | 2631292  |
| 25:  | 2832774  | 3036729  | 3246761  | 3463349  | 3679532  |
| 30:  | 3908776  | 4135857  | 4375541  | 4615794  | 4862059  |
| 35:  | 5114919  | 5365363  | 5621203  | 5881228  | 6146076  |
| 40:  | 6411197  | 6686339  | 6960170  | 7242239  | 7520743  |
| 45:  | 7800337  | 8090825  | 8374483  | 8665139  | 8956739  |
| 50:  | 9256989  | 9554754  | 9851306  | 10147565 | 10457237 |
| 55:  | 10758820 | 11061902 | 11369936 | 11676505 | 11986545 |
| 60:  | 12297700 | 12603559 | 12915230 | 13222187 | 13532663 |
| 65:  | 13849303 | 14157374 | 14469180 | 14773823 | 15089613 |
| 70:  | 15403376 | 15709055 | 16020607 | 16328102 | 16634707 |
| 75:  | 16943501 | 17247254 | 17553164 | 17856079 | 18152301 |
| 80:  | 18460144 | 18754760 | 19057797 | 19353488 | 19648414 |
| 85:  | 19934206 | 20236176 | 20525677 | 20804914 | 21093221 |
| 90:  | 21376601 | 21652055 | 21930183 | 22195780 | 22476984 |
| 95:  | 22741305 | 23008249 | 23272087 | 23525390 | 23777162 |
| 100: | 24042946 | 24296767 | 24532429 | 24782914 | 25028572 |
| 105: | 25268878 | 25503537 | 25733764 | 25958802 | 26179891 |
| 110: | 26398836 | 26624190 | 26839134 | 27038659 | 27236838 |
| 115: | 27438519 | 27626672 | 27828462 | 28016824 | 28196027 |
| 120: | 28384625 | 28549269 | 28728313 | 28885766 | 29043345 |
| 125: | 29201866 | 29361085 | 29496466 | 29640995 | 29776749 |
| 130: | 29915049 | 30049094 | 30172425 | 30283845 | 30396883 |
| 135: | 30504873 | 30613171 | 30706955 | 30803699 | 30881911 |
| 140: | 30969651 | 31043633 | 31115975 | 31182179 | 31245424 |
| 145: | 31289098 | 31353311 | 31386314 | 31425679 | 31458811 |
| 150: | 31495306 | 31513776 | 31525248 | 31539977 | 31536211 |
| 155: | 31546704 | 31522600 | 31528794 | 31508146 | 31476655 |
| 160: | 31447727 | 31410173 | 31389803 | 31344052 | 31286065 |
| 165: | 31221440 | 31163800 | 31101112 | 31021603 | 30945615 |
| 170: | 30849748 | 30768215 | 30656579 | 30562757 | 30443120 |
| 175: | 30328536 | 30212123 | 30075917 | 29936772 | 29805822 |
| 180: | 29653939 | 29515489 | 29350654 | 29184997 | 29017251 |
| 185: | 28841989 | 28661137 | 28477064 | 28285708 | 28095952 |
| 190: | 27888280 | 27680656 | 27466778 | 27244918 | 27020071 |
| 195: | 26791869 | 26556987 | 26302139 | 26054810 | 25809283 |
| 200: | 25537693 | 25287294 | 25001582 | 24744651 | 24453088 |
| 205: | 24162759 | 23874926 | 23580600 | 23279620 | 22965526 |
| 210: | 22652193 | 22339603 | 22017119 | 21673648 | 21346940 |
| 215: | 20998282 | 20660710 | 20304107 | 19947068 | 19580013 |
| 220: | 19219581 | 18852523 | 18474612 | 18090457 | 17704531 |
| 225: | 17310859 | 16913626 | 16518880 | 16109264 | 15696995 |
| 230: | 15281001 | 14878741 | 14485621 | 14101955 | 13710932 |
| 235: | 13335315 | 12965855 | 12606294 | 12258051 | 11913136 |
| 240: | 11579784 | 11246584 | 10918511 | 10603114 | 10288712 |
| 245: | 9984617  | 9688445  | 9397492  | 9110351  | 8827069  |
| 250: | 8558773  | 8282274  | 8027875  | 7760549  | 7508100  |
| 255: | 7264262  | 7020351  | 6788131  | 6559952  | 6331780  |
| 260: | 6111531  | 5893676  | 5692702  | 5484714  | 5288549  |
| 265: | 5089950  | 4899835  | 4716860  | 4537131  | 4358321  |
| 270: | 4189129  | 4021072  | 3861826  | 3706294  | 3556448  |
| 275: | 3404058  | 3267089  | 3119986  | 2986570  | 2854061  |
| 280: | 2727343  | 2606183  | 2484200  | 2374265  | 2261546  |
| 285: | 2153631  | 2050550  | 1949454  | 1851997  | 1760401  |
| 290: | 1670764  | 1582297  | 1500317  | 1422724  | 1341610  |
| 295: | 1272718  | 1199521  | 1130957  | 1066826  | 1004900  |
| 300: | 948500   | 890588   | 837621   | 786769   | 737618   |
| 305: | 693309   | 648365   | 606945   | 568159   | 531472   |
| 310: | 495560   | 463096   | 431690   | 401074   | 374276   |
| 315: | 349165   | 325288   | 302002   | 280371   | 261287   |
| 320: | 241826   | 224933   | 208901   | 192590   | 178062   |
| 325: | 165642   | 153587   | 141563   | 131270   | 120954   |
| 330: | 111319   | 103332   | 94843    | 87791    | 80307    |
| 335: | 73833    | 67680    | 61978    | 56468    | 51601    |
| 340: | 47558    | 43008    | 38882    | 35227    | 32327    |
| 345: | 29325    | 26246    | 24213    | 21677    | 19273    |
| 350: | 17377    | 15511    | 14110    | 12534    | 10891    |
| 355: | 9940     | 8672     | 7731     | 6903     | 6025     |
| 360: | 5251     | 4657     | 4056     | 3313     | 2922     |
| 365: | 2626     | 2140     | 1865     | 1592     | 1281     |
| 370: | 1055     | 938      | 741      | 622      | 509      |
| 375: | 433      | 354      | 318      | 220      | 152      |
| 380: | 151      | 97       | 85       | 49       | 27       |
| 385: | 31       | 15       | 15       | 14       | 7        |
| 390: | 0        | 2        | 3        | 0        | 0        |
| 395: | 0        | 0        | 0        | 0        | 0        |

T:4999950000

| ***** Total Running Time of Kernel = 1034.20288 ms ***** |          |           |          |          |          |  |
|--|----------|-----------|----------|----------|----------|--|
| GPU-based version  |          |           |          |          |          |  |
| 00:  | 1726     | 12084     | 32183    | 62267    | 102025   |  |
| 05:  | 158903   | 209129    | 277000   | 353639   | 439333   |  |
| 10:  | 531528   | 634894    | 743396   | 862620   | 988233   |  |
| 15:  | 1120149  | 1261804   | 1408872  | 1564876  | 1726708  |  |
| 20:  | 1893736  | 2070286   | 2250538  | 2439201  | 2631292  |  |
| 25:  | 2832774  | 3036729   | 3246761  | 3463349  | 3679532  |  |
| 30:  | 3908776  | 4135857   | 4375541  | 4615794  | 4862059  |  |
| 35:  | 5114919  | 5365363   | 5621203  | 5881228  | 6146076  |  |
| 40:  | 6411197  | 6686339   | 6960170  | 7242239  | 7520743  |  |
| 45:  | 7800337  | 8090825   | 8374483  | 8665139  | 8956739  |  |
| 50:  | 9256989  | 9554754   | 9851306  | 10147565 | 10457237 |  |
| 55:  | 10758820 | 11061902  | 11369936 | 11676505 | 11986545 |  |
| 60:  | 12297700 | 12603559  | 12915230 | 13222187 | 13532663 |  |
| 65:  | 13849303 | 14157374  | 14469180 | 14773823 | 15089613 |  |
| 70:  | 15403376 | 15709055  | 16020607 | 16328102 | 16634707 |  |
| 75:  | 16943501 | 17247254  | 17553164 | 17856079 | 18152301 |  |
| 80:  | 18460144 | 18754760  | 19057797 | 19353488 | 19648414 |  |
| 85:  | 19934206 | 20236176  | 20525677 | 20804914 | 21093221 |  |
| 90:  | 21376601 | 21652055  | 21930183 | 22195780 | 22476984 |  |
| 95:  | 22741305 | 23008249  | 23272087 | 23525390 | 23777162 |  |
| 100:   | 24042946 | 24296767  | 24532429 | 24782914 | 25028572 |  |
| 105:   | 25268878 | 25503537  | 25733764 | 25958802 | 26179891 |  |
| 110:   | 26398836 | 26624190  | 26839134 | 27038659 | 27236838 |  |
| 115:   | 27438519 | 27626672  | 27828462 | 28016824 | 28196027 |  |
| 120:   | 28384625 | 28549269  | 28728313 | 28885766 | 29043345 |  |
| 125:   | 29201866 | 29361085  | 29496466 | 29640995 | 29776749 |  |
| 130:   | 29915049 | 30049094  | 30172425 | 30283845 | 30396883 |  |
| 135:   | 30504873 | 30613171  | 30706955 | 30803699 | 30881911 |  |
| 140:   | 30969651 | 31043633  | 31115975 | 31182179 | 31245424 |  |
| 145:   | 31289098 | 31353311  | 31386314 | 31425679 | 31458811 |  |
| 150:   | 31495306 | 31513776  | 31525248 | 31539977 | 31536211 |  |
| 155:   | 31546704 | 31522600  | 31528794 | 31508146 | 31476655 |  |
| 160:   | 31447727 | 31410173  | 31389803 | 31344052 | 31286065 |  |
| 165:   | 31221440 | 31163800  | 31101112 | 31021603 | 30945615 |  |
| 170:   | 30849748 | 30768215  | 30656579 | 30562757 | 30443120 |  |
| 175:   | 30328536 | 30212123  | 30075917 | 29936772 | 29805822 |  |
| 180:   | 29653939 | 29515489  | 29350654 | 29184997 | 29017251 |  |
| 185:   | 28841989 | 28661137  | 28477064 | 28285708 | 28095952 |  |
| 190:   | 27888280 | 27680656  | 27466778 | 27244918 | 27020071 |  |
| 195:   | 26791869 | 26556987  | 26302139 | 26054810 | 25809283 |  |
| 200:   | 25537693 | 25287294  | 25001582 | 24744651 | 24453088 |  |
| 205:   | 24162759 | 23874926  | 23580600 | 23279620 | 22965526 |  |
| 210:   | 22652193 | 22339603  | 22017119 | 21673648 | 21346940 |  |
| 215:   | 20998282 | 20660710  | 20304107 | 19947068 | 19580013 |  |
| 220:   | 19219581 | 18852523  | 18474612 | 18090457 | 17704531 |  |
| 225:   | 17310859 | 169113626 | 16518880 | 16109264 | 15696995 |  |
| 230:   | 15281001 | 14878741  | 14485621 | 14101955 | 13710932 |  |
| 235:   | 13335315 | 12965855  | 12606294 | 12258051 | 11913136 |  |
| 240:   | 11579784 | 11246584  | 10918511 | 10603114 | 10288712 |  |
| 245:   | 9984617  | 9688445   | 9397492  | 9110351  | 8827069  |  |
| 250:   | 8558773  | 8282274   | 8027875  | 7760549  | 7508100  |  |
| 255:   | 7264262  | 7020351   | 6788131  | 6559952  | 6331780  |  |
| 260:   | 6111531  | 5893676   | 5692702  | 5484714  | 5288549  |  |
| 265:   | 5089950  | 4899835   | 4716860  | 4537131  | 4358321  |  |
| 270:   | 4189129  | 4021072   | 3861826  | 3706294  | 3556448  |  |
| 275:   | 3404058  | 3267089   | 3119986  | 2986570  | 2854061  |  |
| 280:   | 2727343  | 2666183   | 2484200  | 2374265  | 2261546  |  |
| 285:   | 2153631  | 2050550   | 1949454  | 1851997  | 1760401  |  |
| 290:   | 1670764  | 1582297   | 1500317  | 1422724  | 1341610  |  |
| 295:   | 1272718  | 1199521   | 1130957  | 1066826  | 1004900  |  |
| 300:   | 948500   | 890588    | 837621   | 786769   | 737618   |  |
| 305:   | 693309   | 648365    | 606945   | 568159   | 531472   |  |
| 310:   | 495560   | 463096    | 431690   | 401074   | 374276   |  |
| 315:   | 349165   | 325288    | 302002   | 280371   | 261287   |  |
| 320:   | 241826   | 224933    | 208901   | 192590   | 178062   |  |
| 325:   | 165642   | 153587    | 141563   | 131270   | 120954   |  |
| 330:   | 111319   | 103332    | 94843    | 87791    | 80307    |  |
| 335:   | 73833    | 67680     | 61978    | 56468    | 51601    |  |
| 340:   | 47558    | 43008     | 38882    | 35227    | 32327    |  |
| 345:   | 29325    | 26246     | 24213    | 21677    | 19273    |  |
| 350:   | 17377    | 15511     | 14110    | 12534    | 10891    |  |
| 355:   | 9940     | 8672      | 7731     | 6903     | 6025     |  |
| 360:   | 5251     | 4657      | 4056     | 3313     | 2922     |  |
| 365:   | 2626     | 2140      | 1865     | 1592     | 1281     |  |
| 370:   | 1055     | 938       | 741      | 622      | 509      |  |
| 375:   | 433      | 354       | 318      | 220      | 152      |  |
| 380:   | 151      | 97        | 85       | 49       | 27       |  |
| 385:   | 31       | 15        | 15       | 14       | 7        |  |
| 390:   | 0        | 2         | 3        | 0        | 0        |  |
| 395:   | 0        | 0         | 0        | 0        | 0        |  |

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Difference between CPU and GPU histograms:

|      |   |   |   |   |   |   |
|------|---|---|---|---|---|---|
| 00:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 05:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 10:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 15:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 20:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 25:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 30:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 35:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 40:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 45:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 50:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 55:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 60:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 65:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 70:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 75:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 80:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 85:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 90:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 95:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 100: | 0 | 0 | 0 | 0 | 0 | 0 |
| 105: | 0 | 0 | 0 | 0 | 0 | 0 |
| 110: | 0 | 0 | 0 | 0 | 0 | 0 |
| 115: | 0 | 0 | 0 | 0 | 0 | 0 |
| 120: | 0 | 0 | 0 | 0 | 0 | 0 |
| 125: | 0 | 0 | 0 | 0 | 0 | 0 |
| 130: | 0 | 0 | 0 | 0 | 0 | 0 |
| 135: | 0 | 0 | 0 | 0 | 0 | 0 |
| 140: | 0 | 0 | 0 | 0 | 0 | 0 |
| 145: | 0 | 0 | 0 | 0 | 0 | 0 |
| 150: | 0 | 0 | 0 | 0 | 0 | 0 |
| 155: | 0 | 0 | 0 | 0 | 0 | 0 |
| 160: | 0 | 0 | 0 | 0 | 0 | 0 |
| 165: | 0 | 0 | 0 | 0 | 0 | 0 |
| 170: | 0 | 0 | 0 | 0 | 0 | 0 |
| 175: | 0 | 0 | 0 | 0 | 0 | 0 |
| 180: | 0 | 0 | 0 | 0 | 0 | 0 |
| 185: | 0 | 0 | 0 | 0 | 0 | 0 |
| 190: | 0 | 0 | 0 | 0 | 0 | 0 |
| 195: | 0 | 0 | 0 | 0 | 0 | 0 |
| 200: | 0 | 0 | 0 | 0 | 0 | 0 |
| 205: | 0 | 0 | 0 | 0 | 0 | 0 |
| 210: | 0 | 0 | 0 | 0 | 0 | 0 |
| 215: | 0 | 0 | 0 | 0 | 0 | 0 |
| 220: | 0 | 0 | 0 | 0 | 0 | 0 |
| 225: | 0 | 0 | 0 | 0 | 0 | 0 |
| 230: | 0 | 0 | 0 | 0 | 0 | 0 |
| 235: | 0 | 0 | 0 | 0 | 0 | 0 |
| 240: | 0 | 0 | 0 | 0 | 0 | 0 |
| 245: | 0 | 0 | 0 | 0 | 0 | 0 |
| 250: | 0 | 0 | 0 | 0 | 0 | 0 |
| 255: | 0 | 0 | 0 | 0 | 0 | 0 |
| 260: | 0 | 0 | 0 | 0 | 0 | 0 |
| 265: | 0 | 0 | 0 | 0 | 0 | 0 |
| 270: | 0 | 0 | 0 | 0 | 0 | 0 |
| 275: | 0 | 0 | 0 | 0 | 0 | 0 |
| 280: | 0 | 0 | 0 | 0 | 0 | 0 |
| 285: | 0 | 0 | 0 | 0 | 0 | 0 |
| 290: | 0 | 0 | 0 | 0 | 0 | 0 |
| 295: | 0 | 0 | 0 | 0 | 0 | 0 |
| 300: | 0 | 0 | 0 | 0 | 0 | 0 |
| 305: | 0 | 0 | 0 | 0 | 0 | 0 |
| 310: | 0 | 0 | 0 | 0 | 0 | 0 |
| 315: | 0 | 0 | 0 | 0 | 0 | 0 |
| 320: | 0 | 0 | 0 | 0 | 0 | 0 |
| 325: | 0 | 0 | 0 | 0 | 0 | 0 |
| 330: | 0 | 0 | 0 | 0 | 0 | 0 |
| 335: | 0 | 0 | 0 | 0 | 0 | 0 |
| 340: | 0 | 0 | 0 | 0 | 0 | 0 |
| 345: | 0 | 0 | 0 | 0 | 0 | 0 |
| 350: | 0 | 0 | 0 | 0 | 0 | 0 |
| 355: | 0 | 0 | 0 | 0 | 0 | 0 |
| 360: | 0 | 0 | 0 | 0 | 0 | 0 |
| 365: | 0 | 0 | 0 | 0 | 0 | 0 |
| 370: | 0 | 0 | 0 | 0 | 0 | 0 |
| 375: | 0 | 0 | 0 | 0 | 0 | 0 |
| 380: | 0 | 0 | 0 | 0 | 0 | 0 |
| 385: | 0 | 0 | 0 | 0 | 0 | 0 |
| 390: | 0 | 0 | 0 | 0 | 0 | 0 |
| 395: | 0 | 0 | 0 | 0 | 0 | 0 |

srun: launch/slurm: \_task\_finish: Received task exit notification for 1 task of StepId=224190.0 (status=0x0000).  
srun: launch/slurm: task\_finish: GPU13: task 0: Completed



```
/apps/GPU_course/runScript.sh proj2-akmal.cu 100000 100 128
```

```
[akmal@forest.usf.edu@gaivi-login1 project2]$ /apps/GPU_course/runScript.sh proj2-akmal.cu 100000 100 128
----- nvcc Info: -----
nvcc: NVIDIA (R) Cuda compiler driver
Copyright (c) 2005-2021 NVIDIA Corporation
Built on Wed_Jun_2_19:15:15_PDT_2021
Cuda compilation tools, release 11.4, V11.4.48
Build cuda_11.4.r11.4/compiler.30033411_0
----- Compiling -----
ptxas info    : 0 bytes gmem
ptxas info    : Compiling entry function '_Z10PDH_kernelP8atomdescP10hist_entryxdi' for 'sm_52'
ptxas info    : Function properties for _Z10PDH_kernelP8atomdescP10hist_entryxdi
  0 bytes stack frame, 0 bytes spill stores, 0 bytes spill loads
ptxas info    : Used 26 registers, 356 bytes cmem[0], 44 bytes cmem[2]
----- Executing -----
srun: defined options
srun: -----
srun: exclusive      : exclusive
srun: gres           : gres:gpu:TitanX:8
srun: partition       : ClsParSystems
srun: reservation     : Spring2025Class
srun: time            : 01:00:00
srun: verbose          : 1
srun: -----
srun: end of defined options
srun: jobid 224874: nodes(1):`GPU13', cpu counts: 16(x1)
srun: launch/slurm: launch_p_step_launch: CpuBindType=(null type)
srun: launching StepId=224874.0 on host GPU13, 1 tasks: 0
srun: route/default: init: route default plugin loaded
srun: launch/slurm: _task_start: Node GPU13, 1 tasks started

CPU-based version
Running time for CPU version: 98271.29800 ms
*****
Total Running Time of Kernel = 1019.28418 ms *****
GPU-based version
```

CPU-based version

Running time for CPU version: 98271.29800 ms

|      |          |          |          |          |          |
|------|----------|----------|----------|----------|----------|
| 05:  | 1726     | 12084    | 32183    | 62267    | 102025   |
| 10:  | 150903   | 209129   | 277000   | 353639   | 439333   |
| 15:  | 531528   | 634894   | 743396   | 862620   | 988233   |
| 20:  | 1120149  | 1261804  | 1408872  | 1564876  | 1726708  |
| 25:  | 1893736  | 2070286  | 2250538  | 2439201  | 2631292  |
| 30:  | 2832774  | 3036729  | 3246761  | 3463349  | 3679532  |
| 35:  | 3908776  | 4135857  | 4375541  | 4615794  | 4862059  |
| 40:  | 5114919  | 5365363  | 5621203  | 5881228  | 6146076  |
| 45:  | 6411197  | 6686339  | 6960170  | 7242239  | 7520743  |
| 50:  | 7800337  | 8090825  | 8374483  | 8665139  | 8956739  |
| 55:  | 9256989  | 9554754  | 9851306  | 10147565 | 10457237 |
| 60:  | 10758820 | 11061902 | 11369936 | 11676505 | 11986545 |
| 65:  | 12297700 | 12603559 | 12915230 | 13222187 | 13532663 |
| 70:  | 13849303 | 14157374 | 14469180 | 14773823 | 15089613 |
| 75:  | 15403376 | 15709055 | 16020607 | 16328102 | 16634707 |
| 80:  | 16943501 | 17247254 | 17553164 | 17856079 | 18152301 |
| 85:  | 18460144 | 18754760 | 19057797 | 19353488 | 19648414 |
| 90:  | 19934206 | 20236176 | 20525677 | 20804914 | 21093221 |
| 95:  | 21376601 | 21652055 | 21930183 | 22195780 | 22476984 |
| 100: | 22741305 | 23008249 | 23272087 | 23525390 | 23771762 |
| 105: | 24042946 | 24296767 | 24532429 | 24782914 | 25028572 |
| 110: | 25268878 | 25503537 | 25733764 | 25958802 | 26179891 |
| 115: | 26398836 | 26624190 | 26839134 | 27038659 | 27236838 |
| 120: | 27438519 | 27626672 | 27828462 | 28016824 | 28196027 |
| 125: | 28384625 | 28549269 | 28728313 | 28885766 | 29043345 |
| 130: | 29201866 | 29361085 | 29496466 | 29640995 | 29776749 |
| 135: | 29915049 | 30049094 | 30172425 | 30283845 | 30396883 |
| 140: | 30504873 | 30613171 | 30706955 | 30803699 | 30881911 |
| 145: | 30969651 | 31043633 | 31115975 | 31182179 | 31245424 |
| 150: | 31289098 | 31353311 | 31386314 | 31425679 | 31458811 |
| 155: | 31495306 | 31513776 | 31525248 | 31539977 | 31536211 |
| 160: | 31546704 | 31522600 | 31528794 | 31508146 | 31476655 |
| 165: | 31447727 | 31410173 | 31389803 | 31344052 | 31286065 |
| 170: | 31221440 | 31163800 | 31101112 | 31021603 | 30945615 |
| 175: | 30849748 | 30768215 | 30656579 | 30562757 | 30443120 |
| 180: | 30328536 | 30212123 | 30075917 | 29936772 | 29805822 |
| 185: | 29653939 | 29515489 | 29350654 | 29184997 | 29017251 |
| 190: | 28841989 | 28661137 | 28477064 | 28285708 | 28095952 |
| 195: | 27888280 | 27680656 | 27466778 | 27244918 | 27020071 |
| 200: | 26791869 | 26556987 | 26302139 | 26054810 | 25809283 |
| 205: | 25537693 | 25287294 | 25001582 | 24744651 | 24453088 |
| 210: | 24162759 | 23874926 | 23580600 | 23279620 | 22965526 |
| 215: | 22652193 | 22339603 | 22017119 | 21673648 | 21346940 |
| 220: | 20998282 | 20660710 | 20304107 | 19947068 | 19580013 |
| 225: | 19219581 | 18852523 | 18474612 | 18090457 | 17704531 |
| 230: | 17310859 | 16913626 | 16518880 | 16109264 | 15696995 |
| 235: | 15281001 | 14878741 | 14485621 | 14101955 | 13710932 |
| 240: | 13335315 | 12965855 | 12606294 | 12258051 | 11913136 |
| 245: | 11579784 | 11246584 | 10918511 | 10603114 | 10288712 |
| 250: | 9984617  | 9688445  | 9397492  | 9110351  | 8827069  |
| 255: | 8558773  | 8282274  | 8027875  | 7760549  | 7508100  |
| 260: | 7264262  | 7020351  | 6788131  | 6559952  | 6331780  |
| 265: | 6111531  | 5893676  | 5692702  | 5484714  | 5288549  |
| 270: | 5089950  | 4899835  | 4716860  | 4537131  | 4358321  |
| 275: | 4189129  | 4021072  | 3861826  | 3706294  | 3556448  |
| 280: | 34040858 | 3267089  | 3119986  | 2986570  | 2854961  |
| 285: | 2727343  | 2606183  | 2484200  | 2374265  | 2261546  |
| 290: | 2153631  | 2050550  | 1949454  | 1851997  | 1760401  |
| 295: | 1670764  | 1582297  | 1500317  | 1422724  | 1341610  |
| 300: | 1272718  | 1199521  | 1130957  | 1066826  | 1004900  |
| 305: | 948500   | 890588   | 837621   | 786769   | 737618   |
| 310: | 693309   | 648365   | 606945   | 568159   | 531472   |
| 315: | 495560   | 463096   | 431690   | 401074   | 374276   |
| 320: | 349165   | 325288   | 302002   | 280371   | 261287   |
| 325: | 241826   | 224933   | 208901   | 192590   | 178062   |
| 330: | 165642   | 153587   | 141563   | 131270   | 120954   |
| 335: | 111319   | 103332   | 94843    | 87791    | 80307    |
| 340: | 73833    | 67680    | 61978    | 56468    | 51601    |
| 345: | 47558    | 43008    | 38882    | 35227    | 32327    |
| 350: | 29325    | 26246    | 24213    | 21677    | 19273    |
| 355: | 17377    | 15511    | 14110    | 12534    | 10891    |
| 360: | 9940     | 8672     | 7731     | 6903     | 6025     |
| 365: | 5251     | 4657     | 4056     | 3313     | 2922     |
| 370: | 2626     | 2140     | 1865     | 1592     | 1281     |
| 375: | 1055     | 938      | 741      | 622      | 509      |
| 380: | 433      | 354      | 318      | 220      | 152      |
| 385: | 151      | 97       | 85       | 49       | 27       |
| 390: | 0        | 2        | 3        | 0        | 0        |
| 395: | 0        | 0        | 0        | 0        | 0        |

\*\*\*\*\* Total Running Time of Kernel = 1019.28418 ms \*\*\*\*\*  
GPL-based version

\*\*\*\*\* Total Running Time of Kernel = 1019.28418 ms \*\*\*\*\*  
 GPU-based version

|      |          |           |          |          |          |  |
|------|----------|-----------|----------|----------|----------|--|
| 00:  | 1726     | 12084     | 32183    | 62267    | 102025   |  |
| 05:  | 150903   | 209129    | 277000   | 353639   | 439333   |  |
| 10:  | 531528   | 634894    | 743396   | 862620   | 988233   |  |
| 15:  | 1120149  | 1261804   | 1408872  | 1564876  | 1726708  |  |
| 20:  | 1893736  | 2070286   | 2250538  | 2439201  | 2631292  |  |
| 25:  | 2832774  | 3036729   | 3246761  | 3463349  | 3679532  |  |
| 30:  | 3908776  | 4135857   | 4375541  | 4615794  | 4862059  |  |
| 35:  | 5114919  | 5365363   | 5621203  | 5881228  | 6146076  |  |
| 40:  | 6411197  | 6686339   | 6960170  | 7242239  | 7520743  |  |
| 45:  | 7800337  | 8090825   | 8374483  | 8665139  | 8956739  |  |
| 50:  | 9256989  | 9554754   | 9851306  | 10147565 | 10457237 |  |
| 55:  | 10758820 | 11061902  | 11369936 | 11676505 | 11986545 |  |
| 60:  | 12297700 | 12603559  | 12915230 | 13222187 | 13532663 |  |
| 65:  | 13849303 | 14157374  | 14469180 | 14773823 | 15089613 |  |
| 70:  | 15403376 | 15709055  | 16020607 | 16328102 | 16634707 |  |
| 75:  | 16943501 | 17247254  | 17553164 | 17856079 | 18152301 |  |
| 80:  | 18460144 | 18754760  | 19057797 | 19353488 | 19648414 |  |
| 85:  | 19934206 | 20236176  | 20525677 | 20804914 | 21093221 |  |
| 90:  | 21376601 | 21652055  | 21930183 | 22195780 | 22476984 |  |
| 95:  | 22741305 | 23008249  | 23272087 | 23525390 | 23777162 |  |
| 100: | 24042946 | 24296767  | 24532429 | 24782914 | 25028572 |  |
| 105: | 25268878 | 25503537  | 25733764 | 25958802 | 26179891 |  |
| 110: | 26398836 | 26624190  | 26839134 | 27038659 | 27236838 |  |
| 115: | 27438519 | 27626672  | 27828462 | 28016824 | 28196027 |  |
| 120: | 28384625 | 28549269  | 28728313 | 28885766 | 29043345 |  |
| 125: | 29201866 | 29361085  | 29496466 | 29640995 | 29776749 |  |
| 130: | 29915049 | 30049094  | 30172425 | 30283845 | 30396883 |  |
| 135: | 30504873 | 30613171  | 30706955 | 30803699 | 30881911 |  |
| 140: | 30969651 | 31043633  | 31115975 | 31182179 | 31245424 |  |
| 145: | 31289098 | 31353311  | 31386314 | 31425679 | 31458811 |  |
| 150: | 31495306 | 31513776  | 31525248 | 31539977 | 31536211 |  |
| 155: | 31546704 | 31522600  | 31528794 | 31508146 | 31476655 |  |
| 160: | 31447727 | 31410173  | 31389803 | 31344052 | 31286065 |  |
| 165: | 31221440 | 31163800  | 31101112 | 31021603 | 30945615 |  |
| 170: | 30849748 | 30768215  | 30656579 | 30562757 | 30443120 |  |
| 175: | 30328536 | 30212123  | 30075917 | 29936772 | 29805822 |  |
| 180: | 29653939 | 29515489  | 29350654 | 29184997 | 29017251 |  |
| 185: | 28841989 | 28661137  | 28477064 | 28285708 | 28095952 |  |
| 190: | 27888280 | 27680656  | 27466778 | 27244918 | 27020071 |  |
| 195: | 26791869 | 26556987  | 26302139 | 26054810 | 25809283 |  |
| 200: | 25537693 | 25287294  | 25001582 | 24744651 | 24453088 |  |
| 205: | 24162759 | 23874926  | 23580600 | 23279620 | 22965526 |  |
| 210: | 22652193 | 22339603  | 22017119 | 21673648 | 21346940 |  |
| 215: | 20998282 | 20660710  | 20304107 | 19947068 | 19580013 |  |
| 220: | 19219581 | 18852523  | 18474612 | 18090457 | 17704531 |  |
| 225: | 17310859 | 169113626 | 16518880 | 16109264 | 15696995 |  |
| 230: | 15281001 | 14878741  | 14485621 | 14101955 | 13710932 |  |
| 235: | 13335315 | 12965855  | 12606294 | 12258051 | 11913136 |  |
| 240: | 11579784 | 11246584  | 10918511 | 10603114 | 10288712 |  |
| 245: | 9984617  | 9688445   | 9397492  | 9110351  | 8827069  |  |
| 250: | 8558773  | 8282274   | 8027875  | 7760549  | 7508100  |  |
| 255: | 7264262  | 7020351   | 6788131  | 6559952  | 6331780  |  |
| 260: | 6111531  | 5893676   | 5692702  | 5484714  | 5288549  |  |
| 265: | 5089950  | 4899835   | 4716860  | 4537131  | 4358321  |  |
| 270: | 4189129  | 4021072   | 3861826  | 3706294  | 3556448  |  |
| 275: | 3404058  | 3267089   | 3119986  | 2986570  | 2854061  |  |
| 280: | 2727343  | 2606183   | 2484200  | 2374265  | 2261546  |  |
| 285: | 2153631  | 2050550   | 1949454  | 1851997  | 1760401  |  |
| 290: | 1670764  | 1582297   | 1500317  | 1422724  | 1341610  |  |
| 295: | 1272718  | 1199521   | 1130957  | 1066826  | 1004900  |  |
| 300: | 948500   | 890588    | 837621   | 786769   | 737618   |  |
| 305: | 693309   | 648365    | 606945   | 568159   | 531472   |  |
| 310: | 495560   | 463096    | 431690   | 401074   | 374276   |  |
| 315: | 349165   | 325288    | 302002   | 280371   | 261287   |  |
| 320: | 241826   | 224933    | 208901   | 192590   | 178062   |  |
| 325: | 165642   | 153587    | 141563   | 131270   | 120954   |  |
| 330: | 111319   | 103332    | 94843    | 87791    | 80307    |  |
| 335: | 73833    | 67680     | 61978    | 56468    | 51601    |  |
| 340: | 47558    | 43008     | 38882    | 35227    | 32327    |  |
| 345: | 29325    | 26246     | 24213    | 21677    | 19273    |  |
| 350: | 17377    | 15511     | 14110    | 12534    | 10891    |  |
| 355: | 9940     | 8672      | 7731     | 6903     | 6025     |  |
| 360: | 5251     | 4657      | 4056     | 3313     | 2922     |  |
| 365: | 2626     | 2140      | 1865     | 1592     | 1281     |  |
| 370: | 1055     | 938       | 741      | 622      | 509      |  |
| 375: | 433      | 354       | 318      | 220      | 152      |  |
| 380: | 151      | 97        | 85       | 49       | 27       |  |
| 385: | 31       | 15        | 15       | 14       | 7        |  |
| 390: | 0        | 2         | 3        | 0        | 0        |  |
| 395: | 0        | 0         | 0        | 0        | 0        |  |

T:4999950000

Difference between CPU and GPU histograms:

|      |   |   |   |   |   |   |   |
|------|---|---|---|---|---|---|---|
| 00:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 05:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 15:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 25:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 30:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 35:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 40:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 45:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 50:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 55:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 60:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 65:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 70:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 75:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 80:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 85:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 90:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 95:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 100: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 105: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 110: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 115: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 120: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 125: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 130: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 135: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 140: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 145: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 150: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 155: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 160: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 165: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 170: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 175: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 180: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 185: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 190: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 195: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 200: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 205: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 210: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 215: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 220: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 225: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 230: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 235: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 240: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 245: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 250: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 255: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 260: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 265: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 270: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 275: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 280: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 285: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 290: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 295: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 300: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 305: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 310: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 315: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 320: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 325: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 330: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 335: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 340: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 345: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 350: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 355: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 360: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 365: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 370: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 375: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 380: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 385: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 390: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 395: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

srun: launch/slurm: \_task\_finish: Received task exit notification for 1 task of StepId=224874.0 (status=0x0000).  
srun: launch/slurm: \_task\_finish: GPU13: task 0: Completed

```
/apps/GPU_course/runScript.sh proj2-akmal.cu 100000 100 256
```

```
● [akmal@forest.usf.edu@gaivi-login1 project2]$ /apps/GPU_course/runScript.sh proj2-akmal.cu 100000 100 256
----- nvcc Info: -----
nvcc: NVIDIA (R) Cuda compiler driver
Copyright (c) 2005-2021 NVIDIA Corporation
Built on Wed_Jun_2_19:15:15_PDT_2021
Cuda compilation tools, release 11.4, V11.4.48
Build cuda_11.4.r11.4/compiler.30033411_0
----- Compiling -----
ptxas info    : 0 bytes gmem
ptxas info    : Compiling entry function '_Z10PDH_kernelP8atomdescP10hist_entryxdi' for 'sm_52'
ptxas info    : Function properties for _Z10PDH_kernelP8atomdescP10hist_entryxdi
  0 bytes stack frame, 0 bytes spill stores, 0 bytes spill loads
ptxas info    : Used 26 registers, 356 bytes cmem[0], 44 bytes cmem[2]
----- Executing -----
srun: defined options
srun: -----
srun: exclusive      : exclusive
srun: gres           : gres:gpu:TitanX:8
srun: partition       : ClsParSystems
srun: reservation     : Spring2025Class
srun: time            : 01:00:00
srun: verbose          : 1
srun: -----
srun: end of defined options
srun: jobid 224868: nodes(1):`GPU13', cpu counts: 16(x1)
srun: launch/slurm: launch_p_step_launch: CpuBindType=(null type)
srun: launching StepId=224868.0 on host GPU13, 1 tasks: 0
srun: route/default: init: route default plugin loaded
srun: launch/slurm: _task_start: Node GPU13, 1 tasks started

CPU-based version
Running time for CPU version: 98300.47400 ms

***** Total Running Time of Kernel = 1018.97333 ms *****
GPU-based version
```

| CPU-based version                            |          |          |          |          |          |
|--|----------|----------|----------|----------|----------|
| Running time for CPU version: 98300.47400 ms |          |          |          |          |          |
| 00:  | 1726     | 12084    | 32183    | 62267    | 102025   |
| 05:  | 150903   | 209129   | 277000   | 353639   | 439333   |
| 10:  | 531528   | 634894   | 743396   | 862620   | 988233   |
| 15:  | 1120149  | 1261804  | 1408872  | 1564876  | 1726708  |
| 20:  | 1893736  | 2070286  | 2250538  | 2439201  | 2631292  |
| 25:  | 2832774  | 3036729  | 3246761  | 3463349  | 3679532  |
| 30:  | 3908776  | 4135857  | 4375541  | 4615794  | 4862059  |
| 35:  | 5114919  | 5365363  | 5621203  | 5881228  | 6146076  |
| 40:  | 6411197  | 6686339  | 6960170  | 7242239  | 7520743  |
| 45:  | 7800337  | 8090825  | 8374483  | 8665139  | 8956739  |
| 50:  | 9256989  | 9554754  | 9851306  | 10147565 | 10457237 |
| 55:  | 10758820 | 11061902 | 11369936 | 11676505 | 11986545 |
| 60:  | 12297700 | 12603559 | 12915230 | 13222187 | 13532663 |
| 65:  | 13849303 | 14157374 | 14469180 | 14773823 | 15089613 |
| 70:  | 15403376 | 15709055 | 16020607 | 16328102 | 16634707 |
| 75:  | 16943501 | 17247254 | 17553164 | 17856079 | 18152301 |
| 80:  | 18460144 | 18754760 | 19057797 | 19353488 | 19648414 |
| 85:  | 19934206 | 20236176 | 20525677 | 20804914 | 21093221 |
| 90:  | 21376601 | 21652055 | 21930183 | 22195780 | 22476984 |
| 95:  | 22741305 | 23008249 | 23272087 | 23525390 | 23777162 |
| 100:   | 24042946 | 24296767 | 24532429 | 24782914 | 25028572 |
| 105:   | 25268878 | 25503537 | 25733764 | 25958802 | 26179891 |
| 110:   | 26398836 | 26624190 | 26839134 | 27038659 | 27236838 |
| 115:   | 27438519 | 27626672 | 27828462 | 28016824 | 28196027 |
| 120:   | 28384625 | 28549269 | 28728313 | 28885766 | 29043345 |
| 125:   | 29201866 | 29361085 | 29496466 | 29640995 | 29776749 |
| 130:   | 29915049 | 30049094 | 30172425 | 30283845 | 30396883 |
| 135:   | 30504873 | 30613171 | 30706955 | 30803699 | 30881911 |
| 140:   | 30969651 | 31043633 | 31115975 | 31182179 | 31245424 |
| 145:   | 31289098 | 31353311 | 31386314 | 31425679 | 31458811 |
| 150:   | 31495306 | 31513776 | 31525248 | 31539977 | 31536211 |
| 155:   | 31546704 | 31522600 | 31528794 | 31508146 | 31476655 |
| 160:   | 31447727 | 31410173 | 31389803 | 31344052 | 31286065 |
| 165:   | 31221440 | 31163800 | 31101112 | 31021603 | 30945615 |
| 170:   | 30849748 | 30768215 | 30656579 | 30562757 | 30443120 |
| 175:   | 30328536 | 30212123 | 30075917 | 29936772 | 29805822 |
| 180:   | 29653939 | 29515489 | 29350654 | 29184997 | 29017251 |
| 185:   | 28841989 | 28661137 | 28477064 | 28285708 | 28095952 |
| 190:   | 27888280 | 27680656 | 27466778 | 27244918 | 27020071 |
| 195:   | 26791869 | 26556987 | 26302139 | 26054810 | 25809283 |
| 200:   | 25537693 | 25287294 | 25001582 | 24744651 | 24453088 |
| 205:   | 24162759 | 23874926 | 23580600 | 23279620 | 22965526 |
| 210:   | 22652193 | 22339603 | 22017119 | 21673648 | 21346940 |
| 215:   | 20998282 | 20660710 | 20304107 | 19947068 | 19580013 |
| 220:   | 19219581 | 18852523 | 18474612 | 18090457 | 17704531 |
| 225:   | 17310859 | 16913626 | 16518880 | 16109264 | 15696995 |
| 230:   | 15281001 | 14878741 | 14485621 | 14101955 | 13710932 |
| 235:   | 13335315 | 12965855 | 12606294 | 12258051 | 11913136 |
| 240:   | 11579784 | 11246584 | 10918511 | 10603114 | 10288712 |
| 245:   | 9984617  | 9688445  | 9397492  | 9110351  | 8827069  |
| 250:   | 8558773  | 8282274  | 8027875  | 7760549  | 7508100  |
| 255:   | 7264262  | 7020351  | 6788131  | 6559952  | 6331780  |
| 260:   | 6111531  | 5893676  | 5692702  | 5484714  | 5288549  |
| 265:   | 5089950  | 4899835  | 4716860  | 4537131  | 4358321  |
| 270:   | 4189129  | 4021072  | 3861826  | 3706294  | 3556448  |
| 275:   | 3404058  | 3267089  | 3119986  | 2986570  | 2854061  |
| 280:   | 2727343  | 2606183  | 2484200  | 2374265  | 2261546  |
| 285:   | 2153631  | 2050550  | 1949454  | 1851997  | 1760401  |
| 290:   | 1670764  | 1582297  | 1500317  | 1422724  | 1341610  |
| 295:   | 1272718  | 1199521  | 1130957  | 1066826  | 1004900  |
| 300:   | 948500   | 890588   | 837621   | 786769   | 737618   |
| 305:   | 693309   | 648365   | 606945   | 568159   | 531472   |
| 310:   | 495560   | 463096   | 431690   | 401074   | 374276   |
| 315:   | 349165   | 325288   | 302002   | 280371   | 261287   |
| 320:   | 241826   | 224933   | 208901   | 192590   | 178062   |
| 325:   | 165642   | 153587   | 141563   | 131270   | 120954   |
| 330:   | 111319   | 103332   | 94843    | 87791    | 80307    |
| 335:   | 73833    | 67680    | 61978    | 56468    | 51601    |
| 340:   | 47558    | 43008    | 38882    | 35227    | 32327    |
| 345:   | 29325    | 26246    | 24213    | 21677    | 19273    |
| 350:   | 17377    | 15511    | 14110    | 12534    | 10891    |
| 355:   | 9940     | 8672     | 7731     | 6903     | 6025     |
| 360:   | 5251     | 4657     | 4056     | 3313     | 2922     |
| 365:   | 2626     | 2140     | 1865     | 1592     | 1281     |
| 370:   | 1055     | 938      | 741      | 622      | 509      |
| 375:   | 433      | 354      | 318      | 220      | 152      |
| 380:   | 151      | 97       | 85       | 49       | 27       |
| 385:   | 31       | 15       | 15       | 14       | 7        |
| 390:   | 0        | 2        | 3        | 0        | 0        |
| 395:   | 0        | 0        | 0        | 0        | 0        |

T:4999950000

\*\*\*\*\* Total Running Time of Kernel = 1018.97333 ms \*\*\*\*\*

GPU-based version

| ***** Total Running Time of Kernel = 1018.97333 ms ***** |          |          |          |          |          |
|--|----------|----------|----------|----------|----------|
| GPU-based version  |          |          |          |          |          |
| 00:  | 1726     | 12084    | 32183    | 62267    | 102025   |
| 05:  | 150903   | 209129   | 277000   | 353639   | 439333   |
| 10:  | 531528   | 634894   | 743396   | 862620   | 988233   |
| 15:  | 1120149  | 1261804  | 1408872  | 1564876  | 1726708  |
| 20:  | 1893736  | 2070286  | 2250538  | 2439201  | 2631292  |
| 25:  | 2832774  | 3036729  | 3246761  | 3463349  | 3679532  |
| 30:  | 3908776  | 4135857  | 4375541  | 4615794  | 4862059  |
| 35:  | 5114919  | 5365363  | 5621203  | 5881228  | 6146076  |
| 40:  | 6411197  | 6686339  | 6960170  | 7242239  | 7520743  |
| 45:  | 7800337  | 8099825  | 8374483  | 8665139  | 8956739  |
| 50:  | 9256989  | 9554754  | 9851306  | 10147565 | 10457237 |
| 55:  | 10758820 | 11061902 | 11369936 | 11676505 | 11986545 |
| 60:  | 12297700 | 12603559 | 12915230 | 13222187 | 13532663 |
| 65:  | 13849303 | 14157374 | 14469180 | 14773823 | 15089613 |
| 70:  | 15403376 | 15709055 | 16020607 | 16328102 | 16634707 |
| 75:  | 16943501 | 17247254 | 17553164 | 17856079 | 18152301 |
| 80:  | 18460144 | 18754760 | 19057797 | 19353488 | 19648414 |
| 85:  | 19934206 | 20236176 | 20525677 | 20804914 | 21093221 |
| 90:  | 21376601 | 21652055 | 21930183 | 22195780 | 22476984 |
| 95:  | 22741305 | 23008249 | 23272087 | 23525390 | 23777162 |
| 100:   | 24042946 | 24296767 | 24532429 | 24782914 | 25028572 |
| 105:   | 25268878 | 25503537 | 25733764 | 25958802 | 26179891 |
| 110:   | 26398836 | 26624190 | 26839134 | 27038659 | 27236838 |
| 115:   | 27438519 | 27626672 | 27828462 | 28016824 | 28196027 |
| 120:   | 28384625 | 28549269 | 28728313 | 28885766 | 29043345 |
| 125:   | 29201866 | 29361085 | 29496466 | 29640995 | 29776749 |
| 130:   | 29915049 | 30049094 | 30172425 | 30283845 | 30396883 |
| 135:   | 30504873 | 30613171 | 30706955 | 30803699 | 30881911 |
| 140:   | 30969651 | 31043633 | 31115975 | 31182179 | 31245424 |
| 145:   | 31289098 | 31353311 | 31386314 | 31425679 | 31458811 |
| 150:   | 31495306 | 31513776 | 31525248 | 31539977 | 31536211 |
| 155:   | 31546704 | 31522600 | 31528794 | 31508146 | 31476655 |
| 160:   | 31447727 | 31410173 | 31389803 | 31344052 | 31286065 |
| 165:   | 31221440 | 31163800 | 31101112 | 31021603 | 30945615 |
| 170:   | 30849748 | 30768215 | 30656579 | 30562757 | 30443120 |
| 175:   | 30328536 | 30212123 | 30075917 | 29936772 | 29805822 |
| 180:   | 29653939 | 29515489 | 29350654 | 29184997 | 29017251 |
| 185:   | 28841989 | 28661137 | 28477064 | 28285708 | 28095952 |
| 190:   | 27888280 | 27680656 | 27466778 | 27244918 | 27020071 |
| 195:   | 26791869 | 26556987 | 26302139 | 26054810 | 25809283 |
| 200:   | 25537693 | 25287294 | 25001582 | 24744651 | 24453088 |
| 205:   | 24162759 | 23874926 | 23580600 | 23279620 | 22965526 |
| 210:   | 22652193 | 22339603 | 22017119 | 21673648 | 21346940 |
| 215:   | 20998282 | 20660710 | 20304107 | 19947068 | 19580013 |
| 220:   | 19219581 | 18852523 | 18474612 | 18090457 | 17704531 |
| 225:   | 17310859 | 16913626 | 16518880 | 16109264 | 15696995 |
| 230:   | 15281001 | 14878741 | 14485621 | 14101955 | 13710932 |
| 235:   | 13335315 | 12965855 | 12606294 | 12258051 | 11913136 |
| 240:   | 11579784 | 11246584 | 10918511 | 10603114 | 10288712 |
| 245:   | 9984617  | 9688445  | 9397492  | 9110351  | 8827069  |
| 250:   | 8558773  | 8282274  | 8027875  | 7760549  | 7508100  |
| 255:   | 7264262  | 7020351  | 6788131  | 6559952  | 6331780  |
| 260:   | 6111531  | 5893676  | 5692702  | 5484714  | 5288549  |
| 265:   | 5089950  | 4899835  | 4716860  | 4537131  | 4358321  |
| 270:   | 4189129  | 4021072  | 3861826  | 3706294  | 3556448  |
| 275:   | 3404058  | 3267089  | 3119986  | 2986570  | 2854061  |
| 280:   | 2727343  | 2606183  | 2484200  | 2374265  | 2261546  |
| 285:   | 2153631  | 2050550  | 1949454  | 1851997  | 1760491  |
| 290:   | 1670764  | 1582297  | 1500317  | 1422724  | 1341610  |
| 295:   | 1272718  | 1199521  | 1130957  | 1066826  | 1004900  |
| 300:   | 948500   | 890588   | 837621   | 786769   | 737618   |
| 305:   | 693309   | 648365   | 606945   | 568159   | 531472   |
| 310:   | 495560   | 463096   | 431690   | 401074   | 374276   |
| 315:   | 349165   | 325288   | 302002   | 280371   | 261287   |
| 320:   | 241826   | 224933   | 208901   | 192590   | 178062   |
| 325:   | 165642   | 153587   | 141563   | 131270   | 120954   |
| 330:   | 111319   | 103332   | 94843    | 87791    | 80307    |
| 335:   | 73833    | 67680    | 61978    | 56468    | 51601    |
| 340:   | 47558    | 43008    | 38882    | 35227    | 32327    |
| 345:   | 29325    | 26246    | 24213    | 21677    | 19273    |
| 350:   | 17377    | 15511    | 14110    | 12534    | 10891    |
| 355:   | 9940     | 8672     | 7731     | 6903     | 6025     |
| 360:   | 5251     | 4657     | 4056     | 3313     | 2922     |
| 365:   | 2626     | 2140     | 1865     | 1592     | 1281     |
| 370:   | 1055     | 938      | 741      | 622      | 509      |
| 375:   | 433      | 354      | 318      | 220      | 152      |
| 380:   | 151      | 97       | 85       | 49       | 27       |
| 385:   | 31       | 15       | 15       | 14       | 7        |
| 390:   | 0        | 2        | 3        | 0        | 0        |
| 395:   | 0        | 0        | 0        | 0        |          |

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Difference between CPU and GPU histograms:

Difference between CPU and GPU histograms:

|      |   |   |   |   |   |   |   |
|------|---|---|---|---|---|---|---|
| 00:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 05:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 15:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 25:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 30:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 35:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 40:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 45:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 50:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 55:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 60:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 65:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 70:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 75:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 80:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 85:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 90:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 95:  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 100: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 105: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 110: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 115: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 120: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 125: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 130: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 135: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 140: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 145: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 150: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 155: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 160: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 165: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 170: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 175: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 180: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 185: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 190: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 195: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 200: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 205: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 210: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 215: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 220: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 225: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 230: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 235: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 240: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 245: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 250: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 255: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 260: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 265: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 270: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 275: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 280: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 285: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 290: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 295: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 300: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 305: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 310: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 315: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 320: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 325: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 330: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 335: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 340: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 345: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 350: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 355: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 360: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 365: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 370: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 375: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 380: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 385: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 390: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 395: | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

srun: launch/slurm: \_task\_finish: Received task exit notification for 1 task of StepId=224868.0 (status=0x0000).  
srun: launch/slurm: \_task\_finish: GPU13: task 0: Completed



```
/apps/GPU_course/runScript.sh proj2-akmal.cu 100000 100 512
```

```
[akmal@forest.usf.edu@gaivi-login1 project2]$ /apps/GPU_course/runScript.sh proj2-akmal.cu 100000 100 512
----- nvcc Info: -----
nvcc: NVIDIA (R) Cuda compiler driver
Copyright (c) 2005-2021 NVIDIA Corporation
Built on Wed_Jun_2_19:15:15_PDT_2021
Cuda compilation tools, release 11.4, V11.4.48
Build cuda_11.4.r11.4/compiler.30033411_0
----- Compiling -----
ptxas info    : 0 bytes gmem
ptxas info    : Compiling entry function '_Z10PDH_kernelP8atomdescP10hist_entryxdi' for 'sm_52'
ptxas info    : Function properties for _Z10PDH_kernelP8atomdescP10hist_entryxdi
    0 bytes stack frame, 0 bytes spill stores, 0 bytes spill loads
ptxas info    : Used 26 registers, 356 bytes cmem[0], 44 bytes cmem[2]
----- Executing -----
srun: defined options
srun: -----
srun: exclusive      : exclusive
srun: gres           : gres:gpu:TitanX:8
srun: partition       : ClsParSystems
srun: reservation     : Spring2025Class
srun: time            : 01:00:00
srun: verbose          : 1
srun: -----
srun: end of defined options
srun: jobid 224883: nodes(1):`GPU13', cpu counts: 16(x1)
srun: launch/slurm: launch_p_step_launch: CpuBindType=(null type)
srun: launching StepId=224883.0 on host GPU13, 1 tasks: 0
srun: route/default: init: route default plugin loaded
srun: launch/slurm: _task_start: Node GPU13, 1 tasks started

CPU-based version
Running time for CPU version: 98332.34000 ms
***** Total Running Time of Kernel = 1026.68396 ms *****
GPU-based version
```

| ***** Total Running Time of Kernel = 1026.68396 ms ***** |          |          |          |          |          |  |
|--|----------|----------|----------|----------|----------|--|
| GPU-based version  |          |          |          |          |          |  |
| 00:  | 1726     | 12084    | 32183    | 62267    | 102025   |  |
| 05:  | 159903   | 209129   | 277000   | 353639   | 439333   |  |
| 10:  | 531528   | 634894   | 743396   | 862620   | 988233   |  |
| 15:  | 1120149  | 1261804  | 1408872  | 1564876  | 1726708  |  |
| 20:  | 1893736  | 2070286  | 2250538  | 2439201  | 2631292  |  |
| 25:  | 2832774  | 3036729  | 3246761  | 3463349  | 3679532  |  |
| 30:  | 3908776  | 4135857  | 4375541  | 4615794  | 4862059  |  |
| 35:  | 5114919  | 5365363  | 5621203  | 5881228  | 6146076  |  |
| 40:  | 6411197  | 6686339  | 6960170  | 7242239  | 7520743  |  |
| 45:  | 7800337  | 8090825  | 8374483  | 8665139  | 8956739  |  |
| 50:  | 9256989  | 9554754  | 9851306  | 10147565 | 10457237 |  |
| 55:  | 10758820 | 11061902 | 11369936 | 11676505 | 11986545 |  |
| 60:  | 12297700 | 12603559 | 12915230 | 13222187 | 13532663 |  |
| 65:  | 13849303 | 14157374 | 14469180 | 14773823 | 15089613 |  |
| 70:  | 15403376 | 15709055 | 16020607 | 16328102 | 16634707 |  |
| 75:  | 16943501 | 17247254 | 17553164 | 17856079 | 18152301 |  |
| 80:  | 18460144 | 18754760 | 19057797 | 19353488 | 19648414 |  |
| 85:  | 19934206 | 20236176 | 20525677 | 20804914 | 21093221 |  |
| 90:  | 21376601 | 21652055 | 21930183 | 22195780 | 22476984 |  |
| 95:  | 22741305 | 23008249 | 23272087 | 23525390 | 23777162 |  |
| 100:   | 24042946 | 24296767 | 24532429 | 24782914 | 25028572 |  |
| 105:   | 25268878 | 25503537 | 25733764 | 25958802 | 26179891 |  |
| 110:   | 26398836 | 26624190 | 26839134 | 27038659 | 27236838 |  |
| 115:   | 27438519 | 27626672 | 27828462 | 28016824 | 28196027 |  |
| 120:   | 28384625 | 28549269 | 28728313 | 28885766 | 29043345 |  |
| 125:   | 29201866 | 29361085 | 29496466 | 29640995 | 29776749 |  |
| 130:   | 29915049 | 30049094 | 30172425 | 30283845 | 30396883 |  |
| 135:   | 30504873 | 30613171 | 30706955 | 30803699 | 30881911 |  |
| 140:   | 30969651 | 31043633 | 31115975 | 31182179 | 31245424 |  |
| 145:   | 31289098 | 31353311 | 31386314 | 31425679 | 31458811 |  |
| 150:   | 31495306 | 31513776 | 31525248 | 31539977 | 31536211 |  |
| 155:   | 31546704 | 31522600 | 31528794 | 31508146 | 31476655 |  |
| 160:   | 31447727 | 31410173 | 31389803 | 31344052 | 31286065 |  |
| 165:   | 31221440 | 31163800 | 31101112 | 31021603 | 30945615 |  |
| 170:   | 30849748 | 30768215 | 30656579 | 30562757 | 30443120 |  |
| 175:   | 30328536 | 30212123 | 30075917 | 29936772 | 29805822 |  |
| 180:   | 29653939 | 29515489 | 29350654 | 29184997 | 29017251 |  |
| 185:   | 28841989 | 28661137 | 28477064 | 28285708 | 28095952 |  |
| 190:   | 27888280 | 27680656 | 27466778 | 27244918 | 27020071 |  |
| 195:   | 26791869 | 26556987 | 26302139 | 26054810 | 25809283 |  |
| 200:   | 25537693 | 25287294 | 25001582 | 24744651 | 24453088 |  |
| 205:   | 24162759 | 23874926 | 23580600 | 23279620 | 22965526 |  |
| 210:   | 22652193 | 22339603 | 22017119 | 21673648 | 21346940 |  |
| 215:   | 20998282 | 20660710 | 20304107 | 19947068 | 19580013 |  |
| 220:   | 19219581 | 18852523 | 18474612 | 18090457 | 17704531 |  |
| 225:   | 17310859 | 16913626 | 16518880 | 16109264 | 15696995 |  |
| 230:   | 15281001 | 14878741 | 14485621 | 14101955 | 13710932 |  |
| 235:   | 13335315 | 12965855 | 12606294 | 12258051 | 11913136 |  |
| 240:   | 11579784 | 11246584 | 10918511 | 10603114 | 10288712 |  |
| 245:   | 9984617  | 9688445  | 9397492  | 9110351  | 8827069  |  |
| 250:   | 8558773  | 8282274  | 8027875  | 7760549  | 7508100  |  |
| 255:   | 7264262  | 7020351  | 6788131  | 6559952  | 6331780  |  |
| 260:   | 6111531  | 5893676  | 5692702  | 5484714  | 5288549  |  |
| 265:   | 5089950  | 4899835  | 4716860  | 4537131  | 4358321  |  |
| 270:   | 4189129  | 4021072  | 3861826  | 3706294  | 3556448  |  |
| 275:   | 3404058  | 3267089  | 3119986  | 2986570  | 2854061  |  |
| 280:   | 2727343  | 2606183  | 2484200  | 2374265  | 2261546  |  |
| 285:   | 2153631  | 2050550  | 1949454  | 1851997  | 1760491  |  |
| 290:   | 1670764  | 1582297  | 1500317  | 1422724  | 1341610  |  |
| 295:   | 1272718  | 1199521  | 1130957  | 1066826  | 1004900  |  |
| 300:   | 948500   | 890588   | 837621   | 786769   | 737618   |  |
| 305:   | 693309   | 648365   | 606945   | 568159   | 531472   |  |
| 310:   | 495560   | 463096   | 431690   | 401074   | 374276   |  |
| 315:   | 349165   | 325288   | 302002   | 280371   | 261287   |  |
| 320:   | 241826   | 224933   | 208901   | 192590   | 178062   |  |
| 325:   | 165642   | 153587   | 141563   | 131270   | 120954   |  |
| 330:   | 111319   | 103332   | 94843    | 87791    | 80307    |  |
| 335:   | 73833    | 67680    | 61978    | 56468    | 51601    |  |
| 340:   | 47558    | 43008    | 38882    | 35227    | 32327    |  |
| 345:   | 29325    | 26246    | 24213    | 21677    | 19273    |  |
| 350:   | 17377    | 15511    | 14110    | 12534    | 10891    |  |
| 355:   | 9940     | 8672     | 7731     | 6903     | 6025     |  |
| 360:   | 5251     | 4657     | 4056     | 3313     | 2922     |  |
| 365:   | 2626     | 2140     | 1865     | 1592     | 1281     |  |
| 370:   | 1055     | 938      | 741      | 622      | 509      |  |
| 375:   | 433      | 354      | 318      | 220      | 152      |  |
| 380:   | 151      | 97       | 85       | 49       | 27       |  |
| 385:   | 31       | 15       | 15       | 14       | 7        |  |
| 390:   | 0        | 2        | 3        | 0        | 0        |  |
| 395:   | 0        | 0        | 0        | 0        | 0        |  |

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Difference between CPU and GPU histograms:

| CPU-based version                            |          |          |          |          |          |
|--|----------|----------|----------|----------|----------|
| Running time for CPU version: 98332.34000 ms |          |          |          |          |          |
| 00:  | 1726     | 12084    | 32183    | 62267    | 102025   |
| 05:  | 150903   | 209129   | 277000   | 353639   | 439333   |
| 10:  | 531528   | 634894   | 743396   | 862620   | 988233   |
| 15:  | 1120149  | 1261804  | 1408872  | 1564876  | 1726708  |
| 20:  | 1893736  | 2070286  | 2250538  | 2439201  | 2631292  |
| 25:  | 2832774  | 3036729  | 3246761  | 3463349  | 3679532  |
| 30:  | 3908776  | 4135857  | 4375541  | 4615794  | 4862059  |
| 35:  | 5114919  | 5365363  | 5621203  | 5881228  | 6146076  |
| 40:  | 6411197  | 6686339  | 6960170  | 7242239  | 7520743  |
| 45:  | 7800337  | 8090825  | 8374483  | 8665139  | 8956739  |
| 50:  | 9256989  | 9554754  | 9851306  | 10147565 | 10457237 |
| 55:  | 10758820 | 11061902 | 11369936 | 11676505 | 11986545 |
| 60:  | 12297700 | 12603559 | 12915230 | 13222187 | 13532663 |
| 65:  | 13849303 | 14157374 | 14469180 | 14773823 | 15089613 |
| 70:  | 15403376 | 15709055 | 16020607 | 16328102 | 16634707 |
| 75:  | 16943501 | 17247254 | 17553164 | 17856079 | 18152001 |
| 80:  | 18460144 | 18754760 | 19057797 | 19353488 | 19648414 |
| 85:  | 19934206 | 20236176 | 20525677 | 20804914 | 21093221 |
| 90:  | 21376601 | 21652055 | 21930183 | 22195780 | 22476984 |
| 95:  | 22741305 | 23008249 | 23272087 | 23525390 | 23777162 |
| 100:   | 24042946 | 24296767 | 24532429 | 24782914 | 25028572 |
| 105:   | 25268878 | 25503537 | 25733764 | 25958802 | 26179891 |
| 110:   | 26398836 | 26624190 | 26839134 | 27038659 | 27236838 |
| 115:   | 27438519 | 27626672 | 27828462 | 28016824 | 28196027 |
| 120:   | 28384625 | 28549269 | 28728313 | 28885766 | 29043345 |
| 125:   | 29201866 | 29361085 | 29496466 | 29640995 | 29776749 |
| 130:   | 29915049 | 30049094 | 30172425 | 30283845 | 30396883 |
| 135:   | 30504873 | 30613171 | 30706955 | 30803699 | 30881911 |
| 140:   | 30969651 | 31043633 | 31115975 | 31182179 | 31245424 |
| 145:   | 31289098 | 31353311 | 31386314 | 31425676 | 31458811 |
| 150:   | 31495306 | 31513776 | 31525248 | 31539977 | 31536211 |
| 155:   | 31546704 | 31522600 | 31528794 | 31508146 | 31476655 |
| 160:   | 31447727 | 31418173 | 31389803 | 31344052 | 31286065 |
| 165:   | 31221440 | 31163800 | 31101112 | 31021603 | 30945615 |
| 170:   | 30849748 | 30768215 | 30656579 | 30562757 | 30443120 |
| 175:   | 30328536 | 30212123 | 30075917 | 29936772 | 29805822 |
| 180:   | 29653939 | 29515489 | 29350654 | 29184997 | 29017251 |
| 185:   | 28841989 | 28661137 | 28477064 | 28285708 | 28095952 |
| 190:   | 27888280 | 27680656 | 27466778 | 27244918 | 27020071 |
| 195:   | 26791869 | 26556987 | 26302139 | 26054810 | 25809283 |
| 200:   | 25537693 | 25287294 | 25001582 | 24744651 | 24453088 |
| 205:   | 24162759 | 23874926 | 23580600 | 23279620 | 22965526 |
| 210:   | 22652193 | 22339603 | 22017119 | 21673648 | 21346940 |
| 215:   | 20998282 | 20660710 | 20304107 | 19947068 | 19580013 |
| 220:   | 19219581 | 18852523 | 18474612 | 18090457 | 17704531 |
| 225:   | 17310859 | 16913626 | 16518880 | 16109264 | 15696995 |
| 230:   | 15281001 | 14878741 | 14485621 | 14101955 | 13710932 |
| 235:   | 13335315 | 12965855 | 12606294 | 12258051 | 11913136 |
| 240:   | 11579784 | 11246584 | 10918511 | 10603114 | 10288712 |
| 245:   | 9984617  | 9688445  | 9397492  | 9110351  | 8827069  |
| 250:   | 8558773  | 8282274  | 8027875  | 7760549  | 7508100  |
| 255:   | 7264262  | 7020351  | 6788131  | 6559952  | 6331780  |
| 260:   | 6111531  | 5893676  | 5692702  | 5484714  | 5288549  |
| 265:   | 5089950  | 4899835  | 4716860  | 4537131  | 4358321  |
| 270:   | 4189129  | 4021072  | 3861826  | 3706294  | 3556448  |
| 275:   | 3404058  | 3267089  | 3119986  | 2986570  | 2854061  |
| 280:   | 2727343  | 2606183  | 2484200  | 2374265  | 2261546  |
| 285:   | 2153631  | 2050550  | 1949454  | 1851997  | 1760401  |
| 290:   | 1670764  | 1582297  | 1500317  | 1422724  | 1341610  |
| 295:   | 1272718  | 1199521  | 1130957  | 1066826  | 1004900  |
| 300:   | 948500   | 890588   | 837621   | 786769   | 737618   |
| 305:   | 693309   | 648365   | 606945   | 568159   | 531472   |
| 310:   | 495560   | 463096   | 431690   | 401074   | 374276   |
| 315:   | 349165   | 325288   | 302002   | 280371   | 261287   |
| 320:   | 241826   | 224933   | 208901   | 192590   | 178062   |
| 325:   | 165642   | 153587   | 141563   | 131270   | 120954   |
| 330:   | 111319   | 103332   | 94843    | 87791    | 80307    |
| 335:   | 73833    | 67680    | 61978    | 56468    | 51601    |
| 340:   | 47558    | 43008    | 38882    | 35227    | 32327    |
| 345:   | 29325    | 26246    | 24213    | 21677    | 19273    |
| 350:   | 17377    | 15511    | 14110    | 12534    | 10891    |
| 355:   | 9940     | 8672     | 7731     | 6903     | 6025     |
| 360:   | 5251     | 4657     | 4056     | 3313     | 2922     |
| 365:   | 2626     | 2140     | 1865     | 1592     | 1281     |
| 370:   | 1055     | 938      | 741      | 622      | 509      |
| 375:   | 433      | 354      | 318      | 220      | 152      |
| 380:   | 151      | 97       | 85       | 49       | 27       |
| 385:   | 31       | 15       | 15       | 14       | 7        |
| 390:   | 0        | 2        | 3        | 0        | 0        |
| 395:   | 0        | 0        | 0        | 0        | 0        |

Difference between CPU and GPU histograms:

|      |   |   |   |   |   |   |
|------|---|---|---|---|---|---|
| 00:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 05:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 10:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 15:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 20:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 25:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 30:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 35:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 40:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 45:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 50:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 55:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 60:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 65:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 70:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 75:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 80:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 85:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 90:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 95:  | 0 | 0 | 0 | 0 | 0 | 0 |
| 100: | 0 | 0 | 0 | 0 | 0 | 0 |
| 105: | 0 | 0 | 0 | 0 | 0 | 0 |
| 110: | 0 | 0 | 0 | 0 | 0 | 0 |
| 115: | 0 | 0 | 0 | 0 | 0 | 0 |
| 120: | 0 | 0 | 0 | 0 | 0 | 0 |
| 125: | 0 | 0 | 0 | 0 | 0 | 0 |
| 130: | 0 | 0 | 0 | 0 | 0 | 0 |
| 135: | 0 | 0 | 0 | 0 | 0 | 0 |
| 140: | 0 | 0 | 0 | 0 | 0 | 0 |
| 145: | 0 | 0 | 0 | 0 | 0 | 0 |
| 150: | 0 | 0 | 0 | 0 | 0 | 0 |
| 155: | 0 | 0 | 0 | 0 | 0 | 0 |
| 160: | 0 | 0 | 0 | 0 | 0 | 0 |
| 165: | 0 | 0 | 0 | 0 | 0 | 0 |
| 170: | 0 | 0 | 0 | 0 | 0 | 0 |
| 175: | 0 | 0 | 0 | 0 | 0 | 0 |
| 180: | 0 | 0 | 0 | 0 | 0 | 0 |
| 185: | 0 | 0 | 0 | 0 | 0 | 0 |
| 190: | 0 | 0 | 0 | 0 | 0 | 0 |
| 195: | 0 | 0 | 0 | 0 | 0 | 0 |
| 200: | 0 | 0 | 0 | 0 | 0 | 0 |
| 205: | 0 | 0 | 0 | 0 | 0 | 0 |
| 210: | 0 | 0 | 0 | 0 | 0 | 0 |
| 215: | 0 | 0 | 0 | 0 | 0 | 0 |
| 220: | 0 | 0 | 0 | 0 | 0 | 0 |
| 225: | 0 | 0 | 0 | 0 | 0 | 0 |
| 230: | 0 | 0 | 0 | 0 | 0 | 0 |
| 235: | 0 | 0 | 0 | 0 | 0 | 0 |
| 240: | 0 | 0 | 0 | 0 | 0 | 0 |
| 245: | 0 | 0 | 0 | 0 | 0 | 0 |
| 250: | 0 | 0 | 0 | 0 | 0 | 0 |
| 255: | 0 | 0 | 0 | 0 | 0 | 0 |
| 260: | 0 | 0 | 0 | 0 | 0 | 0 |
| 265: | 0 | 0 | 0 | 0 | 0 | 0 |
| 270: | 0 | 0 | 0 | 0 | 0 | 0 |
| 275: | 0 | 0 | 0 | 0 | 0 | 0 |
| 280: | 0 | 0 | 0 | 0 | 0 | 0 |
| 285: | 0 | 0 | 0 | 0 | 0 | 0 |
| 290: | 0 | 0 | 0 | 0 | 0 | 0 |
| 295: | 0 | 0 | 0 | 0 | 0 | 0 |
| 300: | 0 | 0 | 0 | 0 | 0 | 0 |
| 305: | 0 | 0 | 0 | 0 | 0 | 0 |
| 310: | 0 | 0 | 0 | 0 | 0 | 0 |
| 315: | 0 | 0 | 0 | 0 | 0 | 0 |
| 320: | 0 | 0 | 0 | 0 | 0 | 0 |
| 325: | 0 | 0 | 0 | 0 | 0 | 0 |
| 330: | 0 | 0 | 0 | 0 | 0 | 0 |
| 335: | 0 | 0 | 0 | 0 | 0 | 0 |
| 340: | 0 | 0 | 0 | 0 | 0 | 0 |
| 345: | 0 | 0 | 0 | 0 | 0 | 0 |
| 350: | 0 | 0 | 0 | 0 | 0 | 0 |
| 355: | 0 | 0 | 0 | 0 | 0 | 0 |
| 360: | 0 | 0 | 0 | 0 | 0 | 0 |
| 365: | 0 | 0 | 0 | 0 | 0 | 0 |
| 370: | 0 | 0 | 0 | 0 | 0 | 0 |
| 375: | 0 | 0 | 0 | 0 | 0 | 0 |
| 380: | 0 | 0 | 0 | 0 | 0 | 0 |
| 385: | 0 | 0 | 0 | 0 | 0 | 0 |
| 390: | 0 | 0 | 0 | 0 | 0 | 0 |
| 395: | 0 | 0 | 0 | 0 | 0 | 0 |

srn: launch/slurm: \_task\_finish: Received task exit notification for 1 task of StepId=224883.0 (status=0x0000).  
srn: launch/slurm: \_task\_finish: GPU13: task 0: Completed

## GPU vs. CPU Performance Comparison

Our experiments demonstrate that optimizing GPU parameters can significantly enhance the performance of spatial distance histogram computations. With a fixed dataset and bucket width, we evaluated block sizes of 64, 128, 256, and 512 threads, and the results indicate that a block size of 256 threads delivers the best performance.

Moreover, the GPU approach with 256 threads exhibits impressive speedups that improve with increased input sizes. For instance, when processing 100,000 points with a bucket width of 100, the CPU version required approximately 98,300 ms, while the GPU kernel completed in about 1,019 ms—yielding a speedup of roughly 96.5×. With an even larger dataset of 500,000 points, the CPU running time soared to about 2,459,081 ms, whereas the GPU kernel finished in roughly 24,569 ms, achieving an approximate 100× speedup.

These substantial performance improvements are primarily attributable to:

- **Efficient Shared Memory Usage:** Reducing memory access latency by leveraging the GPU's fast shared memory.
- **Balanced Workload Distribution:** Ensuring that all threads are effectively utilized and that the workload is evenly distributed.

Overall, these optimizations harness the GPU's architectural strengths to significantly reduce memory access overhead and enhance scalability. The increasing speedup with larger datasets underscores the effectiveness of this approach, making it a highly efficient solution for large-scale spatial distance histogram computations.