Lập trình song song GPU
Đồ án cuối kỳ

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Cập nhật

Cập nhật slide:

- Bổ sung chi tiết slide ‘nội dung’
- Thêm vào bảng thống kê thời gian chạy ở cuối mỗi base.
- Thêm thời gian chạy các kernel và hình ảnh tương ứng của các base.
- Thêm kết quả chạy file cuối cùng, với k = 4 và blockSize lần lượt là 128, 1024

Nội dung

- Base 1 - 2: Radix sort tuần tự và song song theo bài tập 4
- Base 1 - 3: Radix sort song song với k = 1
- Base 4 v1: Radix sort tuần tự theo đồ án k > 1(level 1)
- Base 4 v2: Song song 2 bước hist và scan k > 1(level 1)
- Base 4 v3: Radix sort song song scatter k > 1 (level 2)
- Base 4 v4: Radix sort song song scatter k > 1 (level 2)
- Base 4 v5

Base01 - 02

```
idl6l2858@9aa3d017fc93:~/BT04$ ./bt04_3
**********GPU info**********
Name: GeForce GTX 1080 Ti
Compute capability: 6.1
Num SMs: 28
Max num threads per SM: 2048
Max num warps per SM: 64
GMEM: 11713052672 byte
SMEM per SM: 98304 byte
SMEM per block: 49152 byte
******************************

Input size: 16777217

Num bits per digit: 8

Hist block size: 512, scan block size: 512

Radix sort by host
Time: 1160.960 ms

Radix sort by device
Time: 776.620 ms
CORRECT :)

Sort by thrust
Time: 70.463 ms
CORRECT :)
```

```
idl6l2858@9aa3d017fc93:~/BT04$ nvprof ./bt04_3
==18944== NVPROF is profiling process 18944, command: ./bt04_3
**********GPU info**********
Name: GeForce GTX 1080 Ti
Compute capability: 6.1
Num SMs: 28
Max num threads per SM: 2048
Max num warps per SM: 64
GMEM: 11713052672 byte
SMEM per SM: 98304 byte
SMEM per block: 49152 byte
******************************

Input size: 16777217

Num bits per digit: 8

Hist block size: 512, scan block size: 512

Radix sort by host
Time: 1183.120 ms

Radix sort by device
Time: 754.800 ms
CORRECT :)

Sort by thrust
Time: 41.751 ms
CORRECT :)
```

Base01 - 02

	thời gian	thời gian thực thi (ms)	công đoạn/ghi chú (mặc định k = 8)
Thuật toán Radix Sort tuần tự (**base01**)	16/12/2019	1160	Đã thực hiện ở bài tập số 4.
Song song 2 bước hist và scan (**base02**)	16/12/2019	776	Đã thực hiện ở bài tập số 4.
Thuật toán Radix sort do thrust hỗ trợ		41	

Base 01 - 03

- Ngày thực hiện: 21 - 22/12/2019
- Cài đặt thuật toán Radix sort song song với k = 1.

Base 01 - 03

```
id1612858@9aa3d017fc93:~/final$ ./baselto3
**********GPU info**********
Name: GeForce GTX 1080 Ti
Compute capability: 6.1
Num SMs: 28
Max num threads per SM: 2048
Max num warps per SM: 64
GMEM: 11713052672 byte
SMEM per SM: 98304 byte
SMEM per block: 49152 byte
****************************

Input size: 16777217

Num bits per digit: 8

Hist block size: 512, scan block size: 512

Radix sort by host
Time: 1161.051 ms

Radix sort by device
Time: 777.674 ms
CORRECT :)

Radix sort by device by base03
Avg Time: 179.048 ms
CORRECT :)

Sort by thrust
Time: 41.254 ms
CORRECT :)
```

id1612858@9aa3d017fc93: ~/final

```
id1612858@9aa3d017fc93:~/final$ nvprof ./baselto3
==18841== NVPROF is profiling process 18841, command: ./baselto3
**********GPU info**********
Name: GeForce GTX 1080 Ti
Compute capability: 6.1
Num SMs: 28
Max num threads per SM: 2048
Max num warps per SM: 64
GMEM: 11713052672 byte
SMEM per SM: 98304 byte
SMEM per block: 49152 byte
****************************

Input size: 16777217

Num bits per digit: 8

Hist block size: 512, scan block size: 512

Radix sort by host
Time: 1181.323 ms

Radix sort by device
Time: 759.757 ms
CORRECT :)

Radix sort by device by base03
Time: 144.875 ms
CORRECT :)

Sort by thrust
Time: 42.909 ms
CORRECT :)
```

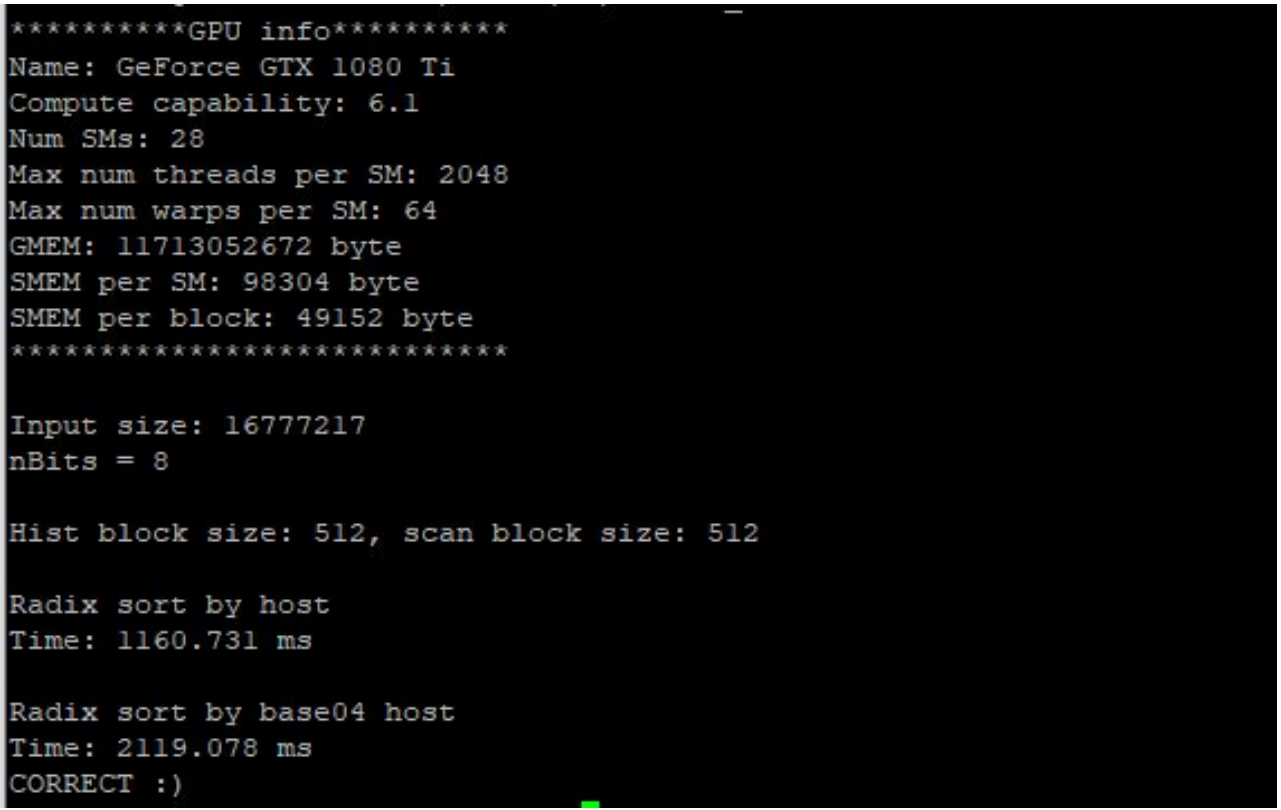
Base 01 - 03

	thời gian	thời gian thực thi (ms)	công đoạn/ghi chú
Thuật toán Radix Sort tuần tự (**base01**)	16/12/2019	1160	Đã thực hiện ở bài tập số 4.
Song song 2 bước hist và scan (**base02**)	16/12/2019	776	Đã thực hiện ở bài tập số 4.
Thuật toán Radix Sort song song với k = 1 (**base03**)	20/12/2019	179	
Thuật toán Radix sort do thrust hỗ trợ		41	

Base 4 v1

- Ngày thực hiện: 24 - 25/12/2019
- Cài đặt **base04 trên host**.
- Cài đặt song song hist được, khó cài đặt song song scan theo cấu trúc mảng lưu được gợi ý trong slide.

Base 4 v1


**********GPU info**********
Name: GeForce GTX 1080 Ti
Compute capability: 6.1
Num SMs: 28
Max num threads per SM: 2048
Max num warps per SM: 64
GMEM: 11713052672 byte
SMEM per SM: 98304 byte
SMEM per block: 49152 byte
****
Input size: 16777217
nBits = 8
Hist block size: 512, scan block size: 512
Radix sort by host
Time: 1160.731 ms
Radix sort by base04 host
Time: 2119.078 ms
CORRECT :)

Base 4 v1

	thời gian	thời gian thực thi (ms)	công đoạn/ghi chú
Thuật toán Radix Sort song song với k = 1 (**base03**)	20/12/2019	179	
Thuật toán Radix Sort tuần tự theo hướng dẫn đồ án (**base04_v1**)	24/12/2019	2119	Cài đặt mảng lưu bin như file hướng dẫn. (hàng là các block, cột là các bin)
Thuật toán Radix sort do thrust hỗ trợ		41	

Base 4 v2

- Ngày thực hiện: 26 - 27 - 28/12/2019
- Đổi cách lưu trữ mảng chứa các giá trị bin base04 trên host.
- Cài đặt base04 với 2 bước song song hóa (tính histogram và scan).
  - Tính histogram trên global memory.
  - Sử dụng lại exclusive scan từ bài trước.
  - Dự định cài đặt hàm scatter nhưng failed.

Base 4 v2

```
id1612858@9aa3d017fc93:~/final$ ./base04_v2
**********GPU info**********
Name: GeForce GTX 1080 Ti
Compute capability: 6.1
Num SMs: 28
Max num threads per SM: 2048
Max num warps per SM: 64
GMEM: 11713052672 byte
SMEM per SM: 98304 byte
SMEM per block: 49152 byte
****************************

Input size: 16777217
nBits: 8

Hist block size: 512, scan block size: 512

Radix sort by host
Time: 1178.955 ms

Radix sort by  host level 1
Time: 2267.336 ms
CORRECT :)

Radix sort by device level 1
Time: 1584.600 ms
CORRECT :)
```

```
==22962== NVPROF is profiling process 22962, command: ./base04_v2
**********GPU info**********
Name: GeForce GTX 1080 Ti
Compute capability: 6.1
Num SMs: 28
Max num threads per SM: 2048
Max num warps per SM: 64
GMEM: 11713052672 byte
SMEM per SM: 98304 byte
SMEM per block: 49152 byte
****************************

Input size: 16777217
nBits: 8

Hist block size: 512, scan block size: 512

Radix sort by host
Time: 1169.313 ms

Radix sort by  host level 1
Time: 2297.162 ms
CORRECT :)

Radix sort by device level 1
Time: 1569.421 ms
CORRECT :)
```

Base 4 v2

```
Radix sort by device level 1
Time: 1550.515 ms
CORRECT :)
==23377== Profiling application: ./base04_v2
==23377== Profiling result:
            Type  Time(%)      Time     Calls       Avg       Min       Max  Name
 GPU activities:   53.96%  48.060ms         8  6.0074ms  12.641us  12.170ms  [CUDA memcpy HtoD]
                   37.49%  33.386ms         8  4.1732ms  11.137us  12.347ms  [CUDA memcpy DtoH]
                    4.99%  4.4413ms         4  1.1103ms  996.89us  1.1497ms  computeHistKernel(unsigned int*, int, int*,
 int, int)
                    2.71%  2.4161ms         4  604.03us  603.54us  604.63us  scanBlkKernel(int*, int, int*, int*)
                    0.85%  756.47us         4  189.12us  187.81us  189.83us  addBlkSums(int*, int, int*)
                    0.01%  4.9600us         4  1.2400us  1.2160us  1.2480us  [CUDA memset]
      API calls:   52.86%  109.68ms         2  54.838ms     741ns  109.68ms  cudaEventCreate
                   39.75%  82.465ms        16  5.1541ms  7.5260us  12.734ms  cudaMemcpy
                    4.13%  8.5665ms        12  713.88us  206.87us  1.3740ms  cudaDeviceSynchronize
                    2.33%  4.8242ms         4  1.2060ms  221.36us  2.2233ms  cudaFree
                    0.31%  638.44us         4  159.61us  116.43us  233.30us  cudaMalloc
                    0.16%  339.89us        96  3.5400us     149ns  150.21us  cuDeviceGetAttribute
                    0.14%  290.82us         1  290.82us  290.82us  290.82us  cuDeviceTotalMem
                    0.14%  284.56us         1  284.56us  284.56us  284.56us  cudaGetDeviceProperties
                    0.05%  101.69us         6  16.948us  1.4760us  47.097us  cudaEventRecord
                    0.04%  88.346us         4  22.086us  19.727us  23.322us  cudaMemset
                    0.04%  82.880us        12  6.9060us  4.6610us  10.492us  cudaLaunchKernel
                    0.03%  55.568us         1  55.568us  55.568us  55.568us  cuDeviceGetName
                    0.02%  40.408us         6  6.7340us  3.1280us  9.7370us  cudaEventSynchronize
                    0.00%  4.3160us         3  1.4380us  1.3000us  1.6650us  cudaEventElapsedTime
                    0.00%  3.3330us         2  1.6660us     571ns  2.7620us  cudaEventDestroy
                    0.00%  2.3930us        12     199ns     143ns     306ns  cudaGetLastError
                    0.00%  1.9440us         1  1.9440us  1.9440us  1.9440us  cuDeviceGetPCIBusId
                    0.00%  1.5560us         3     518ns     167ns  1.1190us  cuDeviceGetCount
                    0.00%  1.0480us         2     524ns     188ns     860ns  cuDeviceGet
```

Base 4 v2

Thuật toán Radix Sort tuần tự theo hướng dẫn đồ án (**base04_v1**)	24/12/2019	2119	Cài đặt mảng lưu bin như file hướng dẫn. (hàng là các block, cột là các bin)
Song song 2 bước tính hist và scan (**base04_v2**)	26/12/2019	1584	Thay đổi cách lưu mảng (hàng là các bin, cột là các block) -> scan dễ dàng hơn. Tính histogram trên global memory.
			Thời gian trung bình các kernel (ms) ● computeHistKernel: 1.1103 ● scanBlkKernel: 0.604 ● addBlkSums: 0.189
Thuật toán Radix sort do thrust hỗ trợ		41	

Base 4 v3

- Ngày thực hiện: 29 - 30/12/2019, 01/01/2020.
- Tính histogram trên shared memory.
- Dự định cài đặt kernel scan work-efficient nhưng failed. Cải tiến kernel scan cũ.
- Scatter song song hóa (kernel preScatter và scatter)
  - preScatter: trả về mảng output là số phần tử có cùng digit-đang-xét đứng trước số đó.
  - scatter: tính rank và scatter.

Base 4 v3

```
id1612858@9aa3d017fc93:~/final$ ./base04_v3
**********GPU info**********
Name: GeForce GTX 1080 Ti
Compute capability: 6.1
Num SMs: 28
Max num threads per SM: 2048
Max num warps per SM: 64
GMEM: 11713052672 byte
SMEM per SM: 98304 byte
SMEM per block: 49152 byte
*****************************

Input size: 16777217
nBits: 8

Hist block size: 512, scan block size: 512

Radix sort by host
Time: 1159.885 ms

Radix sort by host level 1
Time: 2244.580 ms
CORRECT :)

Radix sort by device level 2
Avg Time: 197.436 ms
CORRECT :)

Sort by thrust
Time: 41.314 ms
CORRECT :)
```

```
id1612858@9aa3d017fc93:~/final$ nvprof ./base04_v3
==19423== NVPROF is profiling process 19423, command: ./base04_v3
**********GPU info**********
Name: GeForce GTX 1080 Ti
Compute capability: 6.1
Num SMs: 28
Max num threads per SM: 2048
Max num warps per SM: 64
GMEM: 11713052672 byte
SMEM per SM: 98304 byte
SMEM per block: 49152 byte
*****************************

Input size: 16777217
nBits: 8

Hist block size: 512, scan block size: 512

Radix sort by host
Time: 1172.476 ms

Radix sort by host level 1
Time: 2263.722 ms
CORRECT :)

Radix sort by device level 2
Time: 156.905 ms
CORRECT :)

Sort by thrust
Time: 41.626 ms
CORRECT :)
==19423== Profiling application: ./base04_v3
```

Base 4 v3

```
Radix sort by device level 2
Avg Time: 156.817 ms
CORRECT :)
==23536== Profiling application: ./base04_v3
==23536== Profiling result:
            Type  Time(%)      Time     Calls       Avg       Min       Max  Name
 GPU activities:   45.08%  54.759ms         9  6.0844ms  11.137us  22.959ms  [CUDA memcpy DtoH]
                   34.79%  42.267ms         4  10.567ms  10.549ms  10.574ms  preScatter(unsigned int*, int, int, int, int, int*)
                    9.98%  12.120ms         5  2.4240ms  12.640us  12.069ms  [CUDA memcpy HtoD]
                    4.29%  5.2055ms         4  1.3014ms  1.2958ms  1.3081ms  computeHistKernel(unsigned int*, int, int*, int, int)
                    3.23%  3.9206ms         4  980.15us  768.28us  1.0521ms  scatter(unsigned int*, int*, int, int*, int, int, unsigned in
t*)
                    2.02%  2.4489ms         4  612.22us  611.86us  612.94us  scanBlkKernel(int*, int, int*, int*, int)
                    0.62%  753.88us         4  188.47us  187.62us  189.77us  addBlkSums(int*, int, int*)
                    0.00%  4.9600us         4  1.2400us  1.1840us  1.2800us  [CUDA memset]
      API calls:   45.30%  110.46ms         6  18.411ms     468ns  110.46ms  cudaEventCreate
                   27.92%  68.093ms        14  4.8638ms  7.4540us  23.319ms  cudaMemcpy
                   22.63%  55.187ms        20  2.7593ms  206.48us  10.578ms  cudaDeviceSynchronize
                    3.29%  8.0212ms         5  1.6042ms  159.94us  2.2344ms  cudaFree
                    0.33%  799.33us         5  159.87us  117.87us  228.86us  cudaMalloc
                    0.14%  343.97us        96  3.5830us     165ns  151.92us  cuDeviceGetAttribute
                    0.13%  320.66us         1  320.66us  320.66us  320.66us  cudaGetDeviceProperties
                    0.12%  299.67us         1  299.67us  299.67us  299.67us  cuDeviceTotalMem
                    0.05%  117.66us        20  5.8820us  4.1280us  10.405us  cudaLaunchKernel
                    0.02%  60.732us         6  10.122us  6.5480us  22.590us  cudaEventSynchronize
                    0.02%  40.530us         1  40.530us  40.530us  40.530us  cuDeviceGetName
                    0.02%  40.102us         4  10.025us  5.8970us  20.992us  cudaMemset
                    0.01%  34.430us         6  5.7380us  1.4670us  12.504us  cudaEventRecord
                    0.01%  19.709us         6  3.2840us     401ns  15.210us  cudaEventDestroy
                    0.00%  3.8340us         3  1.2780us  1.0950us  1.4400us  cudaEventElapsedTime
                    0.00%  3.3260us        20     166ns     127ns     263ns  cudaGetLastError
                    0.00%  1.8850us         1  1.8850us  1.8850us  1.8850us  cuDeviceGetPCIBusId
                    0.00%  1.2620us         3     420ns     167ns     789ns  cuDeviceGetCount
                    0.00%  1.0320us         2     516ns     245ns     787ns  cuDeviceGet
```

Base 4 v3

Song song 2 bước tính hist và scan (**base04_v2**)	26/12/2019	1584	Thay đổi cách lưu mảng (hàng là các bin, cột là các block) -> scan dễ dàng hơn. Tính histogram trên global memory.
Cài đặt preScatter và scatter song song (**base04_v3**)	29/12/2019	197	Tính histogram trên SMEM. tối ưu kernel scan. Huấn (pre_Scatter, tối ưu), Khải (scatter).
			Thời gian trung bình các kernel (ms) ● preScatter: 10.567 ● scatter: 0.980 (Tổng Scatter: 11.547) ● computeHistKernel: 1.3014 ● scanBlkKernel: 0.612 ● addBlkSums: 0.188
Thuật toán Radix sort do thrust hỗ trợ		41	

Base 4 v4

- Ngày thực hiện: 02/01/2020.
- Gộp chung 2 kernel (preScatter và scatter) ở base04v3 thành 1 kernel Scatter.

Base 4 v4

```
idl612858@9aa3d017fc93:~/final$ ./base04_v4
**********GPU info**********
Name: GeForce GTX 1080 Ti
Compute capability: 6.1
Num SMs: 28
Max num threads per SM: 2048
Max num warps per SM: 64
GMEM: 11713052672 byte
SMEM per SM: 98304 byte
SMEM per block: 49152 byte
****************************

Input size: 16777217
nBits: 8

Hist block size: 512, scan block size: 512

Radix sort by host
Time: 1161.831 ms

Radix sort by host level 1
Time: 2303.316 ms
CORRECT :)

Radix sort by device level 2
Avg Time: 149.127 ms
CORRECT :)

Sort by thrust
Time: 41.320 ms
CORRECT :)
```

```
idl612858@9aa3d017fc93:~/final$ nvprof ./base04_v4
==19480== NVPROF is profiling process 19480, command: ./base04_v4
**********GPU info**********
Name: GeForce GTX 1080 Ti
Compute capability: 6.1
Num SMs: 28
Max num threads per SM: 2048
Max num warps per SM: 64
GMEM: 11713052672 byte
SMEM per SM: 98304 byte
SMEM per block: 49152 byte
****************************

Input size: 16777217
nBits: 8

Hist block size: 512, scan block size: 512

Radix sort by host
Time: 1170.926 ms

Radix sort by host level 1
Time: 2299.797 ms
CORRECT :)

Radix sort by device level 2
Time: 117.149 ms
CORRECT :)

Sort by thrust
Time: 48.505 ms
CORRECT :)
==19480== Profiling application: ./base04_v4
```

Base 4 v4

```
Radix sort by device level 2
Avg Time: 118.424 ms
CORRECT :)
==23597== Profiling application: ./base04_v4
==23597== Profiling result:
            Type  Time(%)      Time     Calls       Avg       Min       Max  Name
 GPU activities:   48.43%  41.740ms         4  10.435ms  10.406ms  10.449ms  Scatter(unsigned int*, int, int, int, int, int*, unsigned int
*)
                  27.76%  23.928ms         5  4.7855ms  11.105us  23.883ms  [CUDA memcpy DtoH]
                  13.98%  12.054ms         5  2.4108ms  12.640us  12.003ms  [CUDA memcpy HtoD]
                   6.11%  5.2655ms         4  1.3164ms  1.3124ms  1.3198ms  computeHistKernel(unsigned int*, int, int*, int, int)
                   2.84%  2.4490ms         4  612.26us  611.92us  612.59us  scanBlkKernel(int*, int, int*, int*, int)
                   0.88%  754.96us         4  188.74us  188.33us  189.35us  addBlkSums(int*, int, int*)
                   0.00%  4.2880us         4  1.0720us     576ns  1.2480us  [CUDA memset]
      API calls:   53.59%  109.71ms         2  54.855ms     655ns  109.71ms  cudaEventCreate
                  24.81%  50.784ms        16  3.1740ms  205.88us  10.453ms  cudaDeviceSynchronize
                  17.79%  36.423ms        10  3.6423ms  7.2360us  24.258ms  cudaMemcpy
                   2.85%  5.8264ms         4  1.4566ms  170.06us  2.2393ms  cudaFree
                   0.33%  668.38us         4  167.09us  117.71us  240.20us  cudaMalloc
                   0.17%  355.79us        96  3.7060us     164ns  155.33us  cuDeviceGetAttribute
                   0.15%  315.21us         1  315.21us  315.21us  315.21us  cuDeviceTotalMem
                   0.14%  285.02us         1  285.02us  285.02us  285.02us  cudaGetDeviceProperties
                   0.05%  92.574us        16  5.7850us  4.2860us  11.038us  cudaLaunchKernel
                   0.04%  85.644us         6  14.274us  6.5330us  22.250us  cudaEventSynchronize
                   0.03%  68.920us         6  11.486us  1.5140us  33.095us  cudaEventRecord
                   0.02%  42.513us         1  42.513us  42.513us  42.513us  cuDeviceGetName
                   0.02%  40.663us         4  10.165us  6.0790us  21.083us  cudaMemset
                   0.00%  3.8640us         3  1.2880us  1.1610us  1.4120us  cudaEventElapsedTime
                   0.00%  2.8770us         2  1.4380us     522ns  2.3550us  cudaEventDestroy
                   0.00%  2.7590us        16     172ns     157ns     207ns  cudaGetLastError
                   0.00%  1.6240us         1  1.6240us  1.6240us  1.6240us  cuDeviceGetPCIBusId
                   0.00%  1.4100us         3     470ns     202ns     904ns  cuDeviceGetCount
                   0.00%  1.1320us         2     566ns     218ns     914ns  cuDeviceGet
```

Base 4 v4

Song song 2 bước tính hist và scan (**base04_v2**)	26/12/2019	1584	Thay đổi cách lưu mảng (hàng là các bin, cột là các block) -> scan dễ dàng hơn. Tính histogram trên global memory.
Cài đặt preScatter và scatter song song (**base04_v3**)	29/12/2019	197	Tính histogram trên SMEM. tối ưu kernel scan. Huấn (pre_Scatter, tối ưu), Khải (scatter).
Cài Scatter song song (**base04_v4**)	02/01/2020	149	Gộp 2 kernel ở ver3 thành 1 kernel. Thời gian trung bình các kernel (ms) • Scatter: 10.435 • computeHistKernel: 1.3164 • scanBlkKernel: 0.612 • addBlkSums: 0.188
Thuật toán Radix sort do thrust hỗ trợ		41	

Base 4 v5

- Ngày thực hiện: 03 - 09/01/2020.
- Clean code. Loại bỏ các dòng khởi tạo thừa qua các pha.

Base 4 v5

```
id16l2858@9aa3d017fc93:~/final$ ./base04_1
**********GPU info**********
Name: GeForce GTX 1080 Ti
Compute capability: 6.1
Num SMs: 28
Max num threads per SM: 2048
Max num warps per SM: 64
GMEM: 11713052672 byte
SMEM per SM: 98304 byte
SMEM per block: 49152 byte
**************************

Input size: 16777217
nBits: 8

Hist block size: 512, scan block size: 512

Radix sort by host
Time: 1159.284 ms

Radix sort by host level 1
Time: 2232.619 ms
CORRECT :)

Radix sort by device level 2
Time: 138.716 ms
CORRECT :)

Sort by thrust
Time: 41.464 ms
CORRECT :)
```

```
id16l2858@9aa3d017fc93:~/final$ nvprof ./base04_1
==19716== NVPROF is profiling process 19716, command: ./base04_1
**********GPU info**********
Name: GeForce GTX 1080 Ti
Compute capability: 6.1
Num SMs: 28
Max num threads per SM: 2048
Max num warps per SM: 64
GMEM: 11713052672 byte
SMEM per SM: 98304 byte
SMEM per block: 49152 byte
**************************

Input size: 16777217
nBits: 8

Hist block size: 512, scan block size: 512

Radix sort by host
Time: 1170.506 ms

Radix sort by host level 1
Time: 2275.513 ms
CORRECT :)

Radix sort by device level 2
Time: 90.656 ms
CORRECT :)

Sort by thrust
Time: 41.559 ms
CORRECT :)
```

Base 4 v5

```
Radix sort by device level 2
Avg Time: 90.674 ms
CORRECT :)
==23646== Profiling application: ./base04_1
==23646== Profiling result:
            Type  Time(%)      Time     Calls       Avg       Min       Max  Name
 GPU activities:   46.61%  38.573ms         4  9.6433ms  9.6148ms  9.6552ms  Scatter(unsigned int*, int, int, int, int, int*, unsigned int
*)
                  27.61%  22.846ms         5  4.5692ms  11.104us  22.801ms  [CUDA memcpy DtoH]
                  14.60%  12.086ms         5  2.4172ms  12.609us  12.035ms  [CUDA memcpy HtoD]
                   7.30%  6.0392ms         4  1.5098ms  1.5054ms  1.5160ms  computeHistKernel(unsigned int*, int, int*, int, int)
                   2.96%  2.4470ms         4  611.76us  611.50us  612.14us  scanBlkKernel(int*, int, int*, int*, int)
                   0.91%  755.95us         4  188.99us  187.33us  190.44us  addBlkSums(int*, int, int*)
                   0.01%  4.9920us         4  1.2480us  1.2480us  1.2480us  [CUDA memset]
      API calls:   54.69%  110.49ms         2  55.245ms     667ns  110.49ms  cudaEventCreate
                   23.95%  48.397ms        16  3.0248ms  205.51us  9.6597ms  cudaDeviceSynchronize
                   17.50%  35.355ms        10  3.5355ms  7.0480us  23.158ms  cudaMemcpy
                    2.87%  5.8057ms         4  1.4514ms  171.07us  2.2345ms  cudaFree
                    0.37%  741.44us         4  185.36us  116.68us  323.07us  cudaMalloc
                    0.17%  341.70us        96  3.5590us     147ns  150.47us  cuDeviceGetAttribute
                    0.15%  295.42us         1  295.42us  295.42us  295.42us  cuDeviceTotalMem
                    0.14%  283.01us         1  283.01us  283.01us  283.01us  cudaGetDeviceProperties
                    0.04%  86.763us        16  5.4220us  3.9180us  10.891us  cudaLaunchKernel
                    0.04%  71.160us         6  11.860us  6.8990us  23.536us  cudaEventSynchronize
                    0.03%  62.572us         6  10.428us  1.3440us  31.920us  cudaEventRecord
                    0.03%  55.622us         1  55.622us  55.622us  55.622us  cuDeviceGetName
                    0.02%  39.746us         4  9.9360us  6.3760us  20.066us  cudaMemset
                    0.00%  3.9650us         3  1.3210us  1.0420us  1.4860us  cudaEventElapsedTime
                    0.00%  2.8510us        16     178ns     136ns     234ns  cudaGetLastError
                    0.00%  2.6850us         2  1.3420us     512ns  2.1730us  cudaEventDestroy
                    0.00%  2.0350us         3     678ns     176ns  1.5340us  cuDeviceGetCount
                    0.00%  1.9920us         1  1.9920us  1.9920us  1.9920us  cuDeviceGetPCIBusId
                    0.00%  1.0020us         2     501ns     249ns     753ns  cuDeviceGet
```

Base 4 v5

Song song 2 bước tính hist và scan (**base04_v2**)	26/12/2019	1584	Thay đổi cách lưu mảng (hàng là các bin, cột là các block) -> scan dễ dàng hơn. Tính histogram trên global memory.
Cài đặt preScatter và scatter song song (**base04_v3**)	29/12/2019	197	Tính histogram trên SMEM. tối ưu kernel scan. Huấn (pre_Scatter, tối ưu), Khải (scatter).
Cài Scatter song song (**base04_v4**)	02/01/2020	149	gộp 2 kernel ở ver3 thành 1 kernel
base04_v5	03/01/2020	138	Thời gian trung bình các kernel (ms) • Scatter: 9.6433 • computeHistKernel: 1.5098 • scanBlkKernel: 0.611 • addBlkSums: 0.187
Thuật toán Radix sort do thrust hỗ trợ		41	

Base 4 v5

```
idl612858@9aa3d017fc93:~/final$ ./base04_1 4
**********GPU info**********
Name: GeForce GTX 1080 Ti
Compute capability: 6.1
Num SMs: 28
Max num threads per SM: 2048
Max num warps per SM: 64
GMEM: 11713052672 byte
SMEM per SM: 98304 byte
SMEM per block: 49152 byte
*****************************

Input size: 16777217
nBits: 4

Hist block size: 512, scan block size: 512

Radix sort by host
Time: 2300.851 ms

Radix sort by host level 1
Time: 3641.033 ms
CORRECT :)

Radix sort by device level 2
Time: 70.263 ms
CORRECT :)

Sort by thrust
Time: 41.943 ms
CORRECT :)
```

(nBits = 4)

Base 4 v5

```
id1612858@9aa3d017fc93:~/final$ ./base04_1 2
**********GPU info**********
Name: GeForce GTX 1080 Ti
Compute capability: 6.1
Num SMs: 28
Max num threads per SM: 2048
Max num warps per SM: 64
GMEM: 11713052672 byte
SMEM per SM: 98304 byte
SMEM per block: 49152 byte
*****************************

Input size: 16777217
nBits: 2

Hist block size: 512, scan block size: 512

Radix sort by host
Time: 4518.084 ms

Radix sort by host level 1
Time: 6314.721 ms
CORRECT :)

Radix sort by device level 2
Time: 75.967 ms
CORRECT :)

Sort by thrust
Time: 41.343 ms
CORRECT :)
```

(nBits = 2)

Base 4 v5

```
id16l2858@9aa3d017fc93:~/final$ ./base04_1 1
**********GPU info**********
Name: GeForce GTX 1080 Ti
Compute capability: 6.1
Num SMs: 28
Max num threads per SM: 2048
Max num warps per SM: 64
GMEM: 11713052672 byte
SMEM per SM: 98304 byte
SMEM per block: 49152 byte
****************************

Input size: 16777217
nBits: 1

Hist block size: 512, scan block size: 512

Radix sort by host
Time: 9030.948 ms

Radix sort by host level 1
Time: 12495.901 ms
CORRECT :)

Radix sort by device level 2
Time: 91.247 ms
CORRECT :)

Sort by thrust
Time: 41.257 ms
CORRECT :)
```

(nBits = 1)

Base 4 v5

chạy với các kích thước blockSize khác nhau

```
id1612858@9aa3d017fc93:~/final$ ./base04_1 8 128 1024
**********GPU info**********
Name: GeForce GTX 1080 Ti
Compute capability: 6.1
Num SMs: 28
Max num threads per SM: 2048
Max num warps per SM: 64
GMEM: 11713052672 byte
SMEM per SM: 98304 byte
SMEM per block: 49152 byte
****************************

Input size: 16777217
nBits: 8

Hist block size: 128, scan block size: 1024

Radix sort by host
Time: 1160.248 ms

Radix sort by host level 1
Time: 2927.106 ms
CORRECT :)

Radix sort by device level 2
Time: 164.563 ms
CORRECT :)

Sort by thrust
Time: 41.365 ms
CORRECT :)
```

```
id1612858@9aa3d017fc93:~/final$ ./base04_1 8 1024 1024
**********GPU info**********
Name: GeForce GTX 1080 Ti
Compute capability: 6.1
Num SMs: 28
Max num threads per SM: 2048
Max num warps per SM: 64
GMEM: 11713052672 byte
SMEM per SM: 98304 byte
SMEM per block: 49152 byte
****************************

Input size: 16777217
nBits: 8

Hist block size: 1024, scan block size: 1024

Radix sort by host
Time: 1160.936 ms

Radix sort by host level 1
Time: 2168.664 ms
CORRECT :)

Radix sort by device level 2
Time: 142.991 ms
CORRECT :)

Sort by thrust
Time: 41.604 ms
CORRECT :)
```

```
id1612858@9aa3d017fc93:~/final$ ./base04_1 8 512 128
**********GPU info**********
Name: GeForce GTX 1080 Ti
Compute capability: 6.1
Num SMs: 28
Max num threads per SM: 2048
Max num warps per SM: 64
GMEM: 11713052672 byte
SMEM per SM: 98304 byte
SMEM per block: 49152 byte
****************************

Input size: 16777217
nBits: 8

Hist block size: 512, scan block size: 128

Radix sort by host
Time: 1168.471 ms

Radix sort by host level 1
Time: 2247.869 ms
CORRECT :)

Radix sort by device level 2
Time: 142.836 ms
CORRECT :)

Sort by thrust
Time: 41.457 ms
CORRECT :)
```

Base 4 v5

Thuật toán cho kết quả tốt nhất với: k = 4, blockSize1 hist là 128, blockSize2 là 1024.
Thời gian trung bình là 63 (ms) so với thời gian thực hiện của Thrust là 41 (ms).

```
**********GPU info**********
Name: GeForce GTX 1080 Ti
Compute capability: 6.1
Num SMs: 28
Max num threads per SM: 2048
Max num warps per SM: 64
GMEM: 11713052672 byte
SMEM per SM: 98304 byte
SMEM per block: 49152 byte
*****************************

Input size: 16777217
nBits: 4

Hist block size: 128, scan block size: 1024

Radix sort by host
Time: 2281.008 ms

Radix sort by host level 1
Time: 3727.513 ms
CORRECT :)

Radix sort by device level 2
Avg Time: 63.894 ms
CORRECT :)

Sort by thrust
Time: 41.541 ms
CORRECT :)
```

Tham khảo

Using Shared Memory in CUDA C/C++

Slides bài giảng.

File hướng dẫn đồ án, file hướng dẫn Scatter.