GPU Computing

Patterns for massively parallel programming (part 2)

Histograms

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Lab reminder

During the practice session, you ~~will have~~ had to compute the **cumulated histogram** of the image.

There are two major steps:

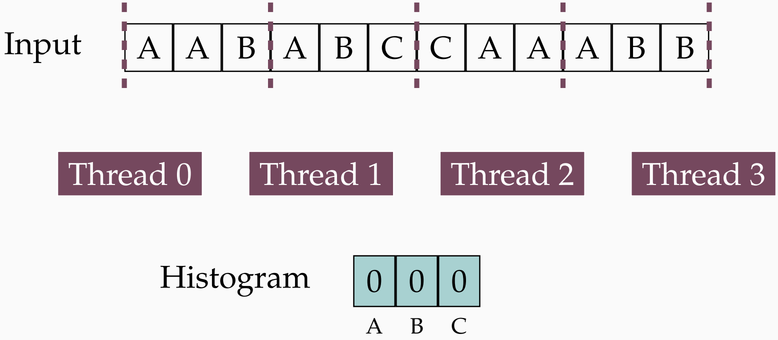
1. Compute the histogram H:
   count the number of occurrences of each value within the image.
2. Compute the cumulated histogram C:
   sum histogram values such that $C[i] = \sum_{k=0}^{i} H[k]$.

We will see how to compute those elements with **efficient parallel algorithms**.

Simple parallel histogram

The very wrong way

A wrong approach consists in **sectioning** the input,
i.e. assigning a chunk of the input to each thread.



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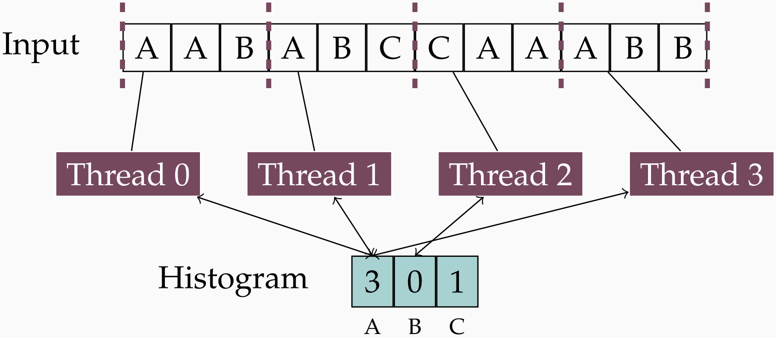

What is the issue?

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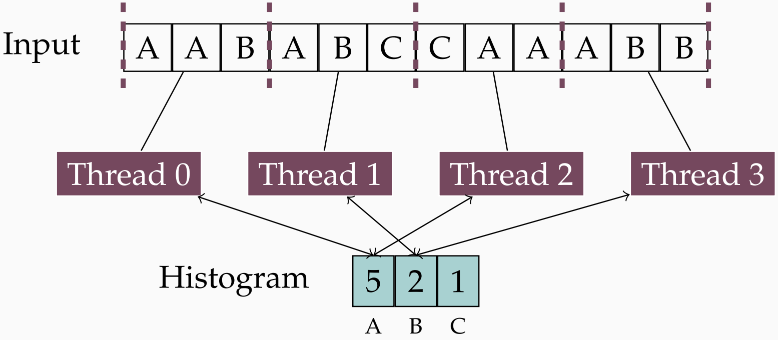

What is the issue?

Inefficient, non-coalesced memory access.

- Does not leverage cache
- Does not make use of full RAM burst

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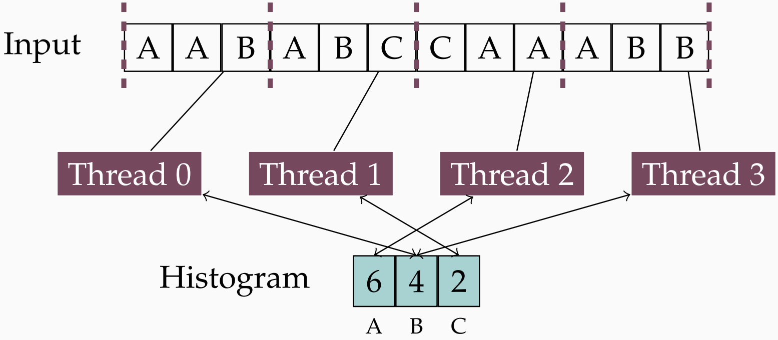

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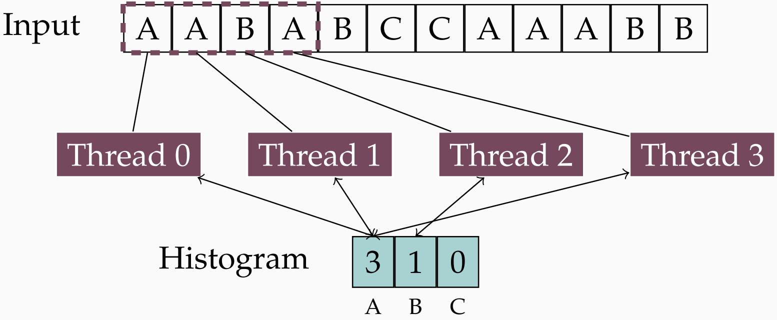
- Does not make use of full RAM burst

Interleaved partitioning of input

This enables coalesced memory accesses.



Interleaved partitioning of input

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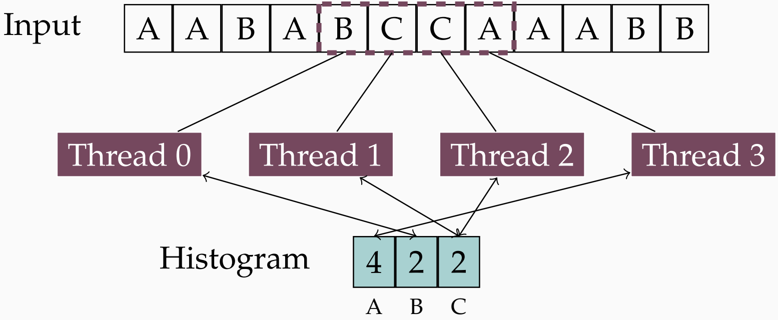

Much more efficient, coalesced memory access.

- All threads process a contiguous secion of elements
- They all move to the next section and repeat

First code sample

```
__global__ void histo(int* buf, int w, int h, int pitch, int hist_size, int* hist)
{
  int x = blockDim.x * blockIdx.x + threadIdx.x;
  int y = blockDim.y * blockIdx.y + threadIdx.y;
  if (x >= w || y >= h) return;
  int cellValue = getValue(buf, x, y, pitch);
  hist[cellValue]++;  // This is wrong!
}
```

What is the issue?

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__global__ void histo(int* buf, int w, int h, int pitch, int hist_size, int* hist)
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}
```

What is the issue?

Data race!

A correct naive version

```
__global__ void histo(int* buf, int w, int h, int pitch, int hist_size, int* hist)
{
  int x = blockDim.x * blockIdx.x + threadIdx.x;
  int y = blockDim.y * blockIdx.y + threadIdx.y;
  if (x >= w || y >= h) return;
  int cellValue = getValue(buf, x, y, pitch);
  atomicAdd(&(hist[cellValue]), 1);
}
```

Parallel algorithm using output privatization

Reminder about *output privatization*

A simple solution called **“output privatization”** works by proceeding in two steps:

1. compute a local histogram for each block in shared memory
   cost to read and write: 1 cycle each
2. at the end of the block, flush each local histogram to global memory

Local histogram: initialization

Shared memory must be initialized.

This can be done with the “comb-like” pattern.

```
__global__ void histo(int* buf, int w, int h, int pitch, int hist_size, int* hist)
{
  extern __shared__ int localHist[];
  // linear thread id and block dim to init the 1D histogram
  int i = blockDim.x * threadIdx.y + threadIdx.x;
  int bs = blockDim.x * blockDim.y;
  for (; i < hist_size; i+=bs)
    localHist[i] = 0;
  // Wait for all block's threads before next stage
  __syncthreads();
}
```

Warning: we need synchronization after this stage.

Local histogram: computation

Like previous code, but with local atomics!

```
__global__ void histo(int* buf, int w, int h, int pitch, int hist_size, int* hist)
{
  // ...

  int x = blockDim.x * blockIdx.x + threadIdx.x;
  int y = blockDim.y * blockIdx.y + threadIdx.y;
  if (x >= w || y >= h) return;
  int cellValue = getValue(buf, x, y, pitch);
  atomicAdd(&(localHist[cellValue]), 1);
  // Wait for all block's threads before next stage
  __syncthreads();
}
```

Warning: we need synchronization after this stage.

Local histogram: commit to global memory

It is the same pattern as for the initialization.

We use a global atomic here.

```
__global__ void histo(int* buf, int w, int h, int pitch, int hist_size, int* hist)
{
  // ...

  // linear thread id and block dim to copy the 1D histogram
  int i = blockDim.x * threadIdx.y + threadIdx.x;
  int bs = blockDim.x * blockDim.y;
  for (; i < hist_size; i+=bs)
    atomicAdd(&(hist[i]), localHist[i]);
}
```

Summary

Histogram summary

Performance boosters:

- coalesced accesses
- output privatization
- (not seen here: cascading)

Requirements:

- atomics
- synchronization

Limitations:

- histograms smaller than the size of the shared memory
- overhead to allocate and initialize private copies, then commit them to global memory