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FIRENZE

Parallel Programming
Final assignment

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12/01/24

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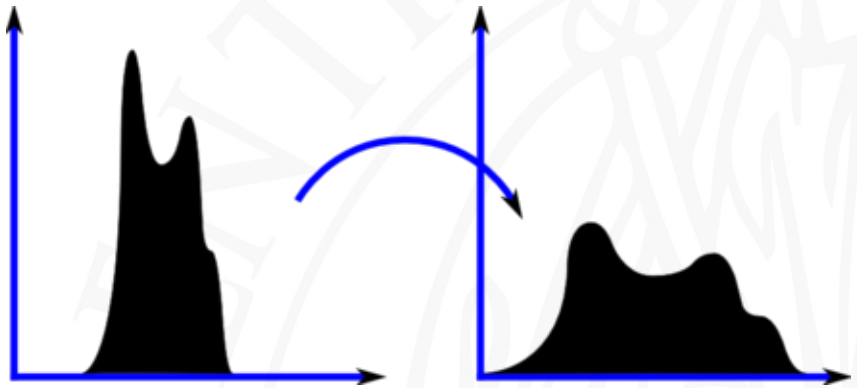
Histogram equalization is a digital image processing method by which you can calibrate the contrast using the image histogram.



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Histogram Equalization

Figure: Image before and after histogram equalization

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Histogram Equalization

- Compute the histogram: for every possible value of a pixel (0 - 255) count how many pixels have that value
  $p(v)$ for $v \in [0, L-1]$, $L = 256$

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Histogram Equalization

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- Compute the CDF:

$$\text{cdf}(v) = \sum_{k=1}^{v} p(k)$$

Histogram Equalization

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  $p(v)$ for $v \in [0, L-1]$, $L = 256$
- Compute the CDF:

$$\text{cdf}(v) = \sum_{k=1}^{v} p(k)$$

- For every image pixel compute the new value:

$$h(v) = \frac{\text{cdf}(v) - \text{cdf}_{\text{min}}}{MN - \text{cdf}_{\text{min}}} \cdot (L-1)$$

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Histogram Equalization

RGB $\rightarrow$ HSV $\rightarrow$ histogram equalization on V $\rightarrow$ RGB

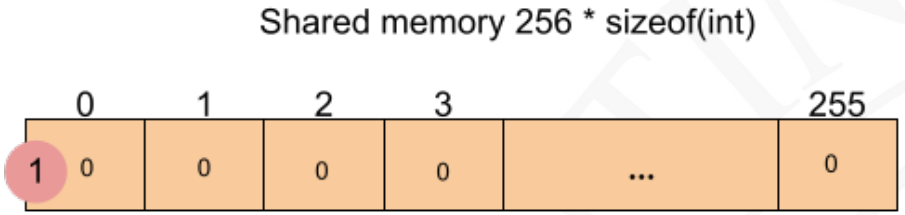
Cuda

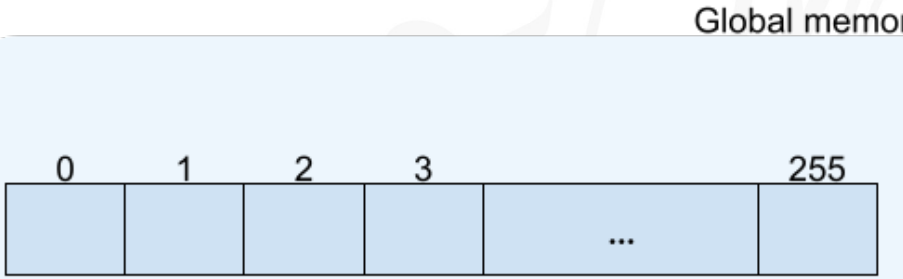
Three kernels:

- `histogram()`
  generates the histogram from the input image
- `Brent_Kung_scan_kernel()`
  calculates the CDF
- `equalizer()`
  generates the output image

Histogram

- $M \cdot N$ threads
- `BLOCK_DIM_X * BLOCK_DIM_Y` threads per block
- **shared memory**: `256 * sizeof(int)` bytes





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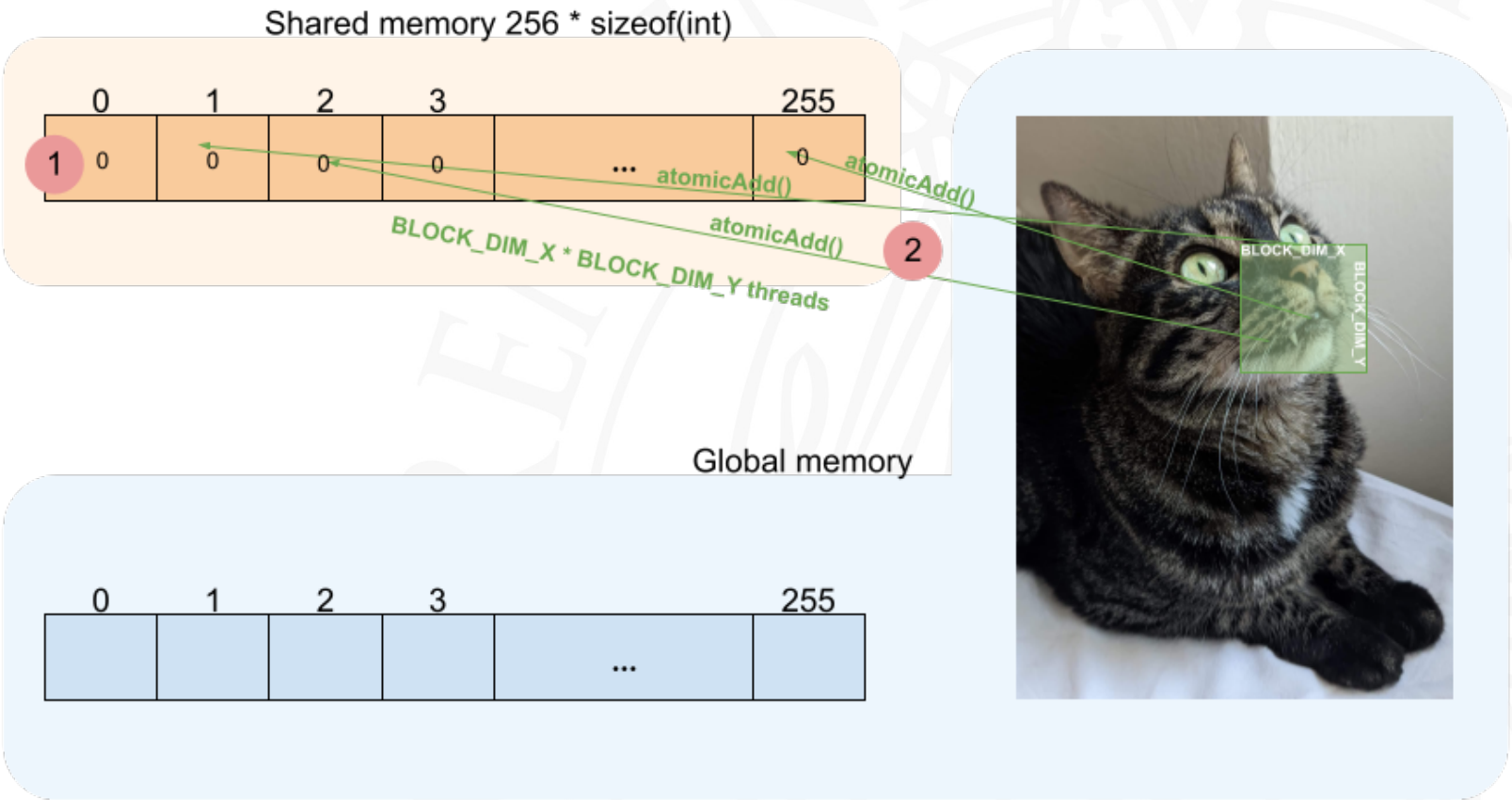

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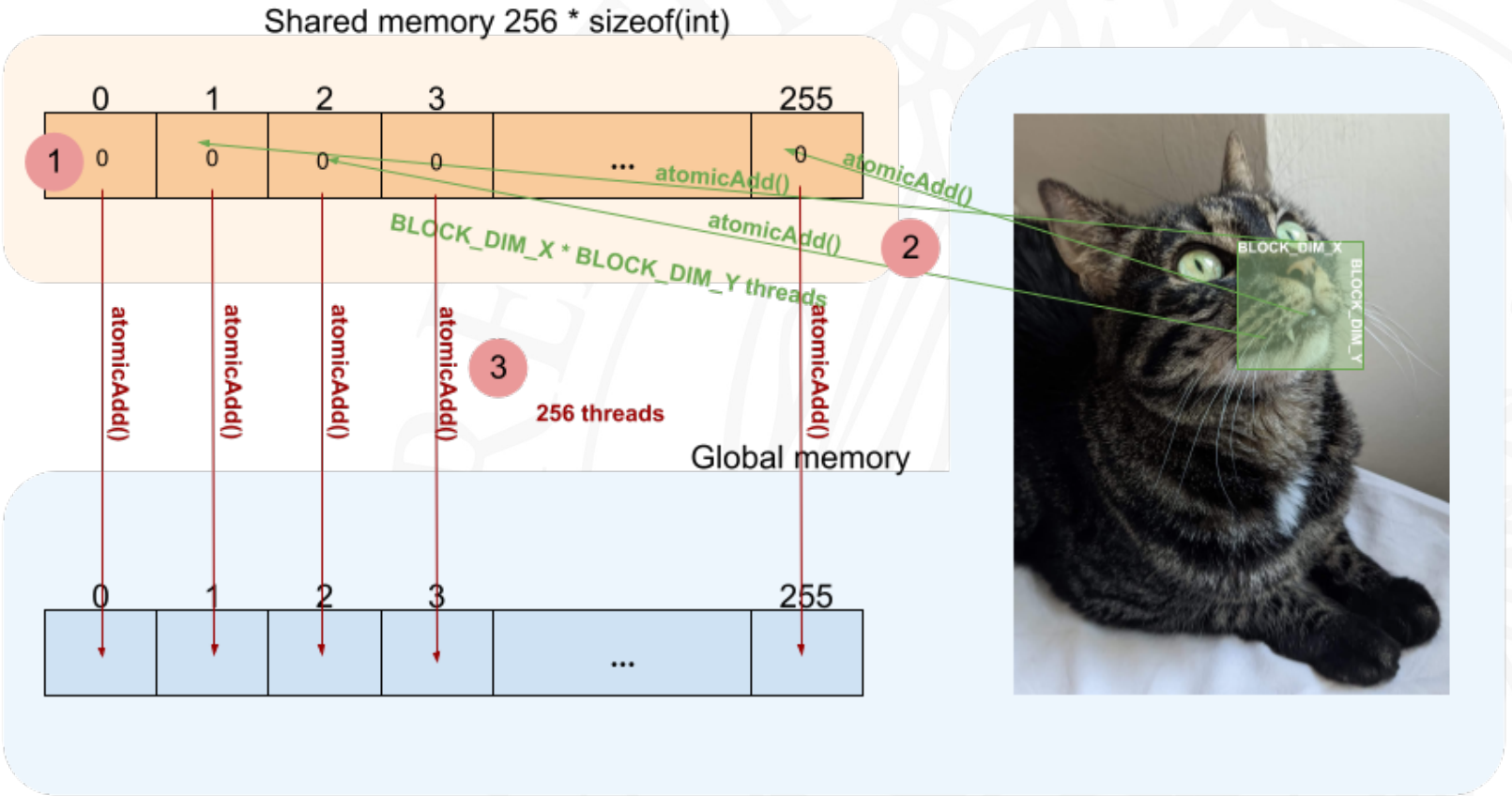

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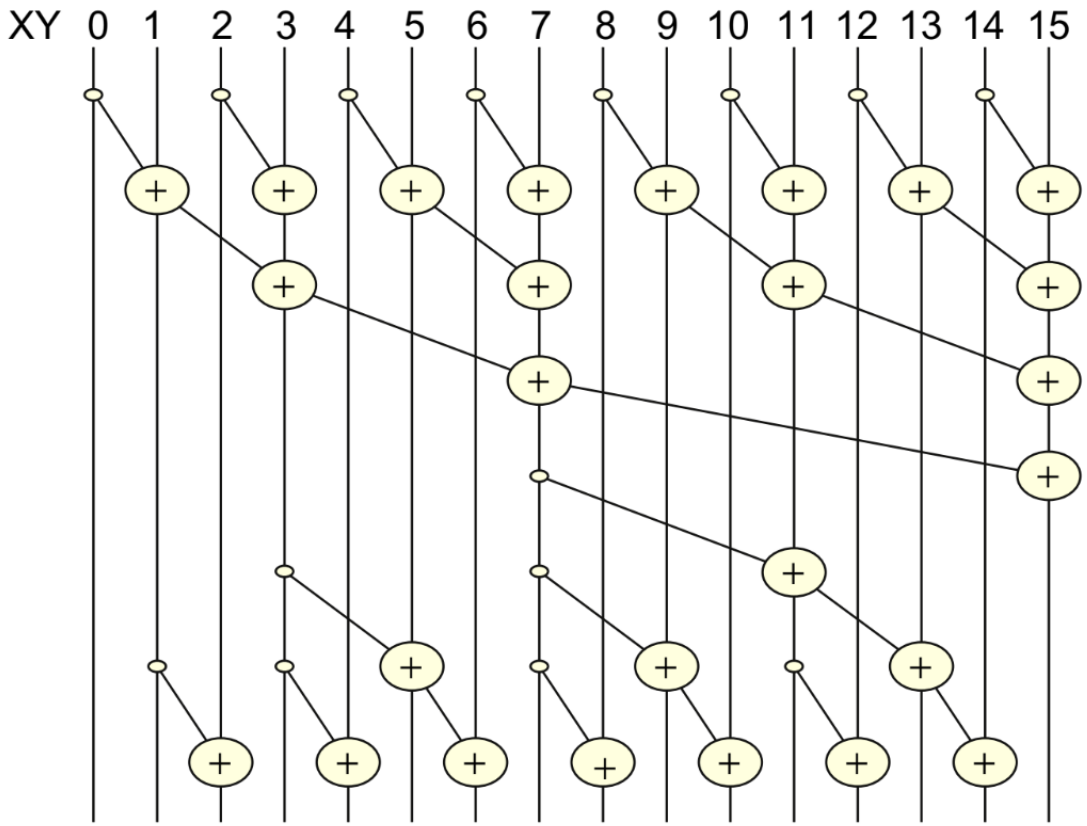
Histogram

```
__global__ void histogram(const unsigned char* image, int* hist, int width, int height) {
    __shared__ int HIST[HIST_SIZE];
    int tx = blockIdx.x * blockDim.x + threadIdx.x;
    int ty = blockIdx.y * blockDim.y + threadIdx.y;
    int t_id = tx + ty * width;
    int t_id_block = threadIdx.x + threadIdx.y * BLOCK_DIM_X;
    if (t_id_block < HIST_SIZE) { // shared memory initialization
        HIST[t_id_block] = 0;
    }
    __syncthreads();
    if (tx < width && ty < height) {
        atomicAdd(&(HIST[image[t_id]]), 1);  // local histogram
    }
    __syncthreads();
    if (t_id_block < HIST_SIZE) {
        atomicAdd(&(hist[t_id_block]), HIST[t_id_block]); // global histogram
    }
}
```

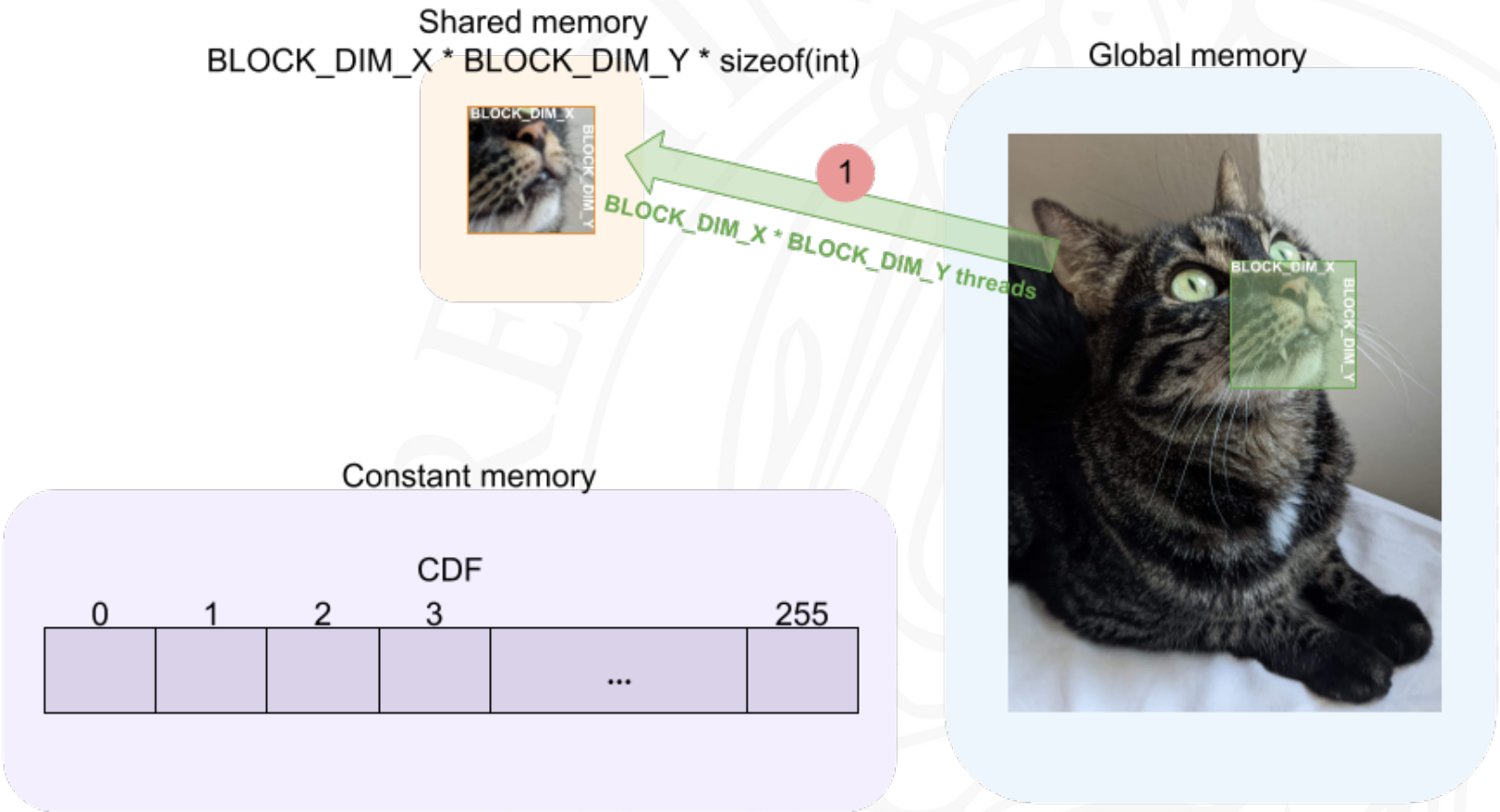
Scanner

Based on the Brent–Kung adder design



Equalizer

- $M \cdot N$ threads
- `BLOCK_DIM_X * BLOCK_DIM_Y` threads per block
- **shared memory**: `BLOCK_DIM_X * BLOCK_DIM_Y * sizeof(int)` bytes



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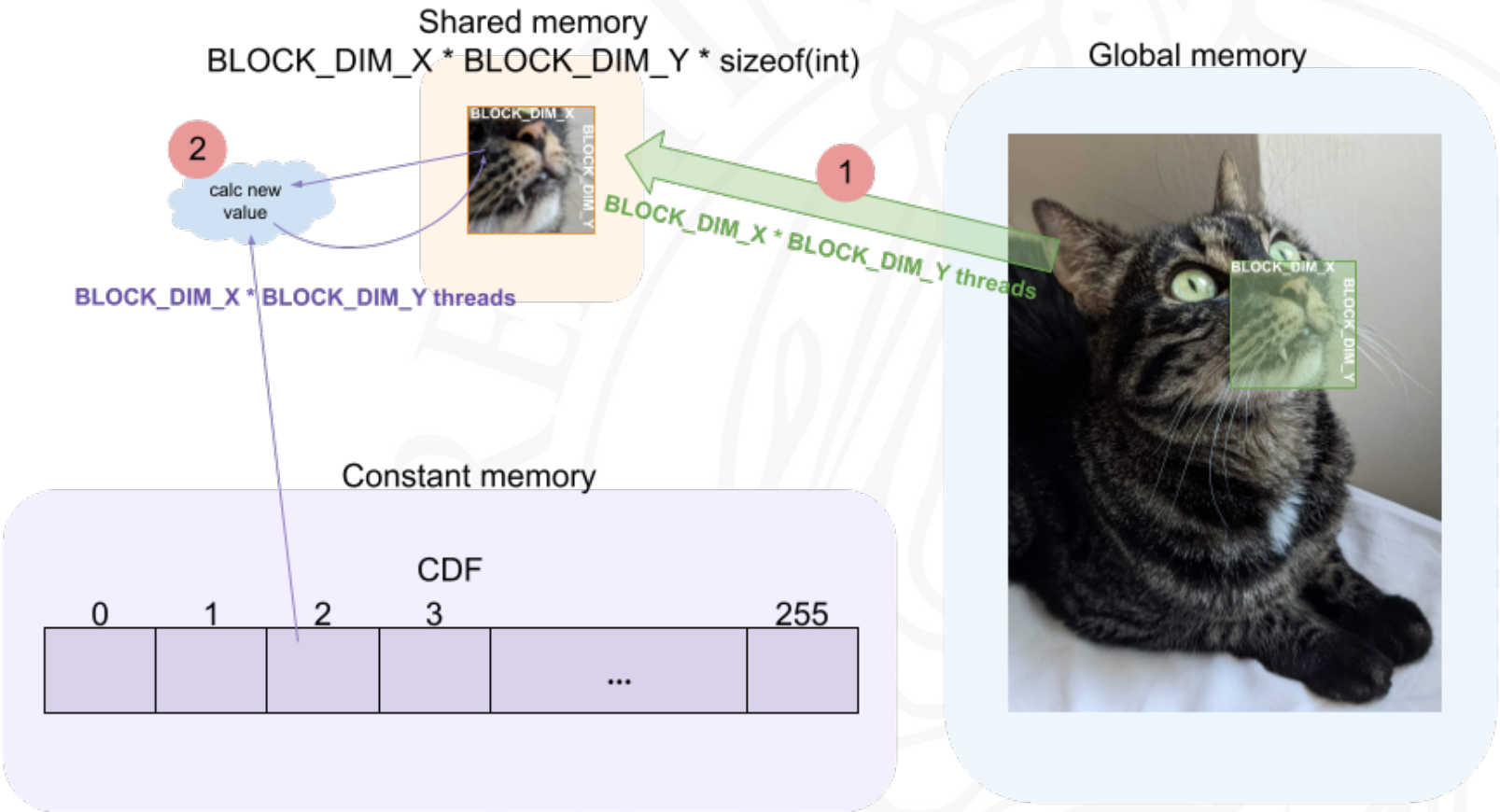

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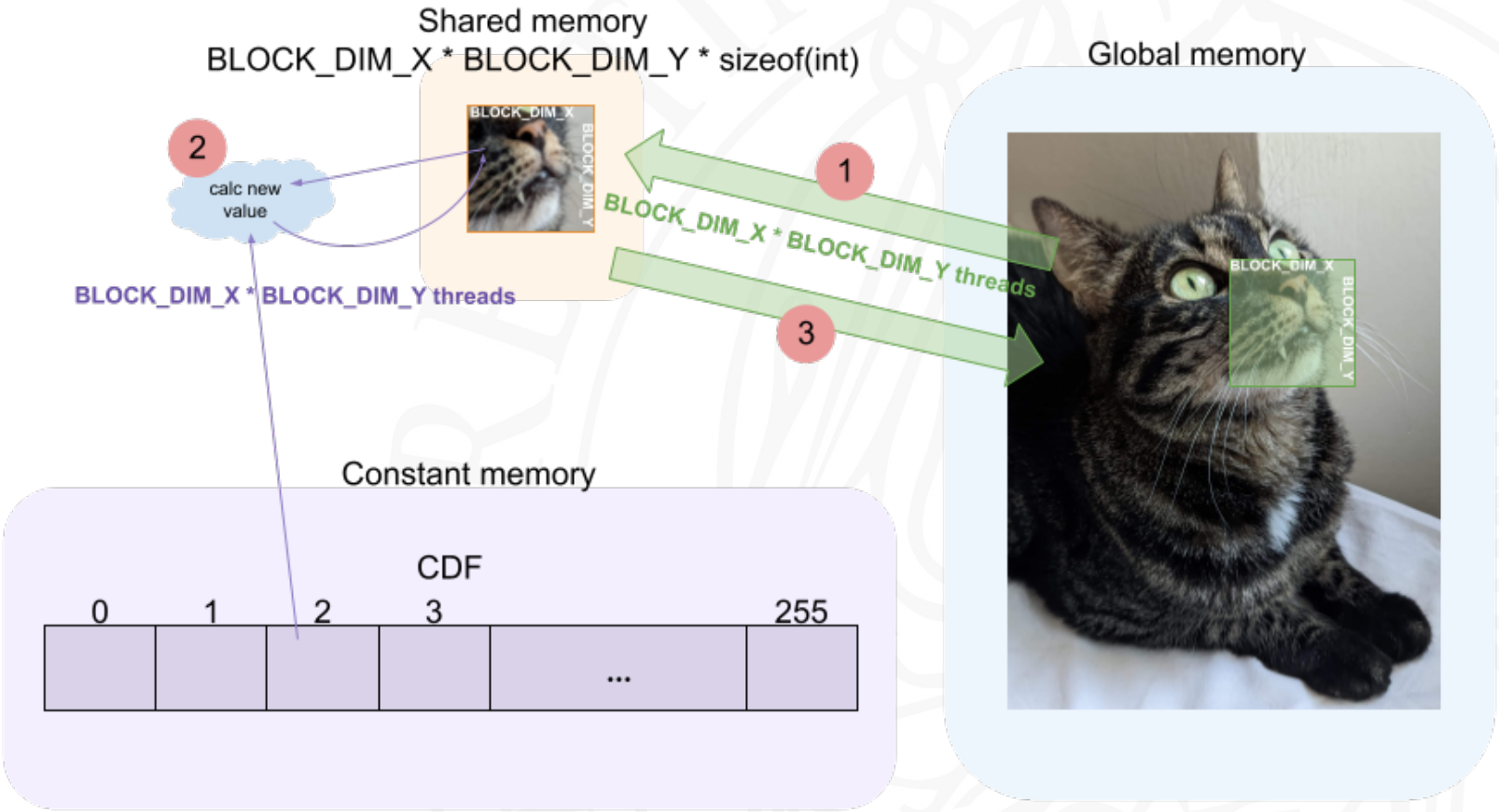

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Equalizer

```
__constant__ int d_CDF[HIST_SIZE];
__global__ void equalizer(unsigned char* image, int cdf_val_min, int width, int height) {
    __shared__ unsigned char IMG[BLOCK_DIM_X * BLOCK_DIM_Y];
    int tx = blockIdx.x * blockDim.x + threadIdx.x;
    int ty = blockIdx.y * blockDim.y + threadIdx.y;
    int t_id = tx + ty * width;
    int t_id_block = threadIdx.x + threadIdx.y * BLOCK_DIM_X;
    if (tx < width && ty < height) {
        IMG[t_id_block] = image[t_id];
    }
    __syncthreads();
    if (tx < width && ty < height) {
        IMG[t_id_block] = long(d_CDF[IMG[t_id_block]] - cdf_val_min) * (HIST_SIZE - 1) /
                                                (width * height - cdf_val_min);
    }
    __syncthreads();
    if (tx < width && ty < height) {
        image[t_id] = IMG[t_id_block];
    }
}
```

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Experiments

- Multiple image sizes
  - 10 images per size (5 vertical + 5 horizontal)

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Experiments

- Multiple image sizes
  - 10 images per size (5 vertical + 5 horizontal)
- Multiple block sizes
  - (min `BLOCK_DIM_X * BLOCK_DIM_Y` = 256)

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Experiments

- Multiple image sizes
  - 10 images per size (5 vertical + 5 horizontal)
- Multiple block sizes
  - (min `BLOCK_DIM_X * BLOCK_DIM_Y` = 256)
- ”Dummy” image for initialization
  - NVIDIA Nsight Systems (profiling)

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Results

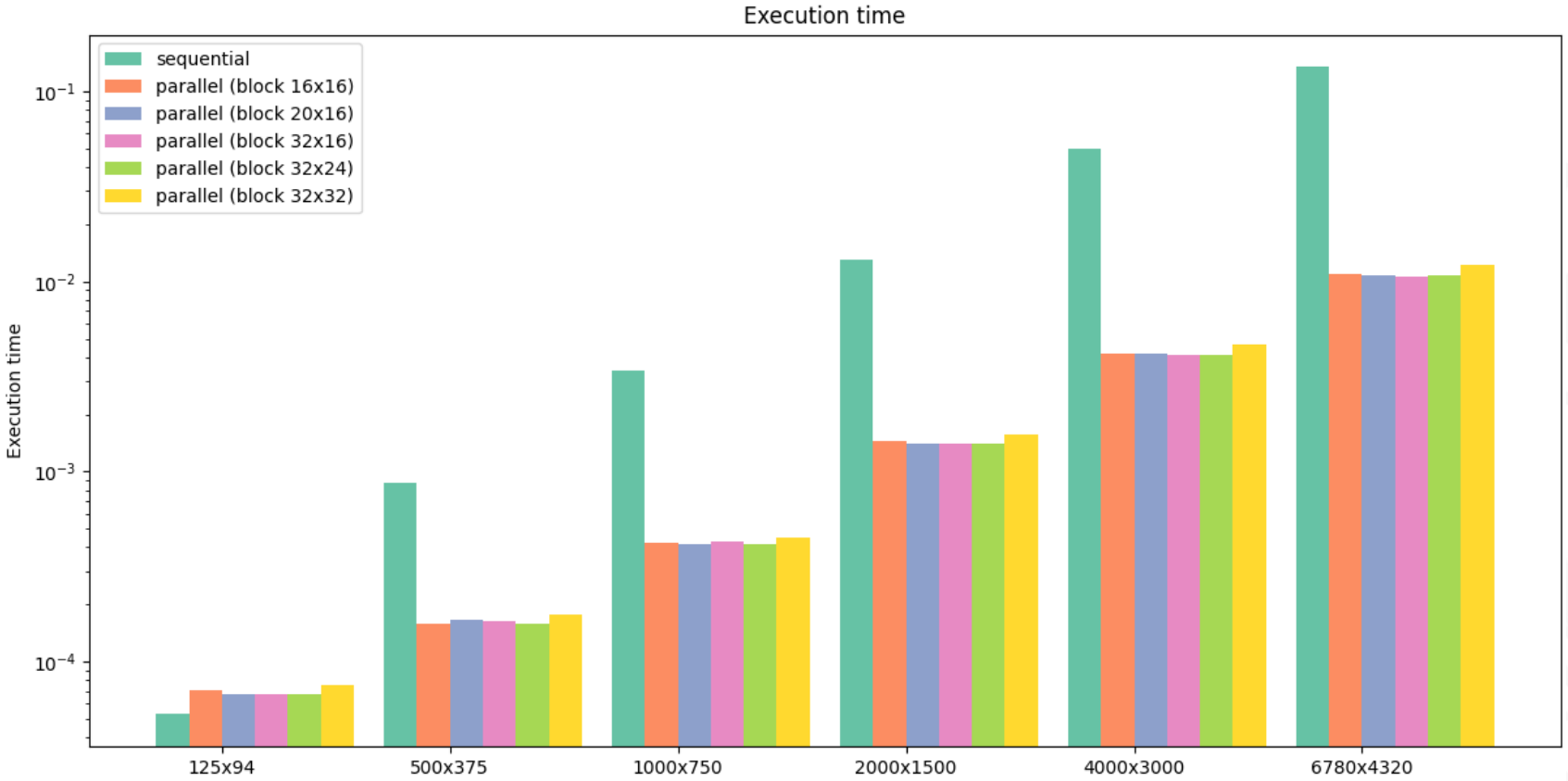

Image size	execution time sequential (s)	execution time 16x16 (s)	execution time 20x16 (s)	execution time 32x16 (s)	execution time 32x24 (s)	execution time 32x32 (s)
125x94	5.3e-05	7.1e-05	6.7e-05	6.8e-05	6.8e-05	7.6e-05
500x375	0.00087	0.000159	0.000165	0.000163	0.000158	0.000176
1000x750	0.003409	0.00042	0.000415	0.000427	0.000414	0.00045
2000x1500	0.013126	0.001457	0.001404	0.001404	0.001404	0.001556
4000x3000	0.049783	0.004177	0.00419	0.004084	0.004086	0.004694
6780x4320	0.134443	0.010917	0.010793	0.010579	0.010857	0.012192

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Results

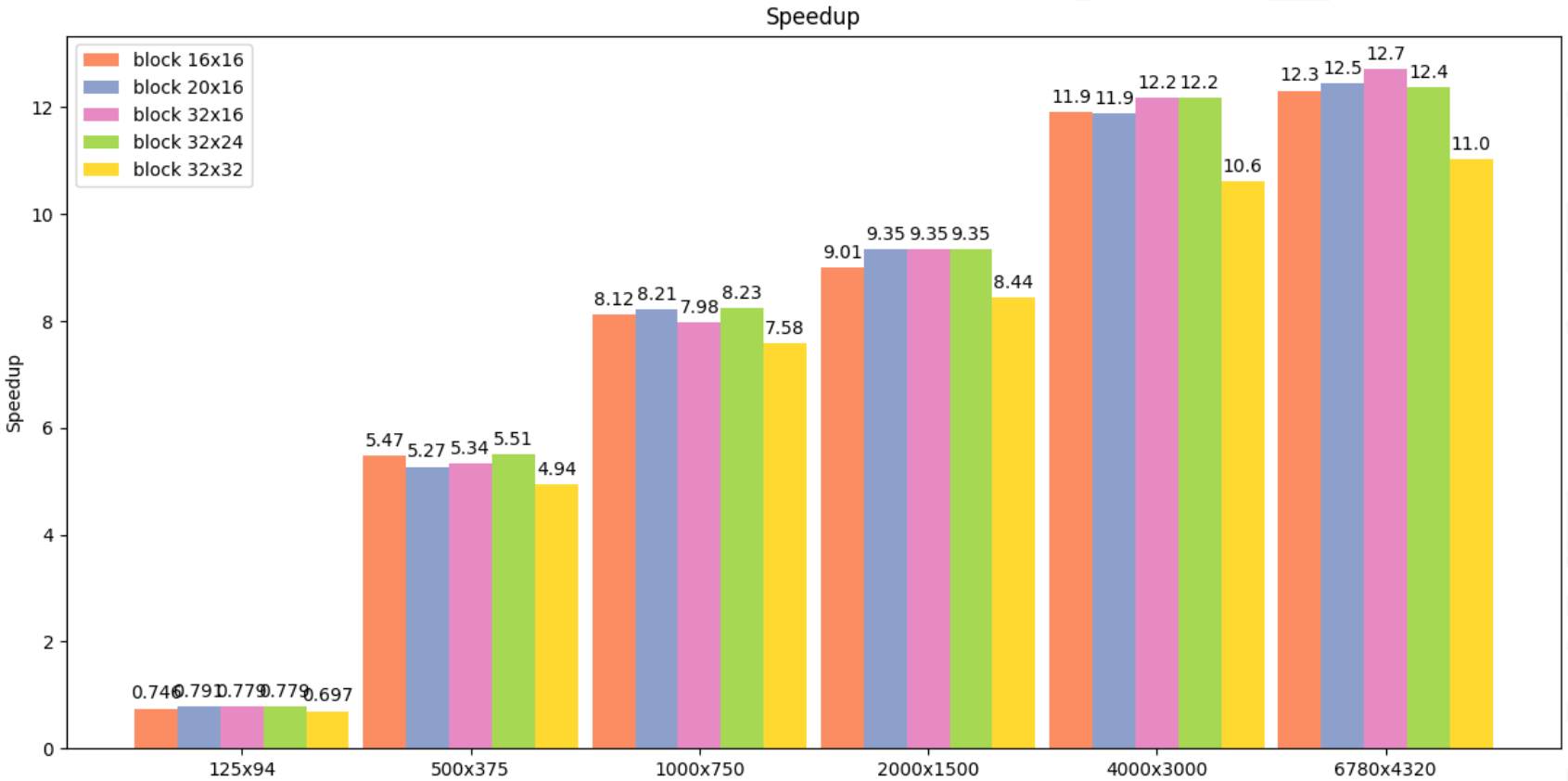

Figure: Speedup

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Occupancy

In order to use
NVIDIA Nsight Compute - Occupancy Calculator

- `__host__ cudaError_t cudaGetDeviceProperties (cudaDeviceProp* prop, int device)`

  for info about the GPU

  - total shared memory per multiprocessor
- `--ptxas-options=-v` flag in `nvcc`

  for info about the kernels

  - number of registers
- NVIDIA website for the compute capability

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Occupancy

- 67% for $32 \times 32 = 1024$ block size
- 83% for $20 \times 16 = 320$ block size
- 100% for the other block sizes

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- 67% for $32 \times 32 = 1024$ block size
- 83% for $20 \times 16 = 320$ block size
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Block size $32 \times 32 = 1024$:

- Maximum number of threads per SM: 1536
- Threads per SM for: 1024
- $1024/1536 = 0.67$

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Equalizer