CUDA Parallel Operations

Advanced Aspects

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Histogram

Histogram

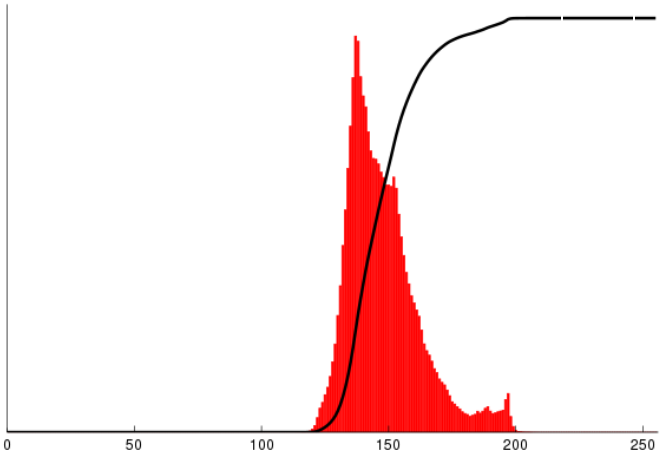
Problem statement

- A histogram is an estimate of the probability distribution of a continuous variable (only one).
  - First, **bin** the range of values (divide the range of values into intervals).
  - Count how many values fall into each **bin** or interval.

- Use case: Histogram Equalization (“a method in image processing of contrast adjustment”).
  - Increase the global contrast of the image.
  - Spread intensity values over the histogram.

Histogram

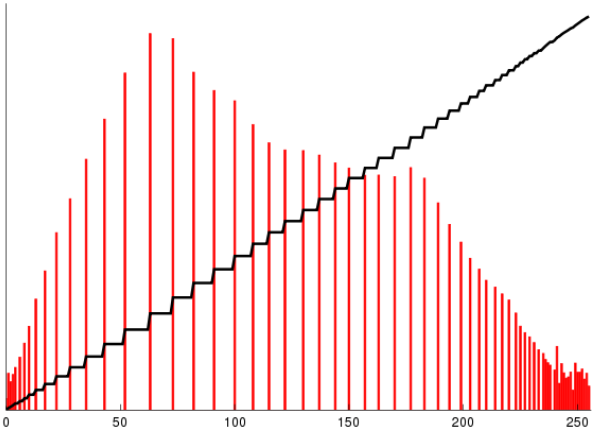
Histogram equalization



Source: https://en.wikipedia.org/wiki/Histogram_equalization

Histogram

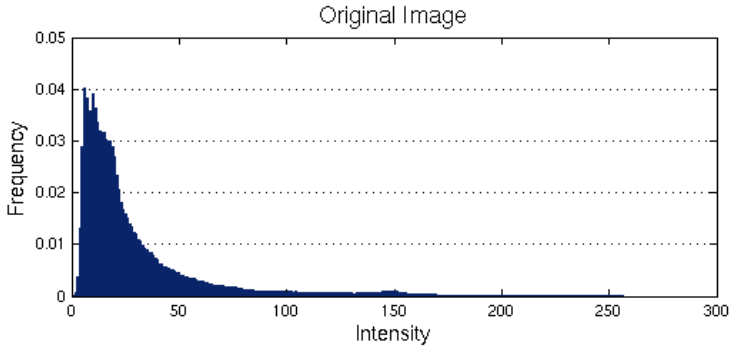
Histogram equalization

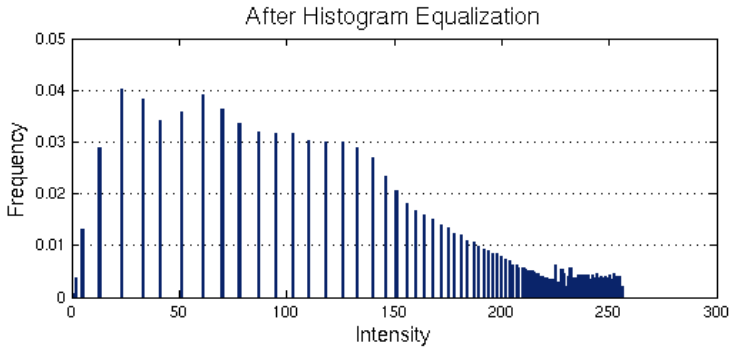


Source: https://en.wikipedia.org/wiki/Histogram_equalization

Histogram

Histogram equalization





Source: http://www.cs.utah.edu/~jfishbau/improc/project2/

Histogram

Histogram equalization pseudocode

```
hist = create histogram for input_image

cdf(0) = hist(0)
for i in range(1, len(hist))
    cdf(i) = cdf(i-1) + hist(i)
end

for p in input_image
     intensity = p
     p = cdf(intensity)
end
```

Histogram

Grayscale image histogram on CPU

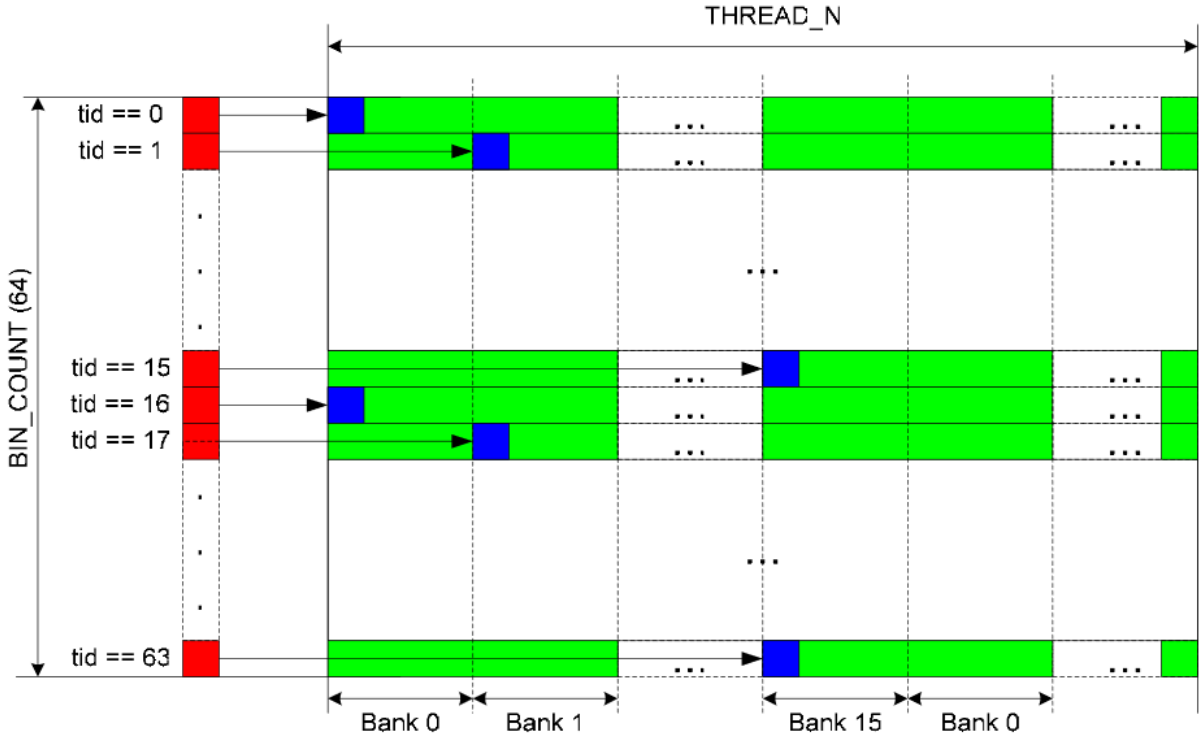
```
const int BIN_COUNT = 256;
int histogram[BIN_COUNT];

for (int i = 0; i < BIN_COUNT; ++i)
        histogram[i] = 0

for (int x = 0; x < IMG_WIDTH; ++x)
        for (int y = 0; y < IMG_HEIGHT; ++y)
                histogram[image[y][x]]++;
```

Histogram

Grayscale image histogram on GPU



Histogram

Grayscale image histogram on GPU

```
__global__
void comp_hist(char *image, int *hist)
{
    int idx_x = blockIdx.x * blockDim.x + threadIdx.x;
    int idx_y = blockIdx.y * blockDim.y + threadIdx.y;

    int idx = idx_y * IMG_WIDTH + idx_x;

    if (idx < IMG_WIDTH * IMG_HEIGHT)
    {
        bin = image[idx];
        atomicAdd(&(hist[bin]), 1)
    }
}
```

Reduce

Reduce

Problem statement and CPU implementation

- Summarize an input set of values into a single value by applying the same operation to all elements.
- Common examples: sum, maximum, minimum, multiplication…
- For instance: Vector Sum on CPU

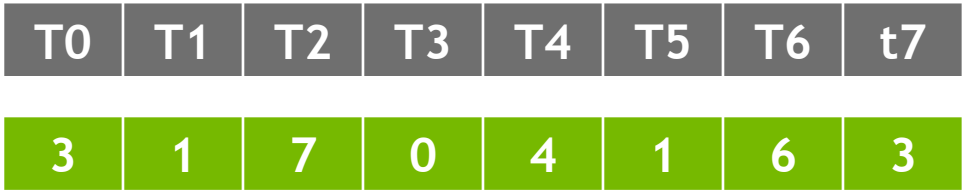
```
const int N= 256;
int x[N];
int acc = 0;

for (int i = 0; i < N; ++i)
        acc += x[i]
```

N additions!

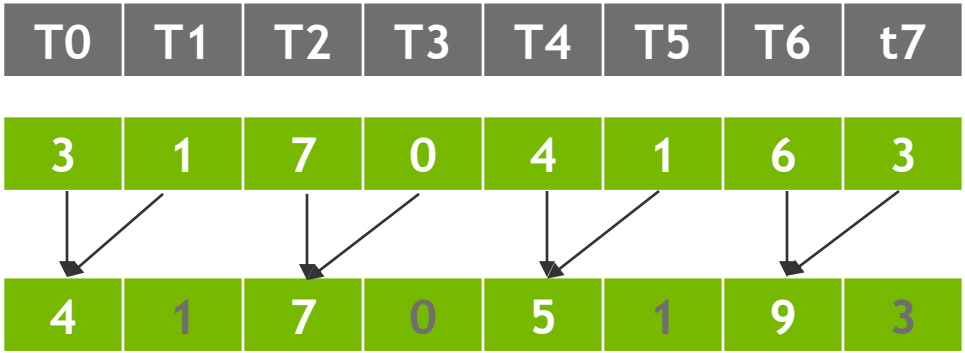
Reduce

Naïve GPU implementation



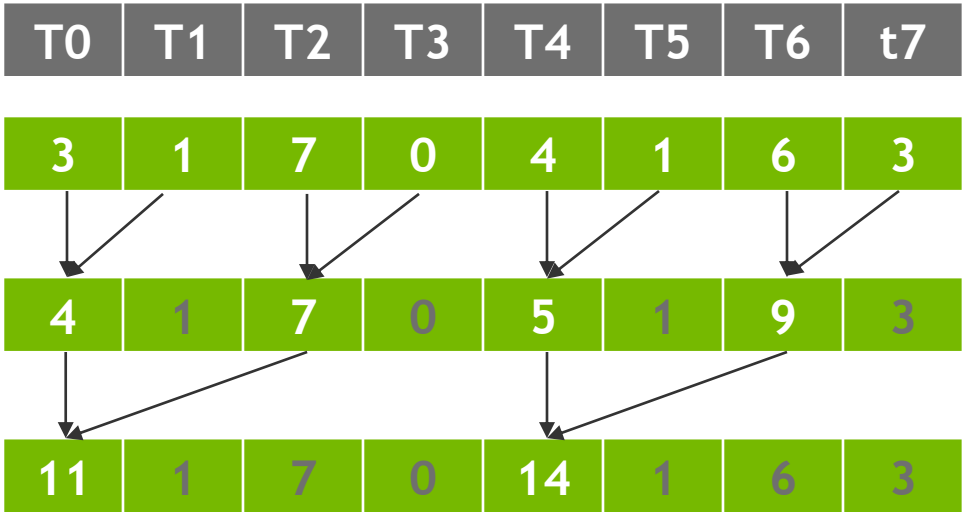
Reduce

Naïve GPU implementation



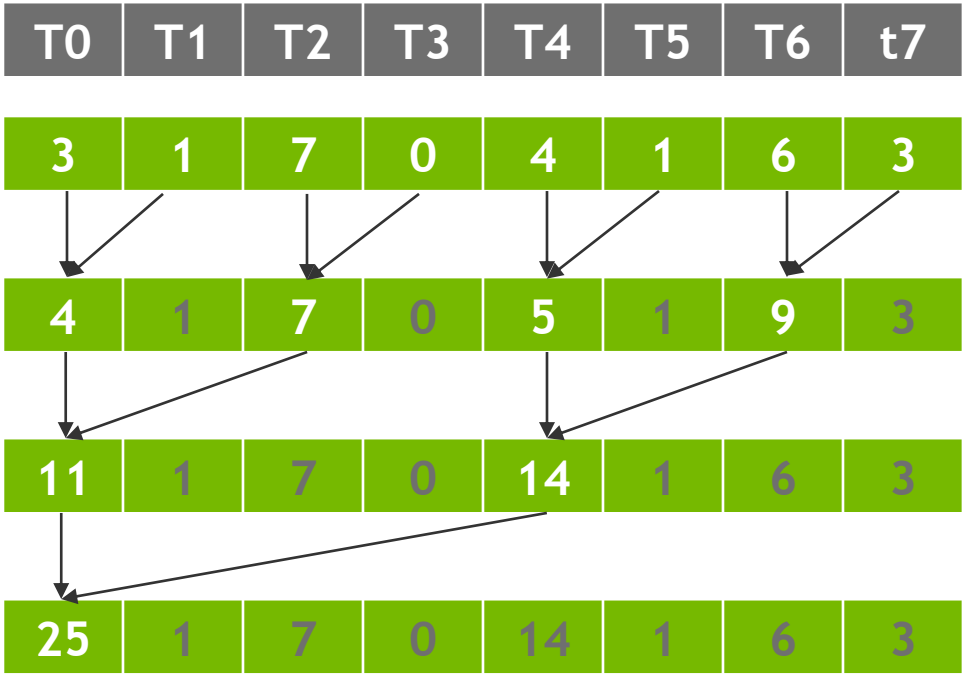
Reduce

Naïve GPU implementation



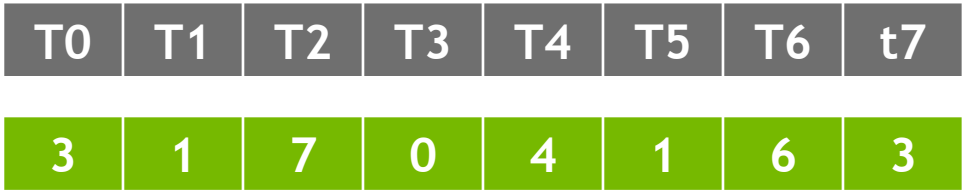
Reduce

Naïve GPU implementation



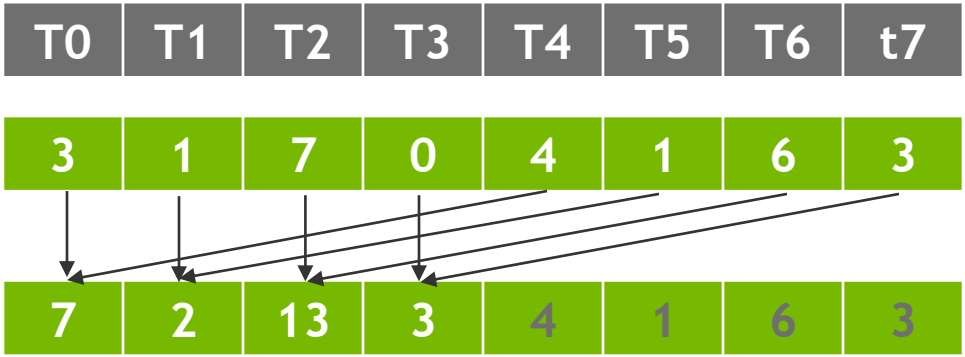
Reduce

Improved GPU implementation



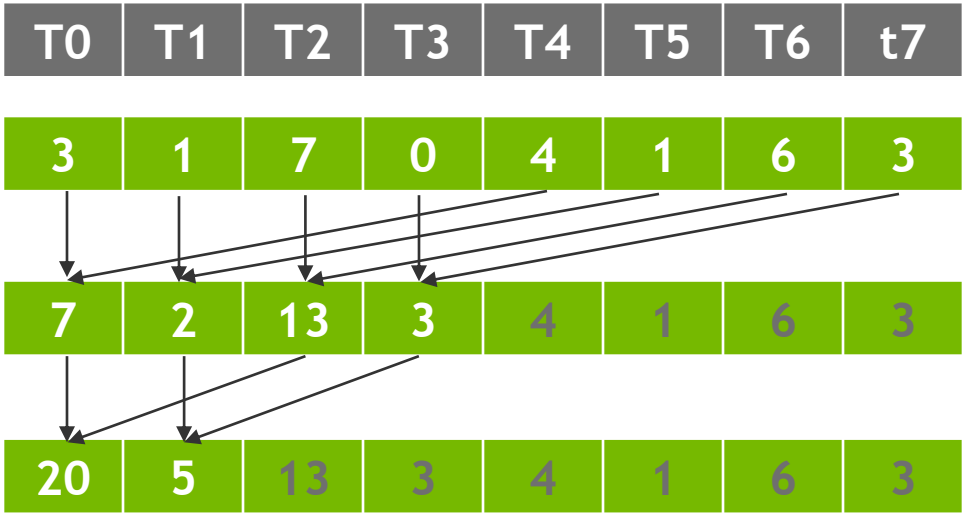
Reduce

Improved GPU implementation



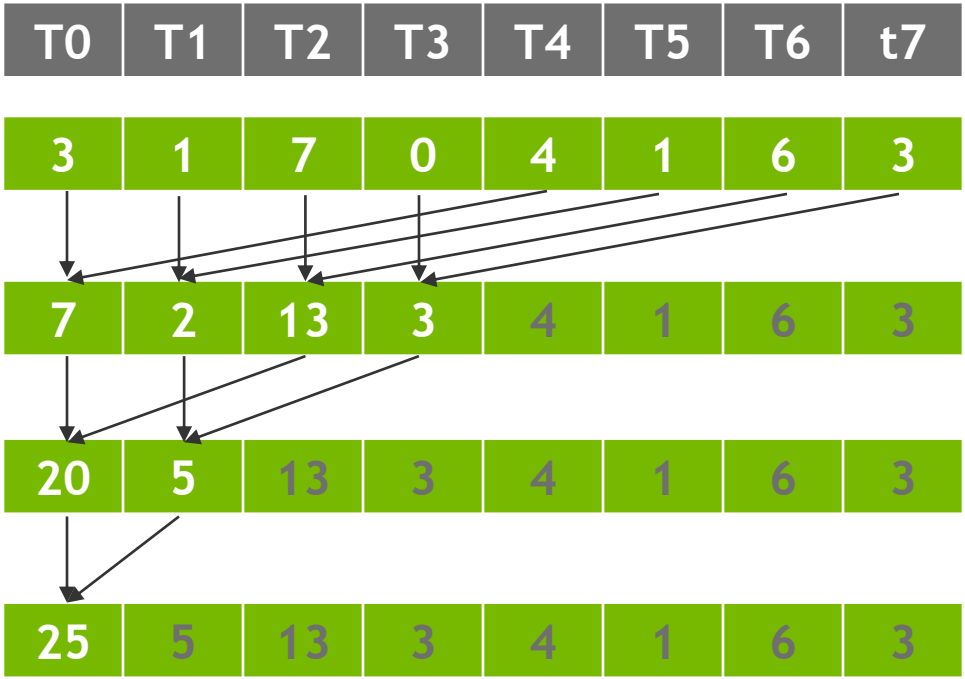
Reduce

Improved GPU implementation



Reduce

Improved GPU implementation



Reduce

More optimizations

- Shared Memory
- Warp Unrolling
- Multiple Elements per Thread
  - http://developer.download.nvidia.com/compute/cuda/1.1-Beta/x86_website/projects/reduction/doc/reduction.pdf

Scan

Scan

Problem statement

- Also named prefix-sum, takes:
  - A binary associative operator $\oplus$ like +, *, /… with identity I
  - An array of N elements: $[a_0, a_1, \dots, a_{N-1}]$
  - Returns the array:
    - $[I, a_0, (a_0 \oplus a_1), \dots, (a_0 \oplus a_1 \oplus \cdots \oplus a_{N-2})]$ if exclusive
    - $[I, a_0, (a_0 \oplus a_1), \dots, (a_0 \oplus a_1 \oplus \cdots \oplus a_{N-1})]$ $if\ inclusive$
    - For instance:
      - For the array [1, 2, 3, 4, 5, 6, 7, 8]
      - Sum (+) scan operation.
      - Result is [0, 1, 3, 6, 10, 15, 21, 28] for exclusive scan
      - Result is [0, 1, 3, 6, 10, 15, 21, 28, 36] for inclusive scan

Scan

Scan (+) on CPU

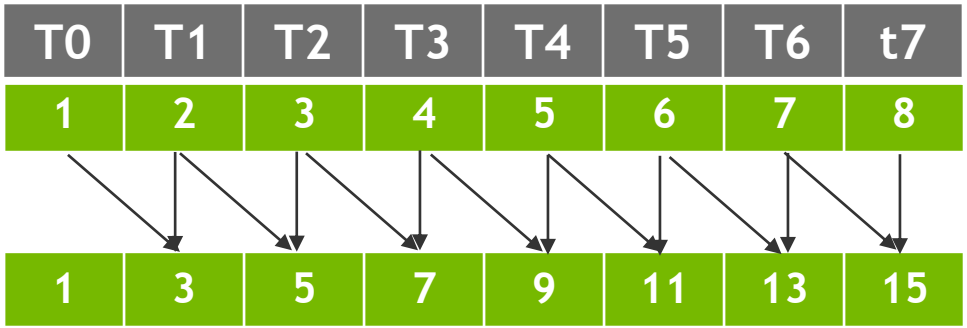
```
void scan(float *input, float *output, int N)
{
    output[0] = 0;

    for (int i = 1; i < N; ++i)
    {
        output[i] = input[i-1] + output[i-1]
    }
}
```

N-1 additions!

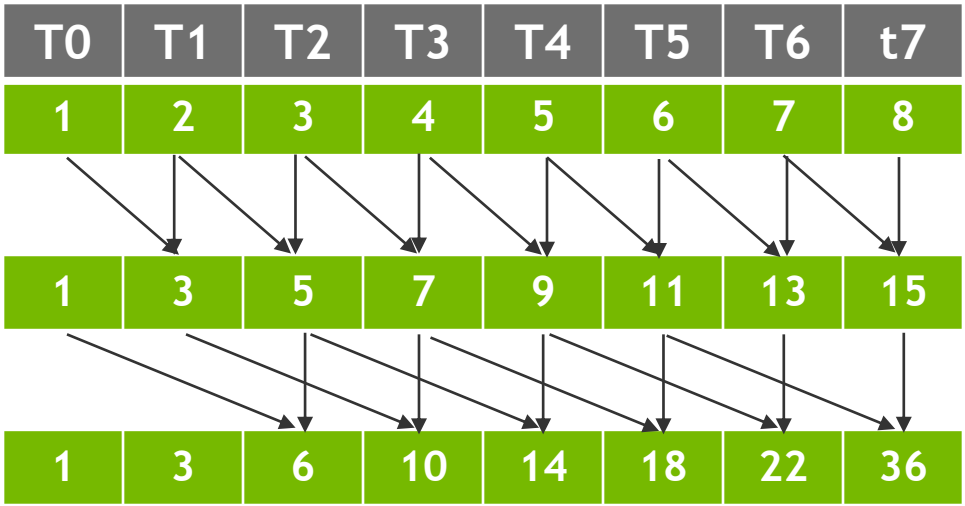
Scan

Naïve GPU implementation (Hillis-Steele)



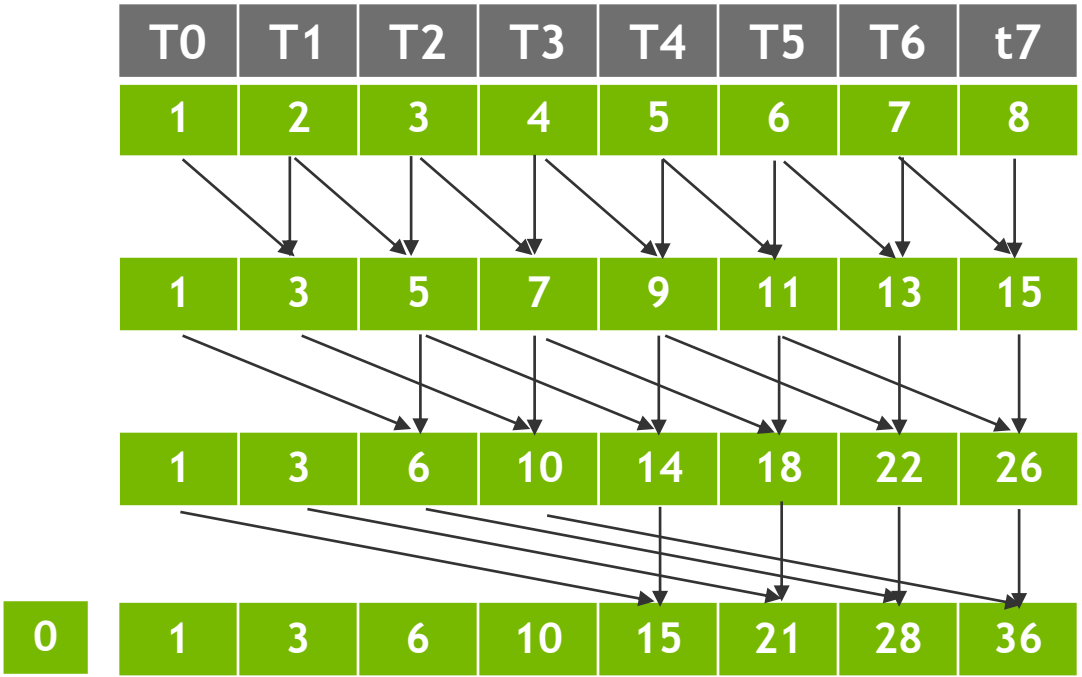
Scan

Naïve GPU implementation (Hillis-Steele)



Scan

Naïve GPU implementation (Hillis-Steele)



And more!

And more!

Other GPU parallel operations

- Radix Sort: https://www.youtube.com/watch?v=dPwAA7j-8o4
- Warp-level Primitives: https://devblogs.nvidia.com/using-cuda-warp-level-primitives/
- Merge Sort: https://onezork.wordpress.com/2014/08/29/gpu-mergesort/

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Thanks for your attention!

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