GPU Architectures SS2019

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Overview

- Execution and measurement framework
- Dimensions of Optimization
- Implementation variants
- Measurement results
- Summary and takeaways

Execution & Measurement Framework

- Automated execution of all algorithm implementations
- Command line configurable
  - sample size, window size, iterations
- Verifying correctness
  - Comparison with Lemire's implmentation
- Measurement of (average) runtime of each algorithm
- Easy to add new algorithm implementations

Sample Session

```
$ ./streaming_min_max_comparison -s 10000000 -w 500 -i 11

Performing a comparison using the following parameters:
  window_size = 500
  sample_size = 10000000
  number_of_iterations = 11

lemire = 2315.039919 milliseconds
cuda plain - cuda malloc = 234.845854 milliseconds
cuda plain - page locked memory = 3055.436376 milliseconds
cuda plain - page locked shared memory = 103.675406 milliseconds
thrust_naive = 221.098370 milliseconds
thrust = 235.481252 milliseconds
cuda plain - cuda tiled = 127.926657 milliseconds
```

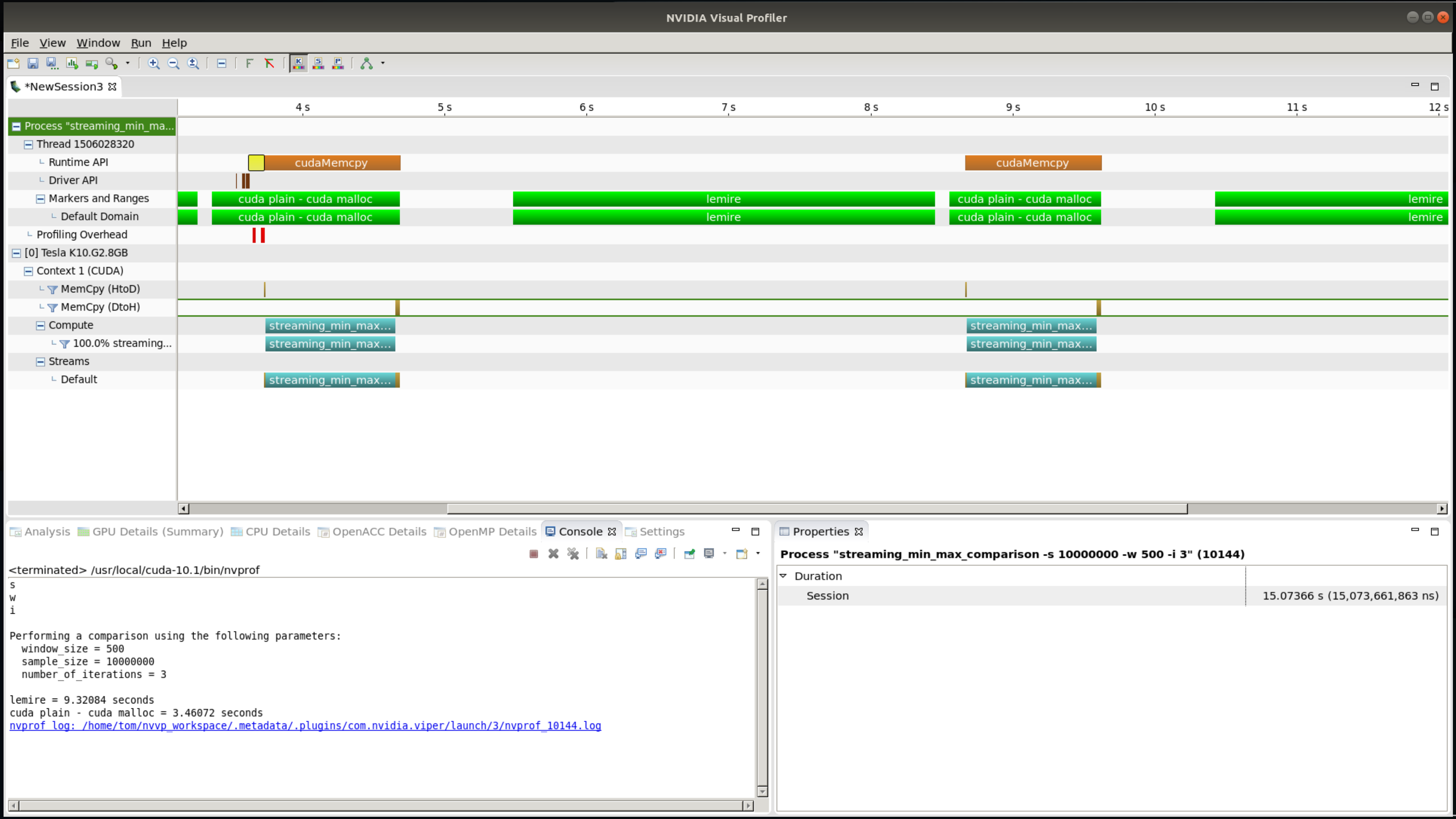
Dimensions of Optimization

- CUDA framework
  - Plain CUDA
  - Thrust
- Memory allocation & data transfer
  - Explicit memory allocation and transfer
  - Page-locked host memory
  - Page-locked host memory + shared memory as cache
- Parallelization strategy
  - One thread per sliding window/output value („linear scan“)
  - Binary reduction and tiling („log linear scan“)

Explicit Memory Alloc. & Transfer (1)

- cudaMalloc()/cudaFree()/cudaMemcpy()
- Expectation
  - Allocation overhead
  - Memory transfer overhead
  - Memory copy overhead (2x each direction!)

Explicit Memory Alloc. & Transfer (2)



```
<terminated> /usr/local/cuda-10.1/bin/nvprof
s
w
i

Performing a comparison using the following parameters:
  window_size = 500
  sample_size = 10000000
  number_of_iterations = 3

lemire = 9.32084 seconds
cuda plain - cuda malloc = 3.46072 seconds
nvprof log: /home/tom/nvvp_workspace/.metadata/.plugins/com.nvidia.viper/launch/3/nvprof_10144.log
```

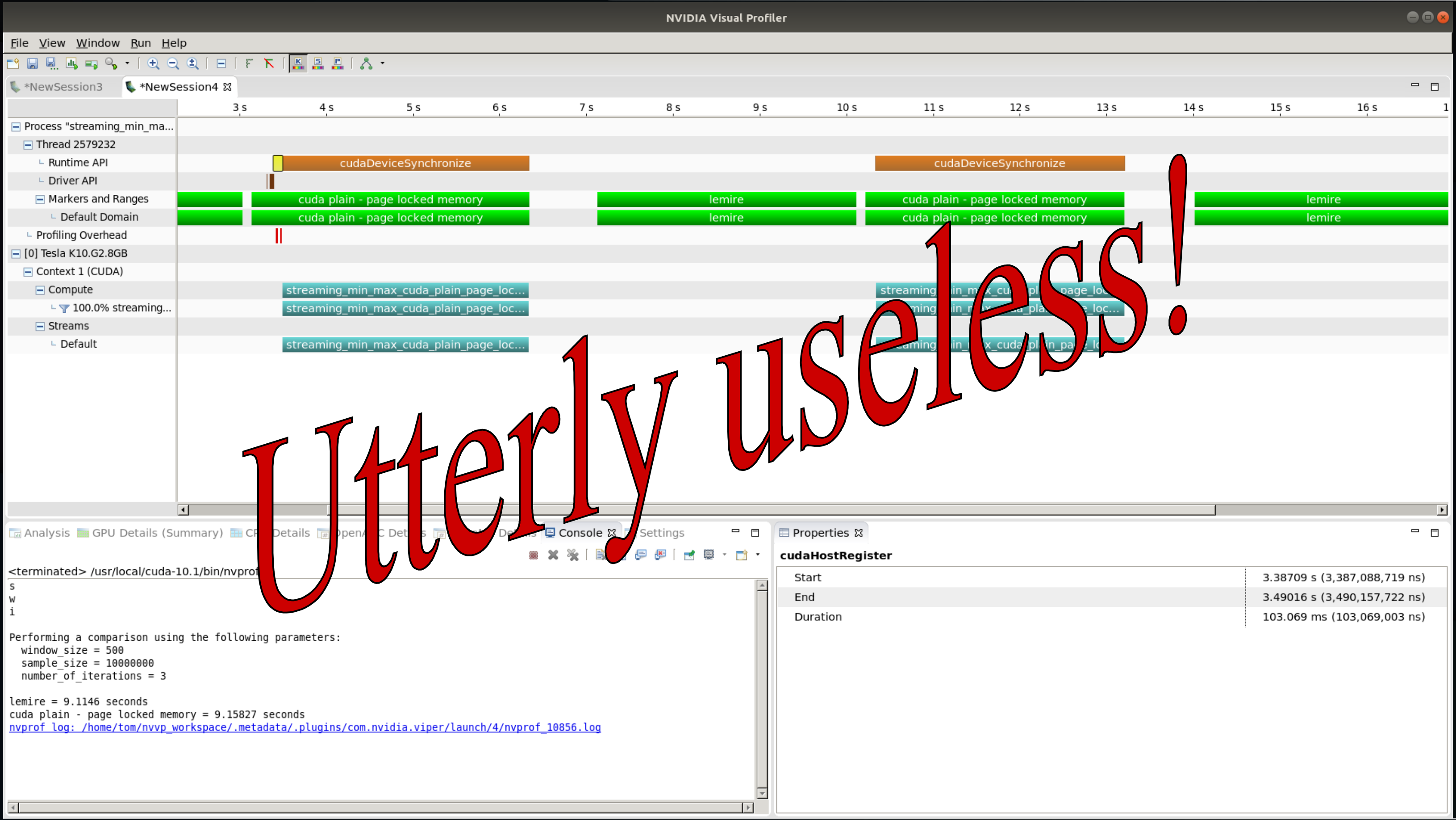
Process "streaming_min_max_comparison -s 10000000 -w 500 -i 3" (10144)

Duration	
Session	15.07366 s (15,073,661,863 ns)

Page-Locked Host Memory (1)

- cudaHostRegister()/cudaHostDeregister()
- Expectation
  - Allocation overhead eliminated
  - Memory transfer overhead still there
  - Memory copy overhead partly eliminated (1 x each direction!)

Page-Locked Host Memory (2)



Utterly useless!

```
<terminated> /usr/local/cuda-10.1/bin/nvprof
s
w
i

Performing a comparison using the following parameters:
  window_size = 500
  sample_size = 10000000
  number_of_iterations = 3

lemire = 9.1146 seconds
cuda plain - page locked memory = 9.15827 seconds
nvprof log: /home/tom/nvvp_workspace/.metadata/.plugins/com.nvidia.viper/launch/4/nvprof_10856.log
```

cudaHostRegister

Start	3.38709 s (3,387,088,719 ns)
End	3.49016 s (3,490,157,722 ns)
Duration	103.069 ms (103,069,003 ns)

Page-Locked Host Memory (3)

- Actually a massive deterioration
- Hypothesised causes
  - Lack of possibility to coalesce small memory accesses into single bulk transfer
  - Slow PCI bus
- Interestingly depends strongly on HW platform

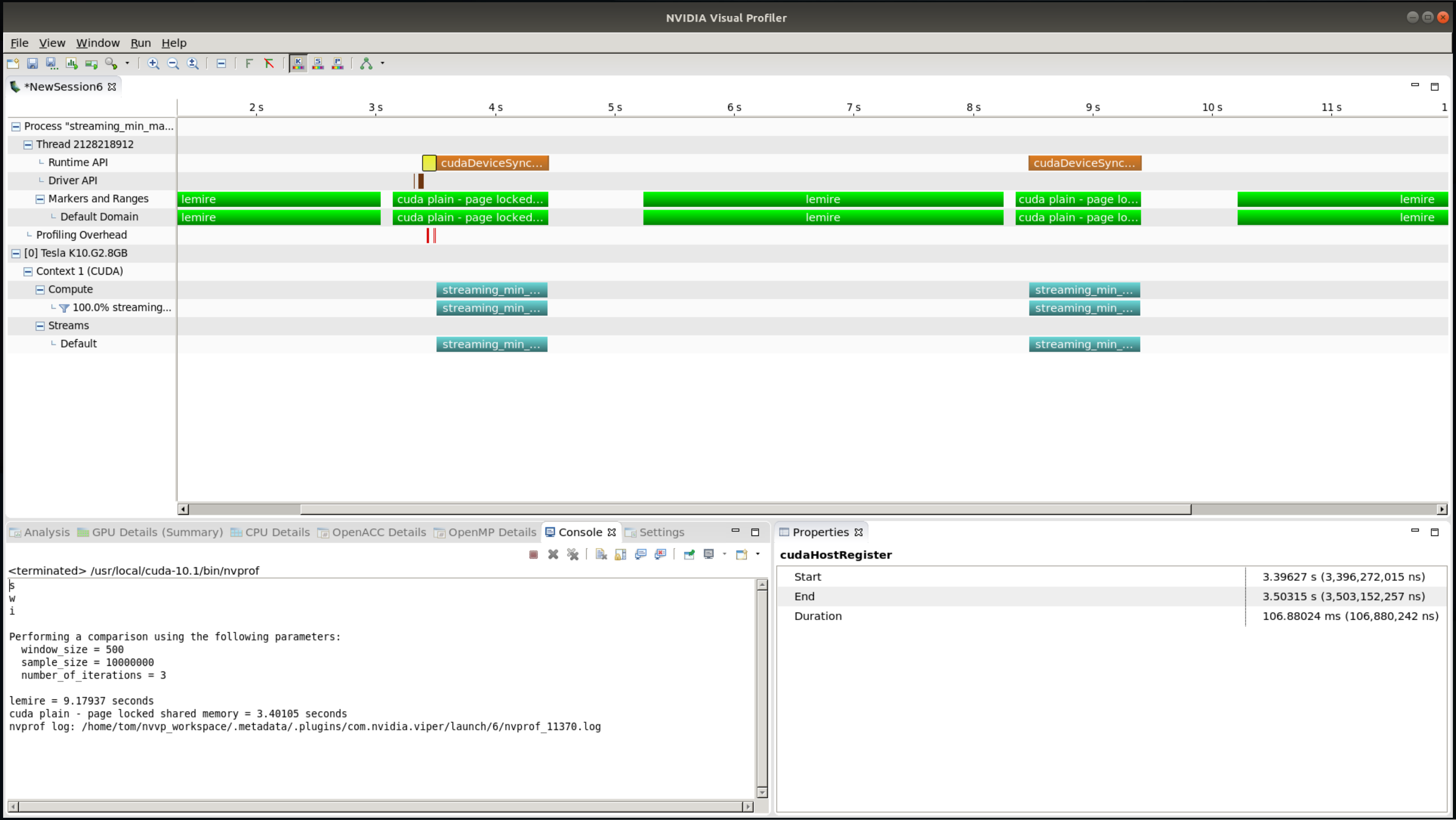
Page-Locked Host Mem. & Cache (1)

- Use page-locked host memory
- Use shared memory on GPU as program controlled cache
  - Shared memory as fast as L1 cache
  - Program controlled instead of LRU
- Expectation
  - Massive memory access overhead of pure page-locked memory drastically reduced

Page-Locked Host Mem. & Cache (2)

- Split computing kernel into two parts
  - Parallelized memory transfer into shared memory
    - Combined effort of all threads of a thread block
  - Actual compuation on shared memory

Page-Locked Host Mem. & Cache (3)



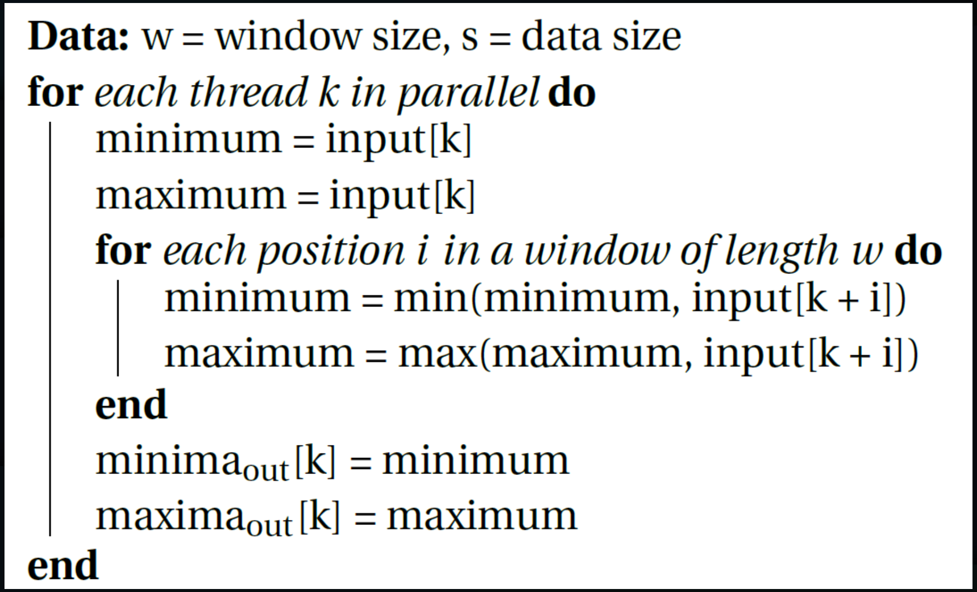
```
<terminated> /usr/local/cuda-10.1/bin/nvprof
s
w
i

Performing a comparison using the following parameters:
  window_size = 500
  sample_size = 10000000
  number_of_iterations = 3

lemire = 9.17937 seconds
cuda plain - page locked shared memory = 3.40105 seconds
nvprof log: /home/tom/nvvp_workspace/.metadata/.plugins/com.nvidia.viper/launch/6/nvprof_11370.log
```

cudaHostRegister

Start	3.39627 s (3,396,272,015 ns)
End	3.50315 s (3,503,152,257 ns)
Duration	106.88024 ms (106,880,242 ns)

Linear Scan

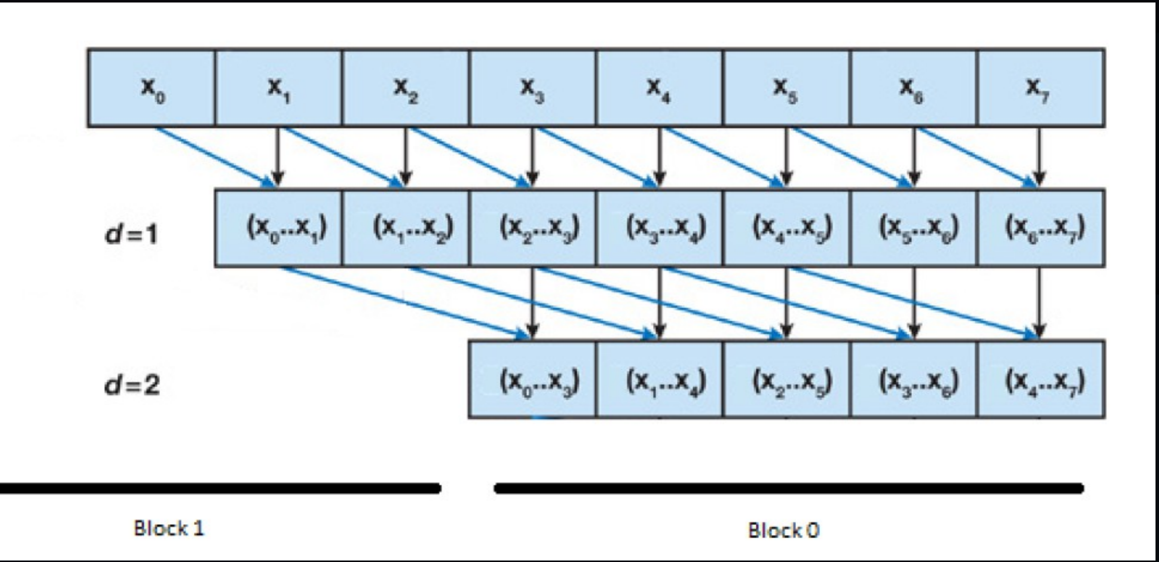
- One thread per output
- Incremental computation

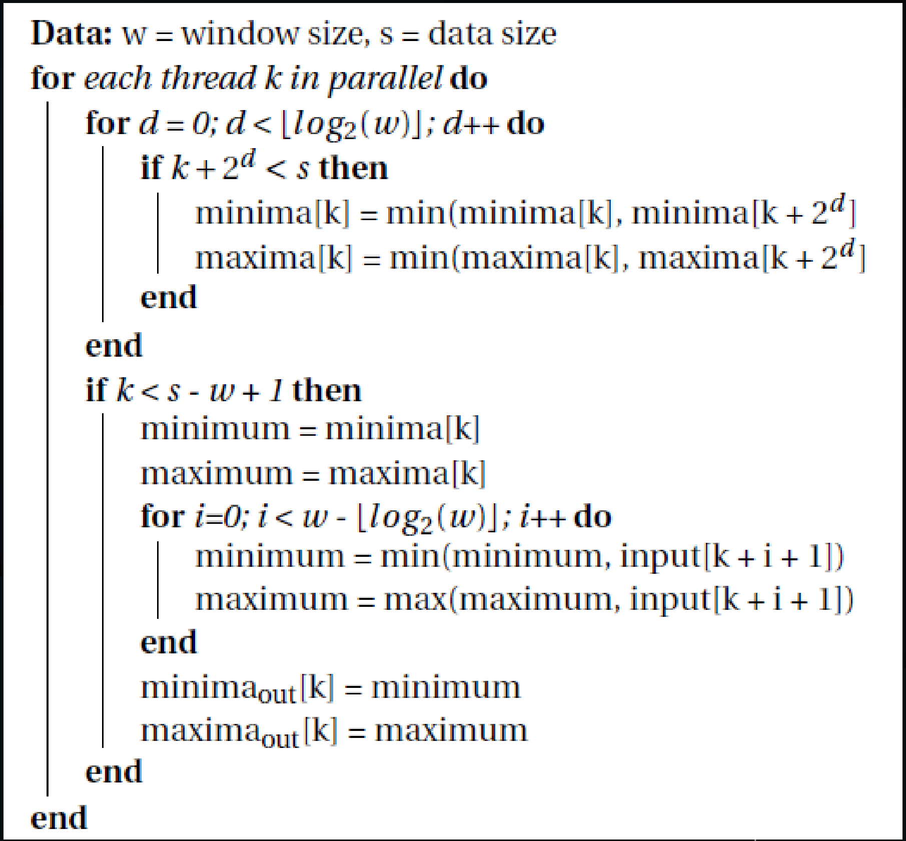


```
Data: w = window size, s = data size
for each thread k in parallel do
    minimum = input[k]
    maximum = input[k]
    for each position i in a window of length w do
        minimum = min(minimum, input[k + i])
        maximum = max(maximum, input[k + i])
    end
    $\text{minima}_{out}$[k] = minimum
    $\text{maxima}_{out}$[k] = maximum
end
```

Log Linear Scan

- Binary reduction
- Combine results





```
**Data:** w = window size, s = data size
**for** *each thread k in parallel* **do**
    **for** $d = 0; d < \lfloor log_2(w) \rfloor; d{+}{+}$ **do**
        **if** $k + 2^d < s$ **then**
            minima[k] = min(minima[k], minima[k + $2^d$]
            maxima[k] = min(maxima[k], maxima[k + $2^d$]
        **end**
    **end**
    **if** $k < s - w + 1$ **then**
        minimum = minima[k]
        maximum = maxima[k]
        **for** $i{=}0; i < w - \lfloor log_2(w) \rfloor; i{+}{+}$ **do**
            minimum = min(minimum, input[k + i + 1])
            maximum = max(maximum, input[k + i + 1])
        **end**
        $minima_{out}$[k] = minimum
        $maxima_{out}$[k] = maximum
    **end**
**end**
```

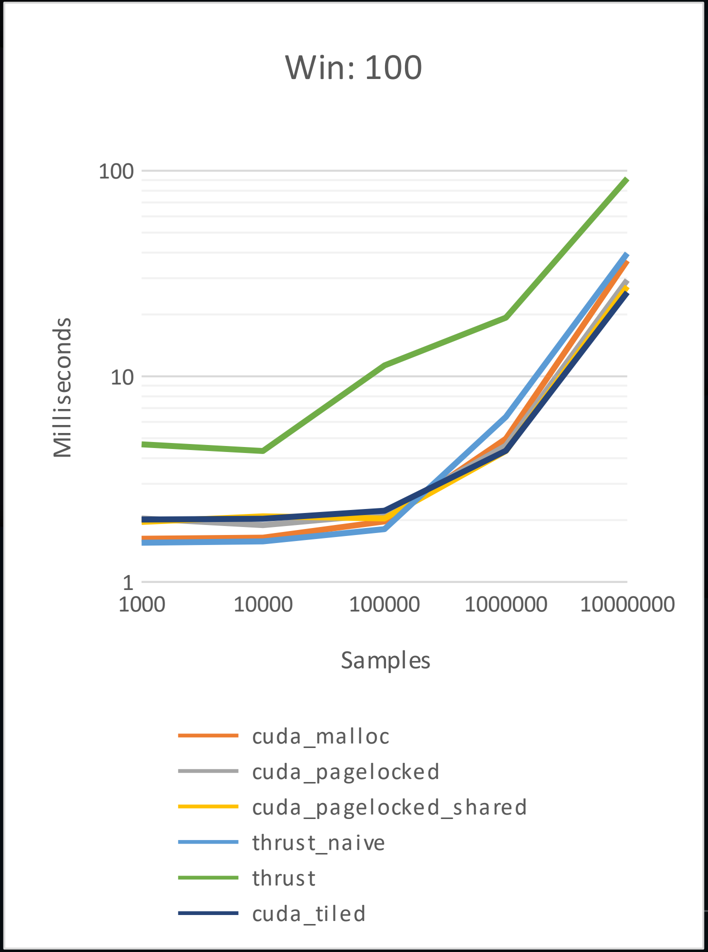
Implementation of Algorithms

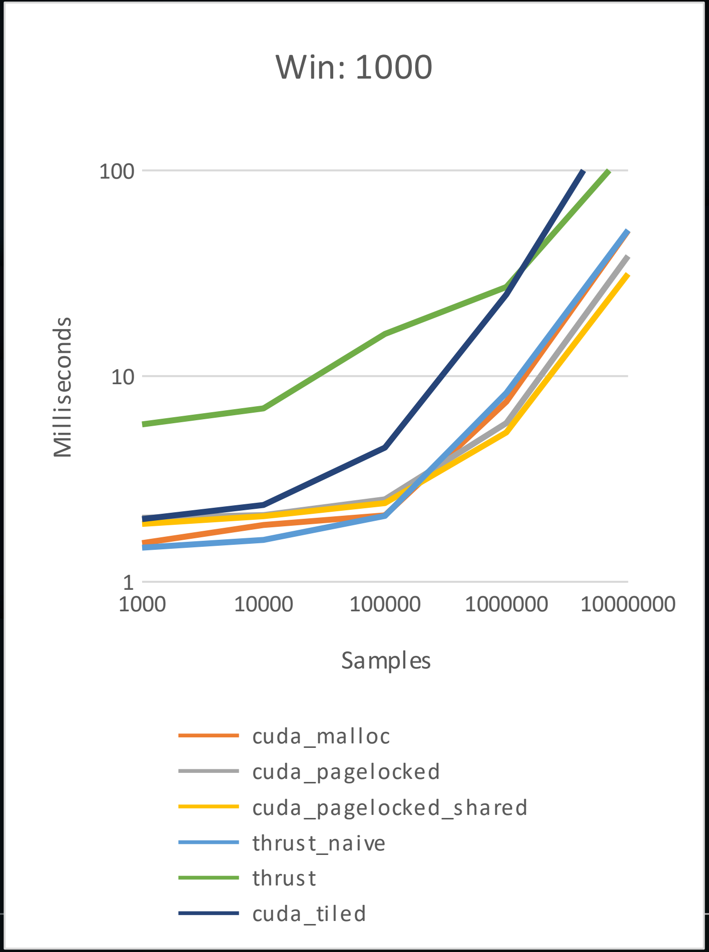
- CUDA
  - cuda_malloc: malloc – linear scan
  - cuda_pagelocked: page-locked – linear scan
  - cuda_pagelocked_shared: page-locked & shared memory – linear scan
  - cuda_tiled: page-locked & shared memory – log linear scan & tiling
- Thrust
  - thrust_naive: linear scan
  - thrust: log linear scan & tiling

Measurements

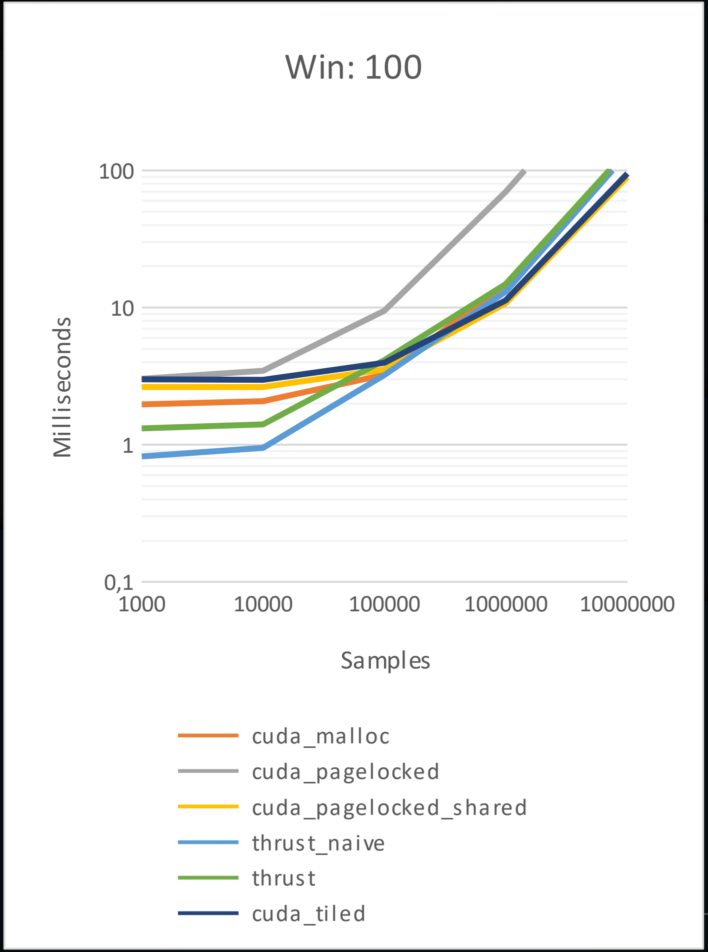
- Conducted for all algorithm flavors
- For various sample and window sizes
- On two different HW platforms
  - NVIDIA RTX2070
  - NVIDIA Tesla K10.G2

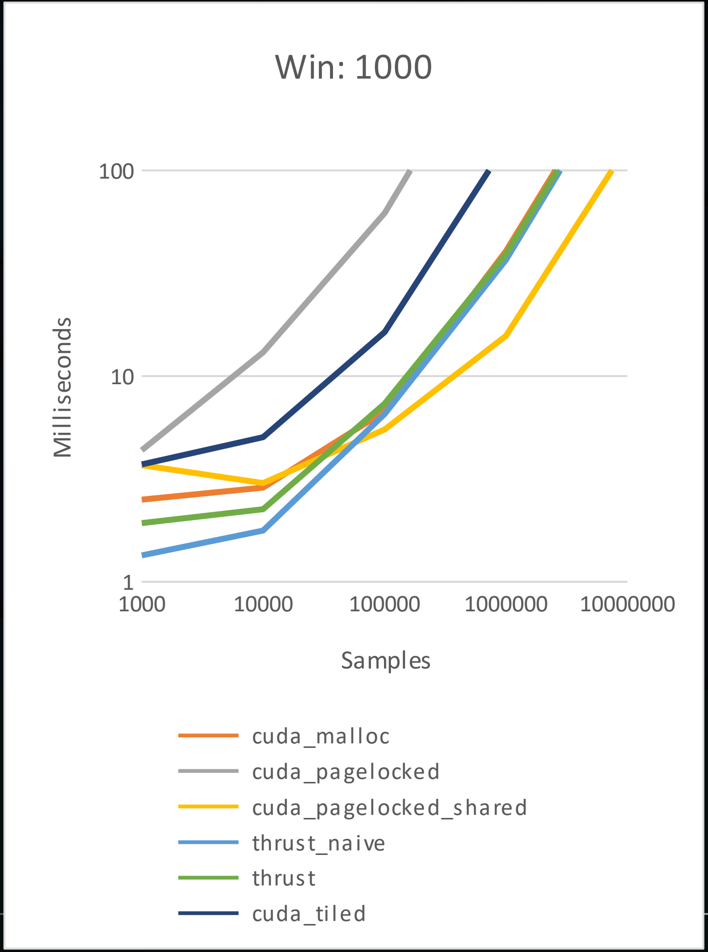
Results – NVIDIA RTX 2070





Results – NVIDIA Tesla K10.G2





Summary & Takeaways (1)

- Performance of code running on a GPU is influenced by a multitude of factors, thus
  - Know your workload and your HW
  - Measure carefully and optimize
    - If measurement result are inconclusive, measure again …
- Optimization for one HW/workload might be a deterioration on another
  - Consider going for a hybrid solution
    - multiple kernels
    - select appropriate one during run-time (based on HW and workload)

Summary & Takeaways (2)

- Don‘t be too clever! - a straight forward „naive“ solution might outperform a complex „smart“ solution
- „Premature optimization is the root of all evil“ [Donald Knuth]