Scan

Parallel Algorithm Design WS21/22

N. Kochendörfer, C. Alles, S. Proß

February 17, 2022

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Scan Theory

- Synonyms: prefix sum, cumulative sum or scan
- inclusive and exclusive version
- further specialization: segmented scan

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Scan Theory

- Synonyms: prefix sum, cumulative sum or scan
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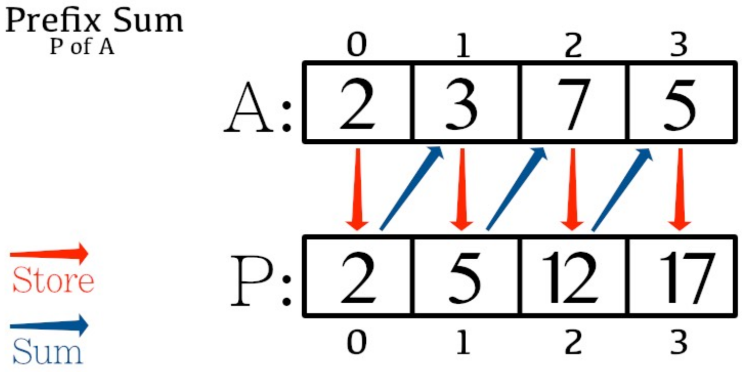
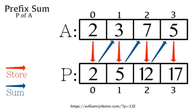
- further specialization: segmented scan

Inclusive Scan



https://williamrjribeiro.com/?p=132

Inclusive Scan



Inclusive vs. Exclusive scan

X	3	4	6	3	8	7	5	4	
Y	0	3	7	13	16	24	31	36	Exclusive Scan
Y	3	7	13	16	24	31	36	40	Inclusive Scan

https://livebook.manning.com/book/parallel-and-high-performance-computing/chapter-5/v-11/

Inclusive vs. Exclusive scan

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Segmented Variant

1	2	3	4	5	6	input
1	0	0	1	0	1	flag bits
1	3	6	4	9	6	segmented scan +

https://en.wikipedia.org/wiki/Segmented_scan

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Implementation

STL Algorithm

STL provides:

- std::inclusive_scan
- std::exclusive_scan

Essentially equivalent to:

```
float sum = 0;
for(size_t i =0; i<N; i++)
{
    sum += input[i];
    output[i] = sum;
}
```

⇒ Sequential to a fault!

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Implementation

Alternatives

Alternatives to STL:

- OpenMP: scan pragma
- TBB: parallel_scan function

Alternative Algorithms:

- Up-Down Sweeping Scan
- Tiled Scan

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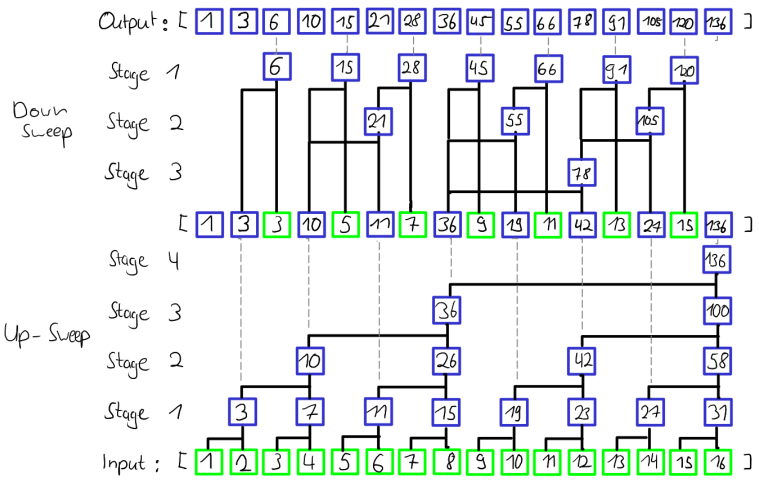
Up-Down Sweep

Schema Inclusive



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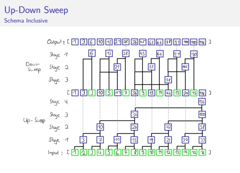
Scan
└Implementation
└Up-Down Sweep



Up-Down Sweep

Dependency:

- Only between stages

⇒ Lots of parallelism

Downsides:

- Workload of 2N
- Communication!
- Workload stage dependent!

Up-Down Sweep
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Tiled Scan

Idea: Process input in independent chunks.

- Each chunk misses previous results
  - $\Rightarrow$ Second pass over data.
- Workload: 2N

Our solution:

- Temporary vector for intermediate sums.
- Only one write to output.

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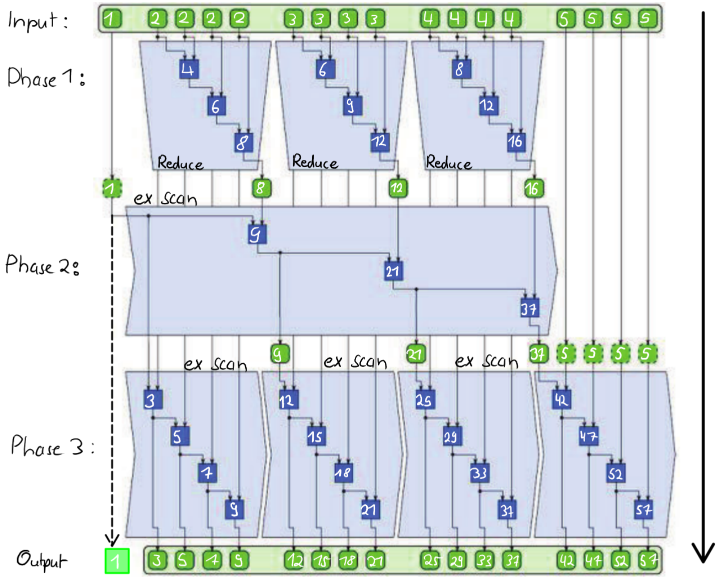
Tiled Scan Schema



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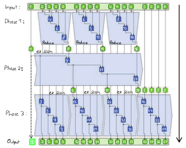
Scan
└Implementation
└Tiled Scan Schema

Tiled Scan Schema



Benchmarks

Parameters:

- In-Place
- Datatype: float
- Values: Linear Distribution. between 0-10.
- Benchmarking Suite: Catch2

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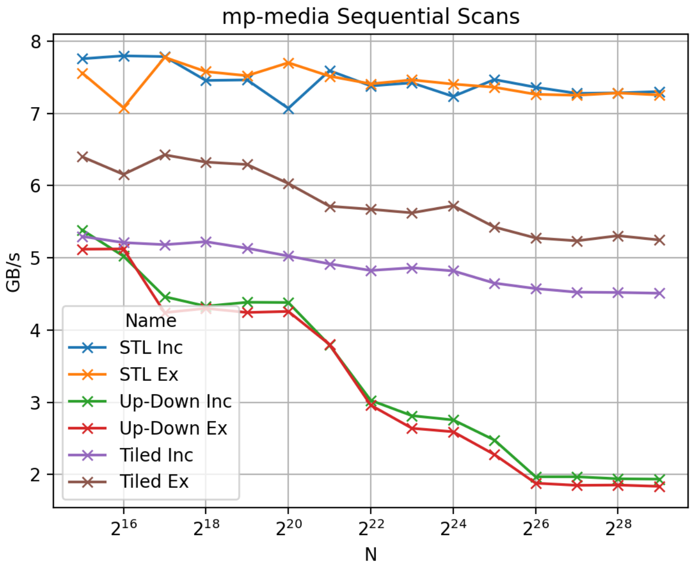
Sequential Scan Results



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Scan
└─Implementation
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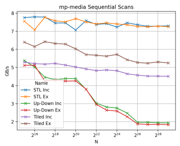

Segmented Scan
Implementation

- Not present in STL!
- No reference implementations...

Solution: Wrapping the binary operation!

```
[binary_op](PairType left, PairType right){
    PairType new_right = right;
    if (not right.flag)
        new_right.value =
            binary_op(left.value, right.value);
    return new_right;
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Segmented Scan

Solution

Works for:

- STL Scans
- Most inclusive scans

Challenge: Exclusive Scan

- Exclusive Segmented is complex
- Custom solution for each variant

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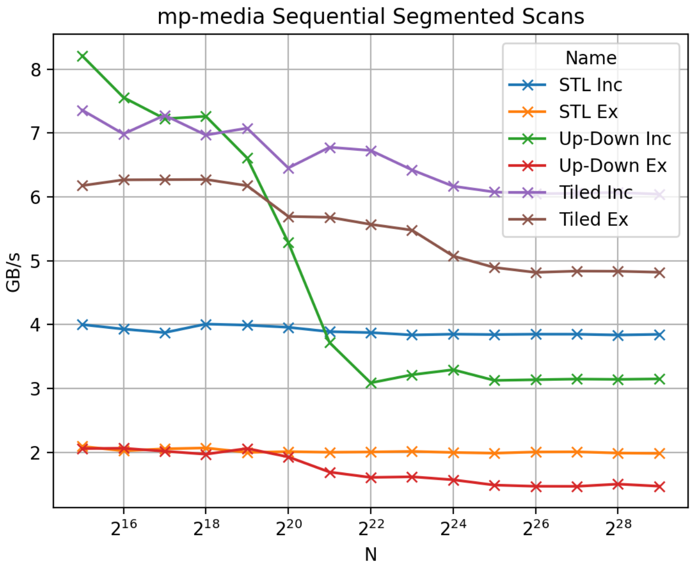
Sequential Segmented Scan Results



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Scan
└Implementation
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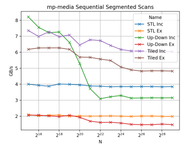
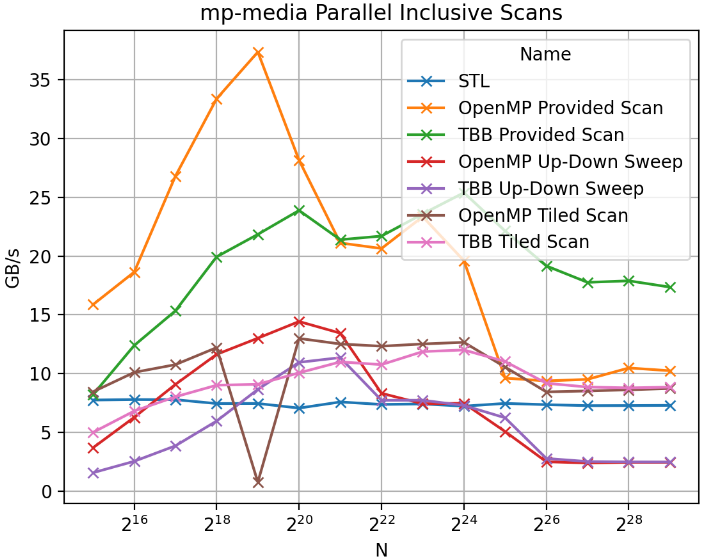
Sequential Segmented Scan Results



Parallel Scan Results



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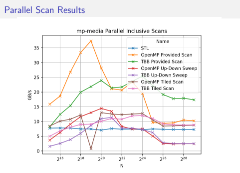
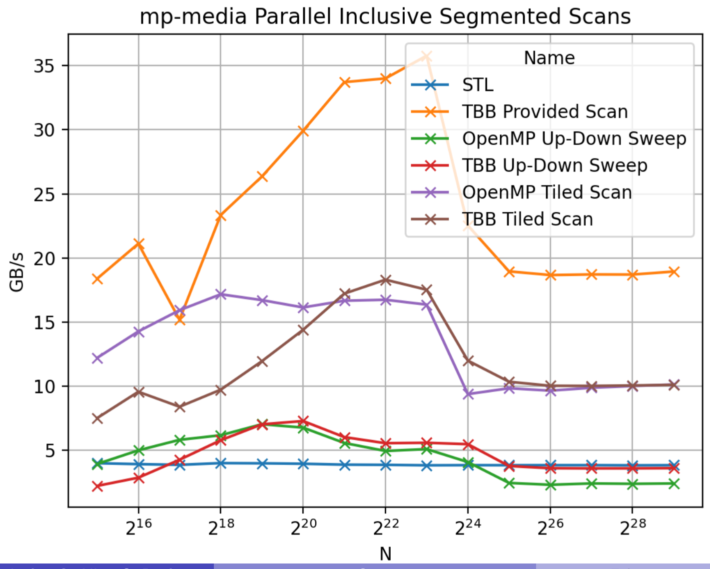
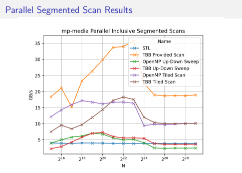


Parallel Segmented Scan Results





Intermediate Results

Ranking:

1. Library provided implementations
2. Tiled Scan
3. Up-Down Sweeping Scan

Remarks:

- OpenMP $>=$ TBB (if available)
- Up-Down Sweep is slow

Can we do better?

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Algorithmic Optimization

Initial Goal: functional correctness.

Algorithmic Optimizations:

- Loop-Fusion:
  - Up-Down Sweep
  - Exclusive Segmented Scan
- Limiting Memory Accesses
- General clean up

Performance gain $\sim$ 1-5 GB/s!

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Data Locality

Ensure that the data generated is local to the node:

```
std::vector<float> data(N);
#pragma omp parallel for schedule(static)
for (size_t i = 0; i < data.size(); i++)
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data[i] = rand();
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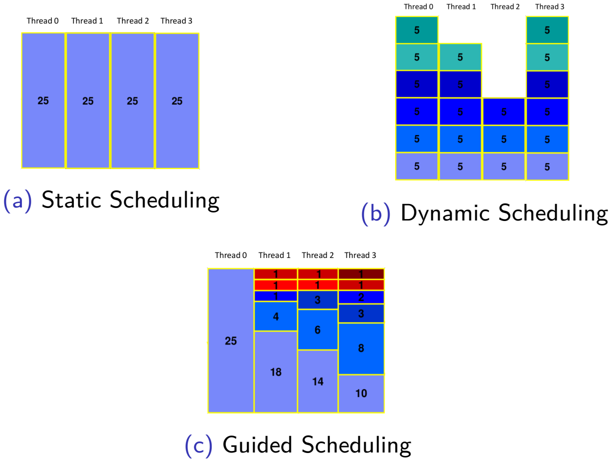
OpenMP Scheduling

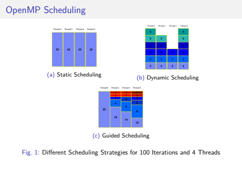


(a) Static Scheduling

(b) Dynamic Scheduling

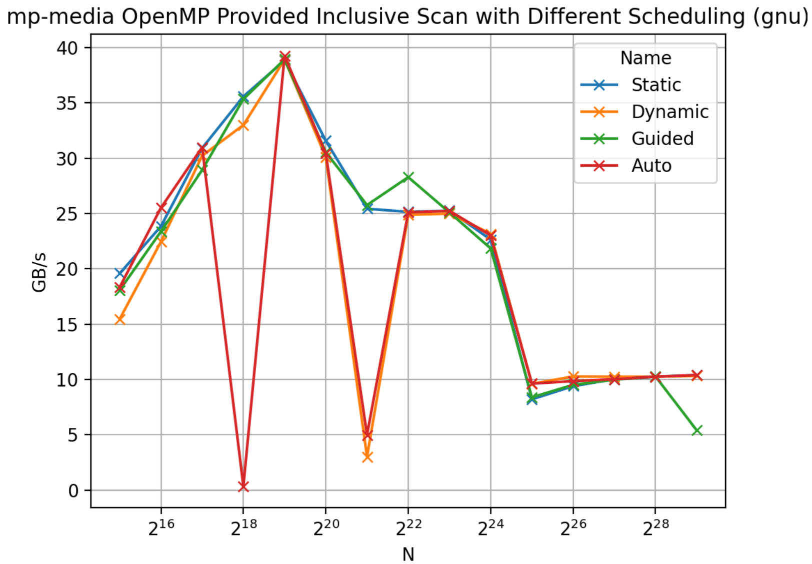
(c) Guided Scheduling

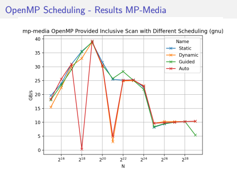
Fig. 1: Different Scheduling Strategies for 100 Iterations and 4 Threads



- Static: Round-robin
- Dynamic: Constant Chunk Size
- Guided: Variable Chunk Size
- Auto: Compiler and/or Runtime System
- Cache Fusion if:
- Export or during runtime

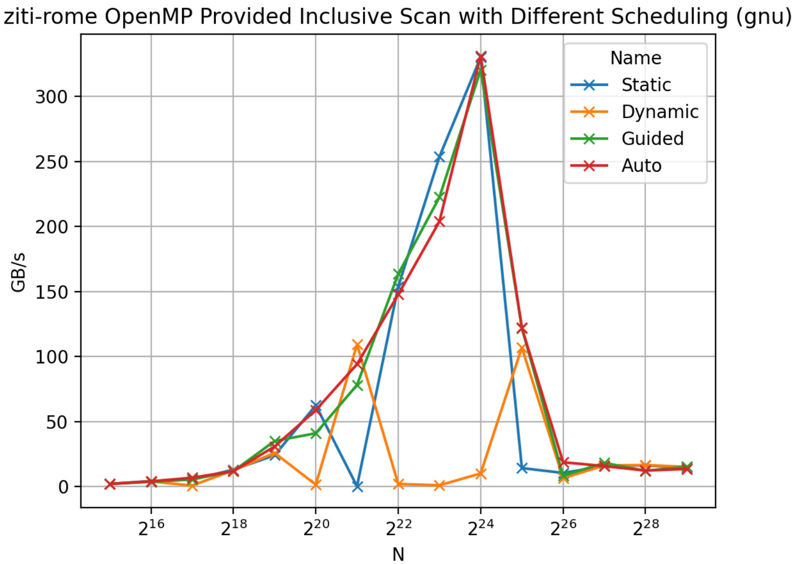
OpenMP Scheduling - Results MP-Media

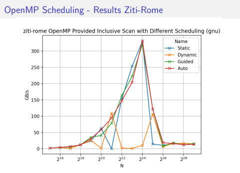




- Static and Guided perform best
- Expected due to overhead

OpenMP Scheduling - Results Ziti-Rome





- More severe difference
- Static least overhead
- Static Bound size and Distribution of Work
- => Static best

TBB Partitioning

TBB parallel constructs used:

- parallel_scan
- parallel_for

available partitioners:

- auto_partitioner
- affinity_partitioner
- simple_partitioner
- static_partitioner

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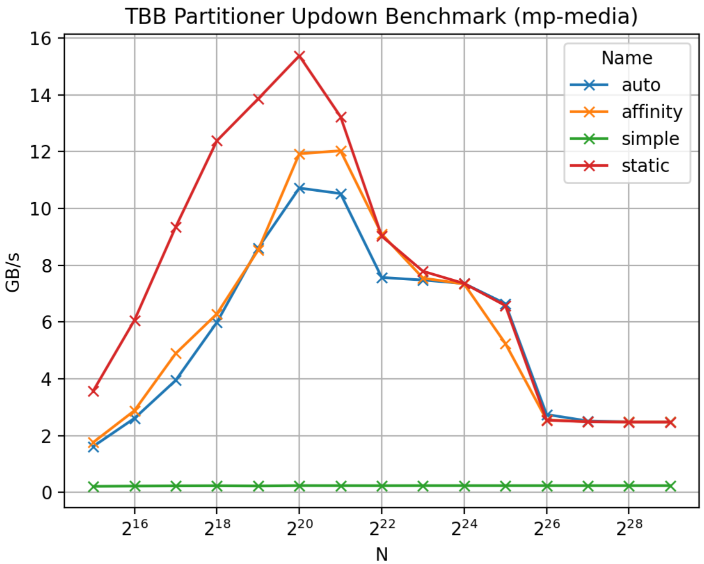
Performance (inclusive scan)



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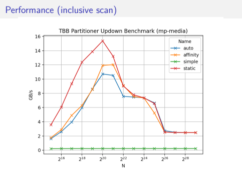
└Optimizations
└Performance (inclusive scan)



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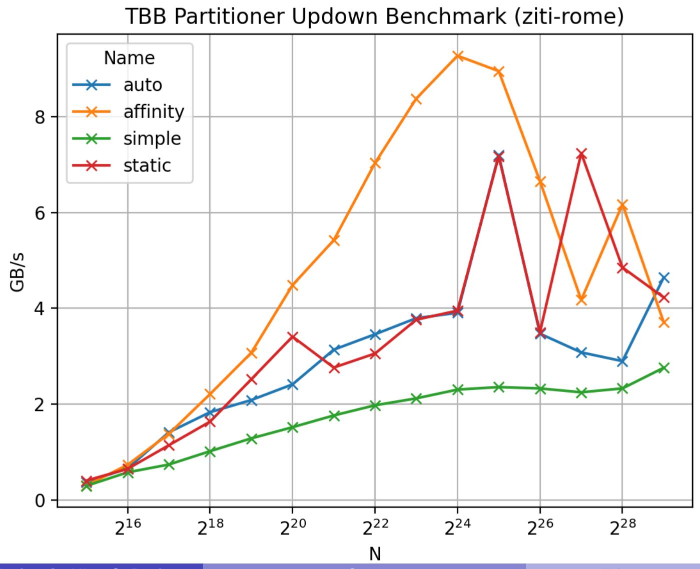

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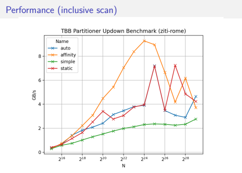

Vectorization

Requirements:

- No loop carried dependency
- Loop bounds
- No jumps in code

Realising it:

- #pragma omp simd
- Compiling with -O3
- Using Intel Icx Compiler

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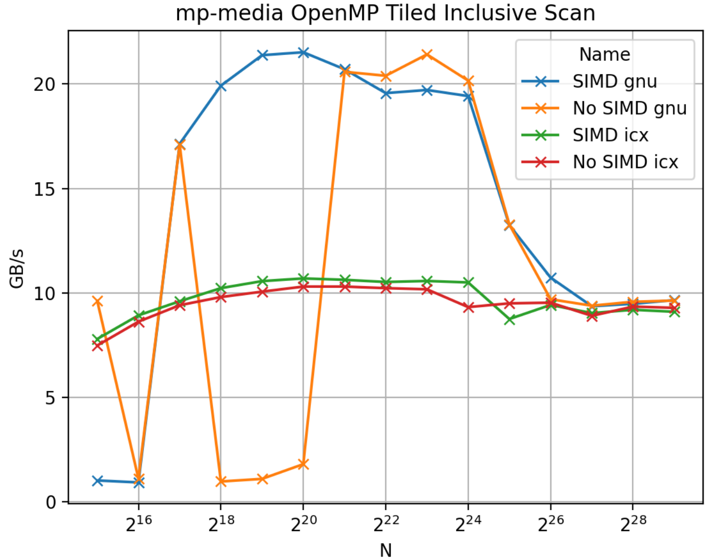
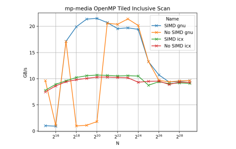
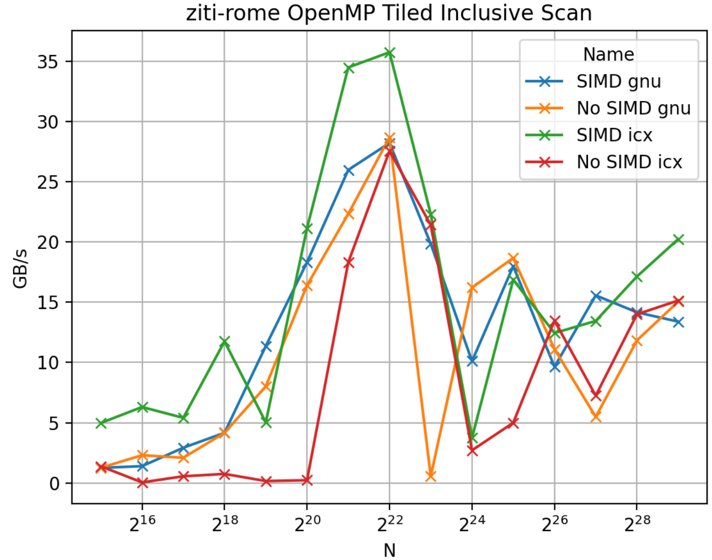


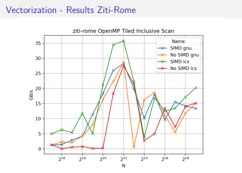
Vectorization - Results MP-Media



- Difference: Annotation of simd to loop
- Both compiled with -O3
- Possibly auto vectorization
- ICX much worse for MP-Media
- SIMD more stable

Vectorization - Results Ziti-Rome





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- ICX much better for ziti-rome
- SIMD better performance
- => SIMD

Summary

Library Provided Scans are fastest

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Optimization done:

- Algorithmic
- Data Locality
- Scheduler & Partitioner
- Vectorization

We have

- 4 versions of Scan
- 3 different algorithms
- 2 parallelization libraries + sequential

$\Rightarrow$ 36 Versions to keep track of!

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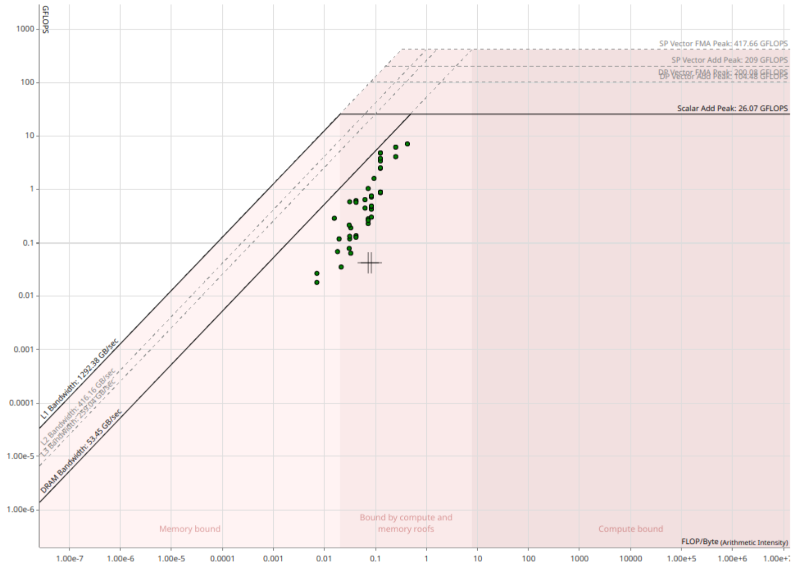
Roofline Mp-Media



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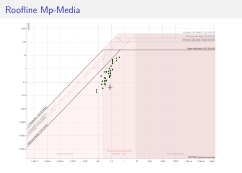
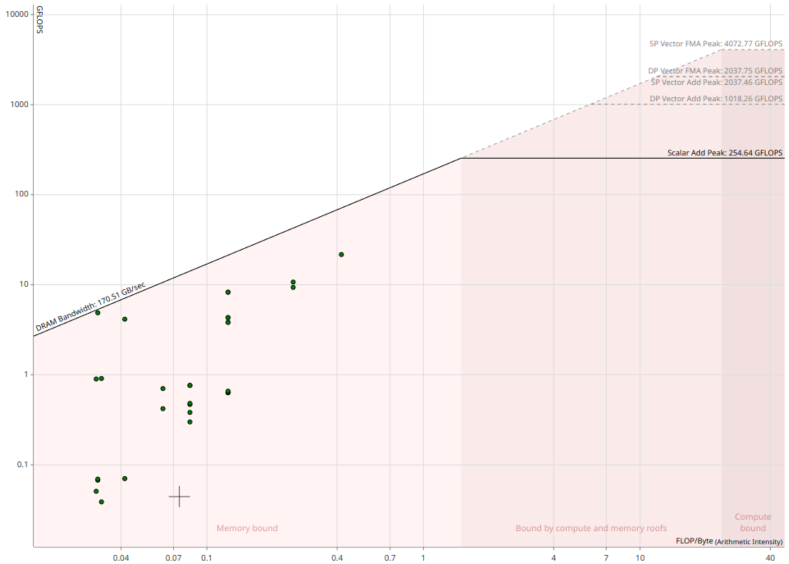


Roofline Ziti-Rome



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