Scan

Parallel Algorithm Design WS21/22

N. Kochendörfer, C. Alles, S. Proß

February 16, 2022

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3. Optimizations
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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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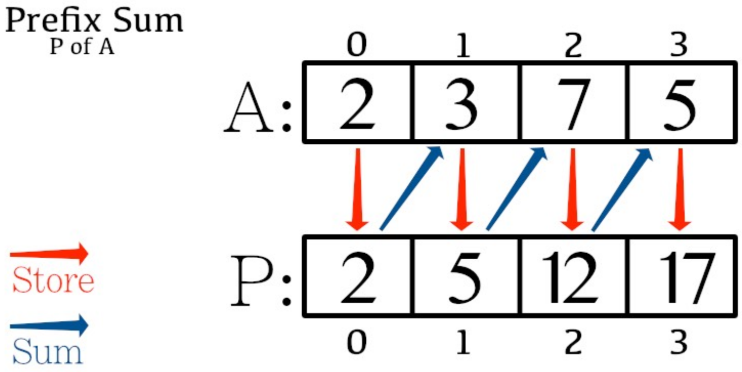
- inclusive and exclusive version
- further specialization: segmented scan

Inclusive Scan



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

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Scan
└Scan Theory
└Inclusive Scan

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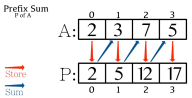
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inclusive vs. exclusive scan

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/

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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;
}
```

$\Rightarrow$ 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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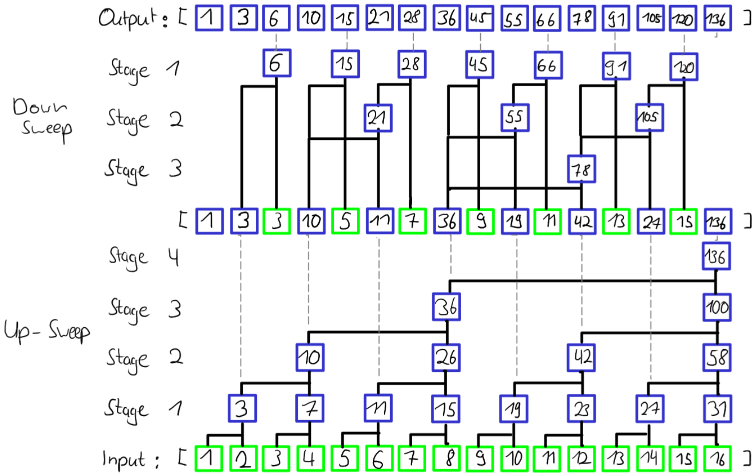
Up-Down Sweep

Schema Inclusive



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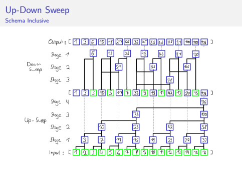
Scan
└Implementation
└Up-Down Sweep



Up-Down Sweep

Dependency:

- Only between stages

⇒ Lots of parallelism

Downsides:

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

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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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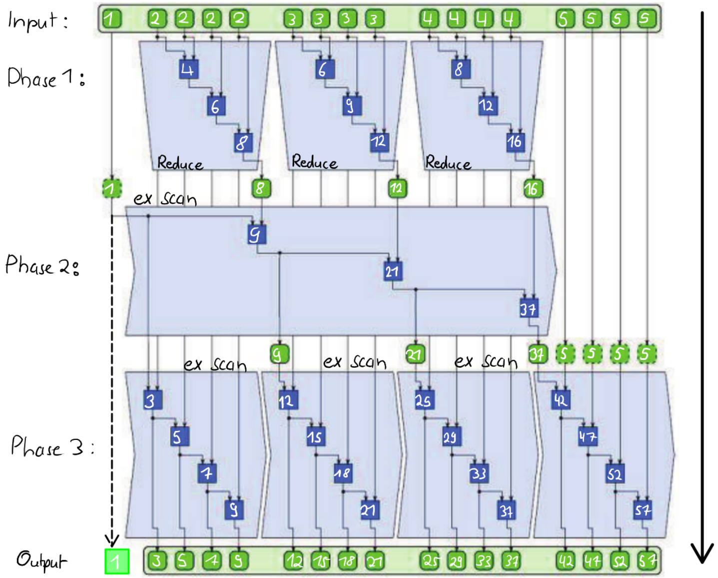
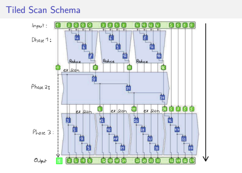
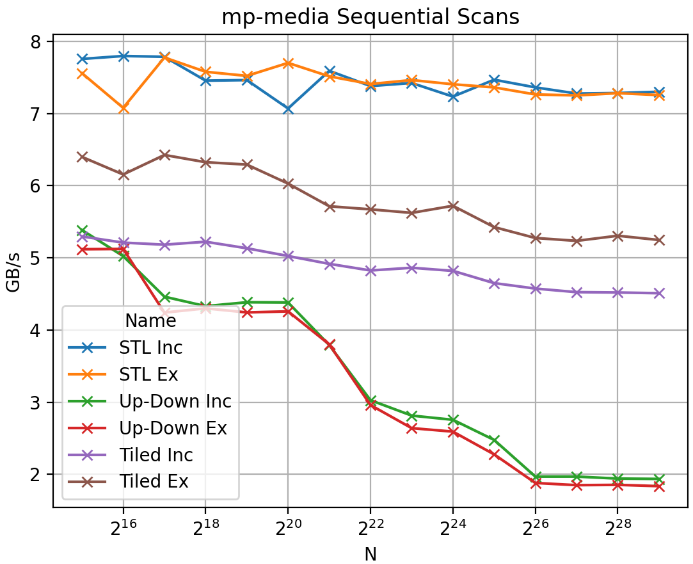
Tiled Scan Schema





Sequential Scan Results



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Scan
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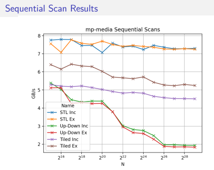

Segmented Scan
Implementation

- 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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Solution

Works for:

- STL Scans
- Most inclusive scans

Challenge: Exclusive Scan

- Exclusive Segmented is complex
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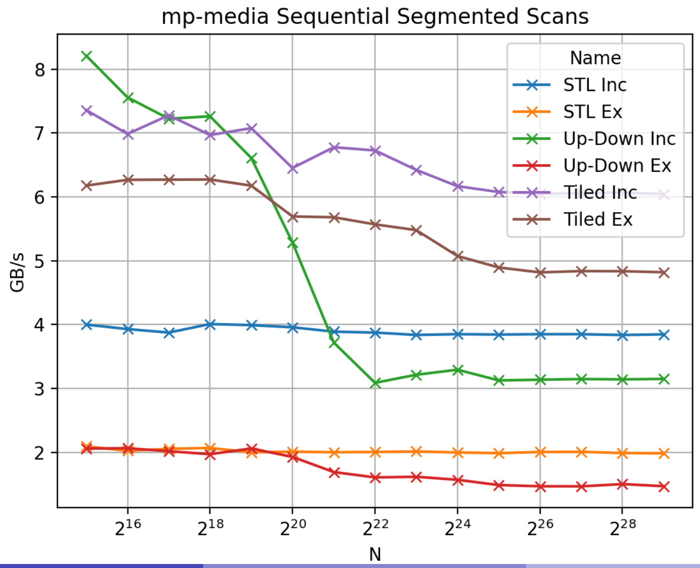

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Scan
└─Implementation
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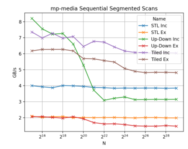
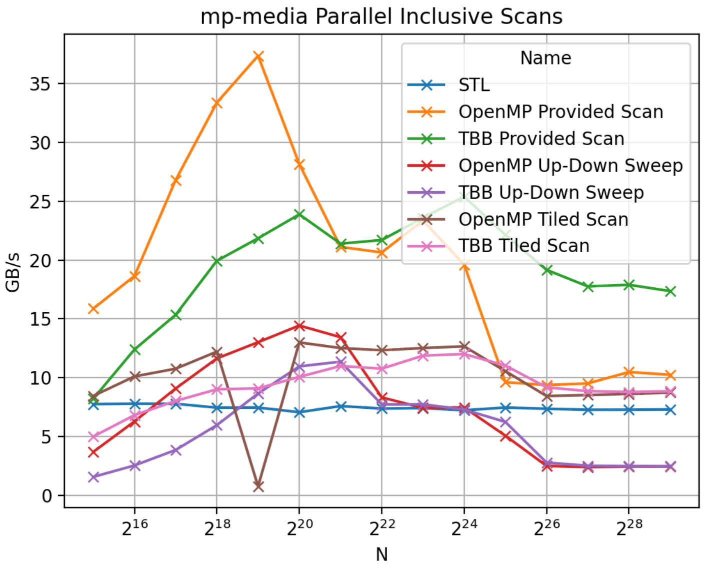
Sequential Segmented Scan Results



Parallel Scan Results



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Scan
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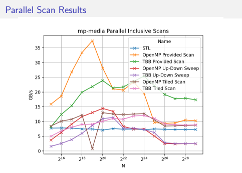
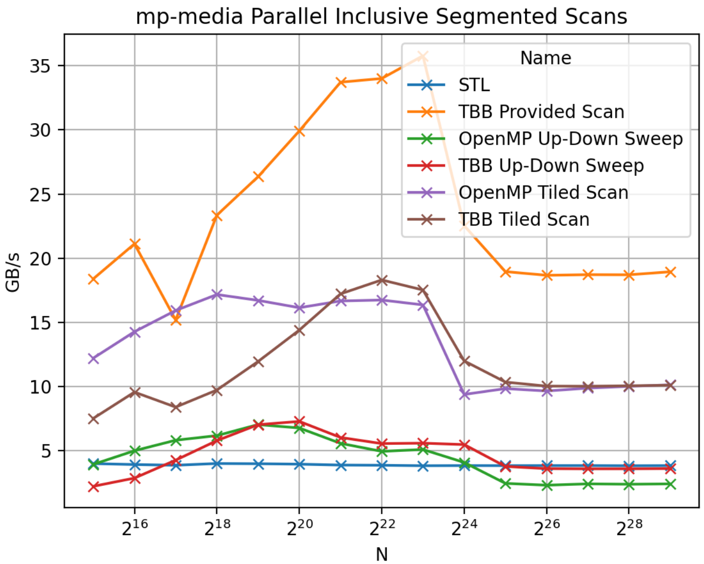
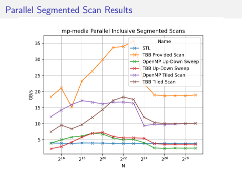


Parallel Segmented Scan Results





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++)
{
data[i] = rand();
}
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- The performance gain by using data local structures is likely to be small due to the warmup of Catch2

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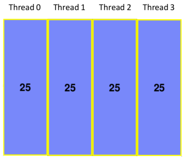
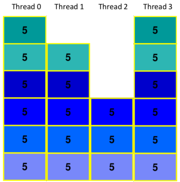
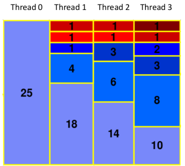
OpenMP Scheduling



(a) Static Scheduling

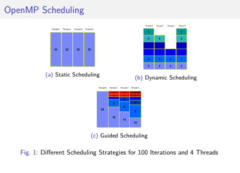


(b) Dynamic Scheduling



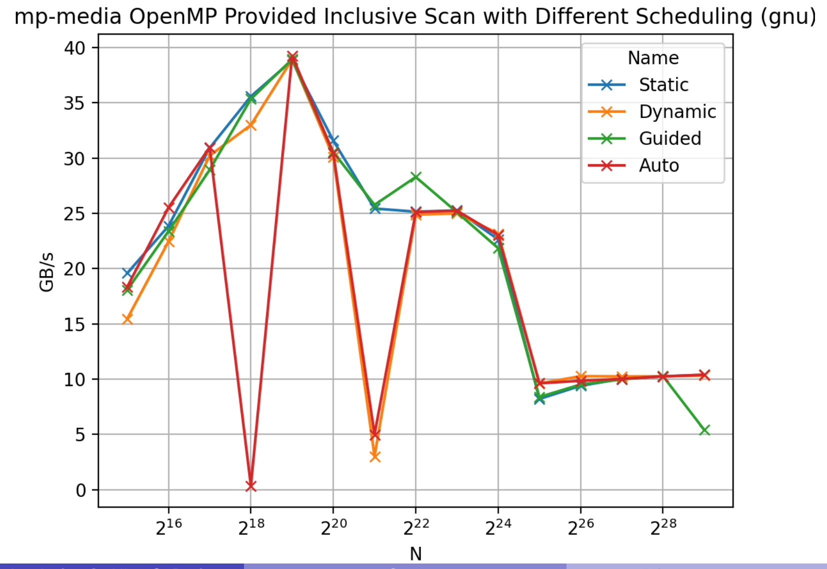
(c) Guided Scheduling

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:
  1. single parallel region executes all of the maps to be fused.
  2. The loop for each map has the same bounds and chunk size.
  3. Each loop uses the static scheduling mode, either as implied by the environment or explicitly specified.
- Export or during runtime

OpenMP Scheduling - Results MP-Media



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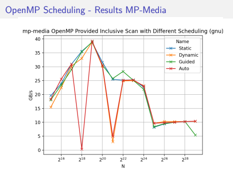
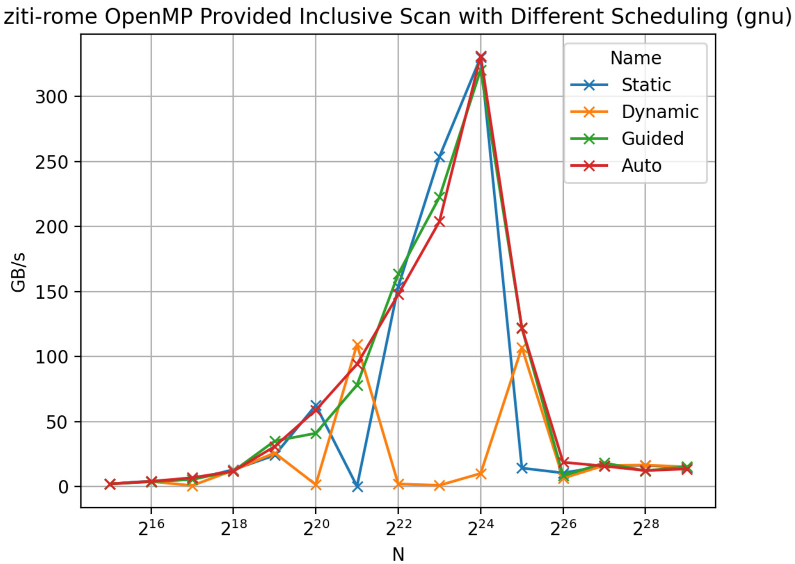


- Static and Guided perform best
- Expected due to overhead

OpenMP Scheduling - Results Ziti-Rome



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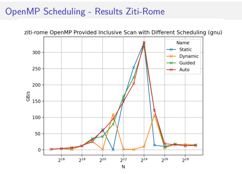

- More severe difference
- Static least overhead
- Static Bound size and Distribution of Work
- => Static best

TBB Partitioning

TBB parallel constructs used:

- parallel_scan
- parallel_for

available partitioners:

- auto_partitioner
- affinity_partitioner
- simple_partitioner
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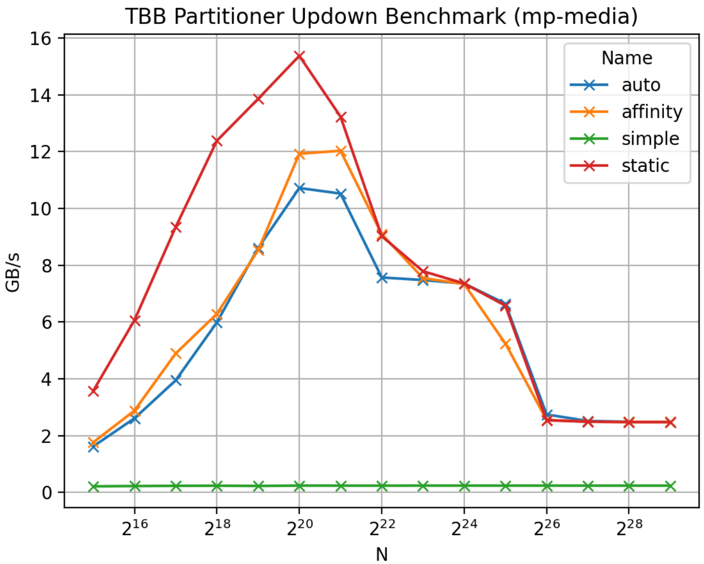
Performance (inclusive scan)



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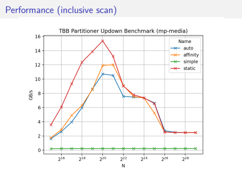

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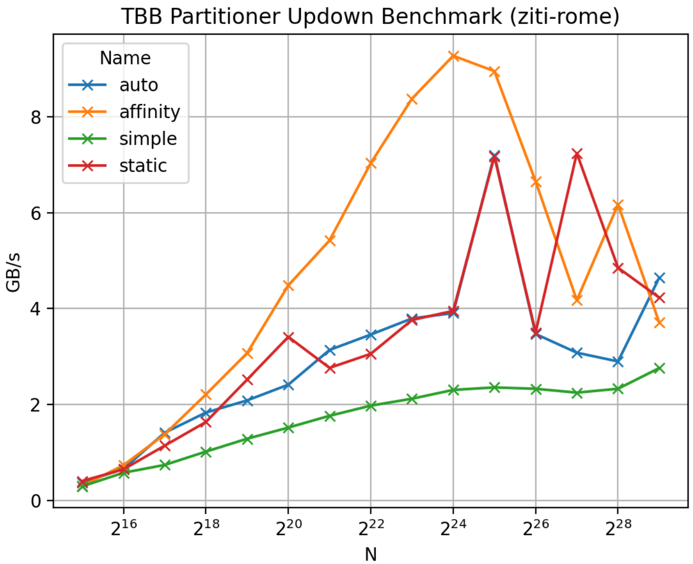

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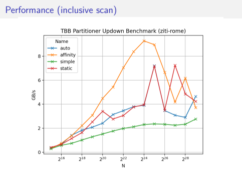

Vectorization

Requirements:

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

Realising it:

- #pragma omp simd
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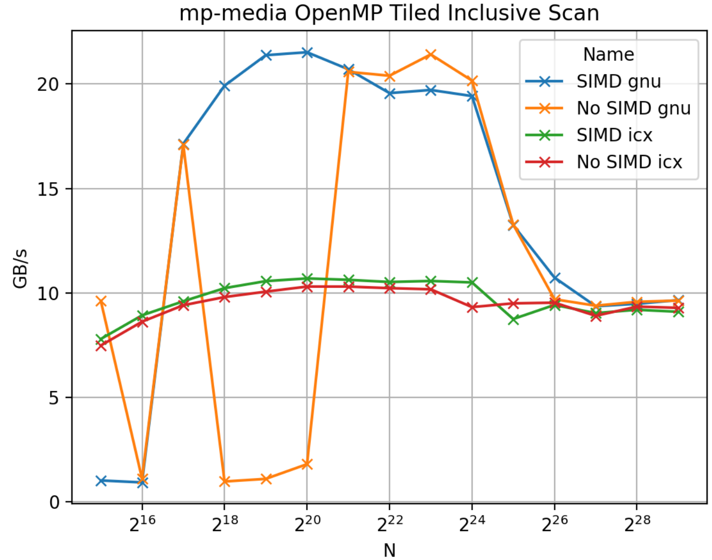
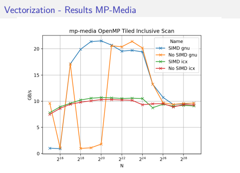
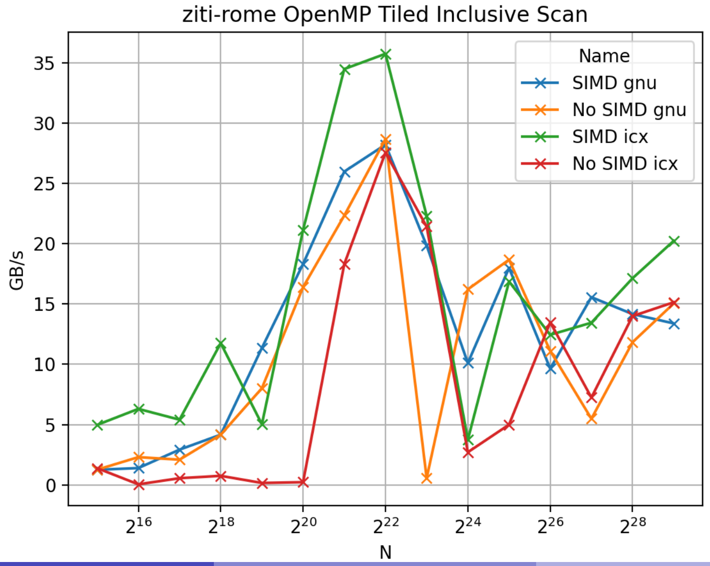
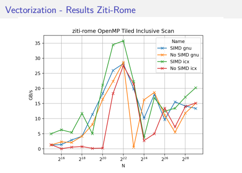




- Difference: Annotation of simd to loop
- Both compiled with -O3
- Possibly auto vectorization
- ICX much worse for MP-Media
- SIMD more stable

Vectorization - Results Ziti-Rome





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- 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

⇒ 36 Versions to keep track of!

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