Scan

Parallel Algorithm Design WS21/22

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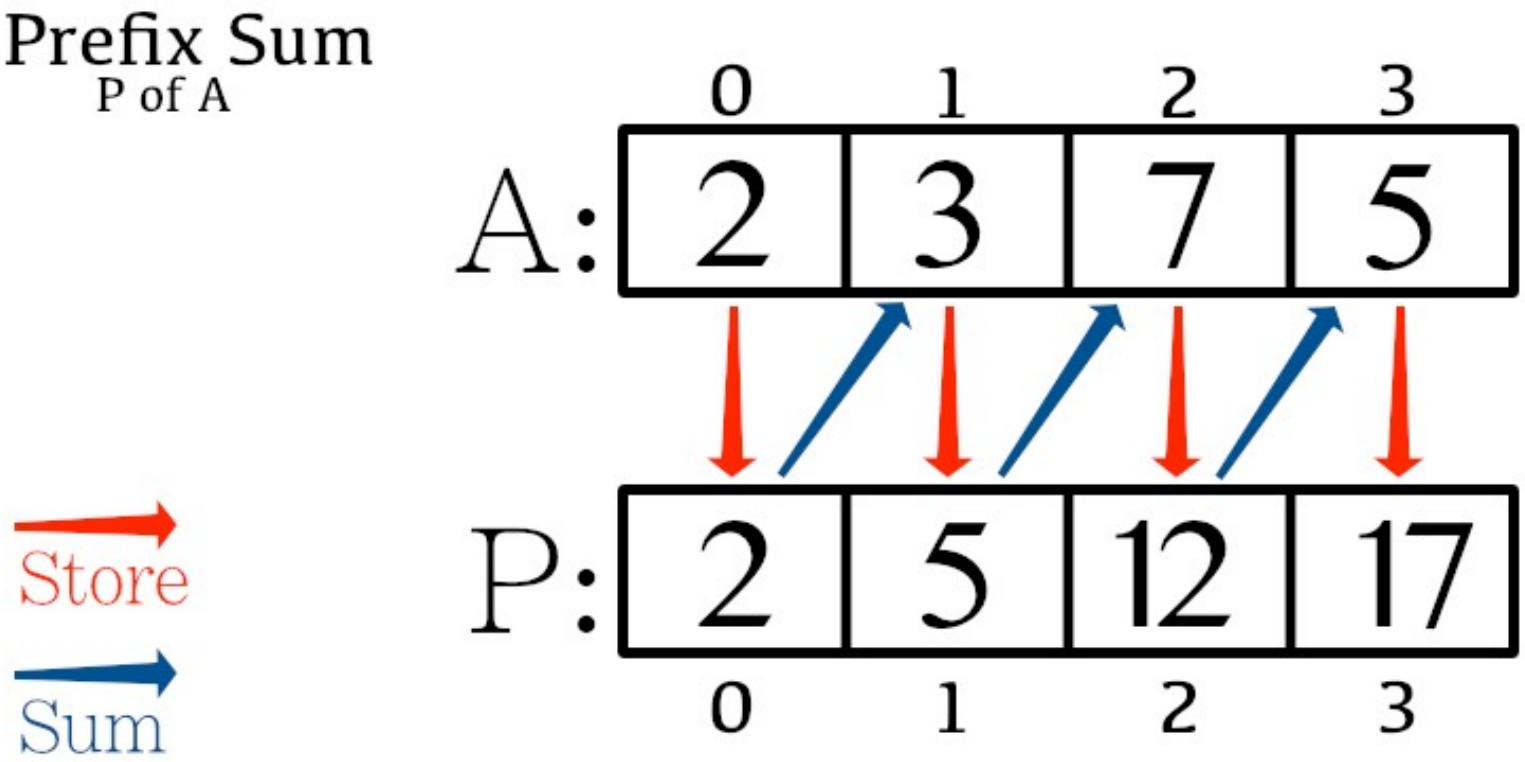
Scan Theory

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

Inclusive Scan



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

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/

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

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!

Implementation

Alternatives

Alternatives to STL:

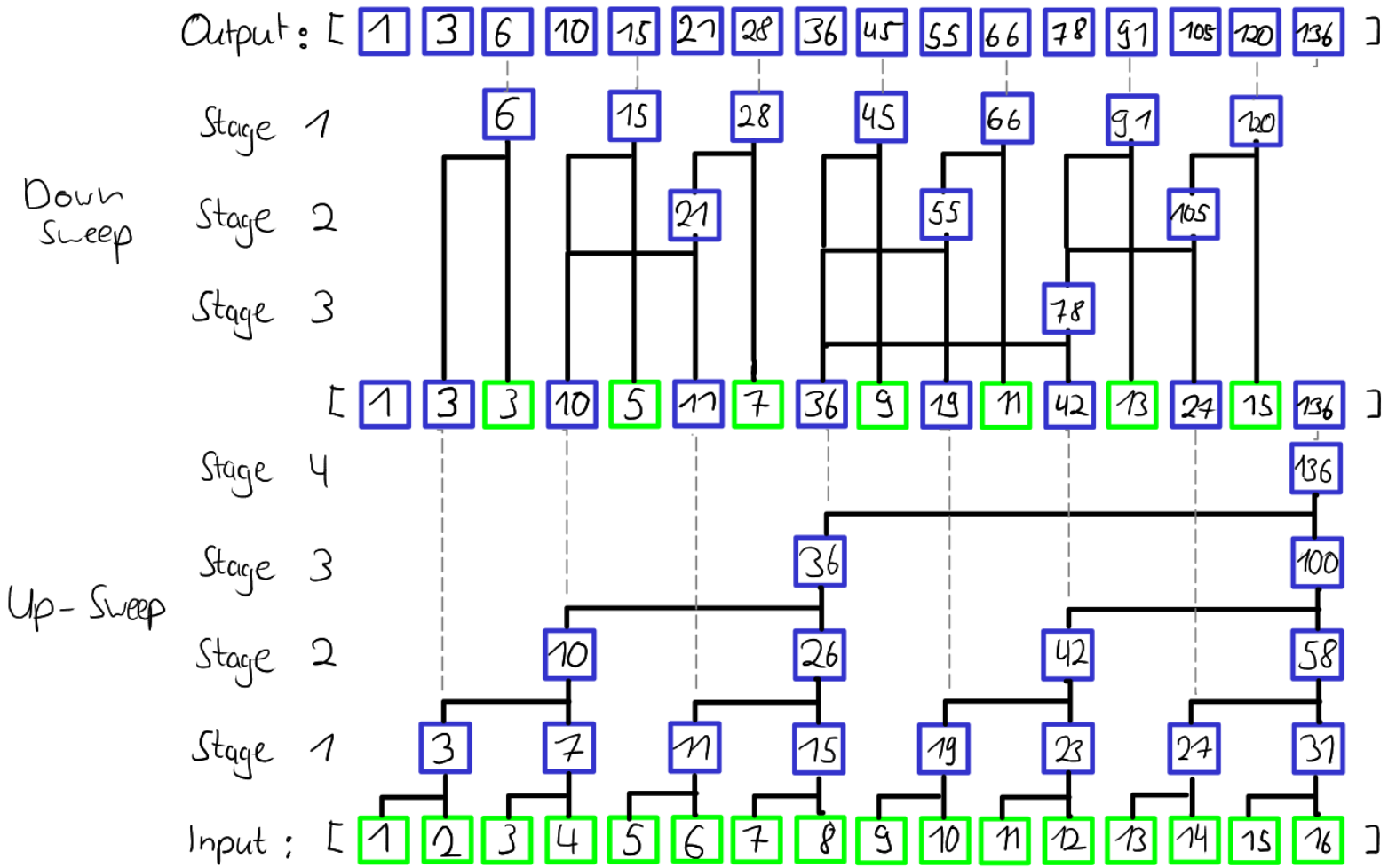
- OpenMP: scan pragma
- TBB: parallel_scan function

Alternative Algorithms:

- Up-Down Sweeping Scan
- Tiled Scan

Up-Down Sweep

Schema Inclusive



Up-Down Sweep

Dependency:

- Only between stages

$\Rightarrow$ Lots of parallelism

Downsides:

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

Tiled Scan

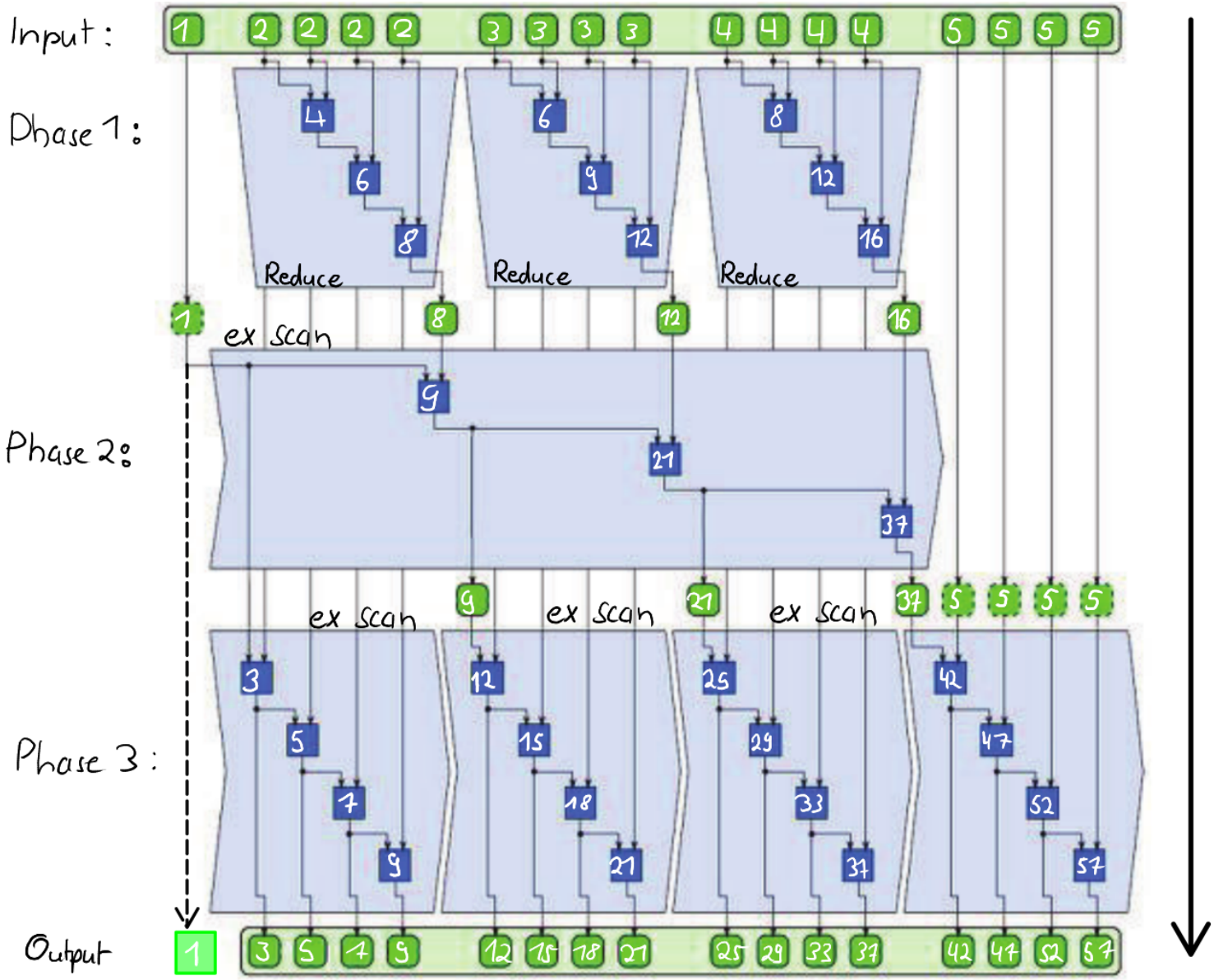
Idea: Process input in independent chunks.

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

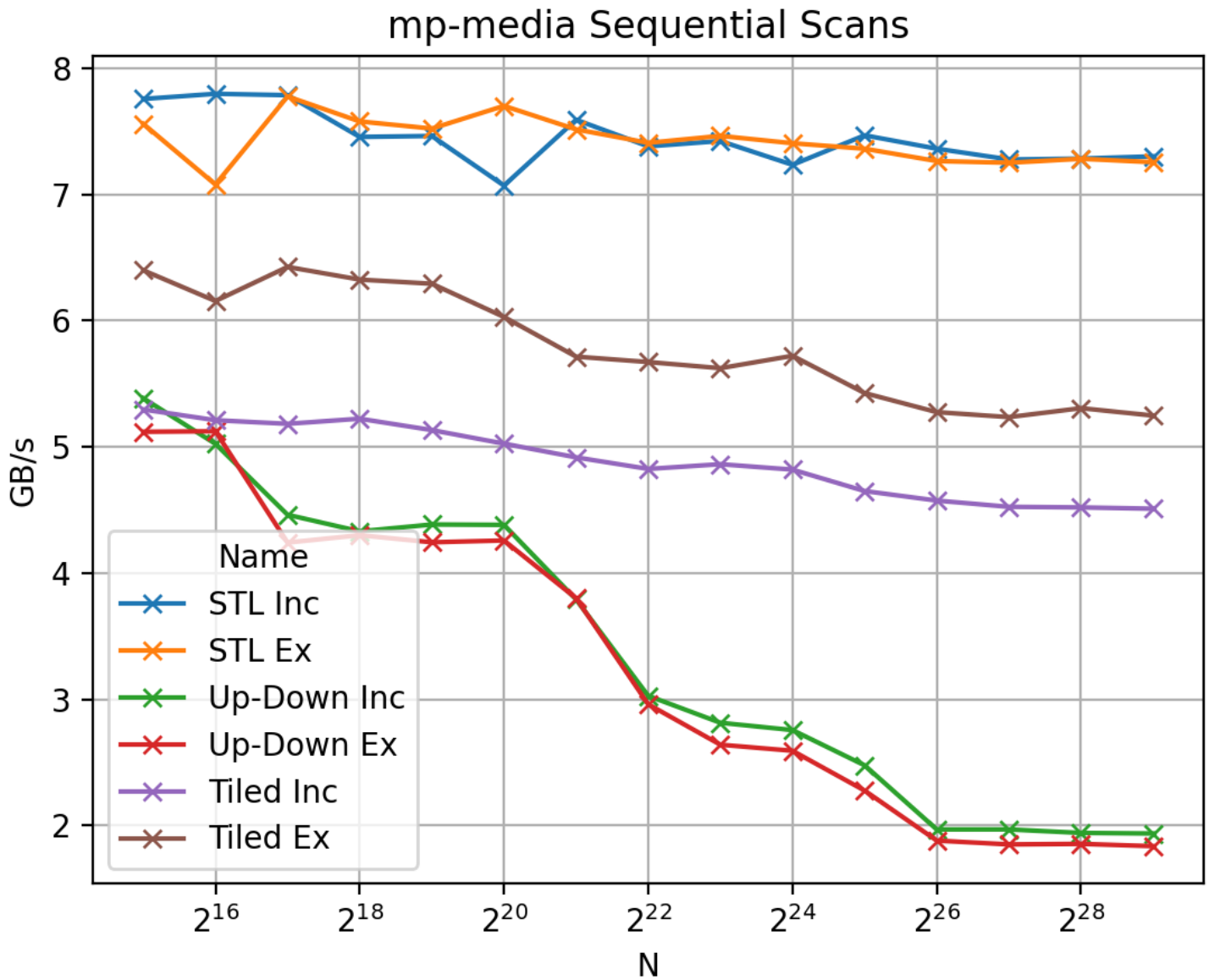
Our solution:

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

Tiled Scan Schema



Sequential Scan Results



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;
});
```

Segmented Scan

Solution

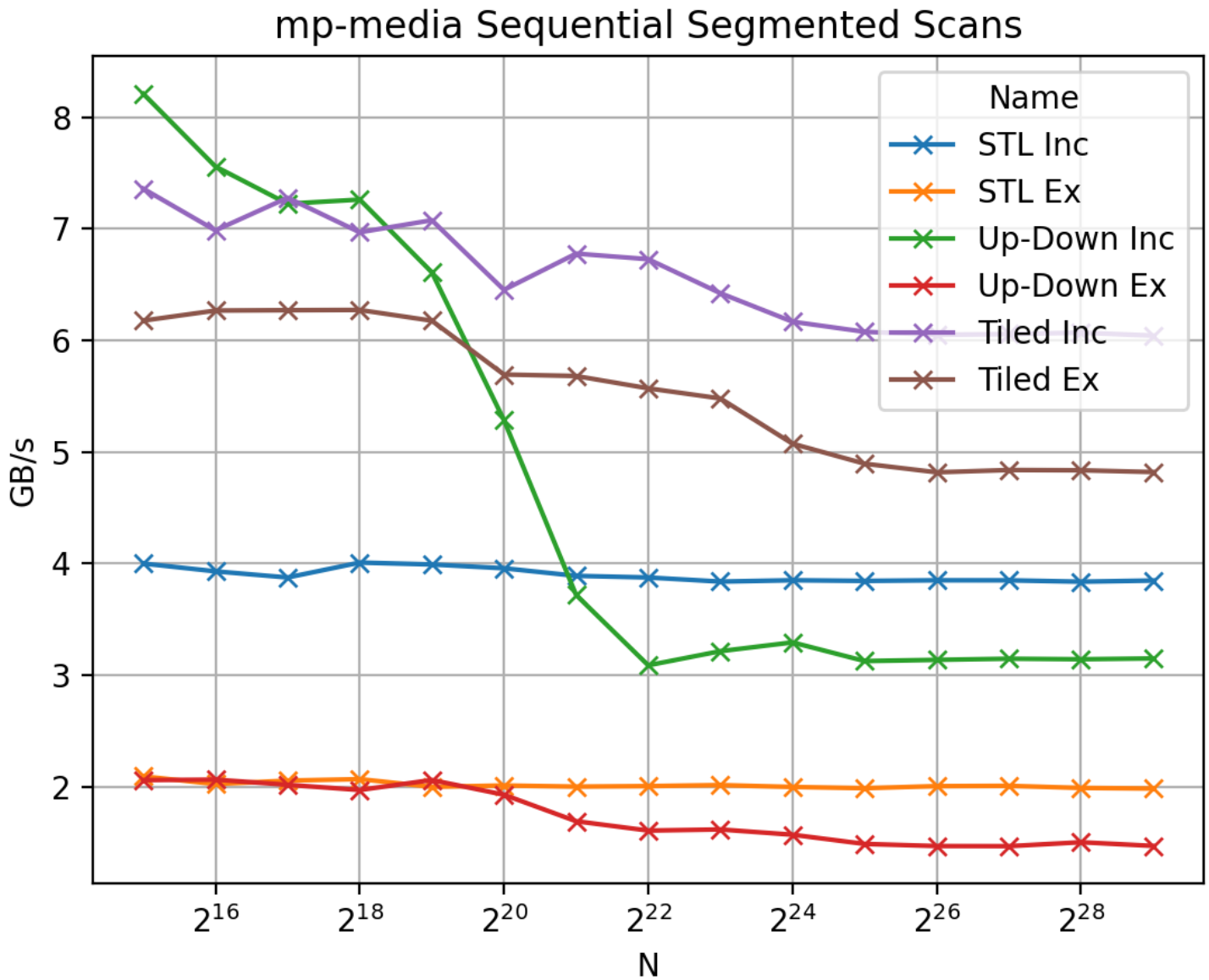
Works for:

- STL Scans
- Most inclusive scans

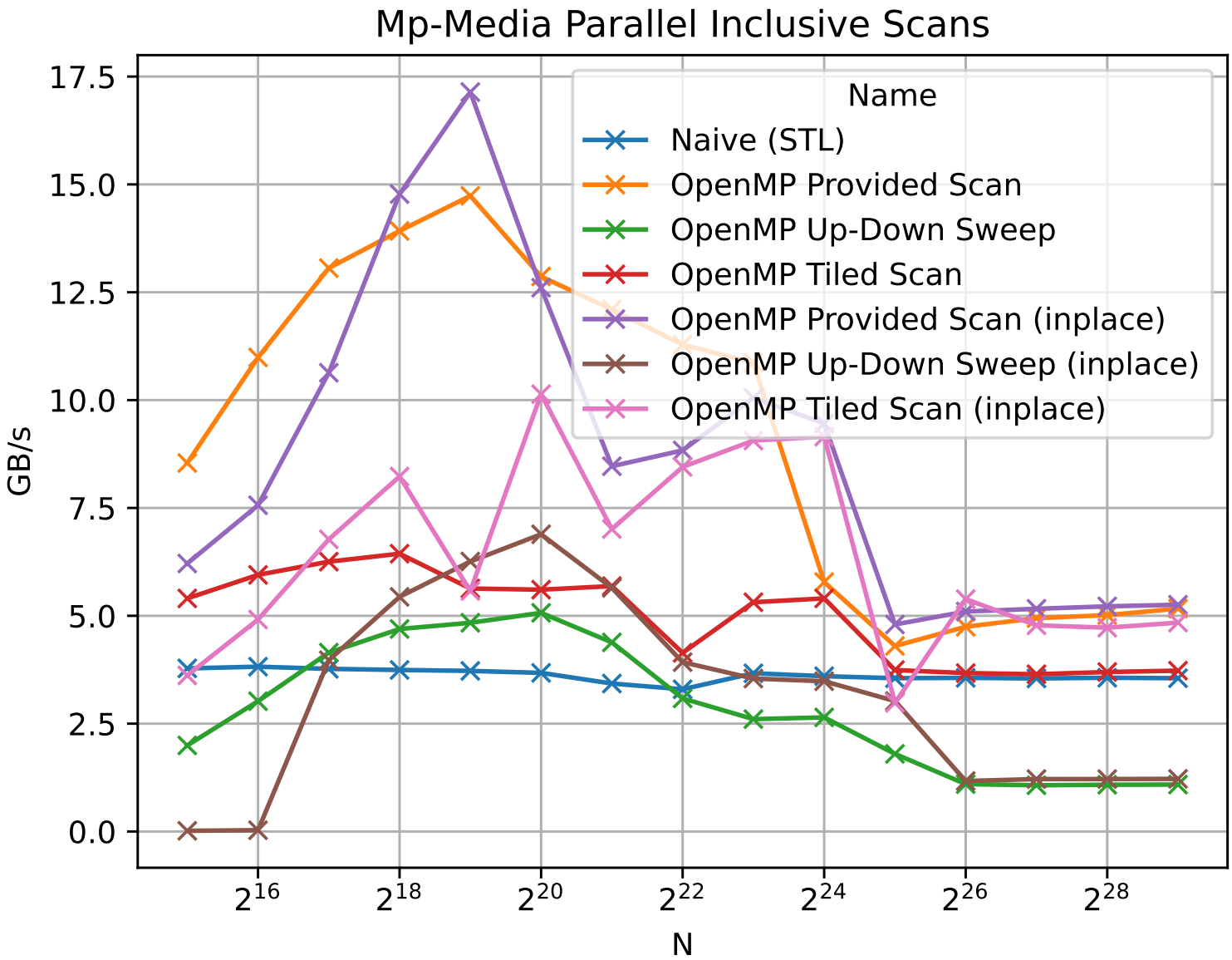
Challenge: Exclusive Scan

- Exclusive Segmented is complex
- Custom solution for each variant

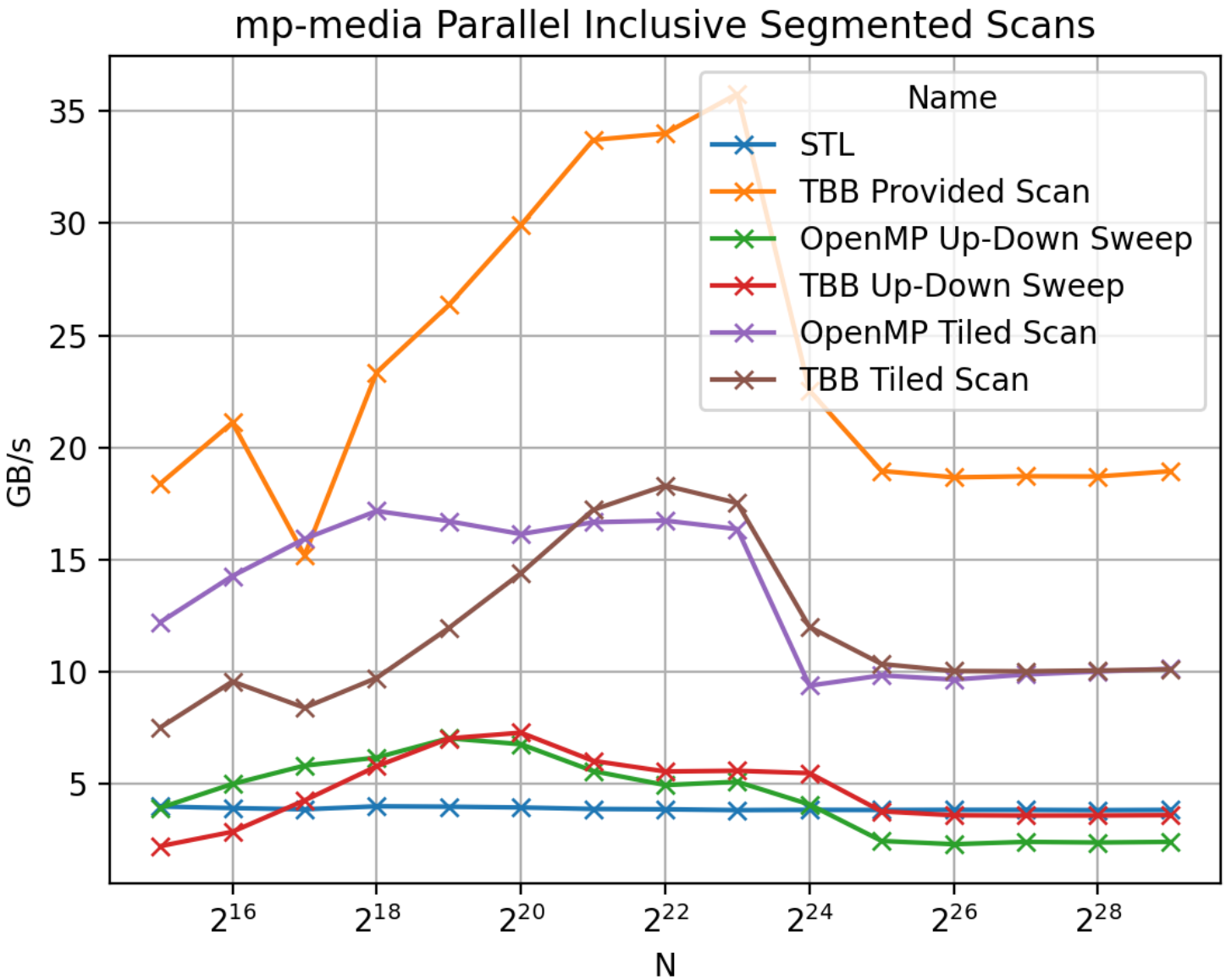
Sequential Segmented Scan Results



Parallel Scan Results



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?

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!

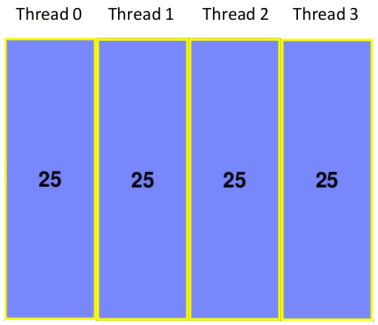
Data Locality

Ensure that the data generated is local to the node:

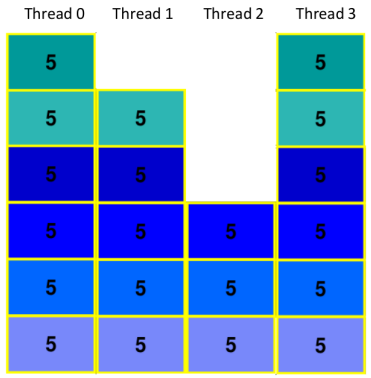
```
std::vector<float> data(N);
#pragma omp parallel for schedule(static)
for (size_t i = 0; i < data.size(); i++)
{
data[i] = rand();
}
```

- The performance gain by using data local structures is likely to be small due to the warmup of Catch2

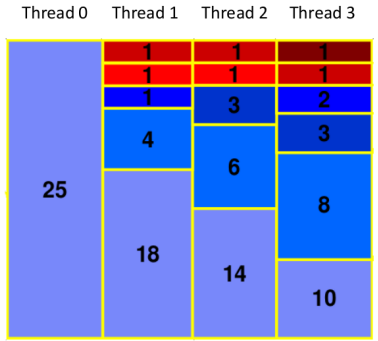
OpenMP Scheduling



(a) Static Scheduling



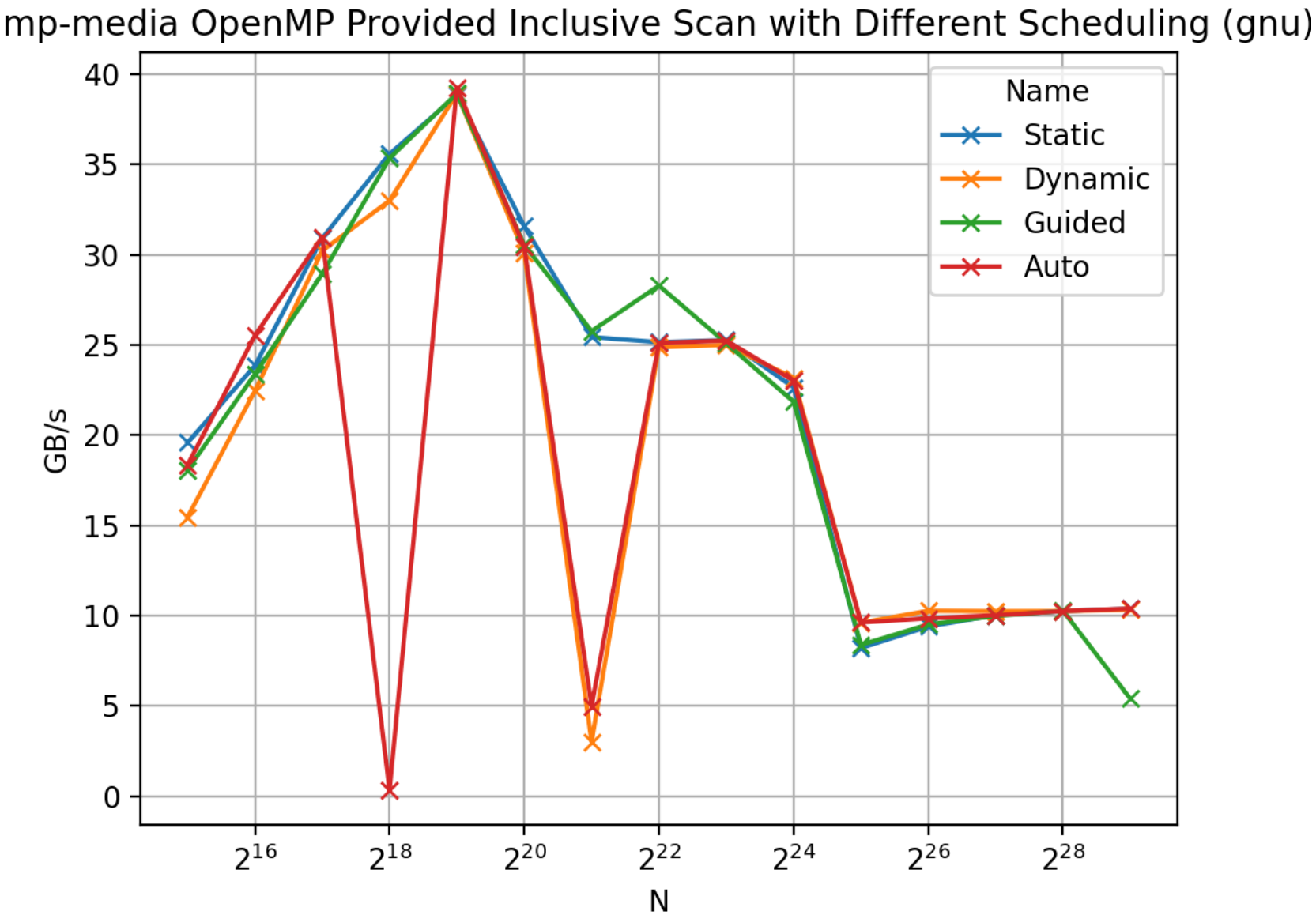
(b) Dynamic Scheduling



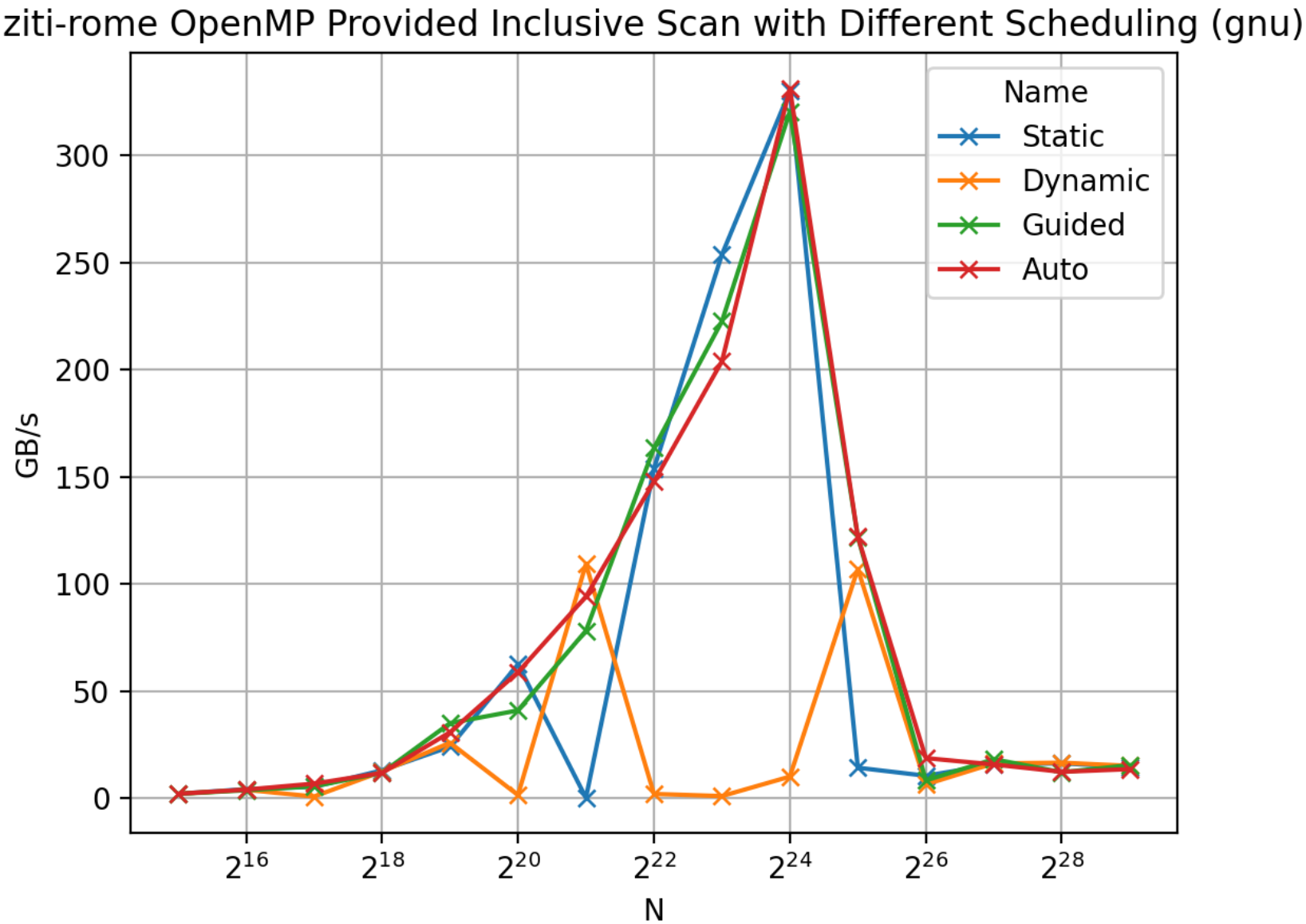
(c) Guided Scheduling

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

OpenMP Scheduling - Results MP-Media



OpenMP Scheduling - Results Ziti-Rome



TBB Partitioning

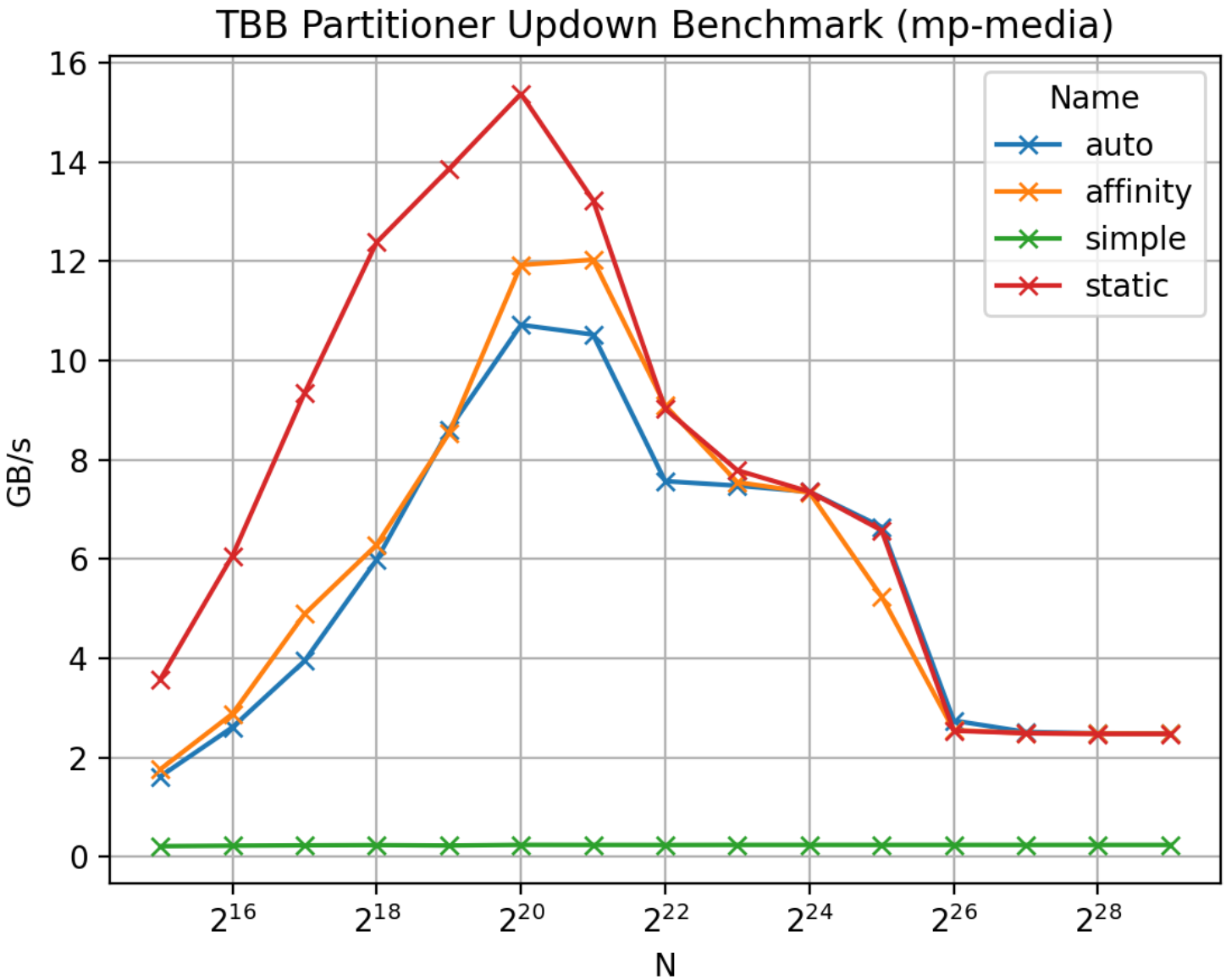
TBB parallel constructs used:

- parallel_scan
- parallel_for

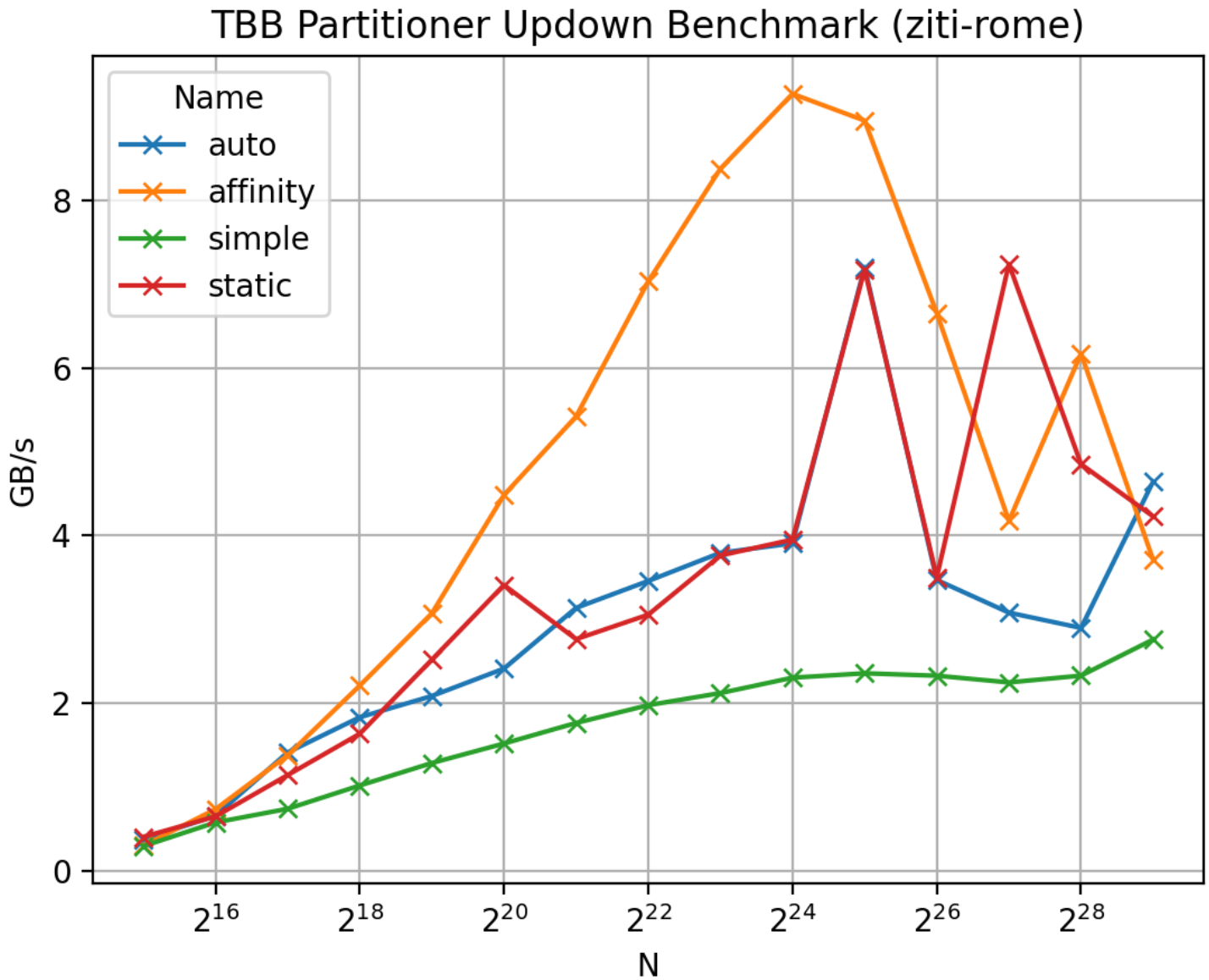
available partitioners:

- auto_partitioner
- affinity_partitioner
- simple_partitioner
- static_partitioner

Performance (inclusive scan)



Performance (inclusive scan)



Vectorization

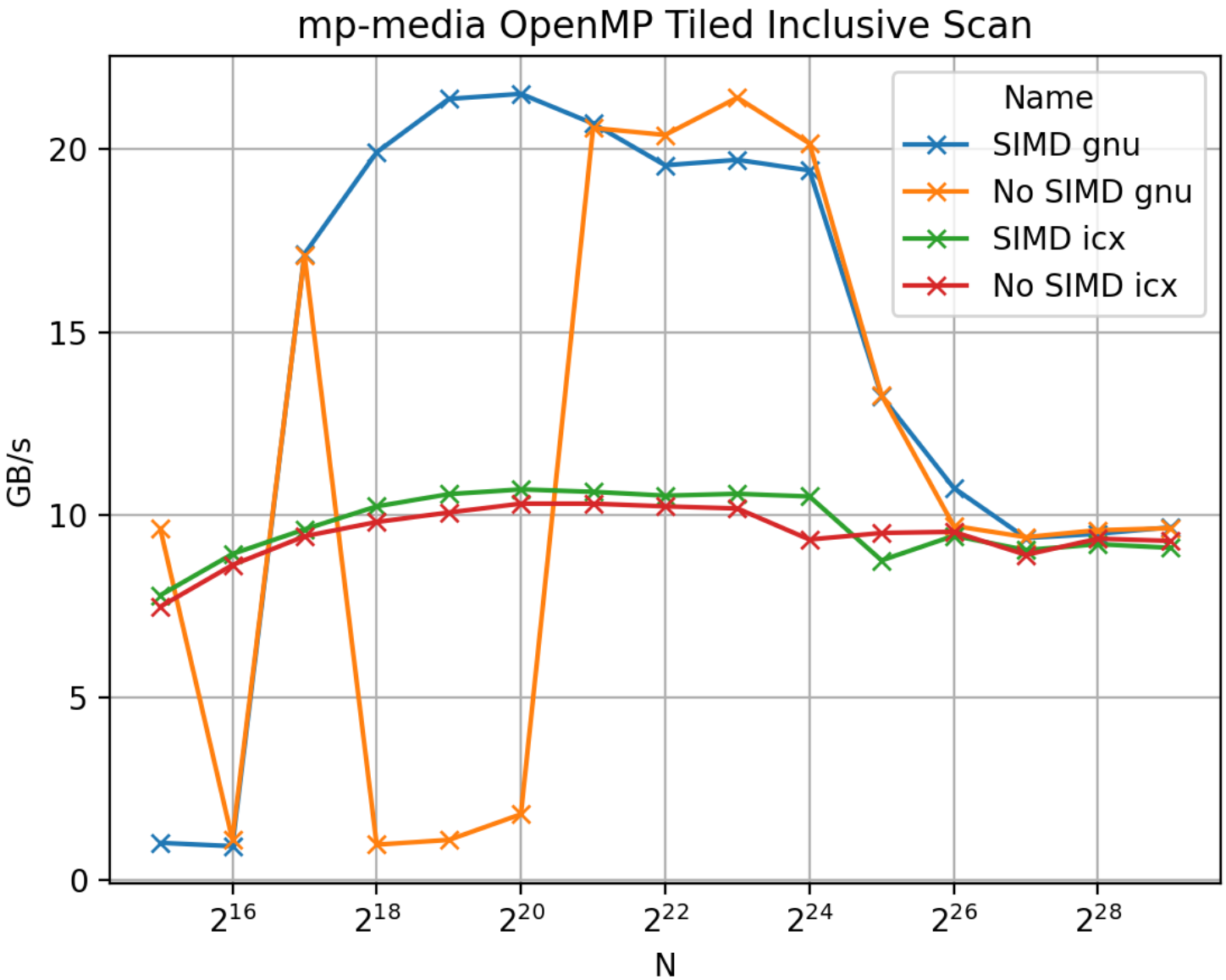
Requirements:

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

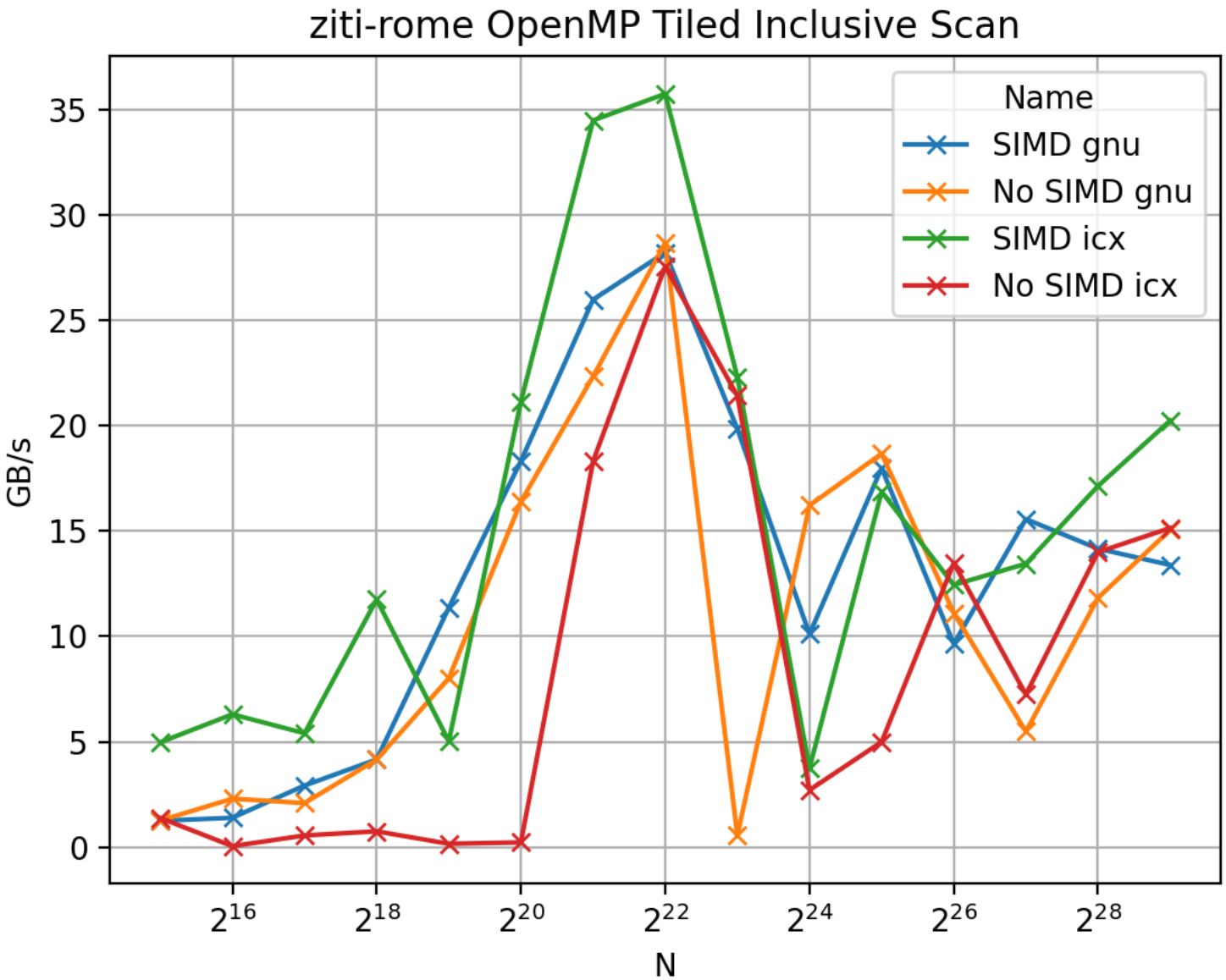
Realising it:

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

Vectorization - Results MP-Media



Vectorization - Results Ziti-Rome



Summary

Library Provided Scans are fastest

Summary

Library Provided Scans are fastest

Optimization done:

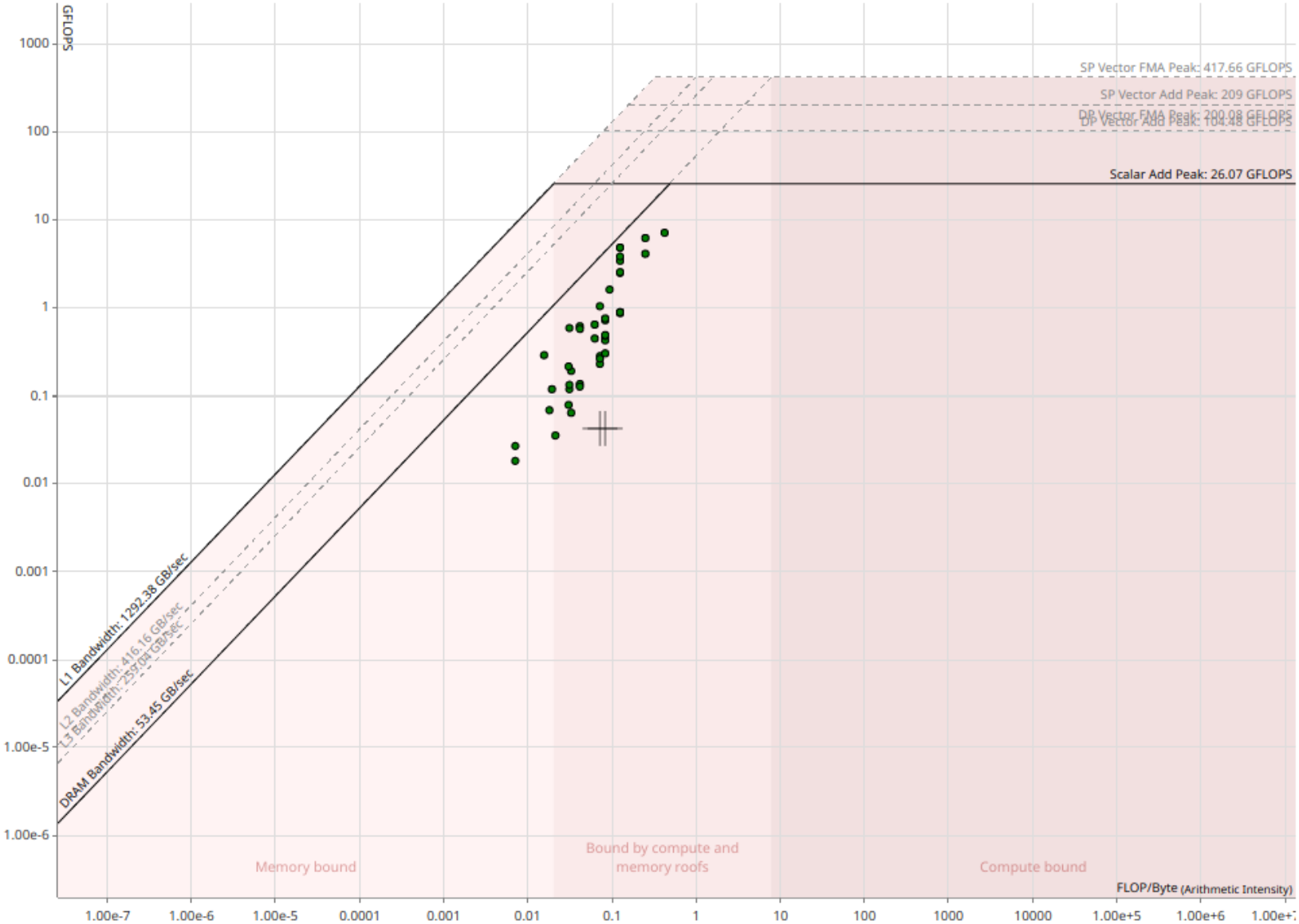
- Algorithmic
- Data Locality
- Scheduler & Partitioner
- Vectorization

We have

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

$\Rightarrow$ 36 Versions to keep track of!

Roofline Mp-Media



Roofline Ziti-Rome