Microbenchmarking for architectural exploration

Probing of the memory hierarchy

Saturation effects

Motivation for Microbenchmarking as a tool

- Isolate small kernels to:
  - Separate influences
  - Determine specific machine capabilities (light speed)
  - Gain experience about software/hardware interaction
  - Determine programming model overhead
  - …
- Possibilities:
  - Readymade benchmark collections (epcc OpenMP, IMB)
  - STREAM benchmark for memory bandwidth
  - Implement own benchmarks (difficult and error prone)
  - **`likwid-bench`** tool: Offers collection of benchmarks and framework for rapid development of assembly code kernels

The parallel vector triad benchmark - *A “swiss army knife” for microbenchmarking*

```
double striad_seq(double* restrict a, double* restrict b, double* restrict c,
double* restrict d, int N, int iter) {
    double S, E;
    S = getTimeStamp();
    for(int j = 0; j < iter; j++) {
#pragma vector aligned
        for (int i = 0; i < N; i++) {
            a[i] = b[i] + d[i] * c[i];
        }
        if (a[N/2] > 2000) printf("Ai = %f\n",a[N-1]);
    }
    E = getTimeStamp();
    return E-S;
}
```

Required to get optimal code with Intel compiler icc! New icx unclear

Keeps smarty-pants compilers from doing “clever” stuff

- Report performance for different **`N`**, choose **`iter`** so that accurate time measurement is possible
- This kernel is limited by data transfer performance for all memory levels on all architectures, ever!

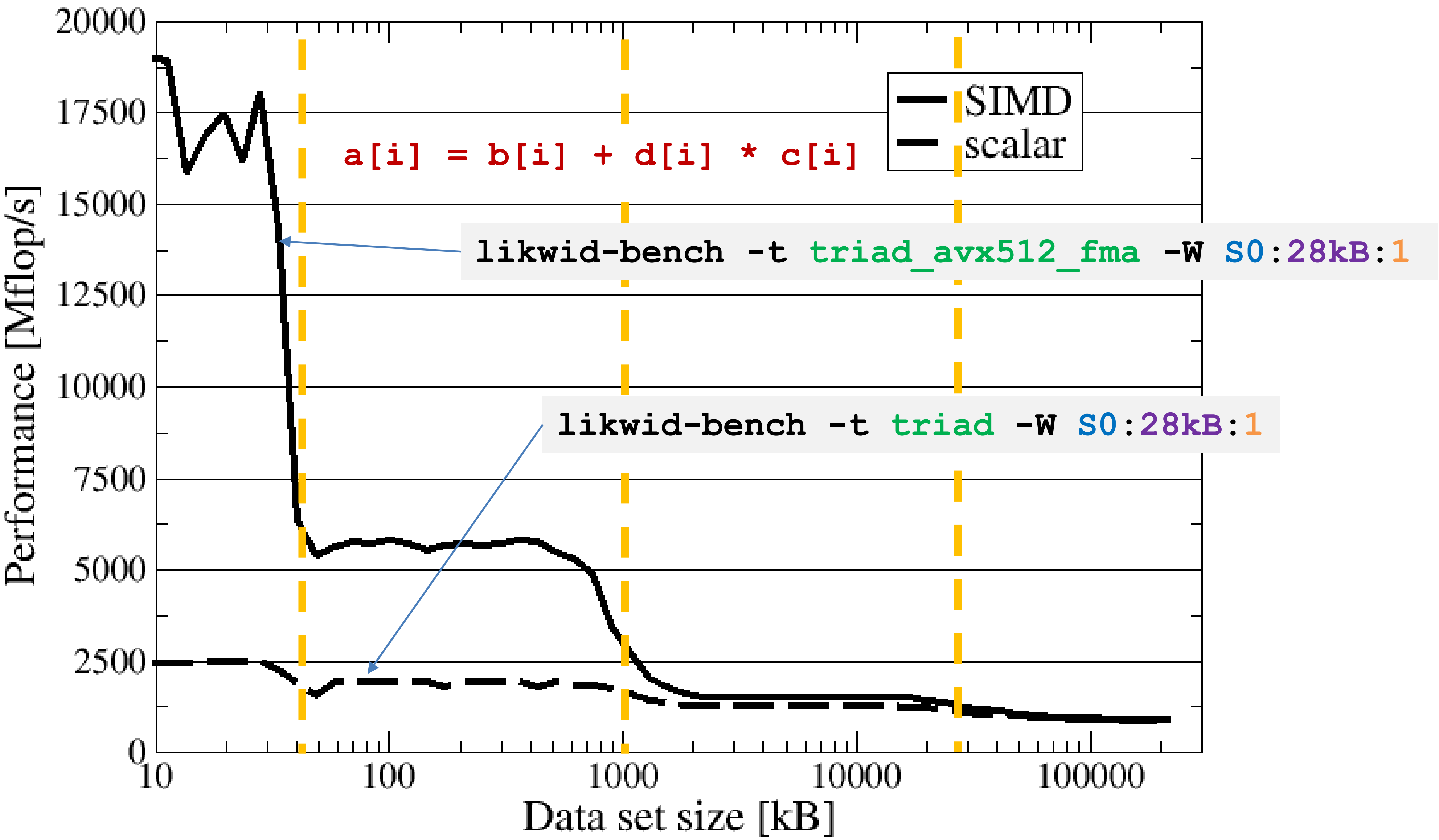
A better way – use a microbenchmarking tool

- Microbenchmarking in high-level language is often difficult
- Solution: assembly-based microbenchmarking framework
  - e.g., **`likwid-bench`**

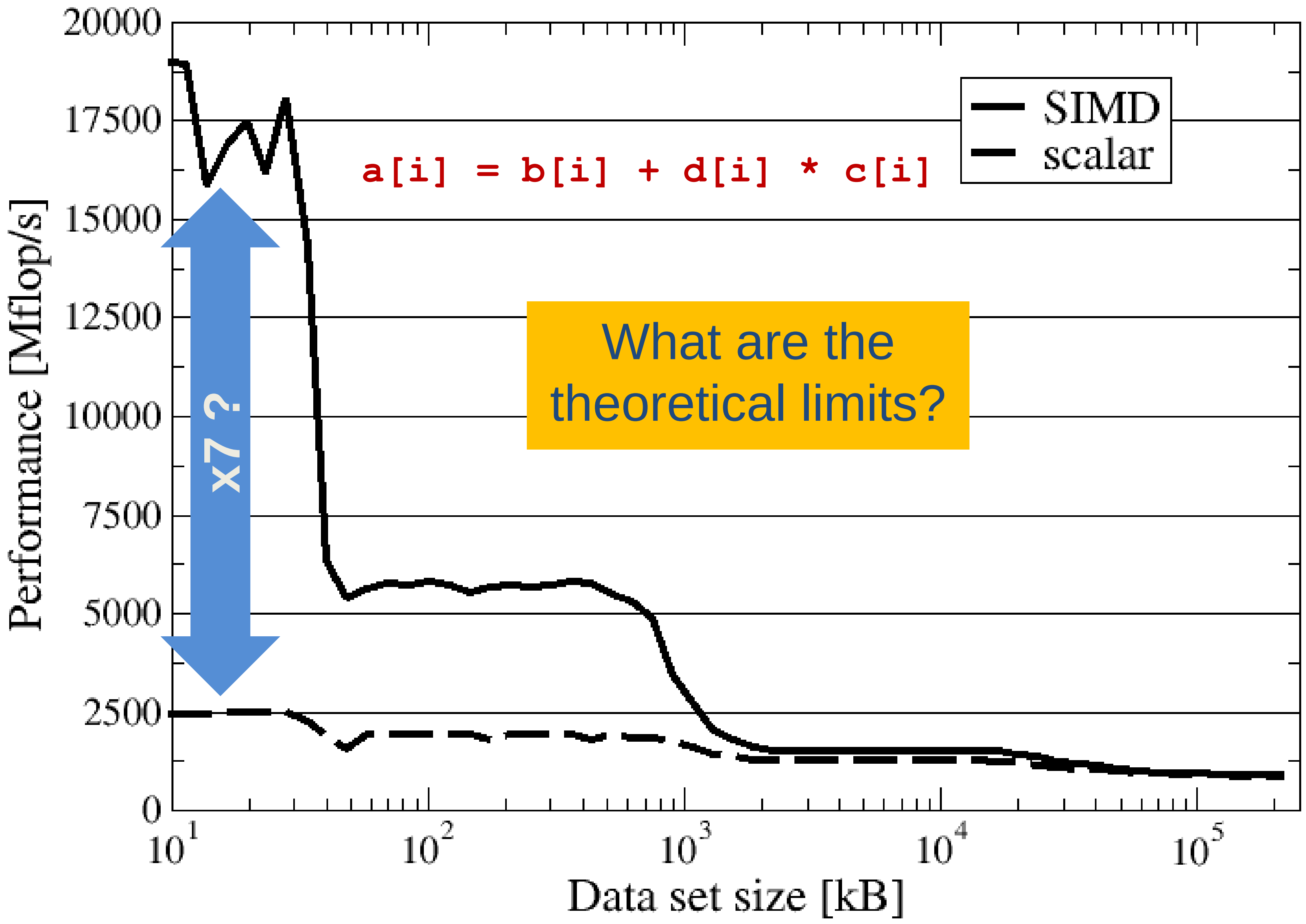
```
$ likwid-bench -t triad_avx512_fma -W S0:28kB:1
```

benchmark type
topological entity (see likwid-pin)
working set
# of threads

Schönauer triad on **one** CascadeLake **core** 2.5GHz



Schönauer triad on **one** CascadeLake **core** 2.5GHz

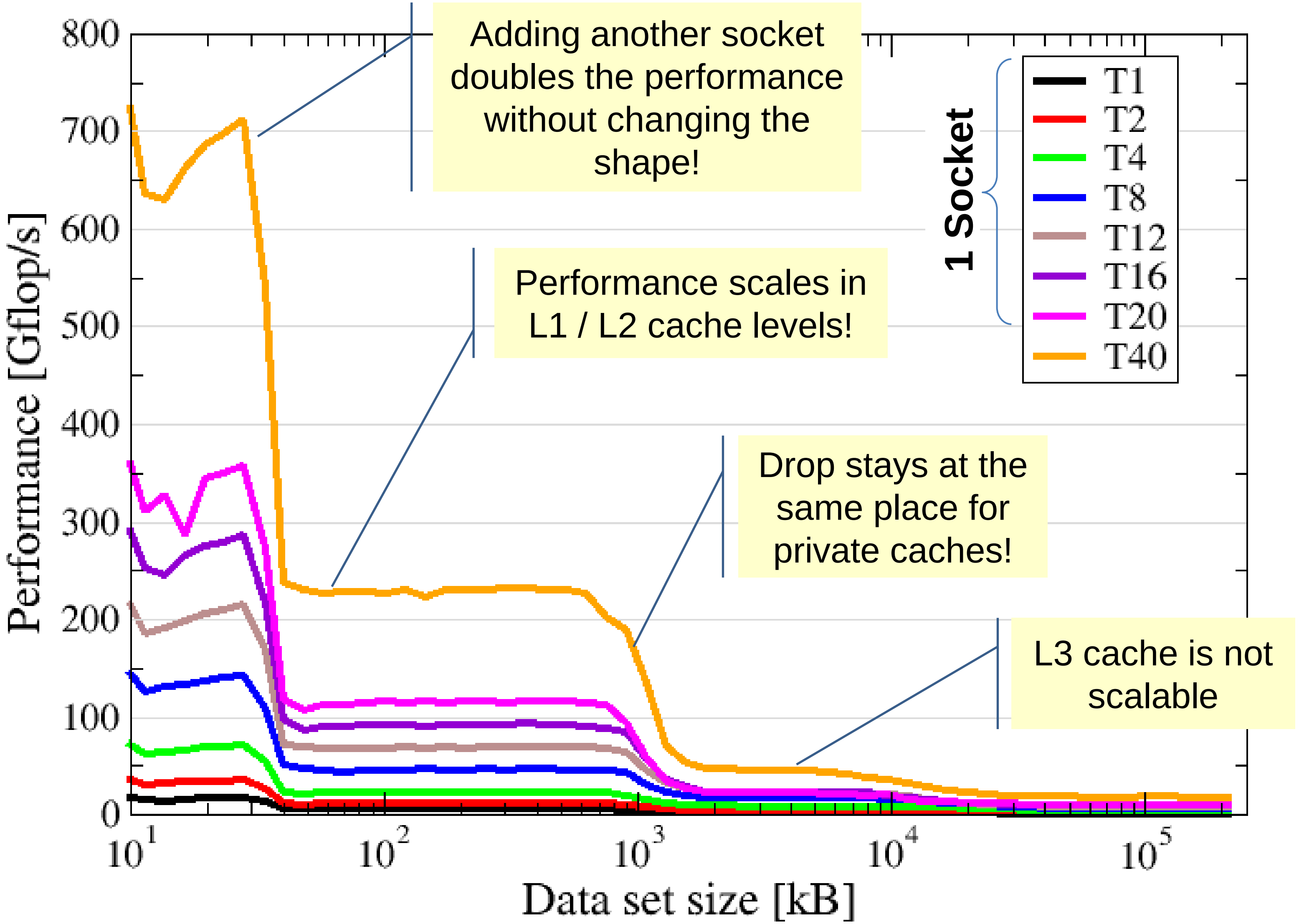


Throughput triad on one CascadeLake node (2.5 GHz)

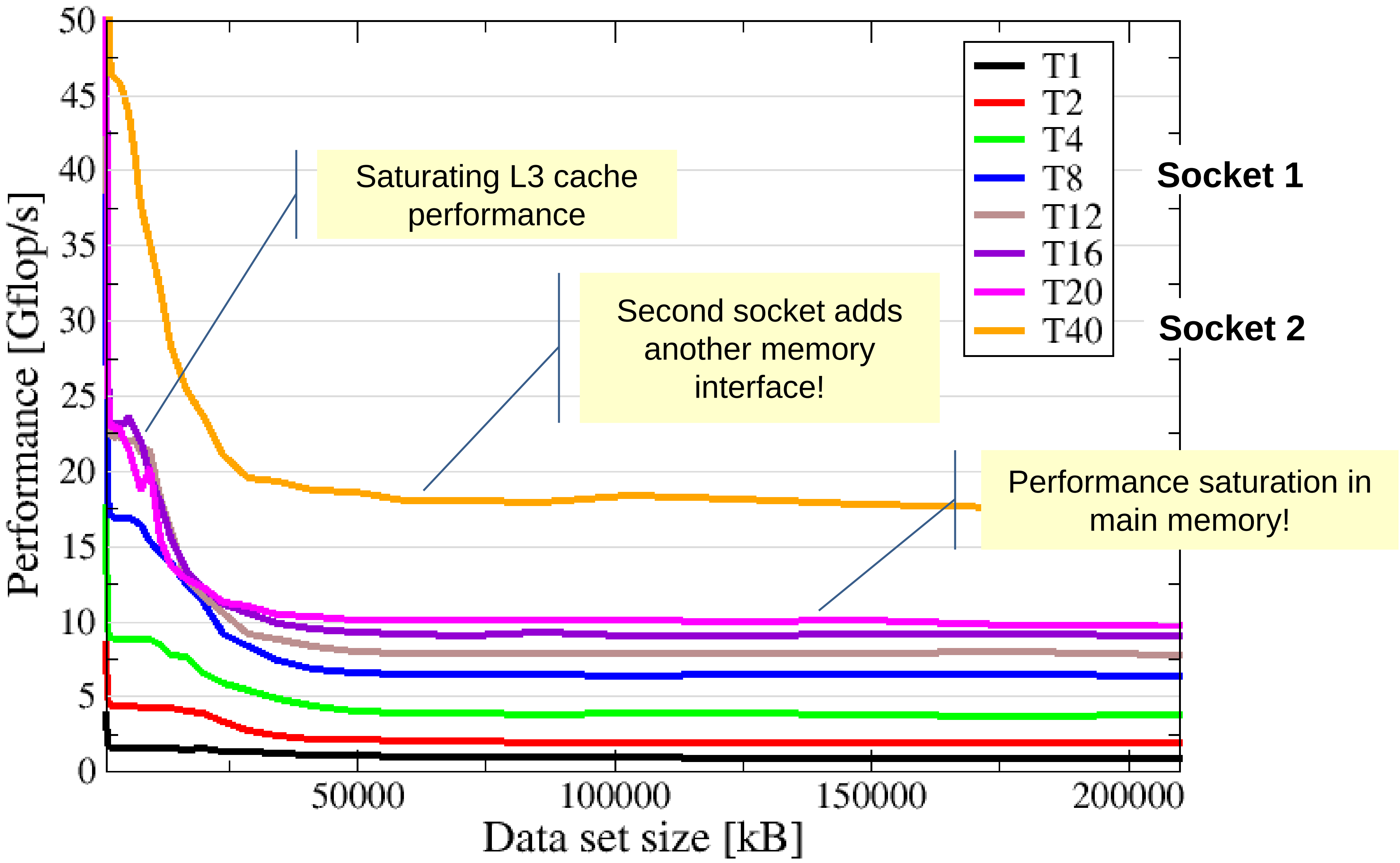
- How does the bandwidth scale across cores?
- Are there any bottlenecks?
- How large are the caches?

```
likwid-bench \
   -t triad_avx512_fma
   -W S0:$size:$threads:1:2
```

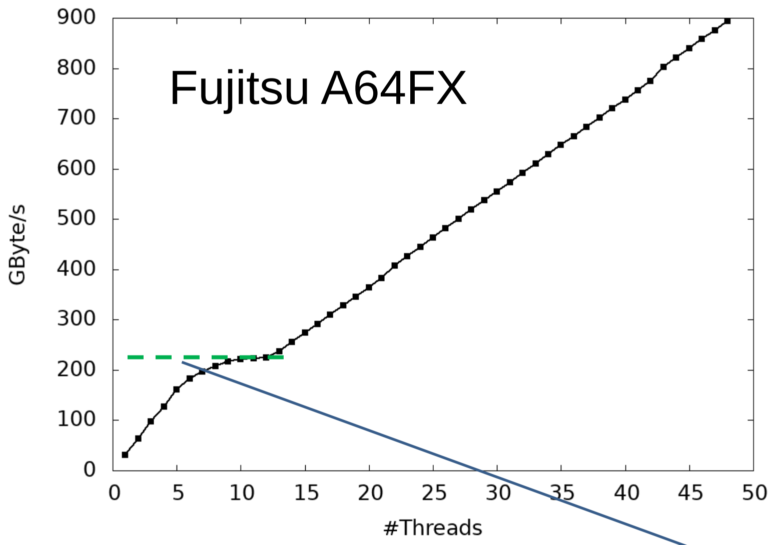
- Scan `$size` and `$threads`
- Pin threads in chunks of 1 with distance of 2 (skip SMT threads)

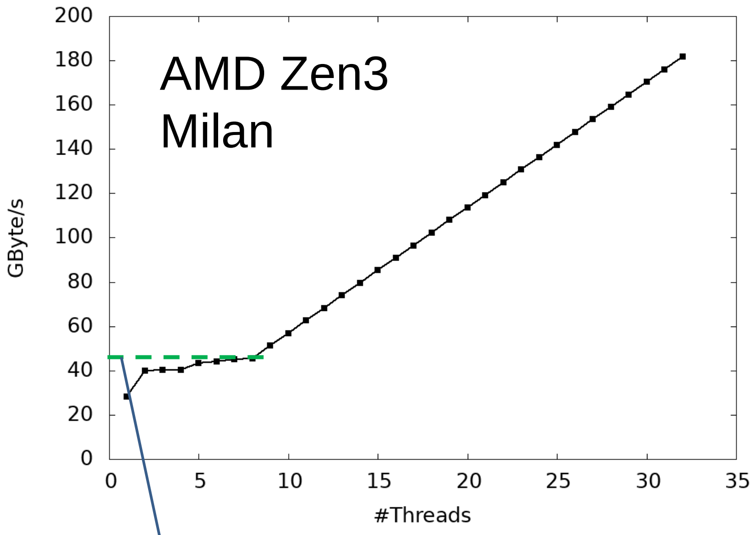


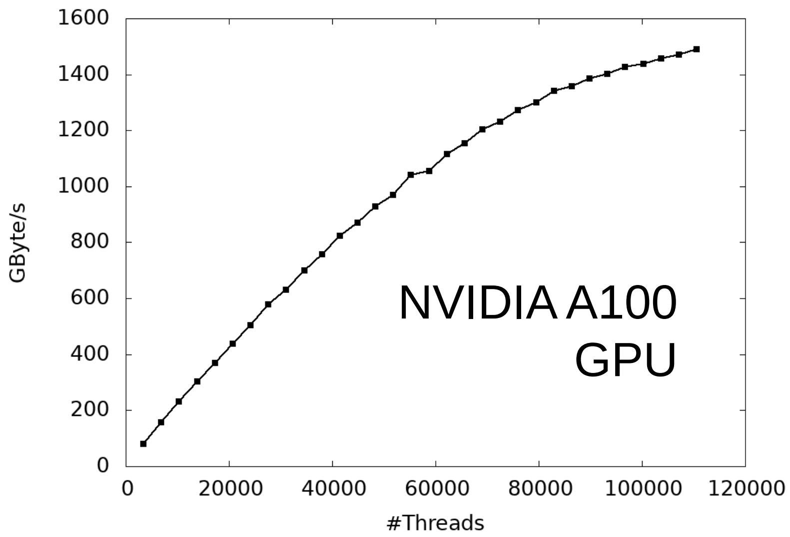
Throughput triad on CascadeLake (memory close-up)

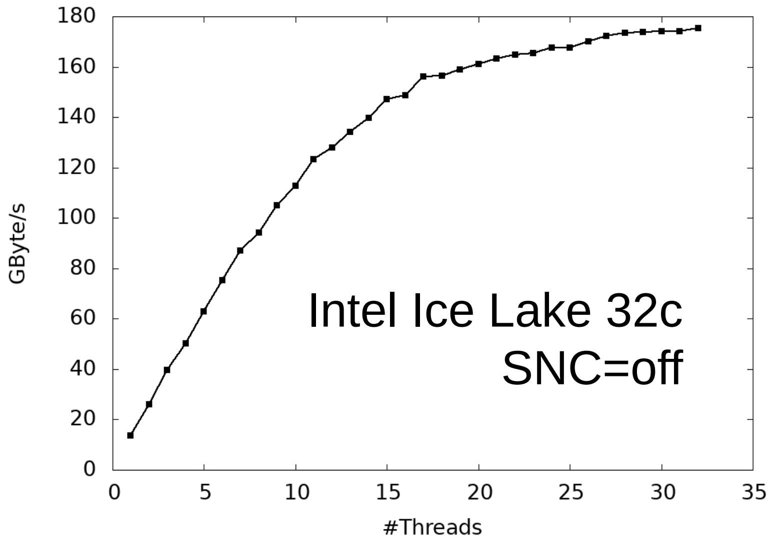


Memory bandwidth saturation (read-only)



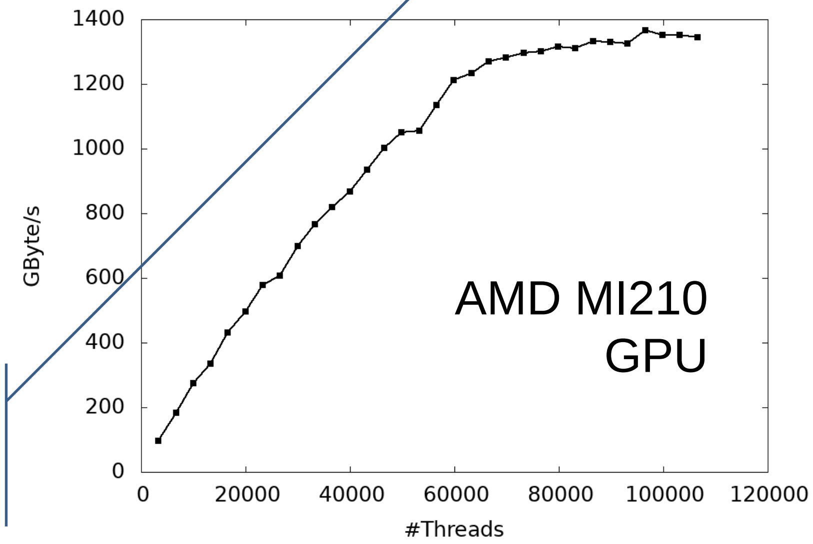






Bandwidth saturation on 1st ccNUMA domain

Massive thread parallelism needed on GPUs to saturate



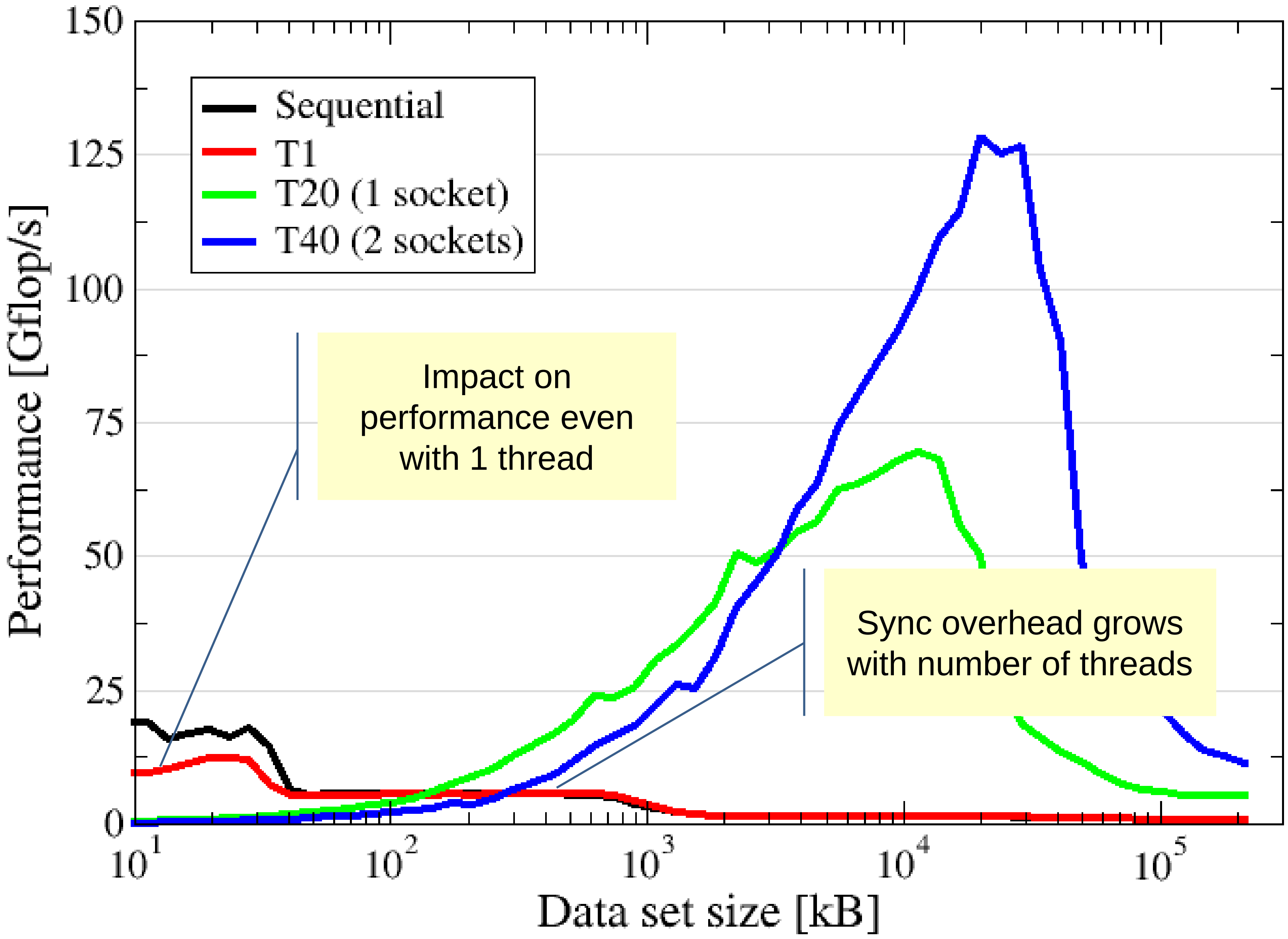
The OpenMP-parallel vector triad benchmark

OpenMP **worksharing** in the benchmark loop

```
    S = getTimeStamp();
#pragma omp parallel
    {
        for(int j = 0; j < iter; j++) {
#pragma omp for
#pragma vector aligned
            for (int i=0; i<N; i++) {
                a[i] = b[i] + d[i] * c[i];
            }
            if (a[N-1] > 2000) printf("Ai = %f\n",a[N-1]);
        }
    }
    E = getTimeStamp();
```

Implicit barrier

OpenMP vector triad on CascadeLake node (2.2 GHz)



Conclusions from the microbenchmarks

- **Microbenchmarks** can yield **surprisingly deep insights**
- **Affinity matters!**
  - Almost all performance properties depend on the position of
    - Data
    - Threads/processes
  - Consequences
    - **Know where your threads are running**
    - **Know where your data is** (see later for that)
- **Bandwidth bottlenecks are ubiquitous**
- **Synchronization overhead** may be an issue
  - … and depends on the system topology!
  - Many-core poses new challenges in terms of synchronization