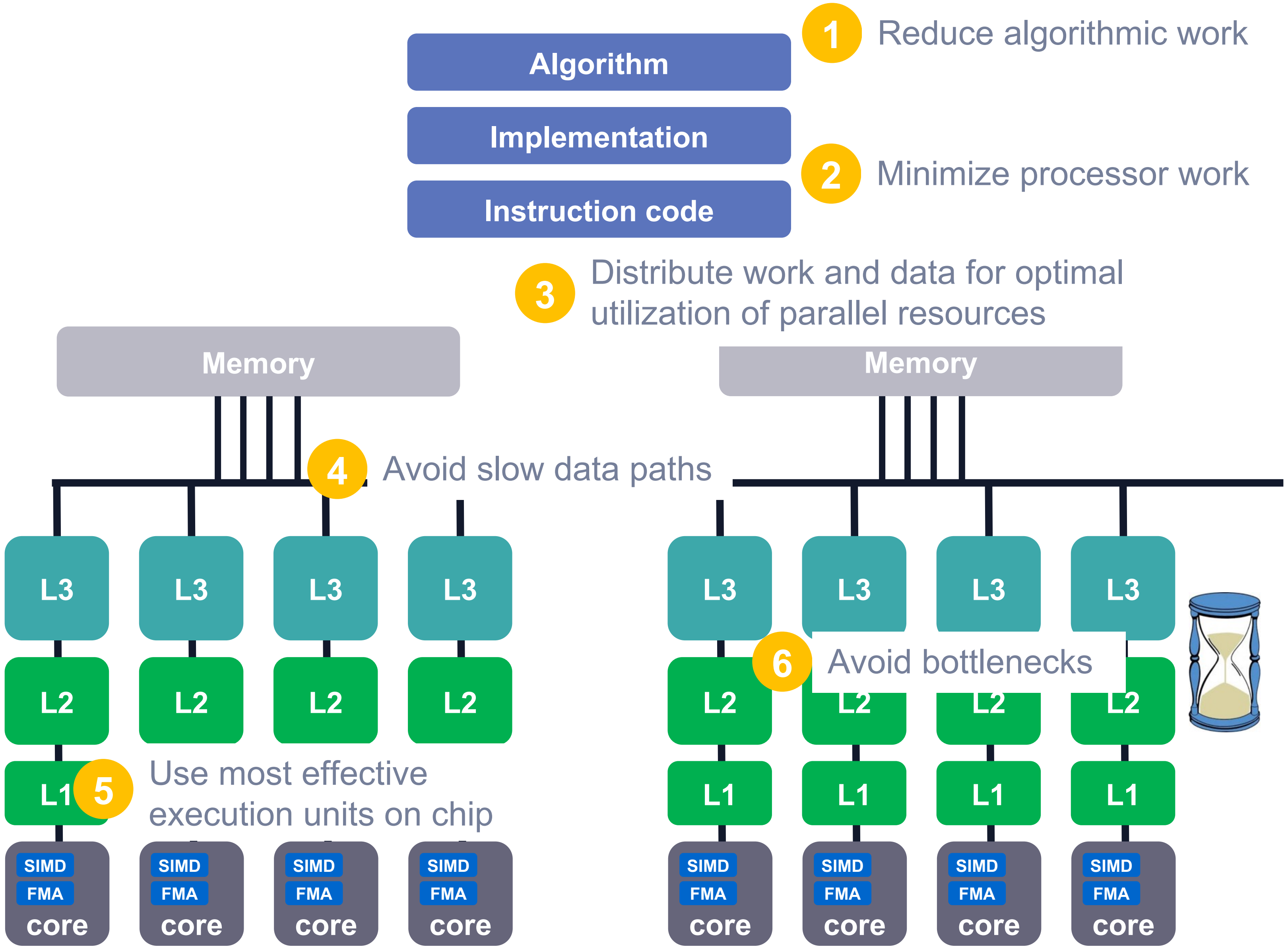
Performance Engineering

Basic skills and knowledge

Optimizing code: The big Picture



Programming language influence

- Programming languages are designed to help with software engineering requirements
- Multi-paradigm language (C++, also Fortran 2003 and newer) tend to lead to over-engineered solutions.
- Language features do not come for free! C++ performance heavily relies on aggressive in-lining. This often fails and makes performance fragile.

Advices:

- Keep it simple stupid! A simpler solution is a better solution.
- Extract numerically intensive tasks into simple kernels.
- Be brave when it comes to refactoring!

Performance Engineering process

Runtime profile

Algorithm/Code Analysis

Application Benchmarking

HPM performance profile

Performance Model

Optional

For every hotspot

Traces/HW metrics

Iteratively

- Identify performance issues
- Develop performance expectation

Change runtime configuration

Optimize implementation

Runtime profiling with gprof

Instrumentation based with gprof

Compile with **-pg** switch:

```
icc -pg -O3 -c myfile1.c
```

Execute the application. During execution a file **`gmon.out`** is generated.

Analyze the results with:

```
gprof ./a.out | less
```

The output contains three parts: A flat profile, the call graph, and an alphabetical index of routines.

The flat profile is what you are usually interested in.

Runtime profile with gprof: Flat profile

Time spent in routine itself

How often was it called

How much time was spent per call

```
Each sample counts as 0.01 seconds.
  %   cumulative   self              self     total
 time   seconds   seconds    calls   s/call   s/call  name
66.86     26.14    26.14      502     0.05     0.05  ForceLJ::compute(Atom&, Neighbor&, Comm&, int)
30.77     38.17    12.03       26     0.46     0.46  Neighbor::build(Atom&)
 1.43     38.73     0.56        1     0.56    38.46  Integrate::run(Atom&, Force*, Neighbor&, Comm&, Thermo&, Timer&)
 0.36     38.87     0.14     2850     0.00     0.00  Atom::pack_comm(int, int*, double*, int*)
 0.15     38.93     0.06     2850     0.00     0.00  Atom::unpack_comm(int, int, double*)
 0.13     38.98     0.05       26     0.00     0.00  Atom::pbc()
 0.10     39.02     0.04                             __intel_ssse3_rep_memcpy
 0.08     39.05     0.03       25     0.00     0.00  Atom::sort(Neighbor&)
 0.08     39.08     0.03        1     0.03     0.03  create_atoms(Atom&, int, int, int, double)
 0.05     39.10     0.02       26     0.00     0.00  Comm::borders(Atom&)
 0.00     39.10     0.00  1221559     0.00     0.00  Atom::pack_border(int, double*, int*)
 0.00     39.10     0.00  1221559     0.00     0.00  Atom::unpack_border(int, double*)
 0.00     39.10     0.00   131072     0.00     0.00  Atom::addatom(double, double, double, double, double, double)
 0.00     39.10     0.00     1025     0.00     0.00  Timer::stamp(int)
 0.00     39.10     0.00      502     0.00     0.00  Thermo::compute(int, Atom&, Neighbor&, Force*, Timer&, Comm&)
 0.00     39.10     0.00      500     0.00     0.00  Timer::stamp()
 0.00     39.10     0.00      475     0.00     0.00  Comm::communicate(Atom&)
 0.00     39.10     0.00       26     0.00     0.00  Comm::exchange(Atom&)
 0.00     39.10     0.00       25     0.00     0.00  Timer::stamp_extra_stop(int)
 0.00     39.10     0.00       25     0.00     0.00  Timer::stamp_extra_start()
 0.00     39.10     0.00       25     0.00     0.00  Neighbor::binatoms(Atom&, int)
 0.00     39.10     0.00        7     0.00     0.00  Timer::barrier_stop(int)
 0.00     39.10     0.00        1     0.00     0.00  create_box(Atom&, int, int, int, double)
 0.00     39.10     0.00        1     0.00     0.00  create_velocity(double, Atom&, Thermo&)
```

Output is sorted according to total time spent in routine.

Sampling-based runtime profile with perf

Call executable with perf:

```
perf record -g ./a.out
```

Analyze the results with:

```
perf report
```

Advantages vs. gprof:

- Works on any binary without recompile
- Also captures OS and runtime symbols

```
Samples: 30K of event 'cycles:uppp', Event count (approx.): 20629160088
Overhead  Command          Shared Object         Symbol
  64.19%  miniMD-ICC       miniMD-ICC            [.] ForceLJ::compute
  31.54%  miniMD-ICC       miniMD-ICC            [.] Neighbor::build
   1.47%  miniMD-ICC       miniMD-ICC            [.] Integrate::run
   0.67%  miniMD-ICC       [kernel]              [k] irq_return
   0.40%  miniMD-ICC       miniMD-ICC            [.] Atom::pack_comm
   0.35%  mpiexec          [kernel]              [k] sysret_check
   0.21%  miniMD-ICC       miniMD-ICC            [.] create_atoms
   0.18%  miniMD-ICC       miniMD-ICC            [.] Atom::unpack_comm
   0.15%  miniMD-ICC       [kernel]              [k] sysret_check
   0.15%  miniMD-ICC       miniMD-ICC            [.] Comm::borders
   0.10%  miniMD-ICC       miniMD-ICC            [.] __intel_ssse3_rep_memcpy
   0.09%  miniMD-ICC       miniMD-ICC            [.] Atom::sort
   0.07%  miniMD-ICC       miniMD-ICC            [.] Neighbor::binatoms
```

Command line version of Intel Amplifier

Works out of the box for MPI/OpenMP parallel applications.

Example usage with MPI:

```
mpirun -np 2 amplxe-cl -collect hotspots -result-dir myresults -- a.out
```

- Compile with debugging symbols
- Can also resolve inlined C++ routines
- Many more collect modules available including hardware performance monitoring metrics

```
Elapsed Time: 8.650s
    CPU Time: 8.190s
        Effective Time: 8.190s
            Idle: 0.020s
            Poor: 8.170s
            Ok: 0s
            Ideal: 0s
            Over: 0s
        Spin Time: 0s
        Overhead Time: 0s
    Total Thread Count: 2
    Paused Time: 0s

Top Hotspots
Function                     Module      CPU Time
---------------------------  ----------  --------
ForceLJ::compute_fullneigh   miniMD-ICC    4.940s
Neighbor::build              miniMD-ICC    2.820s
Integrate::finalIntegrate    miniMD-ICC    0.100s
Integrate::initialIntegrate  miniMD-ICC    0.060s
__intel_ssse3_rep_memcpy     miniMD-ICC    0.040s
[Others]                     N/A           0.230s
```

Application benchmarking preparation

- Discuss and prepare relevant benchmark test case(s)
  - Short turnaround time
  - Representative of real production runs

- For long term multi-site PE projects you may extract a proxy application
  - Simplified version of app (or a part of it) that still captures the relevant performance behavior

- Define an application-specific performance metric
  - Should avoid "trivial" dependencies on problem parameters (see later)
  - Common choice: Useful work performed per time unit

Application benchmarking components

Performance measurements must be accurate, deterministic and reproducible.

Components for application benchmarking:

Timing

Documentation

Affinity control

System configuration

Always run benchmarks on an exclusive system!

Timing within program code

For benchmarking, an accurate wall-clock timer (end-to-end stop watch) is required:

- **`clock_gettime()`** POSIX compliant timing function
- **`MPI_Wtime()`** and **`omp_get_wtime()`** Standardized programming-model-specific timing routines for MPI and OpenMP

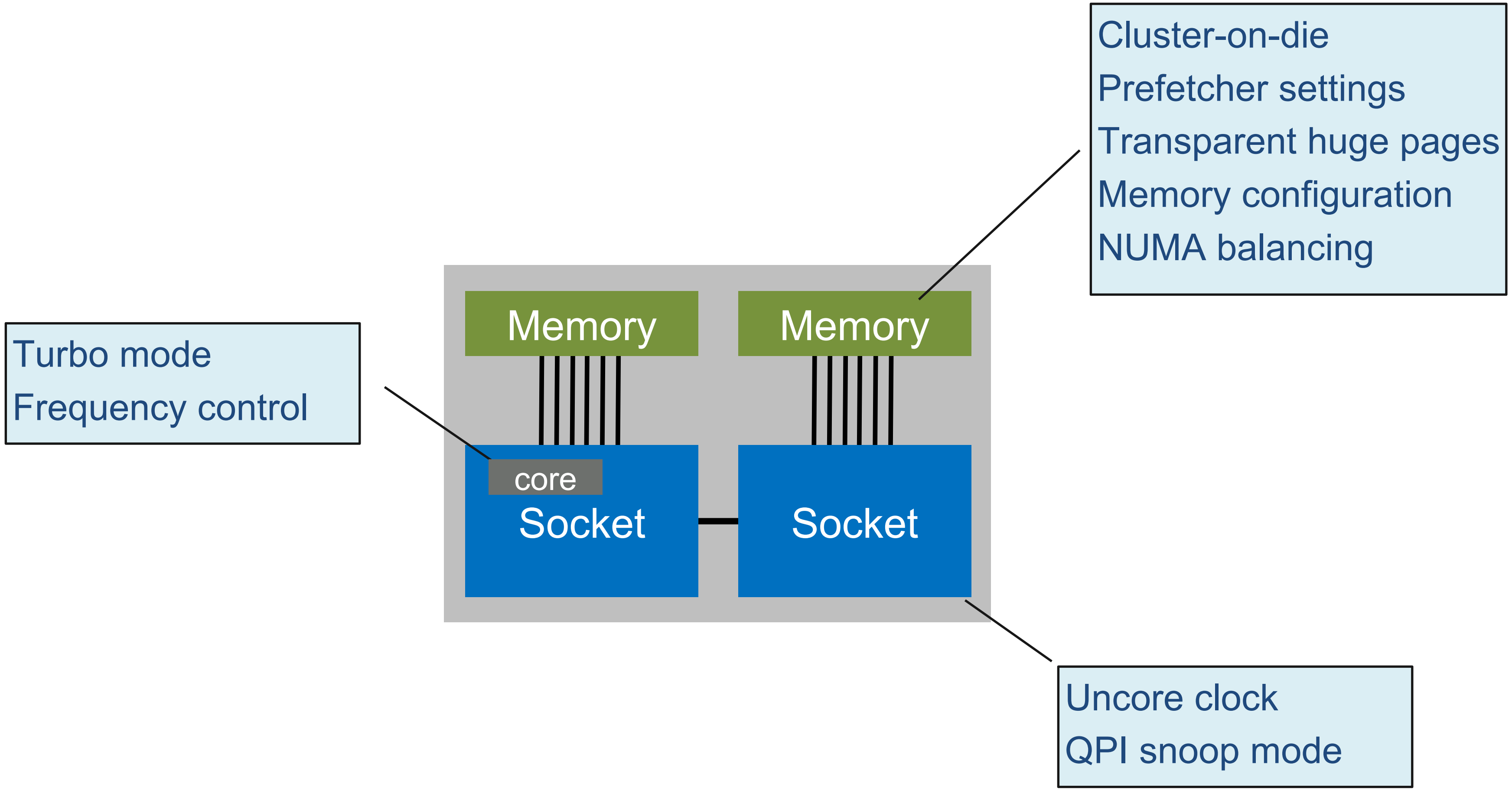
```
#include <stdlib.h>
#include <time.h>

double getTimeStamp()
{
    struct timespec ts;
    clock_gettime(CLOCK_MONOTONIC, &ts);
    return (double)ts.tv_sec + (double)ts.tv_nsec * 1.e-9;
}
```

Usage:

```
double S, E;
S = getTimeStamp();
/* measured code region */
E = getTimeStamp();
return E-S;
```

https://github.com/RRZE-HPC/TheBandwidthBenchmark/

System configuration and clock frequency

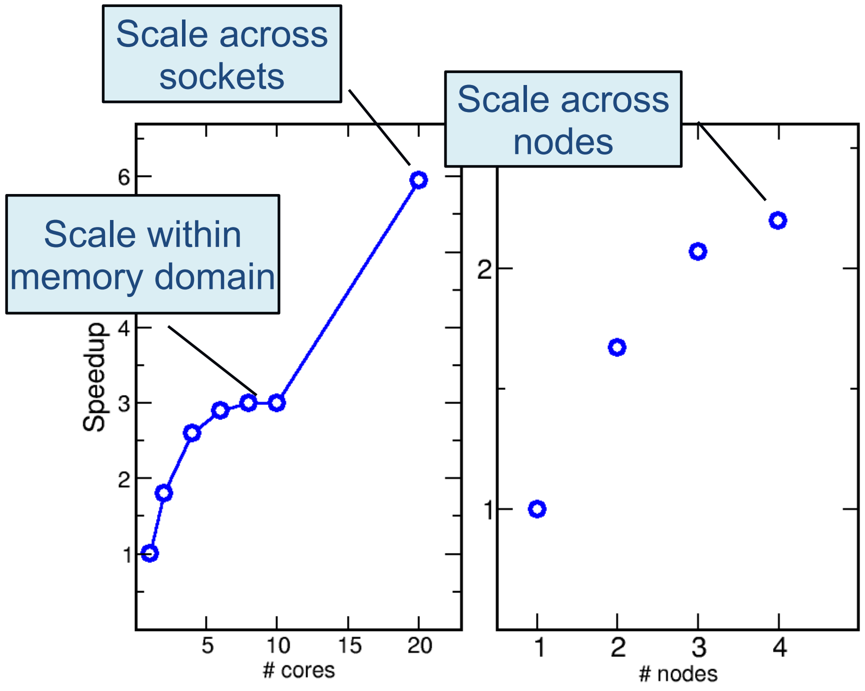


Tool for system state dump (requires Likwid tools):
`https://github.com/RRZE-HPC/MachineState`

Benchmark planning

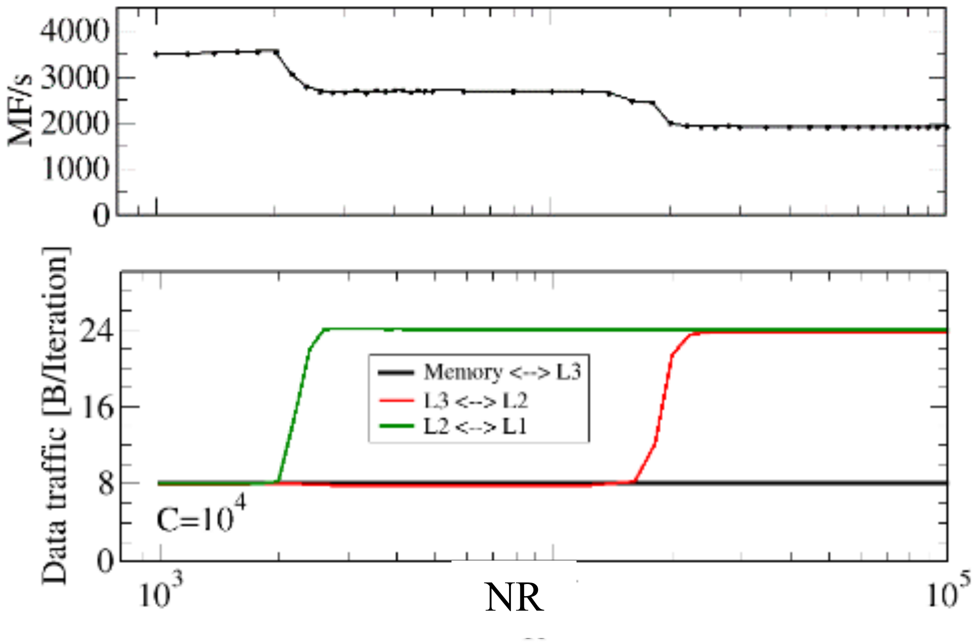
Two common variants:

Core count



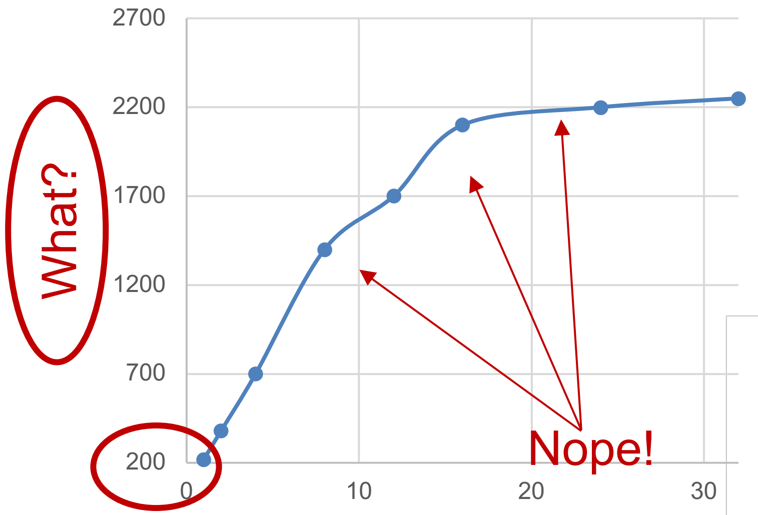
Choosing the right scaling baseline

Dataset size



- Measure with one process (to start with)
- Scan dataset size in fine steps
- Verify the data volumes with a HPM tool

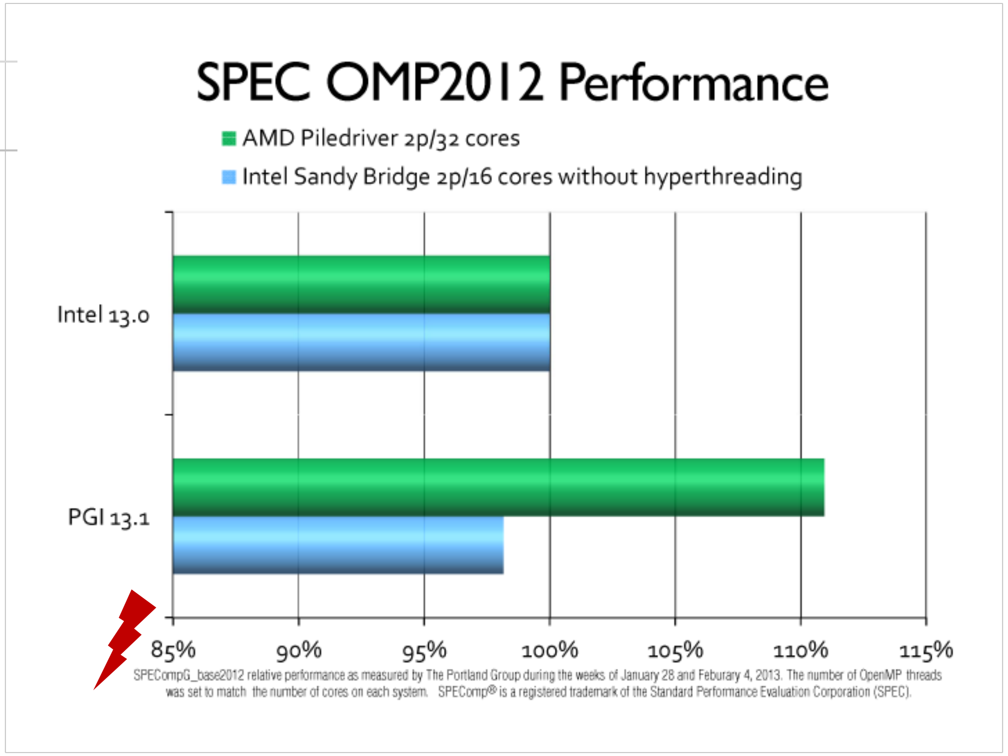
Graphs: the good, the bad, and the ugly



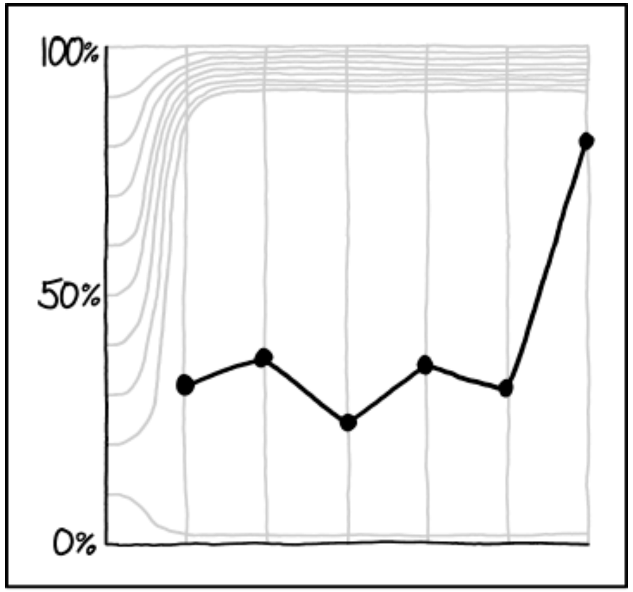
What?

Figure 1: Scaling on Meggie

Scaling of what??



http://www.pgroup.com/images/charts/spec_omp2012_chart_big.png



PEOPLE HAVE WISED UP TO THE "CAREFULLY CHOSEN Y-AXIS RANGE" TRICK, SO WE MISLEADING GRAPH MAKERS HAVE HAD TO GET CREATIVE.

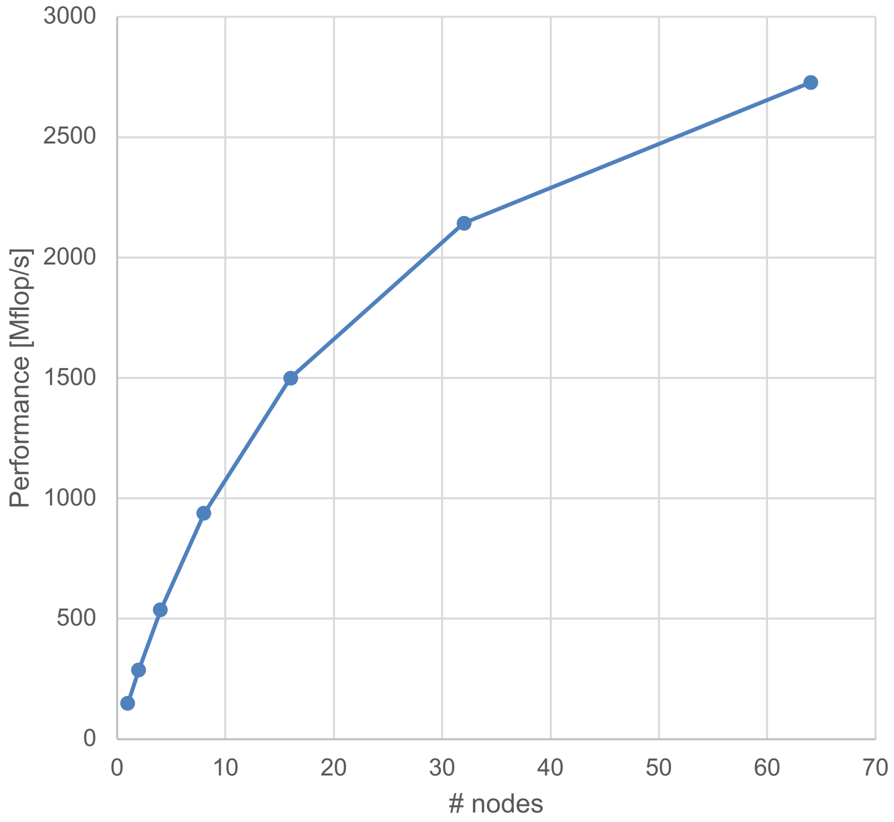
https://xkcd.com/2023/

Runtime or performance scaling?

- Ultimately, the user wants to know "How long will my problem take to solve?"
- Plotting runtime vs. resources answers this question

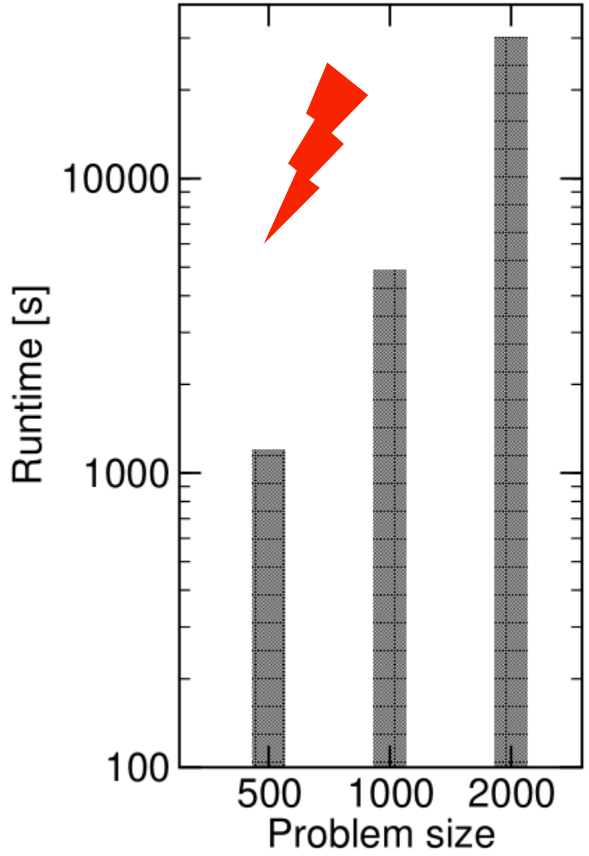
- However,…
  - Scaling behavior hard to visualize
  - Hard to generalize to different problem size

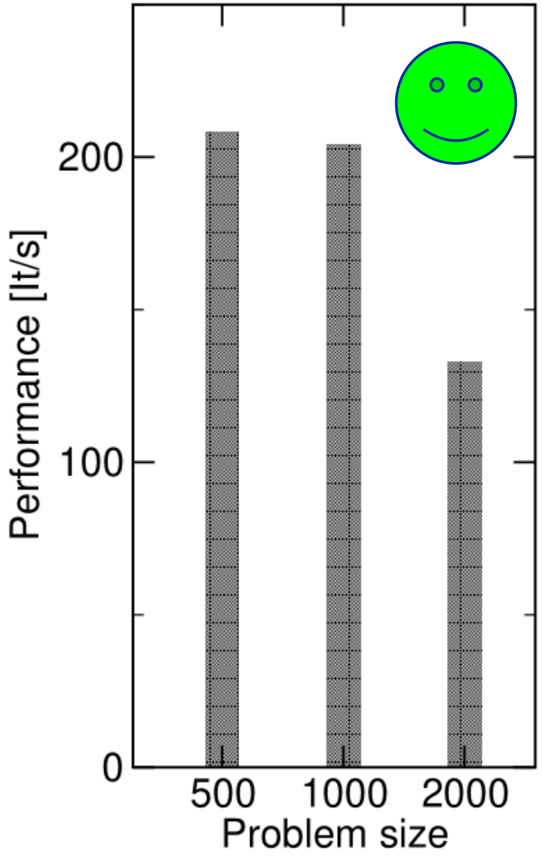
- Performance is normalized to a defined unit of work
- Scaling behavior is easier to read on a linear graph



Exposing the relevant effects

- Present data in a way that exposes the interesting correlations and ignores "trivial" dependencies
- Example: runtime or performance vs. problem size?
  - Runtime has a trivial dependence of "larger problem takes longer"
  - Performance vs. problem size shows clearly a fundamental change with larger problems





- This is highly problem specific!

Best practices for Performance profiling

Focus on resource utilization and instruction decomposition!

Metrics to measure:

- Operation throughput (Flops/s)
- Overall instruction throughput (CPI)
- Instruction breakdown:
  - FP instructions
  - loads and stores
  - branch instructions
  - other instructions
- Instruction breakdown to SIMD width (scalar, SSE, AVX, AVX512 for X86). (only arithmetic instruction on most architectures)

- Data volumes and bandwidths to main memory (GB and GB/s)
- Data volumes and bandwidth to different cache levels (GB and GB/s)

Useful diagnostic metrics are:

- Clock frequency (GHz)
- Power (W)

All above metrics can be acquired using performance groups:

`MEM_DP, MEM_SP, BRANCH, DATA, L2,  L3`

The Performance Logbook

- Manual and knowledge collection how to build, configure and run application
- Document activities and results in a structured way
- Learn about best practice guidelines for performance engineering
- Serve as a well-defined and simple way to exchange and hand over performance projects

The logbook consists of a single markdown document, helper scripts, and directories for input, raw results, and media files.

https://github.com/RRZE-HPC/ThePerformanceLogbook