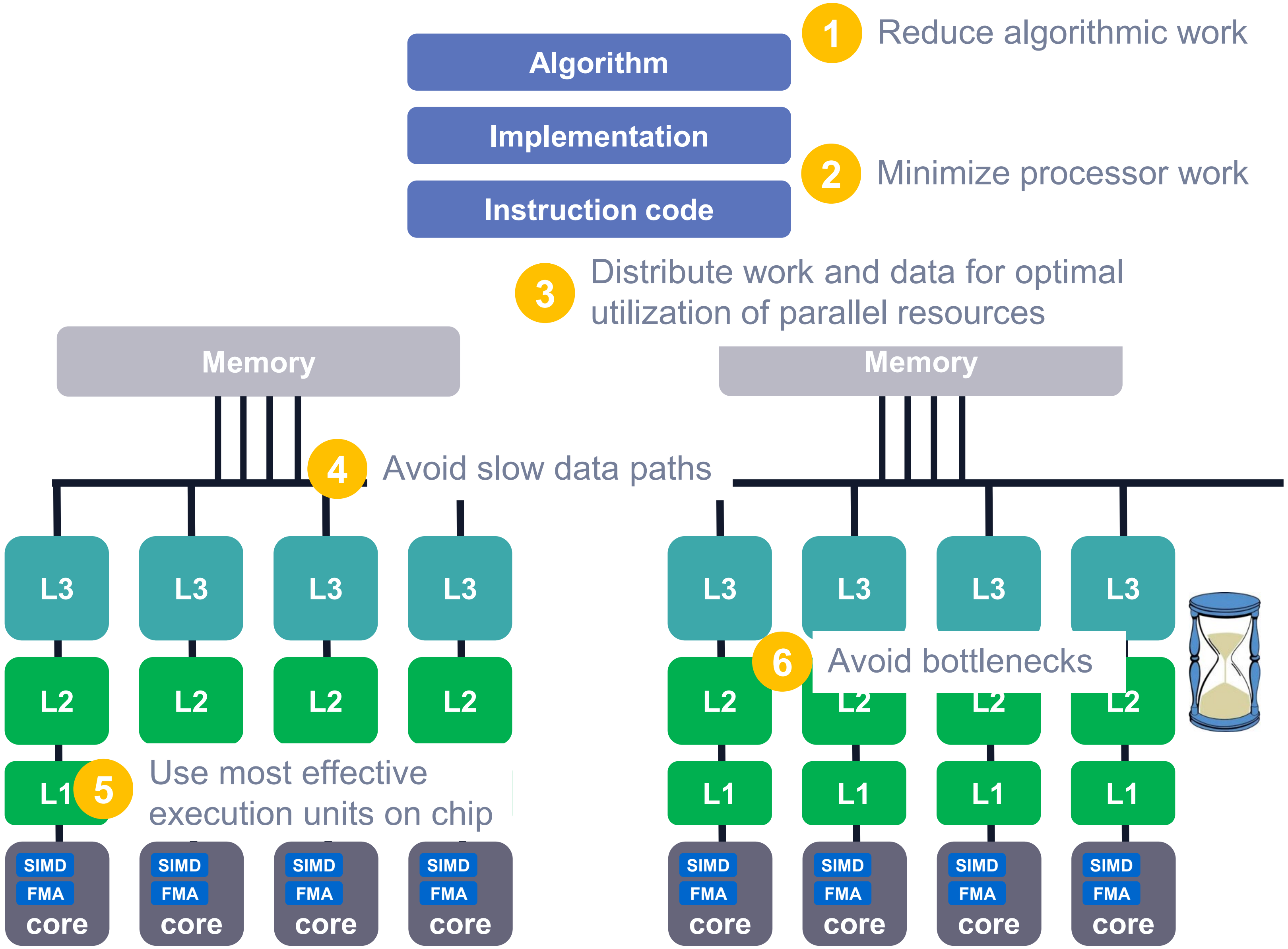
Performance Engineering

Basic skills and knowledge

Optimizing code: The big Picture



Focus on time to solution

- Metrics often used in PE publications:
  - MFlops/s
  - Cache miss rate
  - Speedup

Time to solution is all that matters!

(this does not mean that the above metrics cannot provide useful bits of information, though)

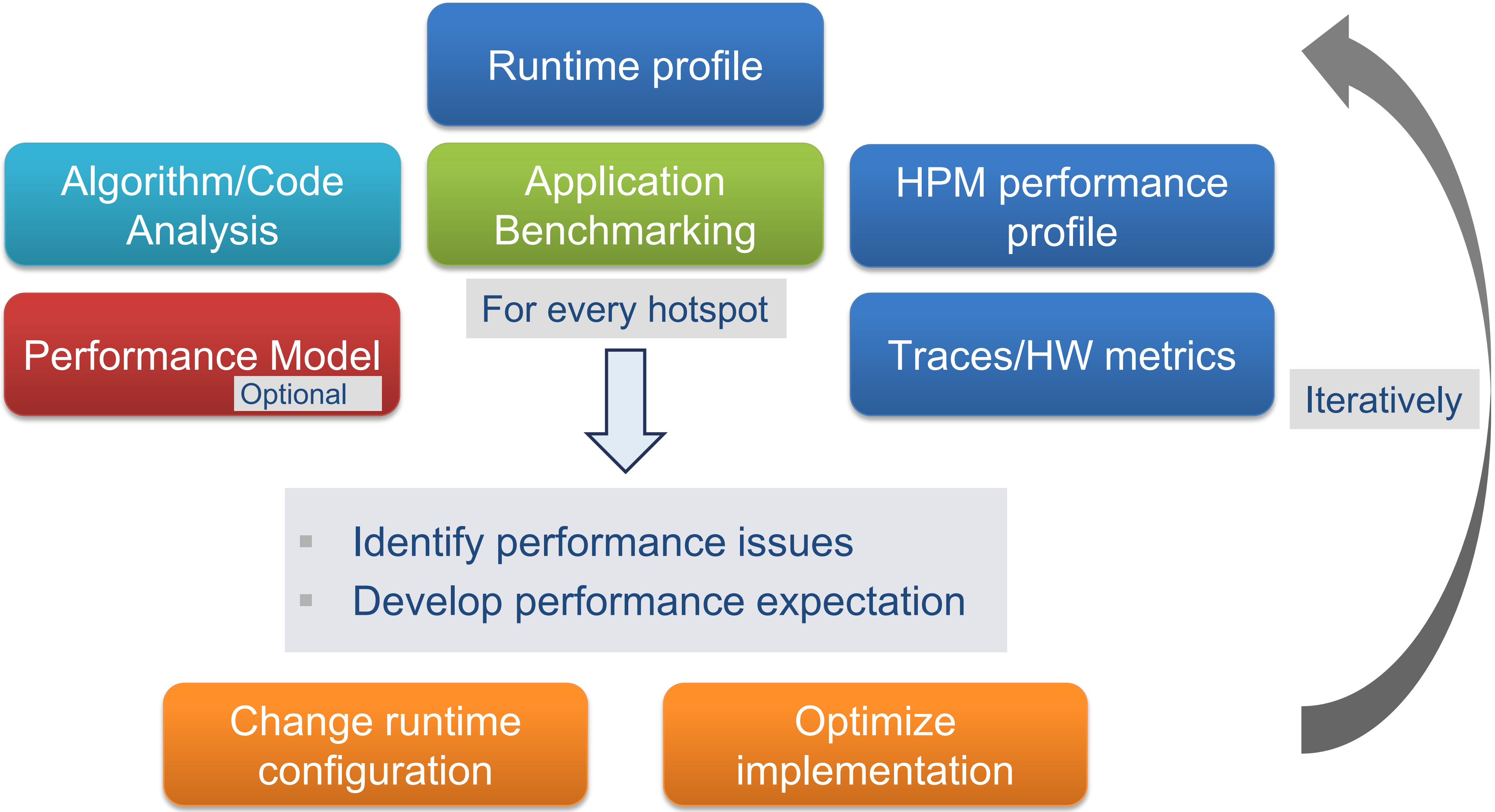
Advice: Define proper benchmark test cases

Runtime contributions and critical path

- Every activity adds a runtime contribution
- Simplest case: all runtime contributions accumulate to time to solution
- Due to concurrency, runtime contributions can overlap with each other
- Critical path is the series of runtime contributions that do not overlap and form the total runtime

Anything that takes time is only relevant for optimization if it appears on the critical path!

Performance Engineering process



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


```
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

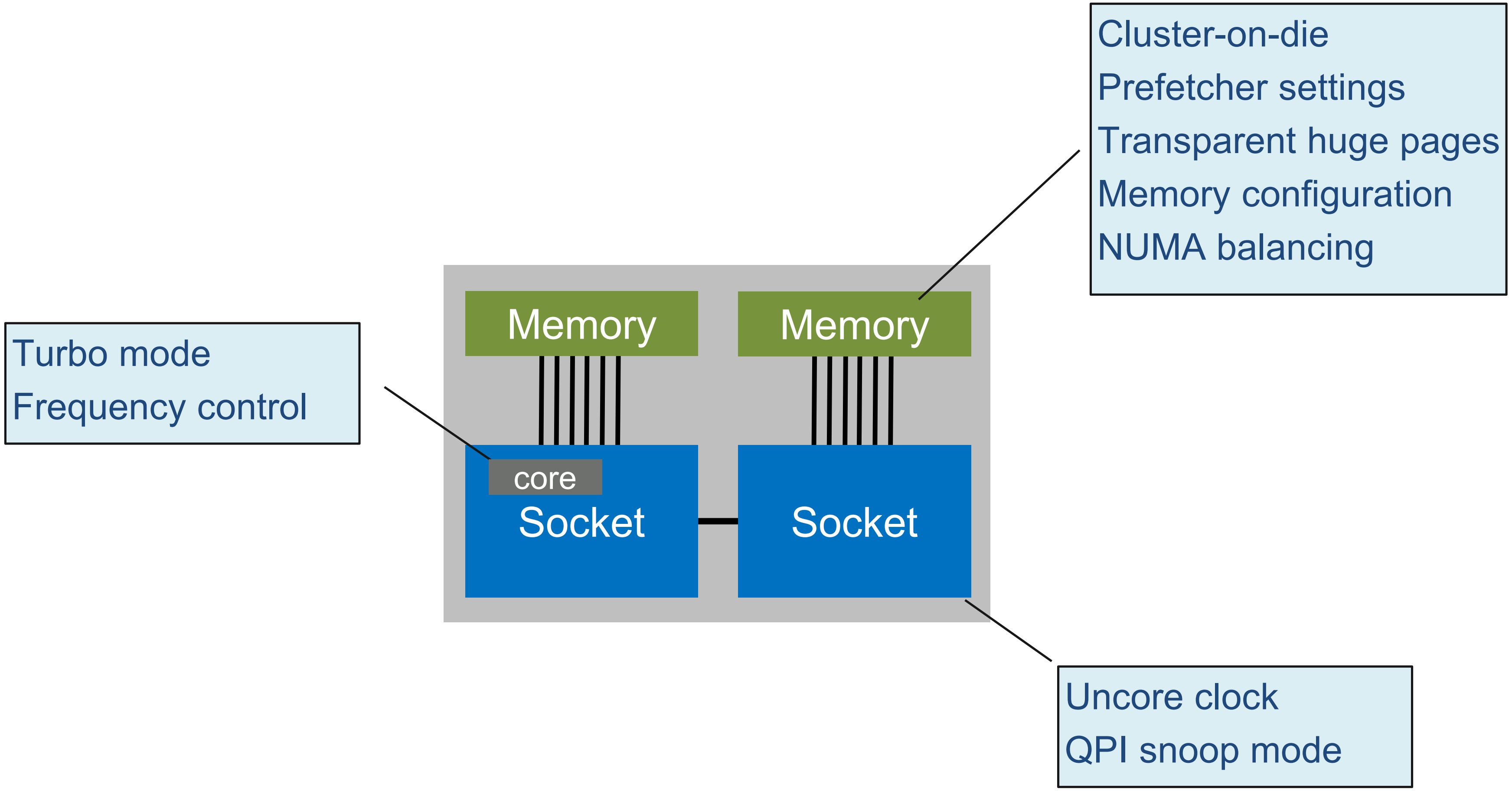
```
#include <stdlib.h>
#include <time.h>

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



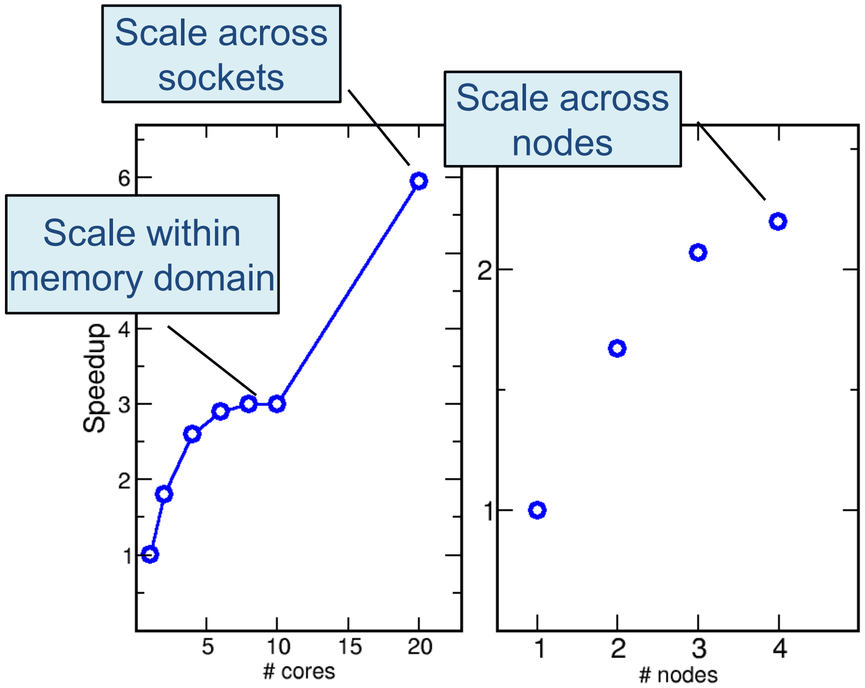
Tool for system state dump (requires Likwid tools):

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

Benchmark planning

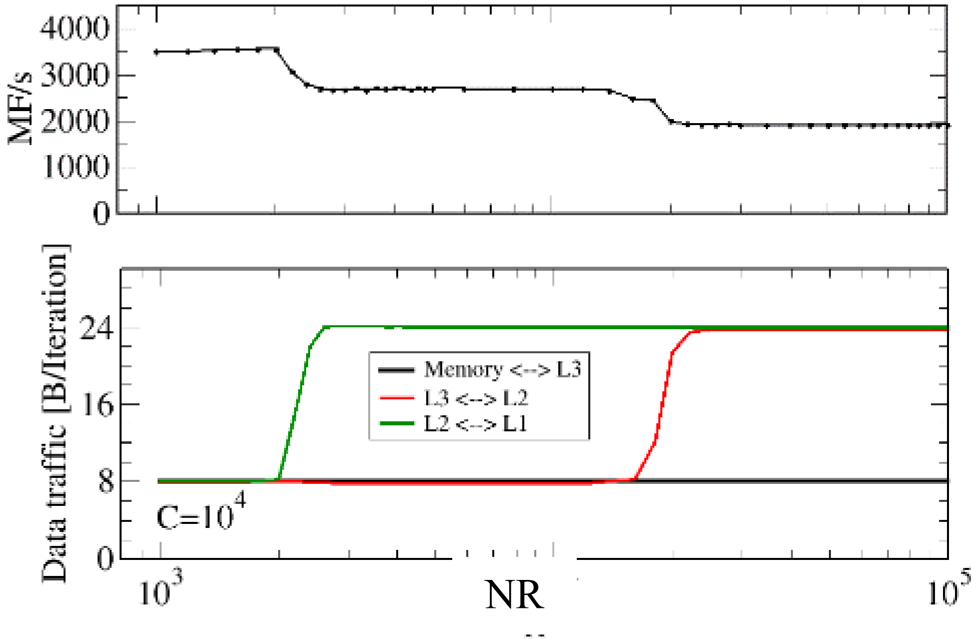
Two common variants:

Core count



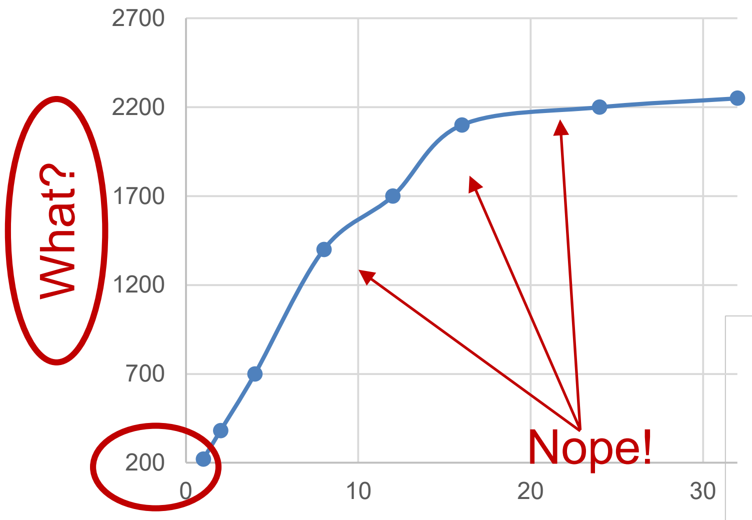
Choosing the right scaling baseline

Dataset size



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

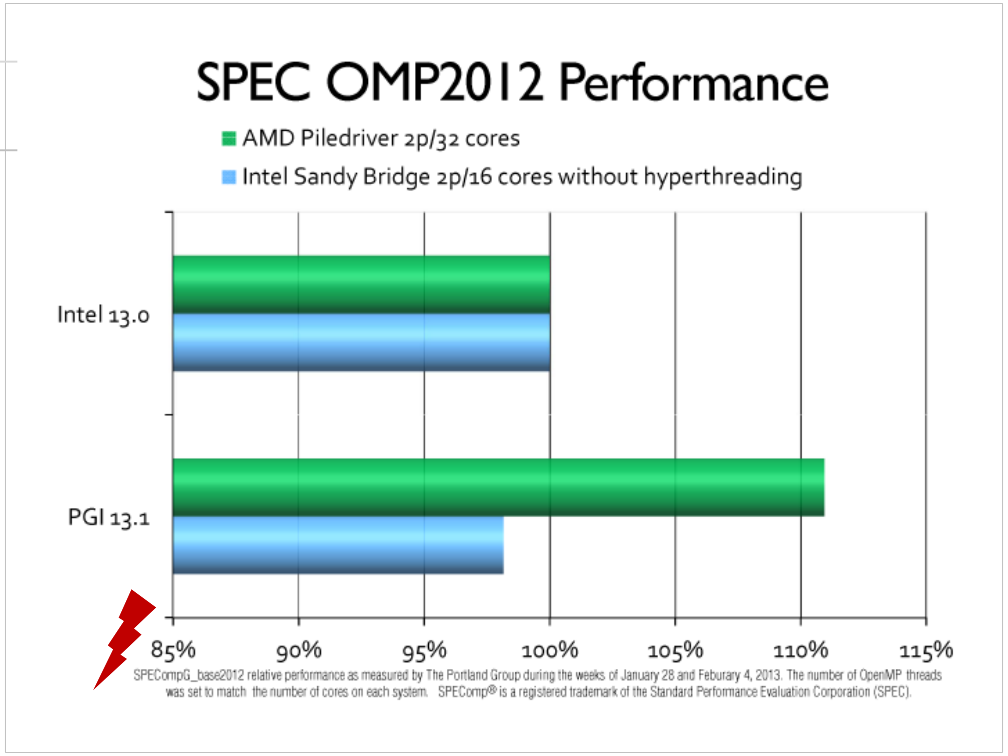
Graphs: the good, the bad, and the ugly



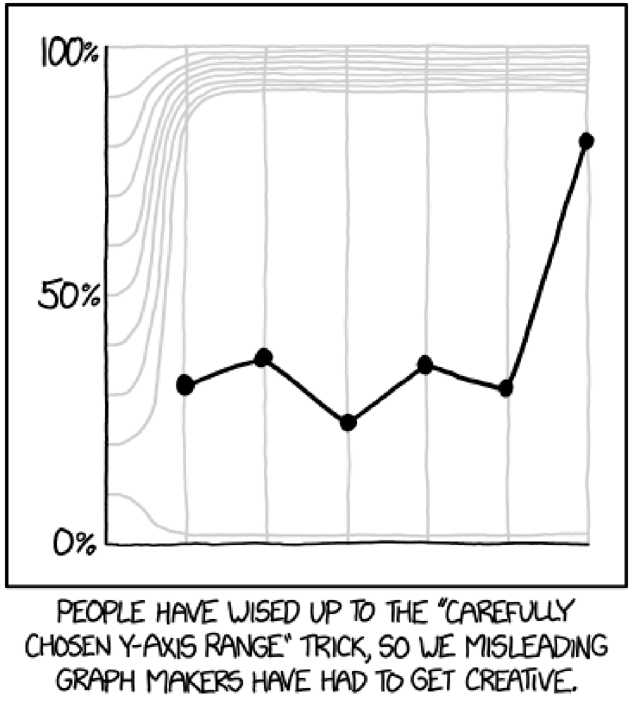
What?

Figure 1: Scaling on Meggie

Scaling of what??

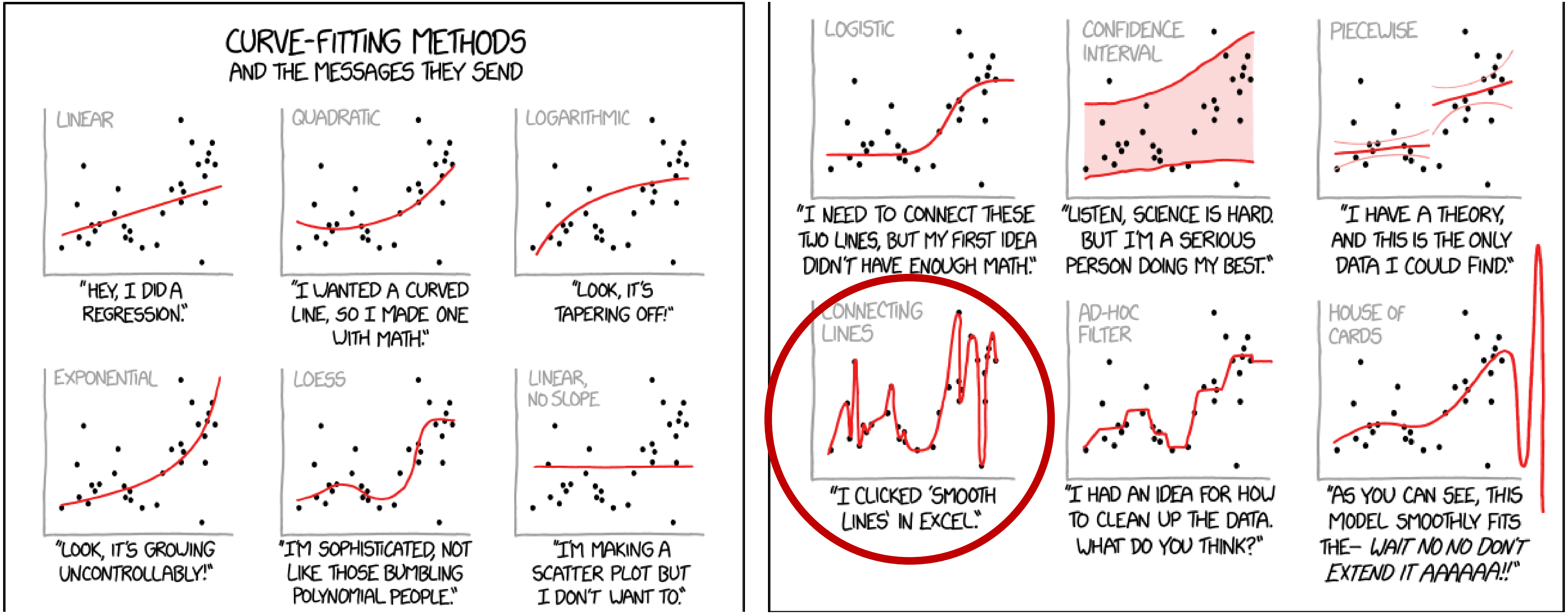


http://www.pgroup.com/images/charts/spec_omp2012_chart_big.png



https://xkcd.com/2023/

Curve fitting

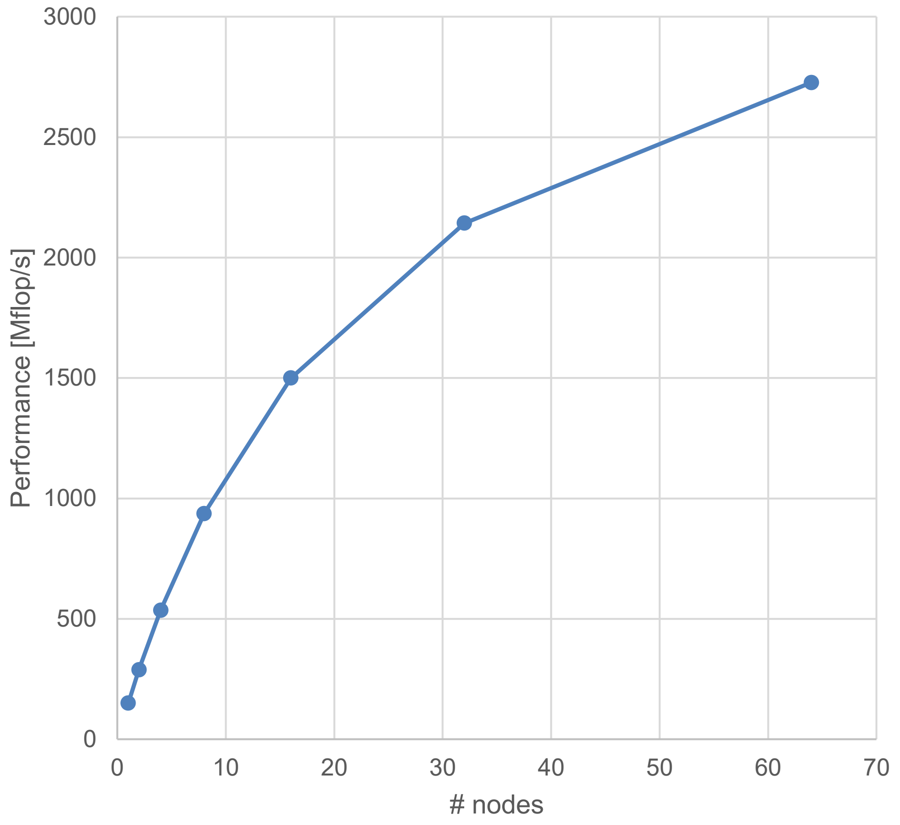


https://xkcd.com/2048

Runtime or performance scaling?

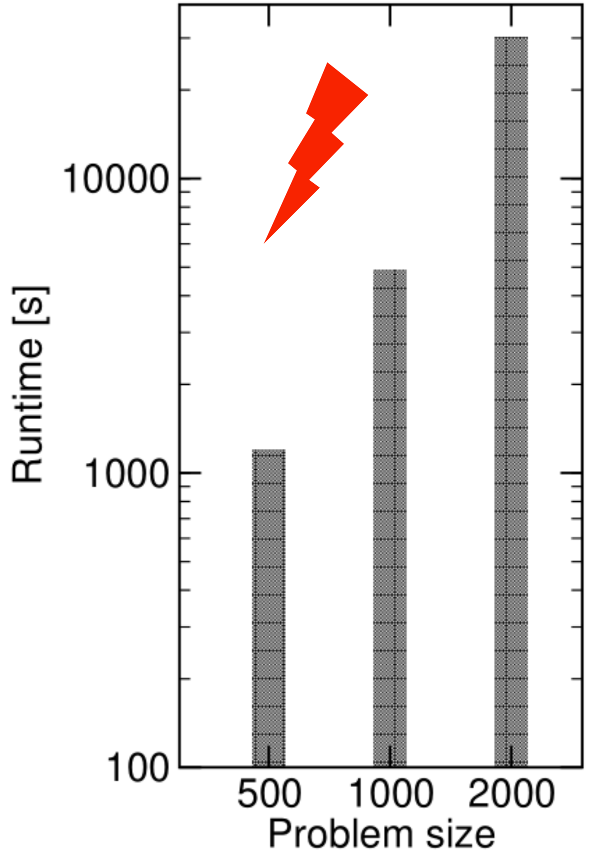
- Ultimately, the user wants to know "How long will my problem take to solve?"
- Plotting runtime vs. resources answers this question
- However,…
  - Scaling behavior hard to visualize
  - Hard to generalize to different problem size

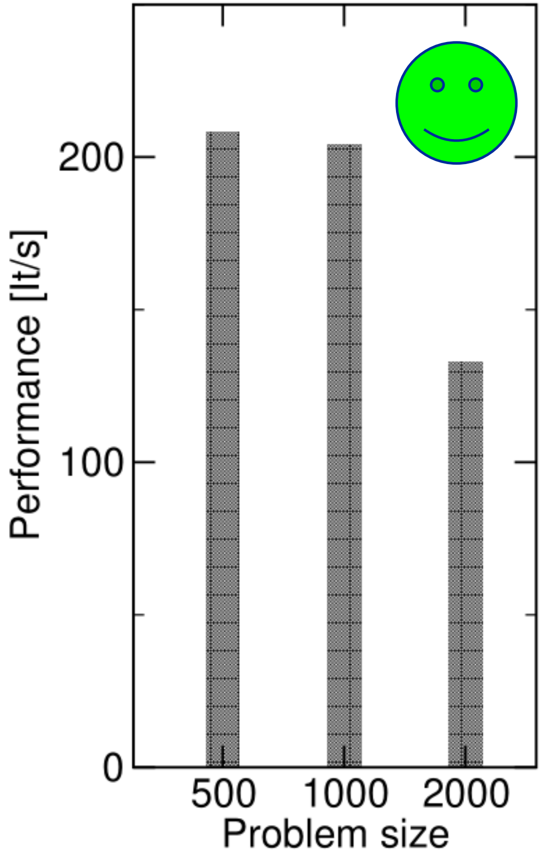
- Performance is normalized to a defined unit of work
- Scaling behavior is easier to read on a linear graph



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!





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