Erlangen Regional Computing Center

FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG

# Performance Engineering

## Basic skills and knowledge

High Performance Computing

# Runtime profiling with gprof

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**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

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**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

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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

Performance measurements have to 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 wallclock 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

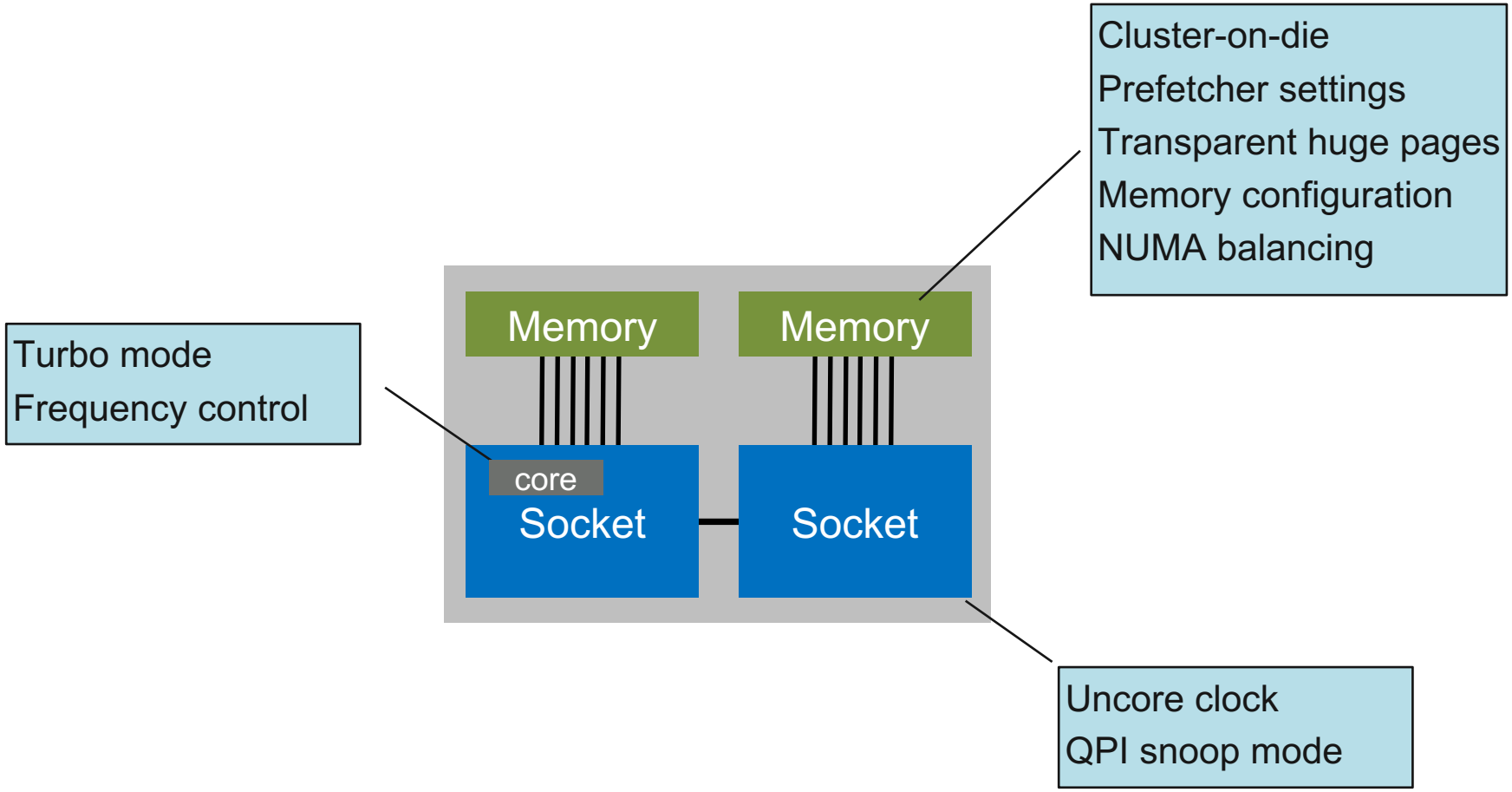
```
#include <stdlib.h>
#include <time.h>

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




Shell script for system state dump (requires Likwid tools):

https://github.com/RRZE-HPC/ThePerformanceLogbook/blob/master/Template/helpers/machine-state.sh

# Turbo mode and frequency control

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## Query turbo mode steps with `likwid-powermeter -i`

```
-------------------------------------------------------------
CPU name:       Intel(R) Xeon(R) Gold 6148 CPU @ 2.40GHz
CPU type:       Intel Skylake SP processor
CPU clock:      2.40 GHz
-------------------------------------------------------------
Base clock:     2400.00 MHz
Minimal clock:  1000.00 MHz
Turbo Boost Steps:
C0 3700.00 MHz
C1 3700.00 MHz
C2 3500.00 MHz
C3 3500.00 MHz
C4 3400.00 MHz
C5 3400.00 MHz
C6 3400.00 MHz
C7 3400.00 MHz
```

```
C17 3100.00 MHz
C18 3100.00 MHz
C19 3100.00 MHz
```

```
Info about Uncore:
Minimal Uncore frequency: 1200 MHz
Maximal Uncore frequency: 2400 MHz
```

Above steps are valid for scalar or SSE code; refer to vendor docs for AVX and AVX515 steps.

## Query and set frequencies with `likwid-setFrequencies`

```
Current CPU frequencies:
CPU 0: governor     ondemand min/cur/max 1.0/1.000/2.401 GHz Turbo 0
CPU 1: governor     ondemand min/cur/max 1.0/1.001/2.401 GHz Turbo 0
CPU 2: governor     ondemand min/cur/max 1.0/1.004/2.401 GHz Turbo 0
CPU 5: governor     ondemand min/cur/max 1.0/1.000/2.401 GHz Turbo 0
CPU 6: governor     ondemand min/cur/max 1.0/1.000/2.401 GHz Turbo 0
```

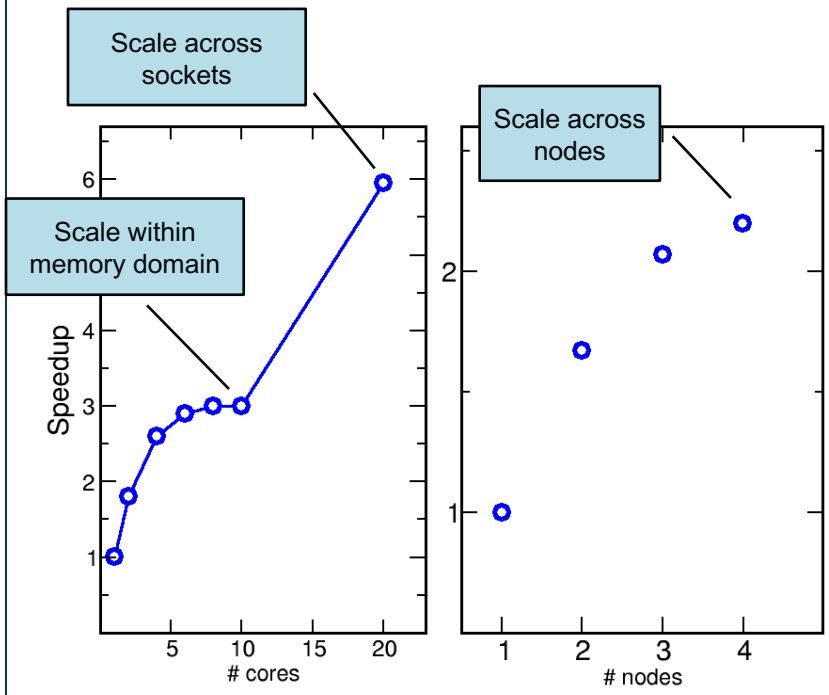
```
CPU 63: governor     ondemand min/cur/max 1.0/1.004/2.401 GHz Turbo 0
CPU 64: governor     ondemand min/cur/max 1.0/1.001/2.401 GHz Turbo 0
CPU 67: governor     ondemand min/cur/max 1.0/1.000/2.401 GHz Turbo 0
CPU 68: governor     ondemand min/cur/max 1.0/1.003/2.401 GHz Turbo 0
CPU 69: governor     ondemand min/cur/max 1.0/1.000/2.401 GHz Turbo 0
CPU 73: governor     ondemand min/cur/max 1.0/1.344/2.401 GHz Turbo 0
CPU 74: governor     ondemand min/cur/max 1.0/1.285/2.401 GHz Turbo 0
CPU 77: governor     ondemand min/cur/max 1.0/1.028/2.401 GHz Turbo 0
CPU 78: governor     ondemand min/cur/max 1.0/1.059/2.401 GHz Turbo 0
CPU 79: governor     ondemand min/cur/max 1.0/1.027/2.401 GHz Turbo 0

Current Uncore frequencies:
Socket 0: min/max 1.2/2.4 GHz
Socket 1: min/max 1.2/2.4 GHz
```

Always measure the actual frequency with a HPM tool. Using `likwid-perfctr`, any performance group reports clock frequencies.

# Benchmark planning

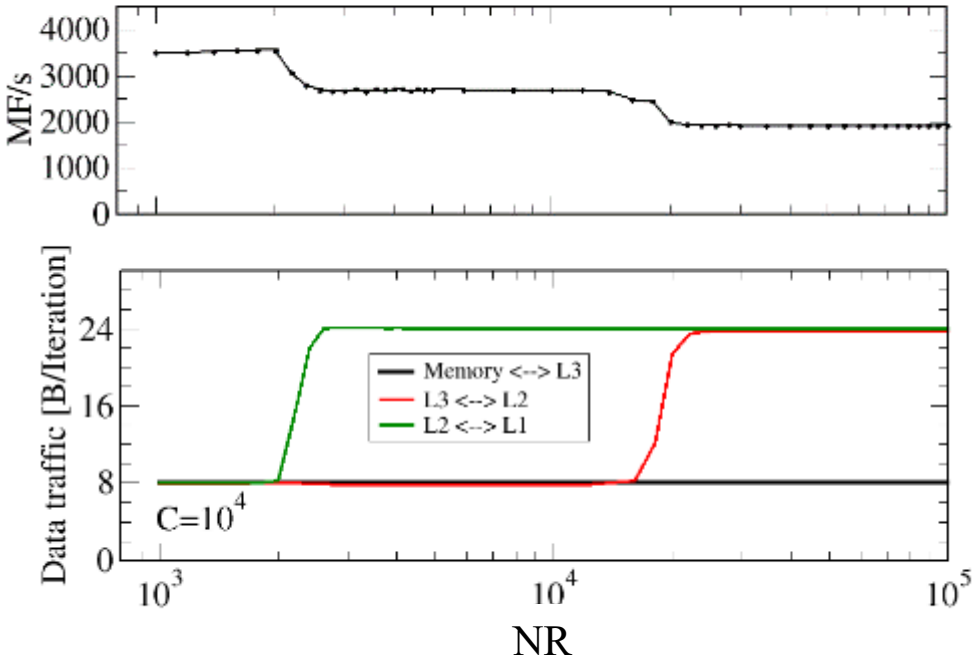
Two main variations:

**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

# 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**

# HPC Wiki

- Generic HPC-specific documentation Wiki
- Open for participation, login using SSO via eduGAIN
- Covers specifically performance engineering topics and skills
- Still work in progress, but improving!

**https://hpc-wiki.info**