# Session 4: Performance measurements

## COMP52315: performance engineering

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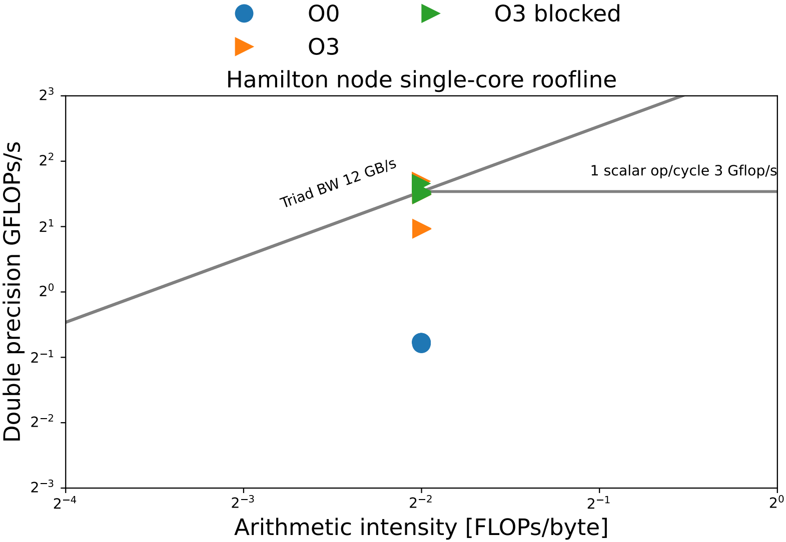
# Roofline dense matrix-vector product



# How and what to measure

- Roofline gives us a high-level overview of what to try next.
- How to drill down and get more information about what is causing the bottleneck?
- How to confirm the hypothesis formed through the roofline analysis?

$\Rightarrow$ *Measure* things about the code.

# Performance measurements

- Modern hardware comes with some special purpose *registers* that you can prod to measure low level performance events.
- Can use this to characterise performance of a piece of code

## Caveats

- Measurements can only tell you about the algorithm you're using
- e.g. Counts the data you moved, not the data you could have moved.
- Do not tell you about potential better algorithms
- Need to work hand in hand with models.

# What kind of things can we measure?

- An almost overwhelming number of different things like:
  - Number of floating point instructions of different type (scalar, sse, avx)
  - Cache miss/hit counts at various levels
  - Branch prediction success rate
  - ...

$\Rightarrow$ Best used to confirm hypothesis from some model

# Abstract metrics

- Can read low-level hardware counters directly (e.g. how many floating point instructions were executed?)
- More useful to group into abstract metrices

$\Rightarrow$ easier to compare across hardware, easier to interpret.

- For example, measure “Instructions per cycle” rather than instructions.

# How do we measure them?

- Use `likwid-perfctr` (installed on Hamilton via the `likwid` module).
- Offers a reasonably friendly command-line interface.
- Provides access both to counters directly, and many useful predefined "groups".

# Example: STREAM

- Will use `likwid-perfctr` to measure memory references in different implementations of the same loop.

**Scalar**

```
for i from 0 to n:
  load a[i:i+1] reg1
  load b[i:i+1] reg2
  load c[i:i+1] reg4
  mul reg1 reg2 reg3
  add reg4 reg3 reg4
  store reg4 c[i:i+1]
```

**SSE**

```
for i from 0 to n by 2:
  vload a[i:i+2] vreg1
  vload b[i:i+2] vreg2
  vload c[i:i+2] vreg4
  vmul vreg1 vreg2 vreg3
  vadd reg4 reg3 reg4
  vstore reg4 c[i:i+2]
```

**AVX**

```
for i from 0 to n by 4:
  vload a[i:i+4] vreg1
  vload b[i:i+4] vreg2
  vload c[i:i+4] vreg4
  vmul vreg1 vreg2 vreg3
  vadd reg4 reg3 reg4
  vstore reg4 c[i:i+4]
```

**AVX2**

```
for i from 0 to n by 4:
  vload a[i:i+4] vreg1
  vload b[i:i+4] vreg2
  vload c[i:i+4] vreg3
  vfma vreg1 vreg2 vreg3
  vstore reg3 c[i:i+4]
```

# Measurement

## Model

For each loop choice, if we choose $n = 10^6$, how many load and store instructions do we expect to measure?

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For each loop choice, if we choose $n = 10^6$, how many load and store instructions do we expect to measure?

## Answer

Each loop iteration has 3 loads and 1 store.

Vector width $v$ and $n$ iterations we need $\frac{3n}{v}$ loads and $\frac{n}{v}$ stores.

$\Rightarrow$ let's attempt to verify this with measurements.

# Exercise

- Goal is to convince ourselves that measurement works!

$\Rightarrow$ Exercise 5 from the usual place.

# Larger code

**Problem**

What if you don't know which part of the code takes all the time?

**Answer**

Use *profiling* to determine hotspots (regions of code where all the time is spent).

$\Rightarrow$ allows us to focus in on important parts.

# Profiling: types

- Goal is to gather information about what a code is doing
  - *Sampling*
  - or *code instrumentation*

### Sampling

- Works with unmodified executables
- Only a statistical model of code execution

⇒ not very detailed for volatile metrics

⇒ needs long-running application

### Instrumentation

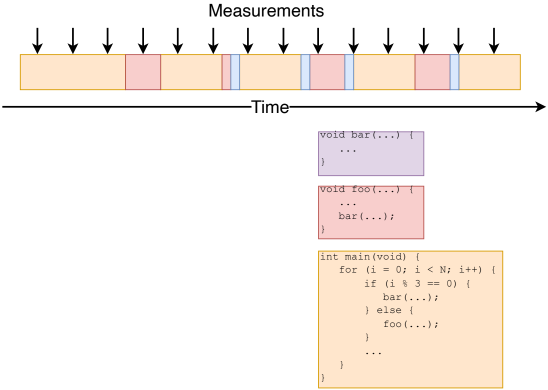
- Requires source code annotations to capture "interesting" information
- Much more details and focused

⇒ Preprocessing of source required

⇒ Can have large *overheads* for small functions.

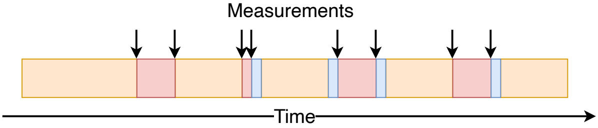
# Sampling

- Running program is periodically interrupted to take a measurement.
- Records which function we are in.



# Tracing

- Measurement code is inserted to capture all the events we care about




```
void bar(...) {
   ...
}

void foo(...) {
   Enter("foo")
   ...
   bar(...);
   Exit("foo");
}

int main(void) {
   for (i = 0; i < N; i++) {
       if (i % 3 == 0) {
          bar(...);
       } else {
          foo(...);
       }
       ...
   }
}
```

# Sampling profiles with gprof

## Workflow

1. Compile *and link* code with symbols (add `-g`) and profile information (`-p`).
2. Run code $\Rightarrow$ produces file `gmon.out`
3. Postprocess data with `gprof`
4. Look at results

# gprof “flat profile”

```
Flat profile:

Each sample counts as 0.01 seconds.
  %   cumulative   self              self     total
 time   seconds   seconds    calls   s/call   s/call  name
 76.14      5.71     5.71      102     0.06     0.06  ForceLJ::compute(Atom&, Neighb
 17.07      6.99     1.28        6     0.21     0.22  Neighbor::build(Atom&)
  2.80      7.20     0.21        3     0.07     0.07  void ForceLJ::compute_halfneig
  1.47      7.31     0.11        1     0.11     7.05  Integrate::run(Atom&, Force*,
  0.93      7.38     0.07                             __intel_avx_rep_memcpy
  0.40      7.41     0.03       11     0.00     0.00  Neighbor::binatoms(Atom&, int)
  0.40      7.44     0.03        6     0.01     0.01  Comm::borders(Atom&)
  0.40      7.47     0.03        1     0.03     0.04  create_atoms(Atom&, int, int,
  0.13      7.48     0.01   285585     0.00     0.00  Atom::unpack_border(int, doubl
```

# gprof “flat profile”

- Code is instrumented (instructions inserted so we know which function we’re in), triggering of measurement is sampling based (not every call).
- GProf provides profile with some tracing information
- Gives both *inclusive* and *exclusive* timings.

  - Blue box shows “inclusive” time for `main`
  - `foo` and `bar` calls (orange) excluded for “exclusive” time.

⇒ exclusive time measures execution in function that is not attributable to some other function.

```
int main(void) {
    for (i = 0; i < N; i++) {
        if (i % 3 == 0) {
            bar(...);
        } else {
            foo(...);
        }
        ...
    }
}
```

# Continued workflow

- After we have identified the hotspot that takes all the time, we'd like to determine if it is optimised

$\Rightarrow$ need more detailed insights.

1. Find relevant bit of code
2. Determine algorithm
3. Add instrumentation markers (see exercise)
4. Profile with more detail/use performance models.

$\Rightarrow$ guidance for appropriate optimisation.

# Exercise: finding the hotspot

- So far, we've looked at very simple code. Now, your task will be to find the hotspot and do some exploration in a larger one.

$\Rightarrow$ Exercise 6 from the usual place.