Lecture 27—Profiler Lies

ECE 459: Programming for Performance

March 13, 2015

Part I

Lies about Calling Context

gprof and KCacheGrind

Who can we trust?

Some profiler results are real.
Other results are interpolated, and perhaps wrong.

Reference: Yossi Kreinin,
http://www.yosefk.com/blog/how-profilers-lie-the-cases-of-gprof-and-kcachegrind.html

Running Example

```
void work(int n) {
  volatile int i=0; //don't optimize away
  while(i++ < n);
}
void easy() { work(1000); }
void hard() { work(1000*1000*1000); }
int main() { easy(); hard(); }
```

Running the Running Example

```
[plam@lynch L27]$ gprof ./try gmon.out
Flat profile:

Each sample counts as 0.01 seconds.
  %   cumulative   self              self     total
 time   seconds   seconds    calls  ms/call  ms/call  name
101.30      1.68     1.68        2   840.78   840.78  work
  0.00      1.68     0.00        1     0.00   840.78  easy
  0.00      1.68     0.00        1     0.00   840.78  hard
```

That's not right!
`easy` takes $\approx$ 0s, `hard` takes 1.68s.

What's Wrong?

Need to understand how `gprof` works.

- **profil()**: asks glibc to record which instruction is currently executing (100×/second).
- **mcount()**: records call graph edges; called by `-pg` instrumentation.

profil information is statistical;
mcount information is exact.

Those Numbers Again

```
[plam@lynch L27]$ gprof ./try gmon.out
Flat profile:

Each sample counts as 0.01 seconds.
  %   cumulative   self              self     total
 time   seconds   seconds    calls  ms/call  ms/call  name
101.30      1.68     1.68        2   840.78   840.78  work
  0.00      1.68     0.00        1     0.00   840.78  easy
  0.00      1.68     0.00        1     0.00   840.78  hard
```

- calls: reliable;
- self seconds: sampled, but OK here;
- total ms/call: interpolated!

total ms/call

gprof sees:

- total of 1.68s in `work`,
- 1 call to `work` from `easy`;
- 1 call to `work` from `hard`.

All of these numbers are reliable.

gprof's unreliable conclusion:
`easy`, `hard` both cause 840ms of `work` time.

Wrong: `work` takes 1000000× longer when called from `hard`!

Where gprof guesses: Call graph edges

- contribution of children to parents;
- total runtime spent in self+children;
- etc.

When are call graph edges right?

Two cases:

- functions with only one caller
  (e.g. `f()` only called by `g()`); or,
- functions which always take the same time to complete
  (e.g. `rand()`).

What's sketchy:

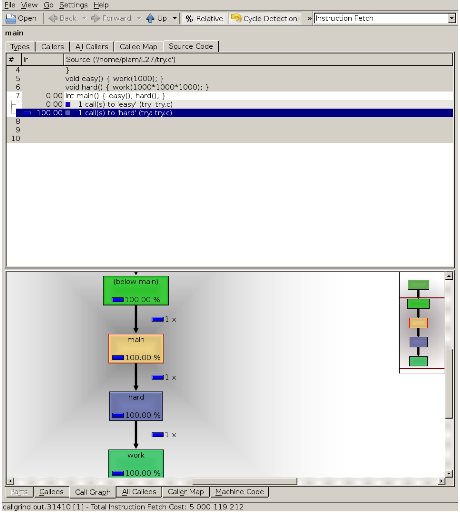
Any function whose running time depends on its inputs, and which is called from multiple contexts.

KCacheGrind

KCacheGrind is a frontend to callgrind.

callgrind is part of valgrind,
and runs the program under an x86 JIT.

KCacheGrind example



Yes, `hard` takes all the time.

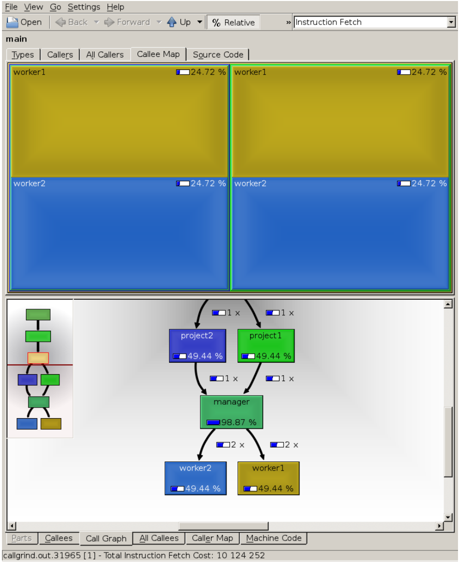
More Complex Example

```c
void worker1(int n) {
  volatile int i=0;
  while(i++<n);
}
void worker2(int n) {
  volatile int i=0;
  while(i++<n);
}
void manager(int n1, int n2) {
  worker1(n1);
  worker2(n2);
}
void project1() {
  manager(1000, 1000000);
}
void project2() {
  manager(1000000, 1000);
}
int main() {
  project1();
  project2();
}
```

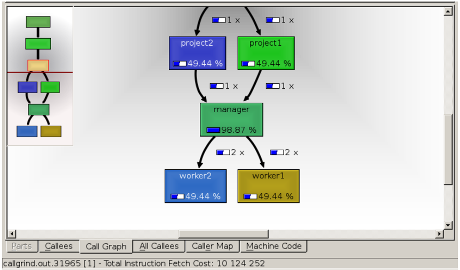
Example explained in 2 lines

Now `worker2` takes all the time in `project1`,
and `worker1` takes all the time in `project2`.

What about KCacheGrind now?



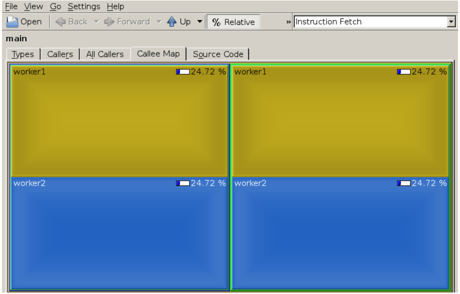
KCacheGrind Truths



This is the call graph.
`worker1` and `worker2` do each take about 50% of time.
So do `project2` and `project1`.

(gprof would interpolate that too.)

KCacheGrind Lies



KCacheGrind is reporting:

- `worker1` and `worker2` doing half the work in each project.

That's not what the code says.

Why KCacheGrind Lies

gprof reports time spent in `f()` and `g()`,
and how many times `f()` calls `g()`.

callgrind also reports
time spent in `g()` when called from `f()`,
i.e. some calling-context information.

callgrind does <u>not</u> report time spent in `g()`
when called from `f()` when called from `h()`.

We don't get the `project1` to `manager` to `worker1` link.

(We have Edges but need Edge-Pairs).

gprof/KCacheGrind summary

Some results are exact;
some results are sampled;
some results are interpolated.

If you understand the tool,
you understand where it can go wrong.

Understand your tools!

Part II

Lies from Metrics

Lying perf counters

While app-specific metrics can lie too,
mostly we'll talk about CPU perf counters.

Reference: Paul Khuong,
http://www.pvk.ca/Blog/2014/10/19/performance-optimisation-~-writing-an-essay/

mfence

We've talked about `mfence`.
Used in spinlocks, for instance.

Profiles said: spinlocking didn't take much time.
Empirically: eliminating spinlocks = better than expected!

Exploring the lie

Next step: create microbenchmarks.

Memory accesses to uncached locations,
or computations,

surrounded by store pairs/mfence/locks.

Use perf to evaluate impact of mfence vs lock.

perf for lock

```
$ perf annotate -s cache_misses
[...]
   0.06 :        4006b0:       and    %rdx,%r10
   0.00 :        4006b3:       add    $0x1,%r9
   ;; random (out of last level cache) read
   0.00 :        4006b7:       mov    (%rsi,%r10,8),%rbp
  30.37 :        4006bb:       mov    %rcx,%r10
   ;; foo is cached, to simulate our internal lock
   0.12 :        4006be:       mov    %r9,0x200fbb(%rip)
   0.00 :        4006c5:       shl    $0x17,%r10
   [... Skipping arithmetic with < 1% weight in the profile]
   ;; locked increment of an in-cache "lock" byte
   1.00 :        4006e7:       lock incb 0x200d92(%rip)
  21.57 :        4006ee:       add    $0x1,%rax
   [...]
   ;; random out of cache read
   0.00 :        400704:       xor    (%rsi,%r10,8),%rbp
  21.99 :        400708:       xor    %r9,%r8
   [...]
   ;; locked in-cache decrement
   0.00 :        400729:       lock decb 0x200d50(%rip)
  18.61 :        400730:       add    $0x1,%rax
   [...]
   0.92 :        400755:       jne    4006b0 <cache_misses+0x30>
```

lock's effects

Reads take $30 + 22 = 52\%$ of runtime
Locks take $19 + 21 = 40\%$.

perf for mfence

```
$ perf annotate -s cache_misses
[...]
    0.00 :          4006b0:        and     %rdx,%r10
    0.00 :          4006b3:        add     $0x1,%r9
    ;; random read
    0.00 :          4006b7:        mov     (%rsi,%r10,8),%rbp
   42.04 :          4006bb:        mov     %rcx,%r10
    ;; store to cached memory (lock word)
    0.00 :          4006be:        mov     %r9,0x200fbb(%rip)
    [...]
    0.20 :          4006e7:        mfence
    5.26 :          4006ea:        add     $0x1,%rax
    [...]
    ;; random read
    0.19 :          400700:        xor     (%rsi,%r10,8),%rbp
   43.13 :          400704:        xor     %r9,%r8
    [...]
    0.00 :          400725:        mfence
    4.96 :          400728:        add     $0x1,%rax
    0.92 :          40072c:        add     $0x1,%rax
    [...]
    0.36 :          40074d:        jne     4006b0 <cache_misses+0x30>
```

mfence's effects

Looks like the reads take 85% of runtime,
while the mfence takes 15% of runtime.

Bigger picture

Must also look at total # of cycles.

No atomic/fence:	2.81e9 cycles
lock inc/dec:	3.66e9 cycles
mfence:	19.60e9 cycles

That 15% number is a total lie.

Conclusions

- mfence underestimated;
- lock overestimated.

Why?

mfence = pipeline flush,
costs attributed to instructions being flushed.

Summary

Saw a bunch of lies today:

- calling-context lies;
- perf attribution lies.