Lecture 25 — Using Google Performance Tools

Patrick Lam
patrick.lam@uwaterloo.ca

Department of Electrical and Computer Engineering
University of Waterloo

January 4, 2019

Part I

gperftools

Introduction to gperftools

Google Performance Tools include:

- CPU profiler.
- Heap profiler.
- Heap checker.
- Faster (multithreaded) `malloc`.

We'll mostly use the CPU profiler:

- purely statistical sampling;
- no recompilation; at most linking; and
- built-in visual output.

You can use the profiler without any recompilation.

- Not recommended—worse data.

```
LD_PRELOAD="/usr/lib/libprofiler.so" \
CPUPROFILE=test.prof ./test
```

The other option is to link to the profiler:

- `-lprofiler`

Both options read the `CPUPROFILE` environment variable:

- states the location to write the profile data.

Other Usage

You can use the profiling library directly as well:

- `#include <gperftools/profiler.h>`

Bracket code you want profiled with:

- `ProfilerStart()`
- `ProfilerStop()`

You can change the sampling frequency with the `CPUPROFILE_FREQUENCY` environment variable.

- **Default value:** 100

Like gprof, it will analyze profiling results.

```
% pprof test test.prof
    Enters "interactive" mode
% pprof --text test test.prof
    Outputs one line per procedure
% pprof --gv test test.prof
     Displays annotated call-graph via 'gv'
% pprof --gv --focus=Mutex test test.prof
    Restricts to code paths including a .*Mutex.* entry
% pprof --gv --focus=Mutex --ignore=string test test.prof
    Code paths including Mutex but not string
% pprof --list=getdir test test.prof
    (Per-line) annotated source listing for getdir()
% pprof --disasm=getdir test test.prof
    (Per-PC) annotated disassembly for getdir()
```

Can also output dot, ps, pdf or gif instead of gv.

Similar to the flat profile in gprof

```
jon@riker examples master % pprof --text test test.prof
Using local file test.
Using local file test.prof.
Removing killpg from all stack traces.
Total: 300 samples
      95  31.7%  31.7%      102  34.0% int_power
      58  19.3%  51.0%       58  19.3% float_power
      51  17.0%  68.0%       96  32.0% float_math_helper
      50  16.7%  84.7%      137  45.7% int_math_helper
      18   6.0%  90.7%      131  43.7% float_math
      14   4.7%  95.3%      159  53.0% int_math
      14   4.7% 100.0%      300 100.0% main
       0   0.0% 100.0%      300 100.0% __libc_start_main
       0   0.0% 100.0%      300 100.0% _start
```

Columns, from left to right:

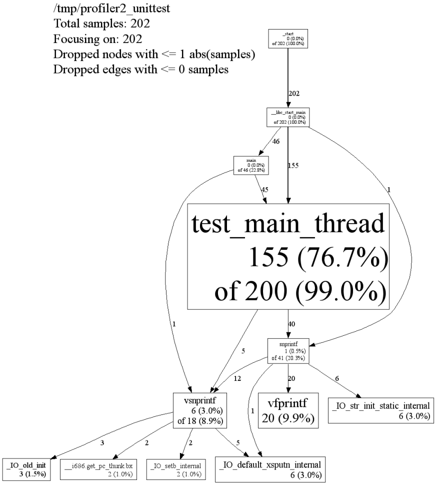
Number of checks (samples) in this function.
Percentage of checks in this function.

- Same as **time** in `gprof`.

Percentage of checks in the functions printed so far.

- Equivalent to **cumulative** (but in %).

Number of checks in this function and its callees.
Percentage of checks in this function and its callees.
Function name.


/tmp/profiler2_unittest
Total samples: 202
Focusing on: 202
Dropped nodes with <= 1 abs(samples)
Dropped edges with <= 0 samples
_start
0 (0.0%)
of 202 (100.0%)
202
__libc_start_main
0 (0.0%)
of 202 (100.0%)
46
155
1
main
0 (0.0%)
of 46 (22.8%)
45
test_main_thread
155 (76.7%)
of 200 (99.0%)
1
5
40
snprintf
1 (0.5%)
of 41 (20.3%)
12
20
6
1
vsnprintf
6 (3.0%)
of 18 (8.9%)
vfprintf
20 (9.9%)
_IO_str_init_static_internal
6 (3.0%)
3
2
2
5
_IO_old_init
3 (1.5%)
__i686.get_pc_thunk.bx
2 (1.0%)
_IO_setb_internal
2 (1.0%)
_IO_default_xsputn_internal
6 (3.0%)

Graphical Output Explained

Output was too small to read on the slide.

- Shows the same numbers as the text output.
- Directed edges denote function calls.
- Note: number of samples in callees =
  number in "this function + callees" -
  number in "this function".
- **Example:**
  `float_math_helper`, 51 (local) of 96 (cumulative)
  96 - 51 = 45 (callees)
  - callee `int_power` = 7 (bogus)
  - callee `float_power` = 38
  - callees total = 45

Things You May Notice

Call graph is not exact.

- In fact, it shows many bogus relations which clearly don't exist.
- For instance, we know that there are no cross-calls between `int` and `float` functions.

As with `gprof`, optimizations will change the graph.

You'll probably want to look at the text profile first, then use the `-focus` flag to look at individual functions.

Part II

System profiling: oprofile, perf, DTrace, WAIT

Introduction: oprofile

`http://oprofile.sourceforge.net`

Sampling-based tool.

Uses CPU performance counters.

Tracks currently-running function;
records profiling data for every application run.

Can work system-wide (across processes).

Technology: Linux Kernel Performance Events
(formerly a Linux kernel module).

Must run as root to use system-wide, otherwise can use per-process.

```
% sudo opcontrol \
    --vmlinux=/usr/src/linux-3.2.7-1-ARCH/vmlinux
% echo 0 | sudo tee /proc/sys/kernel/nmi_watchdog
% sudo opcontrol --start
Using default event: CPU_CLK_UNHALTED:100000:0:1:1
Using 2.6+ OProfile kernel interface.
Reading module info.
Using log file /var/lib/oprofile/samples/oprofiled.log
Daemon started.
Profiler running.
```

Per-process:

```
[plam@lynch nm-morph]$ operf ./test_harness
operf: Profiler started

Profiling done.
```

oprofile Usage (1)

Pass your executable to opreport.

```
% sudo opreport -l ./test
CPU: Intel Core/i7, speed 1595.78 MHz (estimated)
Counted CPU_CLK_UNHALTED events (Clock cycles when not
halted) with a unit mask of 0x00 (No unit mask) count 100000
samples  %        symbol name
7550     26.0749  int_math_helper
5982     20.6596  int_power
5859     20.2348  float_power
3605     12.4504  float_math
3198     11.0447  int_math
2601      8.9829  float_math_helper
160       0.5526  main
```

If you have debug symbols (-g) you could use:

```
% sudo opannotate --source \
--output-dir=/path/to/annotated-source /path/to/mybinary
```

`oprofile` Usage (2)

Use `opreport` by itself for a whole-system view.
You can also reset and stop the profiling.

```
% sudo opcontrol --reset
 Signalling daemon... done
% sudo opcontrol --stop
 Stopping profiling.
```

`perf.wiki.kernel.org/index.php/Tutorial`

Interface to Linux kernel built-in sampling-based profiling.
Per-process, per-CPU, or system-wide.
Can even report the cost of each line of code.

On previous Assignment 3 code:

```
[plam@lynch nm-morph]$ perf stat ./test_harness

 Performance counter stats for './test_harness':

       6562.501429 task-clock                #    0.997 CPUs utilized
               666 context-switches          #    0.101 K/sec
                 0 cpu-migrations            #    0.000 K/sec
             3,791 page-faults               #    0.578 K/sec
    24,874,267,078 cycles                    #    3.790 GHz                     [83.32%]
    12,565,457,337 stalled-cycles-frontend   #   50.52% frontend cycles idle    [83.31%]
     5,874,853,028 stalled-cycles-backend    #   23.62% backend  cycles idle    [66.63%]
    33,787,408,650 instructions              #    1.36  insns per cycle
                                             #    0.37  stalled cycles per insn [83.32%]
     5,271,501,213 branches                  #  803.276 M/sec                   [83.38%]
       155,568,356 branch-misses             #    2.95% of all branches         [83.36%]

       6.580225847 seconds time elapsed
```

perf can tell you which instructions are taking time, or which lines of code.

Compile with `-ggdb` to enable source code viewing.

```
% perf record ./test_harness
% perf annotate
```

`perf annotate` is interactive. Play around with it.

`http://queue.acm.org/detail.cfm?id=1117401`
`http://www.brendangregg.com/blog/2016-10-27/dtrace-for-linux-2016.html`

Intrumentation-based tool.
System-wide.
Meant to be used on production systems. (Eh?)

`http://queue.acm.org/detail.cfm?id=1117401`
`http://www.brendangregg.com/blog/2016-10-27/dtrace-for-linux-2016.html`

Intrumentation-based tool.
System-wide.
Meant to be used on production systems. (Eh?)

(Typical instrumentation can have a slowdown of 100x (Valgrind).)

Design goals:

1. No overhead when not in use;
2. Guarantee safety—must not crash
   (strict limits on expressiveness of probes).

DTrace: Operation

How does DTrace achieve 0 overhead?

- only when activated, dynamically rewrites code by placing a branch to instrumentation code.

Uninstrumented: runs as if nothing changed.

Most instrumentation: at function entry or exit points. You can also instrument kernel functions, locking, instrument-based on other events.

Can express sampling as instrumentation-based events also.

You write this:

```
syscall::read:entry {
    self->t = timestamp;
}

syscall::read:return
/self->t/ {
    printf("%d/%d spent %d nsecs in read\n"
           pid, tid, timestamp - self->t);
}
```

`t` is a thread-local variable.
This code prints how long each call to `read` takes, along with context.

To ensure safety, DTrace limits expressiveness—no loops.

- (Hence, no infinite loops!)

AMD CodeAnalyst—based on oprofile; leverages AMD processor features.

WAIT

- IBM's tool tells you what operations your JVM is waiting on while idle.
- Non-free and not available.

WAIT: Introduction

Built for production environments.

Specialized for profiling JVMs,
uses JVM hooks to analyze idle time.

Sampling-based analysis; infrequent samples
(1–2 per minute!)

WAIT: Operation

At each sample: records each thread's state,

- call stack;
- participation in system locks.

Enables WAIT to compute a "wait state"
(using expert-written rules):
what the process is currently doing or waiting on, e.g.

- disk;
- GC;
- network;
- blocked;
- etc.

You:

- run your application;
- collect data (using a script or manually); and
- upload the data to the server.

Server provides a report.

- You fix the performance problems.

Report indicates processor utilization (idle, your application, GC, etc); runnable threads; waiting threads (and why they are waiting); thread states; and a stack viewer.

Paper presents 6 case studies where WAIT identified performance problems: deadlocks, server underloads, memory leaks, database bottlenecks, and excess filesystem activity.

Other Profiling Tools

Profiling: Not limited to C/C++, or even code.

You can profile Python using `cProfile`; standard profiling technology.

Google's Page Speed Tool: profiling for web pages—how can you make your page faster?

- reducing number of DNS lookups;
- leveraging browser caching;
- combining images;
- plus, traditional JavaScript profiling.