Lecture 25 — Using Google Performance Tools

Patrick Lam
patrick.lam@uwaterloo.ca

Department of Electrical and Computer Engineering
University of Waterloo

December 20, 2018

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.

Google Perf Tools profiler usage

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

pprof Usage

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
```

Text Output Explained

Columns, from left to right:

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

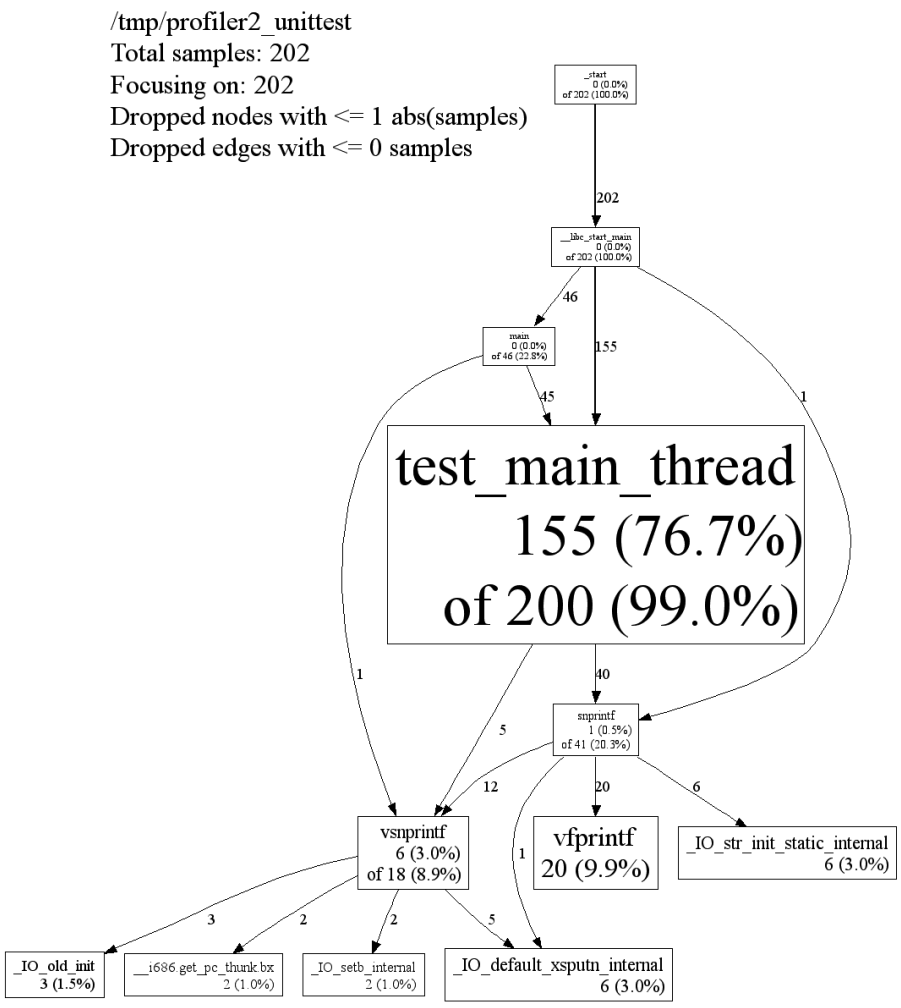
- Same as **time** in `gprof`.

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.

Graphical Output



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).

Setting up `oprofile`

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: Introduction

`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.

Perf: Usage Example

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: Source-level Analysis

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.

DTrace: Introduction

`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?)

DTrace: Introduction

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.

DTrace Example

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!)

Other Tools

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.

WAIT: Workflow

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.