Lecture 25 — Using Google Performance Tools

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Part I

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.

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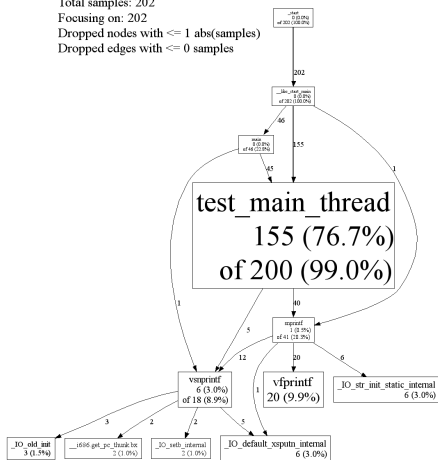Percentage of checks in this function and its callees.
Function name.

/tmp/profiler2_unittest
Total samples: 202
Focusing on: 202
Dropped nodes with <= 1 abs(samples)
Dropped edges with <= 0 samples

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

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

`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.
```

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
```

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.
```

`https://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 last year's 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?)

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).

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 what you write; e.g. 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.

Built for production environments.

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

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

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.

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.