Lecture 22—Midterm Review

ECE 459: Programming for Performance

March 2, 2015

Live Coding Example: Midterm Tree Access Code

I ran the code from the 2013 midterm with:

- a coarse-grained lock;
- per-item fine-grained locks.

Fine-grained locks were suspiciously fast.

Part I

Midterm Review

Key Concepts I: goals

- Bandwidth versus Latency.
- Concurrency versus Parallelism.
- More bandwidth through parallelism.
- Amdahl's Law and Gustafson's Law.

Key Concepts II: leveraging parallelism

- Features of modern hardware.
- Parallelism implementations: pthreads & C++11 threads.
  - definition of a thread;
  - spawning threads.
- Problems with parallelism: race conditions.
  - manual solutions: mutexes, spinlocks, RW locks, semaphores, barriers.
  - lock granuarlity.
- Parallelization patterns; also SIMD.

Key Concepts III: inherently-sequential problems

- Barriers to parallelization: dependencies.
  - loop-carried, memory-carried;
  - RAW/WAR/WAW/RAR.
- Breaking dependencies with speculation.

Key Concepts IV: higher-level parallelization

- Automatic parallelization; when does it work?
- Language/library support through OpenMP.

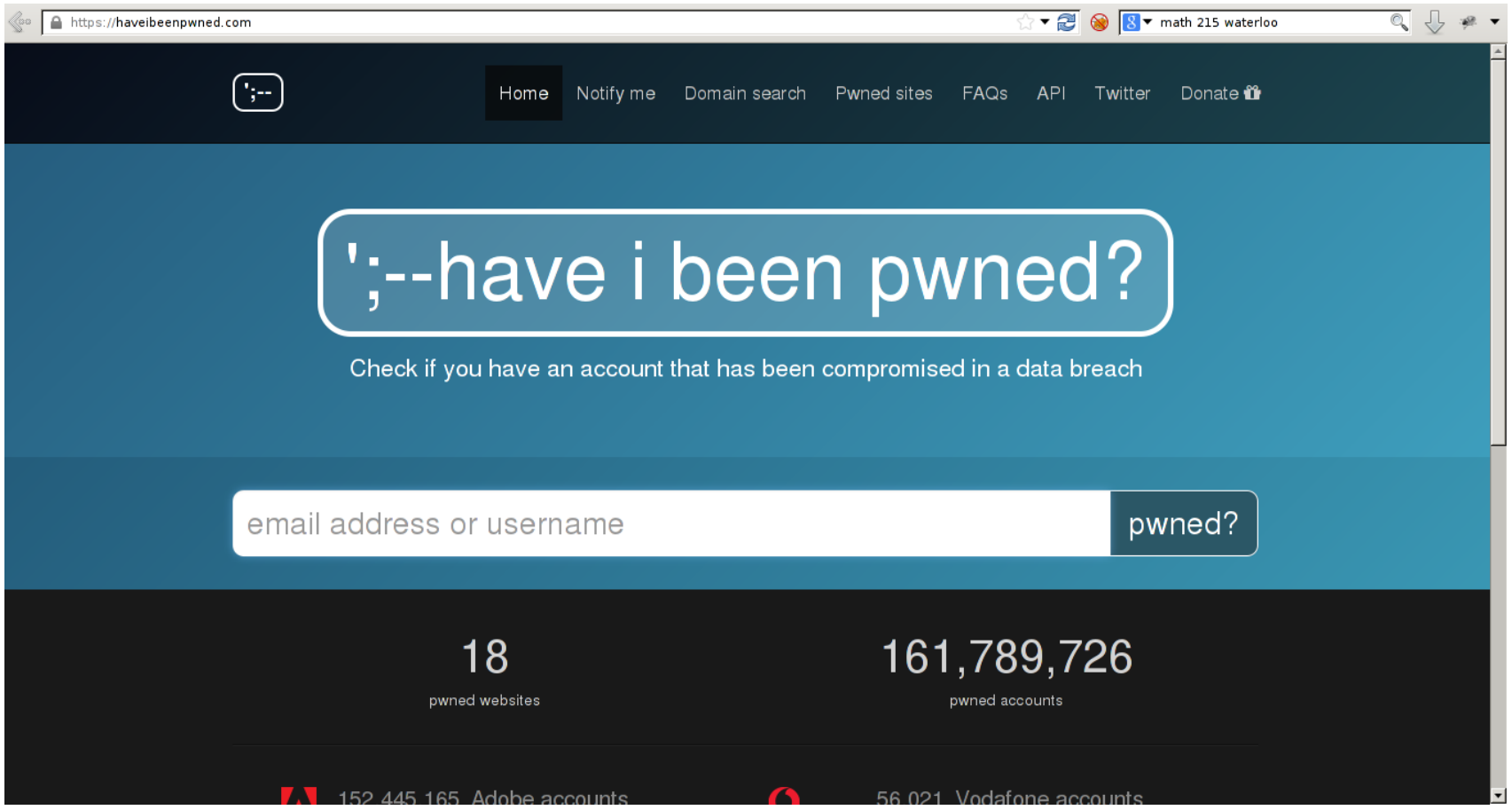
Key Concepts V: hardware considerations

- Unwelcome surprises: memory models & reordering.
  - fences and barriers; atomic instructions.

Part II

Optimizing a Website

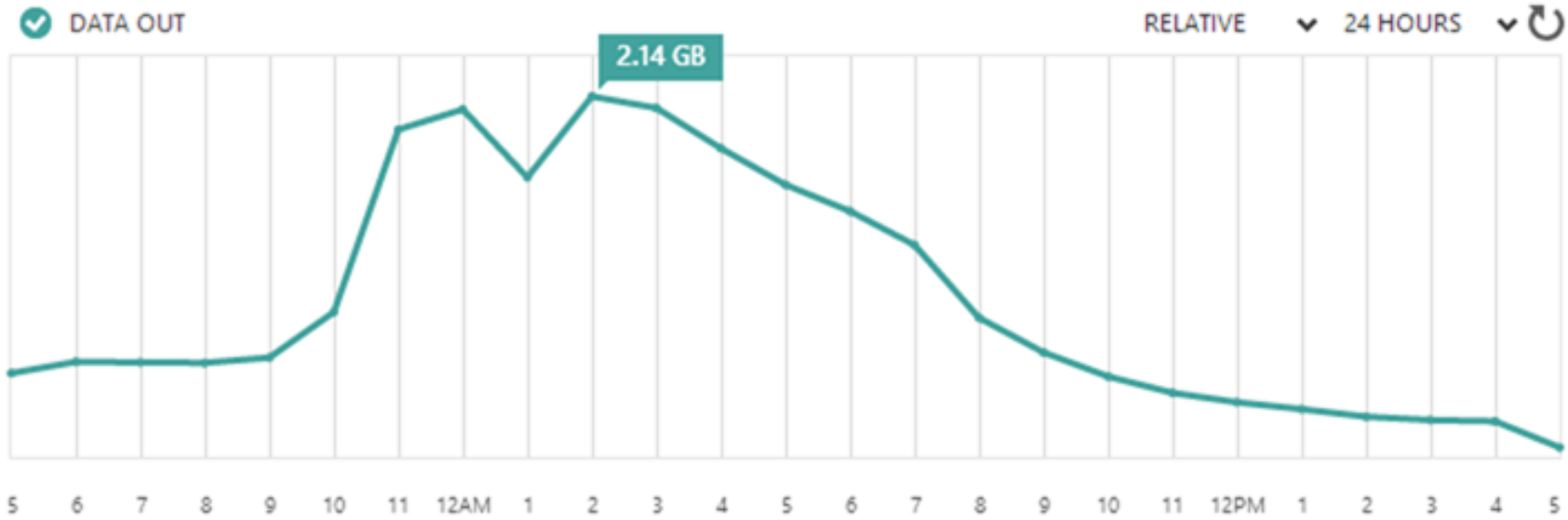
December 2013: Slashdotted...



Discussion:

`http://www.troyhunt.com/2013/12/micro-optimising-web-content-for.html`

The Issue is Bandwidth



23GB in 24 hours.

This is a problem that you could solve with money.
We can do better.

Standard Website Tricks

HTML (and JavaScript) + CSS.

Specifically: Bootstrap, jQuery, Font Awesome.
Bundled and minified.
(2 requests: one for CSS—early, one for JS—late).

Cache expiration = 1 year; gzip everything.

5 images: well-optimized SVGs = 12.1kB.

Disabled all unnecessary response headers.

Ran through YSlow and Web Page Test (A).

Conflicting Objectives

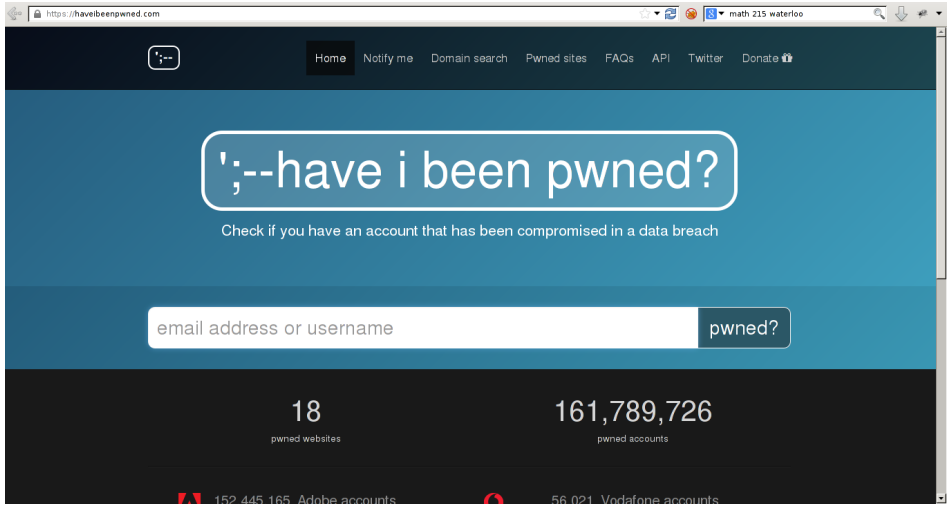
- Speed: load page as fast as possible;
- Data volume: minimize outbound data.

Example of conflict:

load jQuery from Google's Content Distribution Network, at the cost of more latency (separate requests).

About Speed

Want site to be “usable” as soon as possible.



1. Must load the HTML first (compress it!)
2. Then you need the CSS.

That covers everything except for the logos.

At this point, the page is “usable” (but can’t process requests).

Adding intelligence

To actually start processing, need JavaScript.

Don't actually need it until user enters an address
(well, also when clicking on a company;)
(but that's not going to happen instantly either.)

Graceful degradation:
without JS, use form submission and hyperlink.

Prefetching:
load 17 breaches directly in the HTML.

Stages of the Load Lifecycle

1. Readable
2. Visually Complete
3. Functionally Complete

Profiling Page Load

Use e.g. Chrome developer tools.

- Size: actual, compressed.
- Time: including latency.
- Sequencing/staggering of requests: parallelism!

31 requests, 174kB transferred.
Page ready after 200ms, complete after 800ms.

Content Distribution Networks

Initially: bundle then minify JavaScript—1 request, 88kB.

Serve jQuery from Google:

- 2 more requests;
- increase bytes transferred by 2kB.

But you've outsourced JS serving;
now only serve 10kB of JS yourself.

Plus, it's faster: jQuery loaded in parallel, closer to the user, and may be cached.

Also works for other libraries.

Other Tweaks

Make SVG files smaller.

Convert PNG to SVG.

Serve SVG from CDNs.

Do work on client-side (email address validation).

Part III

Profiling

Introduction to Profiling

So far we've been looking at small problems.

Must **profile** to see what takes time in a large program.

Two main outputs:

- flat;
- call-graph.

Two main data gathering methods:

- statistical;
- instrumentation.

Profiler Outputs

Flat Profiler:

- Only computes the average time in a particular function.
- Does not include other (useful) information, like callees.

Call-graph Profiler:

- Computes call times.
- Reports frequency of function calls.
- Gives a call graph: who called what function?

Data Gathering Methods

Statistical:
Mostly, take samples of the system state, that is:

- every 2ns, check the system state.
- will cause some slowdown, but not much.

Instrumentation:
Add additional instructions at specified program points:

- can do this at compile time or run time (expensive);
- can instrument either manually or automatically;
- like conditional breakpoints.

Guide to Profiling

When writing large software projects:

- First, write clear and concise code.
  Don't do any premature optimizations—focus on correctness.
- Profile to get a baseline of your performance:
  - allows you to easily track any performance changes;
  - allows you to re-design your program before it's too late.

Focus your optimization efforts on the code that matters.

Things to Look For

Good signs:

- Time is spent in the right part of the system.
- Most time should not be spent handling errors; in non-critical code; or in exceptional cases.
- Time is not unnecessarily spent in the operating system.

`gprof` introduction

Statistical profiler, plus some instrumentation for calls.

Runs completely in user-space.

Only requires a compiler.

gprof usage

Use the `-pg` flag with `gcc` when compiling and linking.

Run your program as you normally would.

- Your program will now create a `gmon.out` file.

Use gprof to interpret the results: `gprof <executable>`.

gprof example

A program with 100 million calls to two math functions.

```
int main() {
    int i,x1=10,y1=3,r1=0;
    float x2=10,y2=3,r2=0;

    for(i=0;i<100000000;i++) {
        r1 += int_math(x1,y1);
        r2 += float_math(y2,y2);
    }
}
```

- Looking at the code, we have no idea what takes longer.
- Probably would guess floating point math taking longer.
- (Overall, silly example.)

Example (Integer Math)

```
int int_math(int x, int y){
    int r1;
    r1=int_power(x,y);
    r1=int_math_helper(x,y);
    return r1;
}

int int_math_helper(int x, int y){
    int r1;
    r1=x/y*int_power(y,x)/int_power(x,y);
    return r1;
}

int int_power(int x, int y){
    int i, r;
    r=x;
    for(i=1;i<y;i++){
        r=r*x;
    }
    return r;
}
```

Example (Float Math)

```
float float_math(float x, float y) {
    float r1;
    r1=float_power(x,y);
    r1=float_math_helper(x,y);
    return r1;
}

float float_math_helper(float x, float y) {
    float r1;
    r1=x/y*float_power(y,x)/float_power(x,y);
    return r1;
}

float float_power(float x, float y){
    float i, r;
    r=x;
    for(i=1;i<y;i++) {
        r=r*x;
    }
    return r;
}
```

Flat Profile

When we run the program and look at the profile, we see:

```
Flat profile:

Each sample counts as 0.01 seconds.
  %   cumulative   self              self     total
 time   seconds   seconds    calls  ns/call  ns/call  name
 32.58      4.69     4.69 300000000    15.64    15.64  int_power
 30.55      9.09     4.40 300000000    14.66    14.66  float_power
 16.95     11.53     2.44 100000000    24.41    55.68  int_math_helper
 11.43     13.18     1.65 100000000    16.46    45.78  float_math_helper
  4.05     13.76     0.58 100000000     5.84    77.16  int_math
  3.01     14.19     0.43 100000000     4.33    64.78  float_math
  2.10     14.50     0.30                             main
```

- One function per line.
- **% time:** the percent of the total execution time in this function.
- **self:** seconds in this function.
- **cumulative:** sum of this function's time + any above it in table.

Flat Profile

```
Flat profile:

Each sample counts as 0.01 seconds.
  %   cumulative   self              self     total
 time   seconds   seconds    calls  ns/call  ns/call  name
 32.58      4.69     4.69 300000000    15.64    15.64  int_power
 30.55      9.09     4.40 300000000    14.66    14.66  float_power
 16.95     11.53     2.44 100000000    24.41    55.68  int_math_helper
 11.43     13.18     1.65 100000000    16.46    45.78  float_math_helper
  4.05     13.76     0.58 100000000     5.84    77.16  int_math
  3.01     14.19     0.43 100000000     4.33    64.78  float_math
  2.10     14.50     0.30                             main
```

- **calls:** number of times this function was called
- **self ns/call:** just self nanoseconds / calls
- **total ns/call:** average time for function execution, including any other calls the function makes

Call Graph Example (1)

After the flat profile gives you a feel for which functions are costly, you can get a better story from the call graph.

```
index % time    self  children    called     name
                                             <spontaneous>
[1]    100.0    0.30   14.19                 main [1]
                0.58    7.13 100000000/100000000      int_math [2]
                0.43    6.04 100000000/100000000      float_math [3]
-----------------------------------------------
                0.58    7.13 100000000/100000000      main [1]
[2]     53.2    0.58    7.13 100000000          int_math [2]
                2.44    3.13 100000000/100000000      int_math_helper [4]
                1.56    0.00 100000000/300000000      int_power [5]
-----------------------------------------------
                0.43    6.04 100000000/100000000      main [1]
[3]     44.7    0.43    6.04 100000000          float_math [3]
                1.65    2.93 100000000/100000000      float_math_helper [6]
                1.47    0.00 100000000/300000000      float_power [7]
```

Reading the Call Graph

The line with the index is the current function being looked at **(primary line)**.

- Lines above are functions which called this function.
- Lines below are functions which were called by this function (children).

Primary Line

- **time:** total percentage of time spent in this function and its children
- **self:** same as in flat profile
- **children:** time spent in all calls made by the function
  - should be equal to self + children of all functions below

Reading Callers from Call Graph

Callers (functions above the primary line)

- **self:** time spent in primary function, when called from current function.
- **children:** time spent in primary function's children, when called from current function.
- **called:** number of times primary function was called from current function / number of nonrecursive calls to primary function.

Reading Callees from Call Graph

Callees (functions below the primary line)

- **self:** time spent in current function when called from primary.
- **children:** time spent in current function's children calls when called from primary.
  - self + children is an estimate of time spent in current function when called from primary function.
- **called:** number of times current function was called from primary function / number of nonrecursive calls to current function.

Call Graph Example (2)

```
index % time    self  children    called     name

                2.44    3.13 100000000/100000000      int_math [2]
[4]     38.4    2.44    3.13 100000000          int_math_helper [4]
                3.13    0.00 200000000/300000000      int_power [5]
-----------------------------------------------
                1.56    0.00 100000000/300000000      int_math [2]
                3.13    0.00 200000000/300000000      int_math_helper [4]
[5]     32.4    4.69    0.00 300000000          int_power [5]
-----------------------------------------------
                1.65    2.93 100000000/100000000      float_math [3]
[6]     31.6    1.65    2.93 100000000          float_math_helper [6]
                2.93    0.00 200000000/300000000      float_power [7]
-----------------------------------------------
                1.47    0.00 100000000/300000000      float_math [3]
                2.93    0.00 200000000/300000000      float_math_helper [6]
[7]     30.3    4.40    0.00 300000000          float_power [7]
```

We can now see where most of the time comes from, and pinpoint any locations that make unexpected calls, etc.

This example isn't too exciting; we could simplify the math.

Summary (Profiling)

- Saw how to use `gprof`
  (one option for Assignment 3).
- Profile early and often.
- Make sure your profiling shows what you expect.