Lecture 14:

Scaling a Web Site
Scale-out Parallelism, Elasticity, and Caching

Parallel Computer Architecture and Programming
CMU 15-418/15-618, Spring 2015
“Something Good”
(An Awesome Wave)
Alt-J

“Hey, these kids know their stuff!”
- Joe Newman.
IS
THE DEAL.
The Exam 1 Deal

- No exam 1 solutions will be distributed at this time
- You have the opportunity to redo up to 2 questions (of your choosing) from the exam, on your own time.
  - You may discuss the problems with your classmates, instructor, and TAs.
  - You must write your solutions on your own.
  - You will get 50% credit for lost points on regraded questions.
  - This must be completed by Friday, April 10th

But... there’s a catch.
Exam 1 Deal: the Catch

- You must hand in your solution to the course staff at a designated office hours.

- And you are not allowed to hand in unless you are able to successfully answer a series of questions we ask you.

- The questions will a subset of the six questions on exam 1 (or simple follow up variants).
It’s time to start thinking about projects

- **Timeline**
  - Project proposal due: April 1th
  - Project checkpoint: April 15th
  - Parallelism competition finals! (project presentations): May 11th

- **Ideas**
  - Pick an application, parallelize it, and analyze its performance
  - Modify a parallel library or compilation tool
  - Write a hardware simulator, play around with FPGAs, do real hardware design
  - Free to experiment with fun new parallel platforms: FPGAs, mobile devices, Tegra devkits, Raspberry Pis, Oculus Rift, etc.

- We will be making a web page of ideas over spring break

- See examples from last year:
  - [http://15418.courses.cs.cmu.edu/spring2014/competition](http://15418.courses.cs.cmu.edu/spring2014/competition)
Today’s focus: the basics of scaling a web site

- I’m going to focus on performance issues
  - Parallelism and locality

- Many other issues in developing a successful web platform
  - Reliability, security, privacy, etc.
  - There are other great courses at CMU for these topics (distributed systems, databases, cloud computing)
A simple web server for static content

```c
while (1) {
    request = wait_for_request();
    filename = parse_request(request);
    contents = read_file(filename);
    send contents as response
}
```

Question: is site performance a question of throughput or latency? (we’ll revisit this question later)
A simple parallel web server

```
while (1) {
    request = wait_for_request();
    filename = parse_request(request);
    contents = read_file(filename);
    send contents as response
}
```

What factors would you consider in setting the value of N for a multi-core web server?

- **Parallelism**: use all the server’s cores
- **Latency hiding**: hide long-latency disk read operations (by context switching between worker processes)
- **Concurrency**: many outstanding requests, want to service quick requests while long requests are in progress (e.g., large file transfer shouldn’t block serving index.html)
- **Footprint**: don’t want too many threads so that aggregate working set causes thrashing
Example: Apache’s parent process dynamically manages size of worker pool

Desirable to maintain a few idle workers in pool (avoid process creation in critical path of servicing requests)
Limit maximum number of workers to avoid excessive memory footprint (thrashing)

Key parameter of Apache's “prefork” multi-processing module: MaxRequestWorkers
Aside: why partition server into processes, not threads?

- **Protection**
  - Don’t want a crash in one worker to bring down the whole web server
  - Often want to use non-thread safe libraries (e.g., third-party libraries) in server operation

- **Parent process can periodically recycle workers**
  (robustness to memory leaks)

- **Of course, multi-threaded web server solutions exist as well**
  (e.g., Apache’s “worker” module)
Dynamic web content

"Response" is not a static page on disk, but the result of application logic running in response to a request.
Consider the amount of logic and the number database queries required to generate your Facebook News Feed.
Scripting language performance (poor)

- Two popular content management systems (PHP)
  - Wordpress ~ 12 requests/sec/core (DB size = 1000 posts)
  - MediaWiki ~ 8 requests/sec/core
  [Source: Talaria Inc.]

- Recent interest in making scripted code execute faster
  - Facebook’s HipHop: PHP to C source-to-source converter
  - Google’s V8 Javascript engine: JIT Javascript to machine code
“Scale out” to increase throughput

Use many web servers to meet site’s throughput goals.

Load balancer maintains list of available web servers and an estimate of load on each.

Distributes requests to pool of web servers. (Redistribution logic is cheap: one load balancer typically can service many web servers)

Web Server
Worker Process

Web Server
Worker Process

Web Server
Worker Process

Database (e.g., mySQL)
Load balancing with persistence

All requests associated with a session are directed to the same server (aka. session affinity, “sticky sessions”)

Requests
1. SessionId = X
2. SessionId = Y
3. SessionId = X
4. SessionId = X

map(sessionId, serverName)

Good:
- Do not have to change web-application design to implement scale out

Bad:
- Stateful servers can limit load balancing options. Also, session is lost if server fails
Desirable: avoid persistent state in web server

Maintain stateless servers, treat sessions as persistent data to be stored in the DB.
Dealing with database contention

Option 1: “scale up”: buy better hardware for database server, buy professional-grade DB that scales (see database systems course by Prof. Pavlo)
Good: no change to software
Bad: High cost, limit to scaling
Scaling out a database: replicate

Replicate data and parallelize reads
(most DB accesses are reads)
Cost: extra storage, consistency issues

Adopt relaxed consistency models:
propagate updates “eventually”
Scaling out a database: partition

Can tune database for access characteristics of data stored (common to use different database implementations for different workloads)
Inter-request parallelism

Parallelize generation of a single page

Amount of user traffic is directly correlated to response latency.

How many web servers do you need?
Web traffic is bursty

Amazon.com Page Views

HuffingtonPost.com Page Views Per Week

HuffingtonPost.com Page Views Per Day

More examples:
- Facebook gears up for bursts of image uploads on Halloween and New Year’s Eve.
- Twitter topics trend after world events

(fewer people read news on weekends)
15-418/618 site traffic

Spring 2014

Exam 1

Spring 2015

Pageviews

Pageviews

Feb 8
Feb 15
Feb 22
Mar 1
Feb 8
Feb 15
Feb 22
Mar 1

CMU 15-418, Spring 2015

CMU 15-418, Spring 2015
**Problem**

- Site load is bursty

- Provisioning site for the average case load will result in poor quality of service (or failures) during peak usage
  - Peak usage tends to be when users care the most... since by the definition the site is important at these times

- Provisioning site for the peak usage case will result in many idle servers most of the time
  - Not cost efficient (must pay for many servers, power/cooling, datacenter space, etc.)
Elasticity!

- Main idea: site automatically adds or removes web servers from worker pool based on measured load

- Need source of servers available on-demand
  - Example: Amazon.com EC2 instances
Example: Amazon’s elastic compute cloud (EC2)

- Amazon had an over-provisioning problem
- Solution: make machines available for rent to others in need of compute
  - For those that don’t want to incur cost of, or have expertise to, manage own machines at scale
  - For those that need elastic compute capability
Site configuration: normal load

Requests

Perf. Monitor
Load: moderate

Load Balancer

Web Server

Web Server

Web Server

Database (potentially multiple machines)

DB Slave 1

DB Slave 2

Master
Event triggers spike in load

Heavily loaded servers: slow response times

@justinbieber: OMG, parallel prog. class @ CMU is awesome. Look 4 my final project on hair sim. #15418
Heavily loaded servers = slow response times

- If requests arrive faster than site can service them, queue lengths will grow
- **Latency** of servicing request is wait time in queue + time to actually process request
  - Assume site has capability to process $R$ requests per second
  - Assume queue length is $L$
  - Time in queue $= L/R$

- How does site **throughput** change under heavy load?
Site configuration: high load

Site performance monitor detects high load
Instantiates new web server instances
Informs load balancer about presence of new servers
Site configuration: return to normal load

Site performance monitor detects low load
Released extra server instances (to save operating cost)
Informs load balancer about loss of servers

Note convenience of stateless servers in elastic environment: can kill server without loss of important information.
Today: many “turn-key” environment-in-a-box services

Offer elastic computing environments for web applications

CloudWatch+Auto Scaling
Amazon Elastic Beanstalk

Google App Engine

RightScale

Engine Yard

Google Cloud Platform
The story so far: parallelism
scale out, scale out, scale out

(+ elasticity to be able to scale out on demand)

Now: reuse and locality
Recall: basic site configuration

Example PHP Code

```php
$query = "SELECT * FROM users WHERE username='kayvonf';
$user = mysql_fetch_array(mysql_query($userquery));

echo "<div> . $user['FirstName'] . " " . $user['LastName'] . "</div>";
```

Response Information Flow

HTML: `<div>Kayvon Fatahalian</div>`
Work repeated every page

Example PHP Code

```php
$query = "SELECT * FROM users WHERE username='kayvonf';
$user = mysql_fetch_array(mysql_query($userquery));

echo "<div>" . $user['FirstName'] . " " . $user['LastName'] . "</div>";
```

Response Information Flow

- HTML
- PHP 'user' object
- 'users' table

Steps repeated to emit my name at the top of every page:
- Communicate with DB
- Perform query
- Marshall results from database into object model of scripting language
- Generate presentation
- etc...

Remember, DB can be hard to scale!
Solution: cache!

- Cache commonly accessed objects
  - Example: memcached, in memory key-value store (e.g., a big hash table)
  - Reduces database load (fewer queries)
  - Reduces web server load:
    - Less data shuffling between DB response and scripting environment
    - Store intermediate results of common processing
Caching example

userid = $_SESSION[‘userid’];

check if memcache->get(userid) retrieves a valid user object

if not:
    make expensive database query
    add resulting object into cache with memcache->put(userid)
    (so future requests involving this user can skip the query)

continue with request processing logic

- Of course, there is complexity associated with keeping caches in sync with data in the DB in the presence of writes
  - Must invalidate cache
  - Very simple “first-step” solution: only cache read-only objects
  - More realistic solutions provide some measure of consistency
    - But we’ll leave this to your distributed computing and database courses
Site configuration

- **Load Balancer**
  - Requests
  - Perf. Monitor
  - Web Server
  - Web Server
    - Web Server
      - Web Server
      - Web Server
  - Database (potentially multiple machines)
    - DB Slave 1
    - DB Slave 2
    - Master

- **Memcached servers**
  - Value = get(key)
  - Put(key, value)
Example: Facebook memcached deployment

- Facebook, circa 2008
  - 800 memcached servers
  - 28 TB of cached data

- Performance
  - 200,000 UDP requests per second @ 173 msec latency
  - 300,000 UDP requests per second possible at “unacceptable” latency

More caching

- Cache web server responses (e.g. entire pages, pieces of pages)
  - Reduce load on web servers
  - Example: Varnish-Cache application “accelerator”
Caching using content distribution networks (CDNs)

- Serving large media assets can be expensive to serve (high bandwidth costs, tie up web servers)
  - E.g., images, streaming video
- Physical locality is important
  - Higher bandwidth
  - Lower latency

Source: http://www.telco2.net/blog/2008/11/amazon_cloudfront_yet_more_tra.html
CDN usage example

Facebook photo:
Page URL:

Image source URL:
https://scontent.xx.fbcdn.net/hphotos-xfa1/v/t1.0-9/10620790_10152757936103897_6717527434353029782_n.jpg?oh=8ca648afbd05a9d936797ad70198318c&oe=55771D3B
CDN integration

Local CDN (Pittsburgh)

Page Requests

Local CDN (San Francisco)

Media Requests

Perf. Monitor

Load Balancer

Front-End Cache

Web Server

Database

Memcached servers

Page Requests

Web Server

Web Server

Web Server

DB Slave 2

Master

DB Slave 1
Summary: scaling modern web sites

- **Use parallelism**
  - Scale-out parallelism: leverage many web servers to meet throughput demand
  - Elastic scale-out: cost-effectively adapt to bursty load
  - Scaling databases can be tricky (replicate, shard, partition by access pattern)
    - Consistency issues on writes

- **Exploit locality and reuse**
  - Cache everything (key-value stores)
    - Cache the results of database access (reduce DB load)
    - Cache computation results (reduce web server load)
    - Cache the results of processing requests (reduce web server load)
  - Localize cached data near users, especially for large media content (CDNs)

- **Specialize implementations for performance**
  - Different forms of requests, different workload patterns
Final comments

- It is true that performance of straight-line application logic is often very poor in web-programming languages (orders of magnitude left on the table in Ruby and PHP).

- BUT... web development is not just trivial hacking in slow scripting languages. Scaling a web site is a very challenging parallel-systems problem that involves many of the optimization techniques and design choices studied in this class: just at different scales.
  - Identifying parallelism and dependencies
  - Workload balancing: static vs. dynamic partitioning issues
  - Data duplication vs. contention
  - Throughput vs. latency trade-offs
  - Parallelism vs. footprint trade-offs
  - Identifying and exploiting reuse and locality

- Many great sites (and blogs) on the web to learn more:
  - www.highscalability.com has great case studies (see “All Time Favorites” section)
  - James Hamilton’s blog: http://perspectives.mvdirona.com
Assignment 4 Intro
Assignment 4

- You will implement a simple web site that efficiently handles a request stream

- Diagram:
  - **Client Requests**
  - **Master server** (load balancer)
  - **Worker**
    - Two six-core CPUs
  - **Worker**
    - Two six-core CPUs
Assignment 4

- You will implement a load balancer/scheduler to efficiently handle a request stream

Diagram:
- Client request
  - Master server (load balancer)
- Request forwarded
- Worker
  - Two six-core CPUs
- Worker response
  - Server response
Assignment 4: the master node

- The master is a load balancer
- The master is structured as an event-driven system
  - The master has only one thread of control, but processes client requests concurrently

You implement:

```cpp
void handle_client_request(Client_handle client_handle, const RequestMsg& req);

void handle_worker_response(Worker_handle worker_handle, const ResponseMsg& resp);
```

We give you:

```cpp
void send_job_to_worker(Worker_handle worker_handle, const RequestMsg& req);

void send_client_response(Client_handle client_handle, const ResponseMsg& resp);
```
Assignment 4: the worker nodes

- The worker nodes are responsible for the “heavy lifting” (executing the specified requests)

You implement:

```c++
void worker_handle_request(const RequestMsg& req);
```

We give you:

```c++
void worker_send_response(const ResponseMsg& resp);

void execute_work(const RequestMsg& req, ResponseMsg& resp);
```
Assignment 4: challenge 1

There are a number of different types of requests with different workload characteristics
- Compute intensive requests (both long and short)
- Memory intensive requests...

```json
{"time": 0, "work": "cmd=highcompute;x=5", "resp": "42"}
{"time": 10, "work": "cmd=highcompute;x=10", "resp": "59"}
{"time": 20, "work": "cmd=highcompute;x=15", "resp": "78"}
{"time": 21, "work": "cmd=popular;start=2013-02-13;end=2013-03-23", "resp": "lecture/cachecoherence1 -- 856 views"}
{"time": 22, "work": "cmd=highcompute;x=20", "resp": "10"}
{"time": 23, "work": "cmd=highcompute;x=20", "resp": "10"}
{"time": 24, "work": "cmd=highcompute;x=20", "resp": "10"}
{"time": 30, "work": "cmd=popular;start=2013-02-13;end=2013-03-23", "resp": "lecture/cachecoherence1 -- 856 views"}
{"time": 40, "work": "cmd=popular;start=2013-02-13;end=2013-03-23", "resp": "lecture/cachecoherence1 -- 856 views"}
{"time": 50, "work": "cmd=popular;start=2013-02-13;end=2013-03-23", "resp": "lecture/cachecoherence1 -- 856 views"}
```
Assignment 4: challenge 2

- The load varies over time! Your server must be elastic!

```json
{"time": 0, "work": "cmd=highcompute;x=5", "resp": "42"}
{"time": 10, "work": "cmd=highcompute;x=10", "resp": "59"}
{"time": 20, "work": "cmd=highcompute;x=15", "resp": "78"}
{"time": 21, "work": "cmd=popular;start=2013-02-13;end=2013-03-23", "resp": "lecture/cache\textcoherence1 -- 856 views"}
{"time": 22, "work": "cmd=highcompute;x=20", "resp": "10"}
{"time": 23, "work": "cmd=highcompute;x=20", "resp": "10"}
{"time": 24, "work": "cmd=highcompute;x=20", "resp": "10"}
{"time": 30, "work": "cmd=popular;start=2013-02-13;end=2013-03-23", "resp": "lecture/cache\textcoherence1 -- 856 views"}
{"time": 40, "work": "cmd=popular;start=2013-02-13;end=2013-03-23", "resp": "lecture/cache\textcoherence1 -- 856 views"}
{"time": 50, "work": "cmd=popular;start=2013-02-13;end=2013-03-23", "resp": "lecture/cache\textcoherence1 -- 856 views"}
```

We give you:

```c
// ask for another worker node
void request_boot_worker(int tag);

// request a worker be shut down
void kill_worker(Worker_handle worker_handle);
```

You implement:

```c
// notification that the worker is up and running
void handle_worker_boot(Worker_handle worker_handle, int tag);
```
Assignment 4

- Goal: service the request stream as efficiently as possible (low latency response time) using as few workers as possible (low website operation cost)

- Ideas you might want to consider:
  - What is a smart assignment of jobs (work) to workers?
  - When to [request more/release idle] worker nodes?
  - Can overall costs be reduced by caching?
Have a nice spring break!

Don’t forget the photo competition!
(post on Piazza)

Send postcards from amusing places to:
Smith Hall 225, 5000 Forbes Ave., Pittsburgh, PA 15208