IEMS 5780 / IERG 4080
Building and Deploying Scalable Machine Learning Services

Lecture 12 - Scaling Network Applications

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Scaling Network Applications

Scaling Network Applications

- What does **scalable** mean? We need to understand what is **scalability** before we can build something that is scalable.
- Is **scalable** the same as:
  - High availability (always available to the users)?
  - High performance (handle every request very quickly)?
  - Cost effective (low cost to build a system that serves many users)?

Scalability

Why should online services be scalable?

- Consider what would happen when a lot of users are browsing your website, using your app, or accessing your APIs
- Growth in **traffic** and **data**
- Our objectives:
  - To keep the service **available**
  - To keep the **performance** of the system at a certain level
  - To keep it **cost-effective** to operate the service

Scalability

Consider the following systems:

- Common client-server system with a **database**
- Clients are distributed **geo-graphically**
- Different **types** of clients (e.g. Web, mobile, API)
- Different **kinds** of requests (e.g. retrieval, data submission, image uploading, file editing, video encoding…)
- Different kinds of **data** (e.g. relational data, text, images, videos…)
- ...

Scalability

Scalability does **NOT only** mean:

- Improving your codes
- Using a more powerful machine
- Adding more RAMs

Scalability is about

- Identifying and mitigating bottlenecks
- Considering the whole architecture of the system in order to engineer a solution

Scalability

Scalability is **NOT** equal to

- Performance
- Choosing a particular operating system
- Choosing a particular programming language
- Choosing a particular storage technology

Scalability - Related Concepts

High Availability (HA)

- A system is **highly available** if it is operational for most of the time in a specific period (e.g. a year)
- For example, if a service has 99.9% availability, it is expected that the service will be operational for 24 x 365 x 0.999 = 8751.24 hours in a year (also known as **up time**)
- Ref: Slack's Service Level Agreement (SLA)
- **Principles** of HA: eliminate single points of failure, avoid data loss in case of failure, and detection of failures as they occur
- A highly available system will be a distributed one, hence usually scalable

Scalability - Related Concepts

System Performance

- How efficient is the system in performing a task given certain amount of computing resources (CPU time, memory, etc.)
- Using a language that **executes code faster** at runtime
- Using a faster sorting **algorithm**
- **Optimizing your SQL queries** to shorten the time to retrieve data from the database
- ...

Scalability - Definition

Two common definitions/views of "scalability":

1. Scalability is the ability to handle increased workload
   (without adding resources to a system)

2. Scalability is the ability to handle increased workload by repeatedly applying a cost-effective strategy for extending a system's capacity

Reference: Charles et al., 2006. On System Scalability.
http://resources.sei.cmu.edu/library/asset-view.cfm?assetid=7887

Scalability - Definition

The first definition is of less interest to us in this course

- It does NOT focus on whether the system can be improved / extended when the workload increases
- It focus on whether the system has good performance on a large problem, not on how the system can be scaled

Instead, we are more interested in the second definition, in particular:

- **"repeatedly applying a cost-effective strategy"** to extend the system's capacity

Scalability - Definition

"Repeatedly applying a cost-effective strategy"

- We are **NOT** interested in **one-time increase** in capacity, such as:
  - replacing a O(n2) algorithm with an O(n log n) one
  - coding in a language which produces programs that run faster

- We are **NOT** interested in solutions that requires **a relatively high cost**, such as:
  - replacing a 4-core CPU within a 16-core CPU
  - building a super-computer using advanced HPC technologies

Horizontal vs. Vertical

Vertical scaling – also known as **"scale UP"**

- Add resources to a single node in a system
- E.g. adding CPU or RAMs, increasing the disk size of a DB server, etc.

Horizontal scaling – also known as **"scale OUT"**

- Add more nodes to a system
- Systems are designed to be distributed
- E.g. adding more servers to a cluster of computers

Scaling Out

In order to achieve scalability, we usually aim to build a system that can easily **scale-out (horizontally)**

- Allow distributing workload easily
- If you scale-up, you will quickly reach a **limit** (either technically or financially)
- Trade-off: you need something to **manage** your large number of nodes

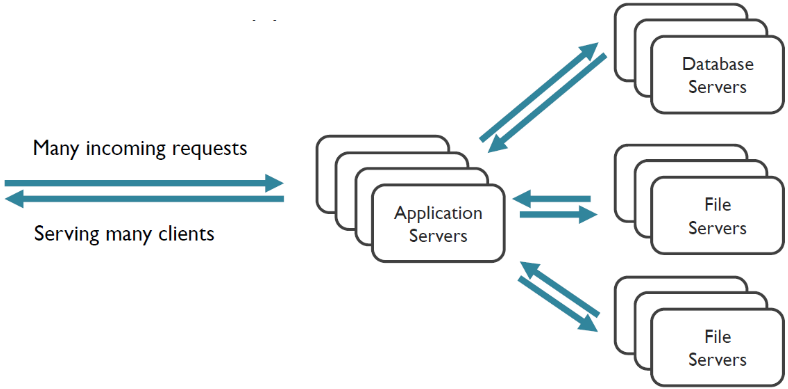
Scaling Out

- Have you ever imagined how many servers are supporting **Google** or **Facebook**?
- Let's take a look at Facebook's report of Fourth Quarter and Full Year 2017:

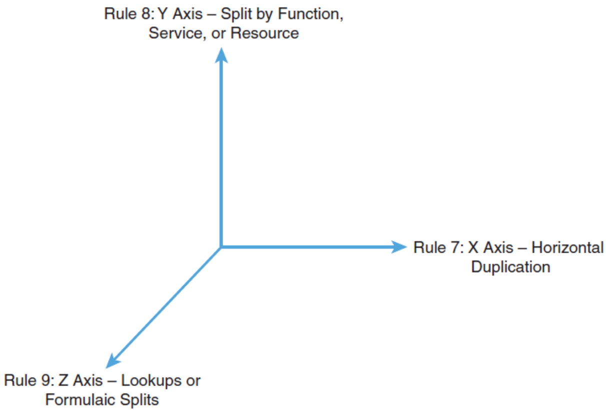
- **Daily active users (DAUs)** – DAUs were 1.40 billion on average for December 2017, an increase of 14% year-over-year.
- **Monthly active users (MAUs)** – MAUs were 2.13 billion as of December 31, 2017, an increase of 14% year-over-year.
- **Mobile advertising revenue** – Mobile advertising revenue represented approximately 89% of advertising revenue for the fourth quarter of 2017, up from approximately 84% of advertising revenue in the fourth quarter of 2016.
- **Capital expenditures** – Capital expenditures were $2.26 billion and $6.73 billion for the fourth quarter and full year 2017, respectively.
- **Cash and cash equivalents and marketable securities** – Cash and cash equivalents and marketable securities were $41.71 billion at the end of the fourth quarter of 2017.
- **Headcount** – Headcount was 25,105 as of December 31, 2017, an increase of 47% year-over-year.

Scaling Out

- How more servers help you to scale?



Scalability

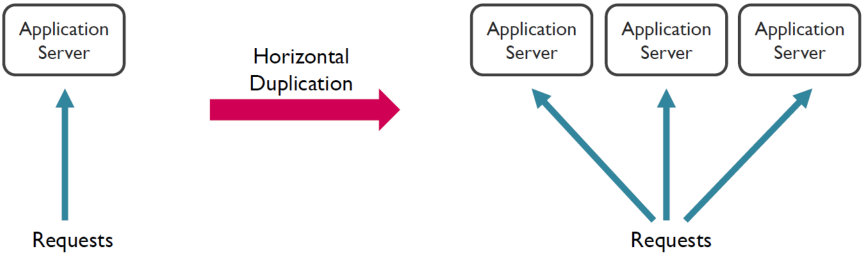


Scalability Rules: 50 Principles for Scaling Web Sites Chapter 2 (Figure 2.2)

- Principles for distributing workloads in a system
    1. **Horizontal Duplication** (Introduce redundancy)
    2. **Split by Functions** (Split by verbs or nouns)
    3. **Split by Storage** (Formulaic split: split database based on one or more columns)

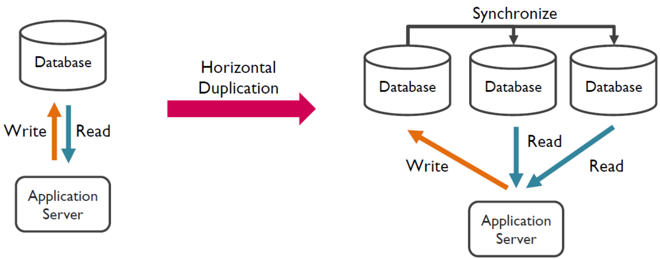
1. Horizontal Duplication

- When multiple instances of your service can operate **independently**:



1. Horizontal Duplication

- When the **read-to-write ratio** of your database is high (e.g. 5:1):
  - For many applications, the database is read much more frequently than is written to
  - Consider how often your post a new status on Facebook vs. how often you read your news feed
  - Simple way to scale: have multiple **read-only** database to handle the many read requests



2. Split by Functions

Scaling through distribution based on the **separation of distinct / different functions** (verbs) and **data** (nouns)

By functions (verbs)

- Registration
- Authentication / Login
- Search
- Recommend
- Resize images

By data (nouns)

- User profiles
- Items for sale
- Product catalogues
- Images

3. Split by Storage

- Also known as **sharding** - take a data set and partition it into multiple parts based on some rules
- Consider an online services that serves multiple enterprise users (each company has an account and data are not supposed to be seen by another company)
  - You are not going to combine data from different companies in any function
  - You can have dedicated servers storing data for each company

Summary

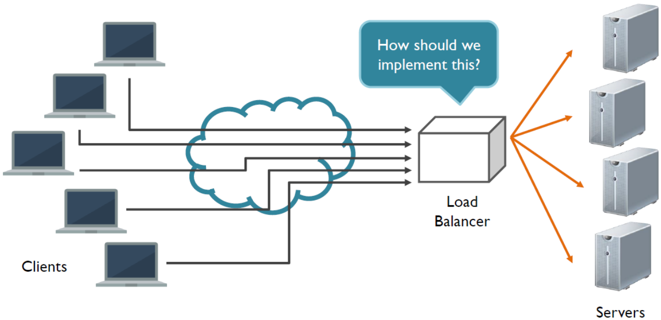
The keys to build scalable systems are:

- Identifying **bottlenecks** of the system
- **Horizontal duplication**: allow scaling to be done quickly
- **De-coupling**: let loosely-coupled modules interact through simple and well-defined interfaces

Load Balancing

Load Balancing

The act of distributing workloads across multiple computing nodes



- Avoid overloading a single node
- Maximise utilization of different nodes
- Optimise usage of resources
- Increase reliability and availability

Load Balancing

Different ways to implement a load balancer

- DNS / Hardware / Software
- Implement it on different networking layers
- Algorithms: random / Round-robin / dynamic scheduling

Load Balancing Algorithms

- **Random**
- **Round-Robin**
  - Distribute load equally by using a rotating scheme
- **Weighted Round-Robin**
  - A performance weight is assigned to each server
- **Least Connections**
  - Sends requests to a server with the fewest number of connections
- **Fastest Response Time**
  - Select the server that responded in the shortest time

Server Health Checking

- A load balancer might need to check whether the servers are operating normally and are able to give responses.
- How can we check if one of the servers has died?
    1. **Passive**: **Observe** the **network traffic**
    2. **Active**: **Probe** the server for a **quick response**
- What are the pros and cons of these two?
- How can health checking be done?

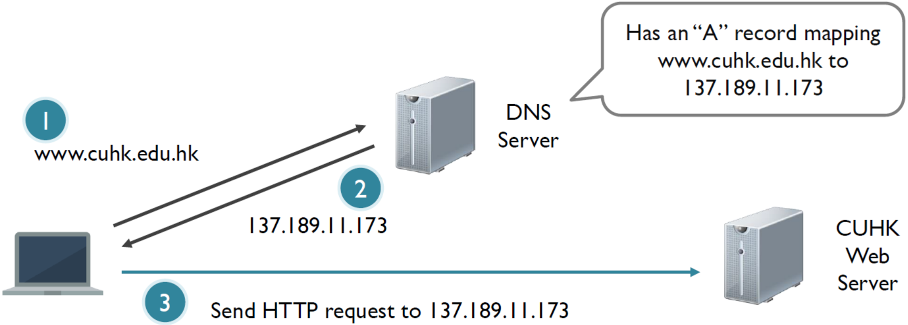
Server Health Checking

- **Ping**
  - Send an ICMP message to the server and check for response
- **TCP Connection**
  - Attempt to establish a TCP connection to the server (on port 80)
- **HTTP GET (Header)**
  - Check the status code of a GET request
- **HTTP GET (Content)** Check the content returned by the server for a GET request

- **Question**: What are the limitations of the first three methods?

DNS

- DNS stands for **Domain Name System**
- A **directory service** of the Internet



DNS Load Balancing

A simple way of implementing load balancing

- Create two or more **“A” records** in the DNS zone
- The DNS server sends the client a list of records in **random order** or in a round-robin fashion
- The client attempts to connect to the application server using the **first IP address** in the list

DNS Load Balancing

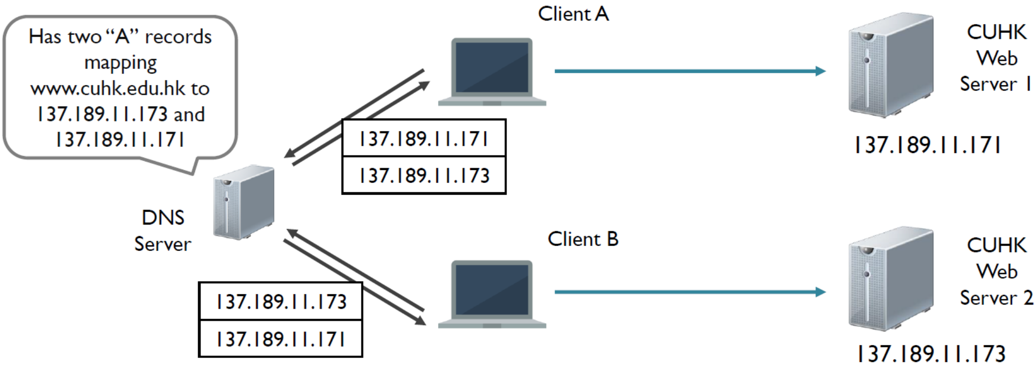
What are "A" records?

- Address record: mapping a domain name to an IPv4 address

Other records:

- AAAA: domain name to IPv6 address
- CNAME: alias of a domain name
- MX: mail exchange (identifies the mail server of the domain)
- NS: name server record

Round-robin DNS Load Balancing



DNS Load Balancing - An Example

```
$ dig www.youtube.com
; <<>> DiG 9.9.5-3ubuntu0.5-Ubuntu <<>> www.youtube.coma
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 33788
;; flags: qr rd ra; QUERY: 1, ANSWER: 5, AUTHORITY: 0, ADDITIONAL: 1

;; OPT PSEUDOSECTION: ; EDNS: version: 0, flags:; udp: 512
;; QUESTION SECTION: ;www.youtube.com. IN A

;; ANSWER SECTION:
www.youtube.com. 21423  IN    CNAME  youtube-ui.l.google.com.
youtube-ui.l.google.com. 146  IN     A 64.233.187.190
youtube-ui.l.google.com. 146  IN     A 64.233.187.136
youtube-ui.l.google.com. 146  IN     A 64.233.187.91
youtube-ui.l.google.com. 146  IN     A 64.233.187.93
```

DNS Load Balancing

Simple, but a few limitations:

- **Stickiness**: It takes time to propagate changes in DNS records adding or removing servers can be slow
- Loading can NOT be balanced accurately due to **DNS caching** (e.g. when a lot of users are from the same ISP)
- It does NOT take into account transaction time, server load, network congestions, etc.
- NO **fault tolerance** (DNS server does not know if a server is operating or not)

DNS Load Balancing

- While having some limitations, DNS load balancing is an important method for achieving **availability**
- The **only way** to divert traffic to **different data centres**

Amazon Web Services Suffers Crash, Takes Down Netflix, Reddit, Tinder And Other Huge Parts Of The Internet

By Romellaine Arsenio, Tech Times | September 23, 11:14 AM

Like | Follow | Share(19) | Tweet(14) | Reddit | 5 Comments | SUBSCRIBE

The Amazon Web Services crashed Neflix, Reddit, Tinder and other online applications, causing users' problems reported throughout the day.
(Photo : David McNew | Getty Images)

A monstrous outage from Amazon Web Services crashed down Netflix, Reddit, Tinder and other major websites, sending netizens in fury for missing movies, hook-ups and other fun online activities.

AWS powers web and mobile applications, and provides data processing and warehousing, storage and archiving to websites all over the world.

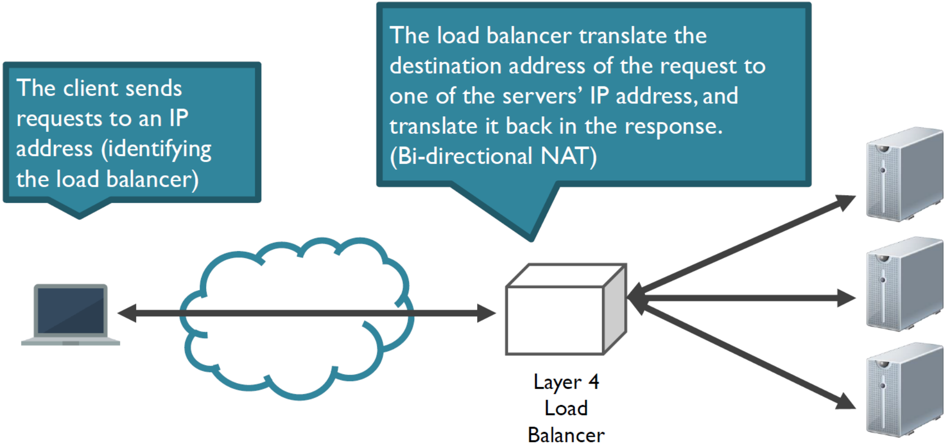
Hardware / Software Load Balancing

- Load balancing can be done at the different layers

OSI model Layer 4 (Transport Layer) Load Balancing

- Relatively simple
- Balancing server load without inspecting the content of messages
- Distribute traffic based on servers' response time
- Routing is based on inspecting the first packet of the data stream

Layer 4 Load Balancing



Layer 4 Load Balancing

What are the advantages of Layer 4 Load Balancing?

- **Simple**: easy to implement
- **Efficient**: load balancer only inspect the **first packet**

However

- It CANNOT maintain application session information
- It CANNOT route requests to different servers **dynamically** based on their content (e.g. requesting static content vs. dynamic content)

Layer 7 Load Balancing

Layer 7 (Application Layer) Load Balancing

- **Application-level** load balancing
- Parse requests in the **application layer** (e.g. HTTP), and distribute them to servers **based on the content** of the request (e.g. the URL or the cookie)
- Relatively **high overhead** in parsing the metadata
- Mostly **HTTP** (because of the popularity of Web apps)

Layer 7 Load Balancing

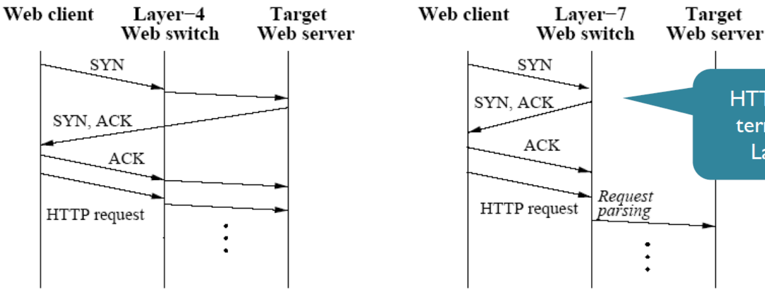


Figure 8: Operations of layer-4 routing (left) and layer-7 routing (right).

HTTP requests are terminated at the Layer-7 switch

Ref: Cardellini, Casalicchio, Colajanni, and Yu. 2002. The state of the art in locally distributed Web-server systems. ACM Computer. Survey, 34, 2 (June 2002), 263-311.

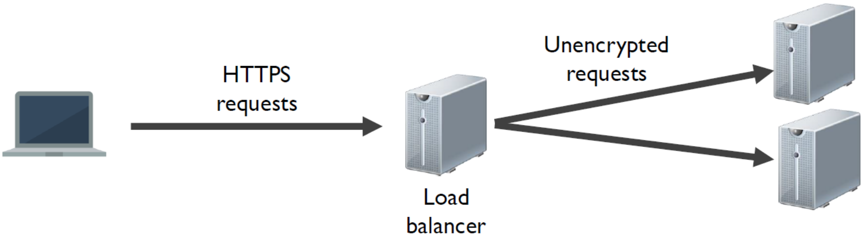
Layer 7 Load Balancing

Characteristics of Layer 7 Load Balancing

- More CPU-intensive (e.g. for parsing HTTP content)
- Can also apply compression, encryption or caching on the content to be delivered
- Does not require all servers in the backend to have serve the same content (compare with Layer 4 load balancing) Layer 7 load balancers are also called **Application Delivery Controllers**

Layer 7 Load Balancing

- One important ability of a layer 7 load balancer is **SSL termination**
- The load balancer has to be able to decrypt the request in order to **inspect the content**
- It therefore must be configured with **a valid SSL certificate**



Caching

Caching

- **Cache** is a **temporary** data storage that stores data for **quick retrieval** in the future
- Mostly implemented as a key-value store, where the unique key can be used to retrieve the value at `O(1)` time
- Cache is usually **small** (RAM is expensive!)
- Cache can be persistent, if it also stores the current state into some persistent storage (e.g. the hard disk)

Caching using Redis

- **Redis** can be used as a cache using it's key/value store function

```python
# import redis
from redis import StrictRedis  # StrictRedis offers API official Redis commands

# Establish a connection to redis on localhost
r = StrictRedis('localhost')

# Set the value of a key
r.set('test_key', 'test_value')

# Get the value of a key
# value will be None if no such key is found in redis
value = r.get('test_key')
```

Caching ML Model Predictions

- Sometimes, generating a prediction takes time and computing resources
- If it is possible that the **same inputs** will be received, we can **cache predictions** to respond more quickly

```python
# Let's assume x is a feature vector
# And let's assume we have a hash function that hash the vector into a string
input_hash = hash_vector(x)

# Attempt to retrieve cached prediction
cached = r.get(input_hash)

if cached is not None:
    return cached
else:
    # Submit x to the model
    # ...
```

Cache Replacement Algorithms

- **Hit** (found) vs. **Miss** (not found)
- To make efficient use of a cache, we want to have **high hit rate**
- We need to determine **what** should be cached
- **Ideal case**: discard the information that will NOT be needed for the **longest time** in the future
- Some commonly used **algorithms**:
    - FIFO (First-in-first-out) (i.e. a queue)
    - LRU (Least recently used)
    - LFU (Least frequently used)
- More can be found at https://en.wikipedia.org/wiki/Cache_replacement_policies

End of Lecture 12