Large-Scale Web Applications

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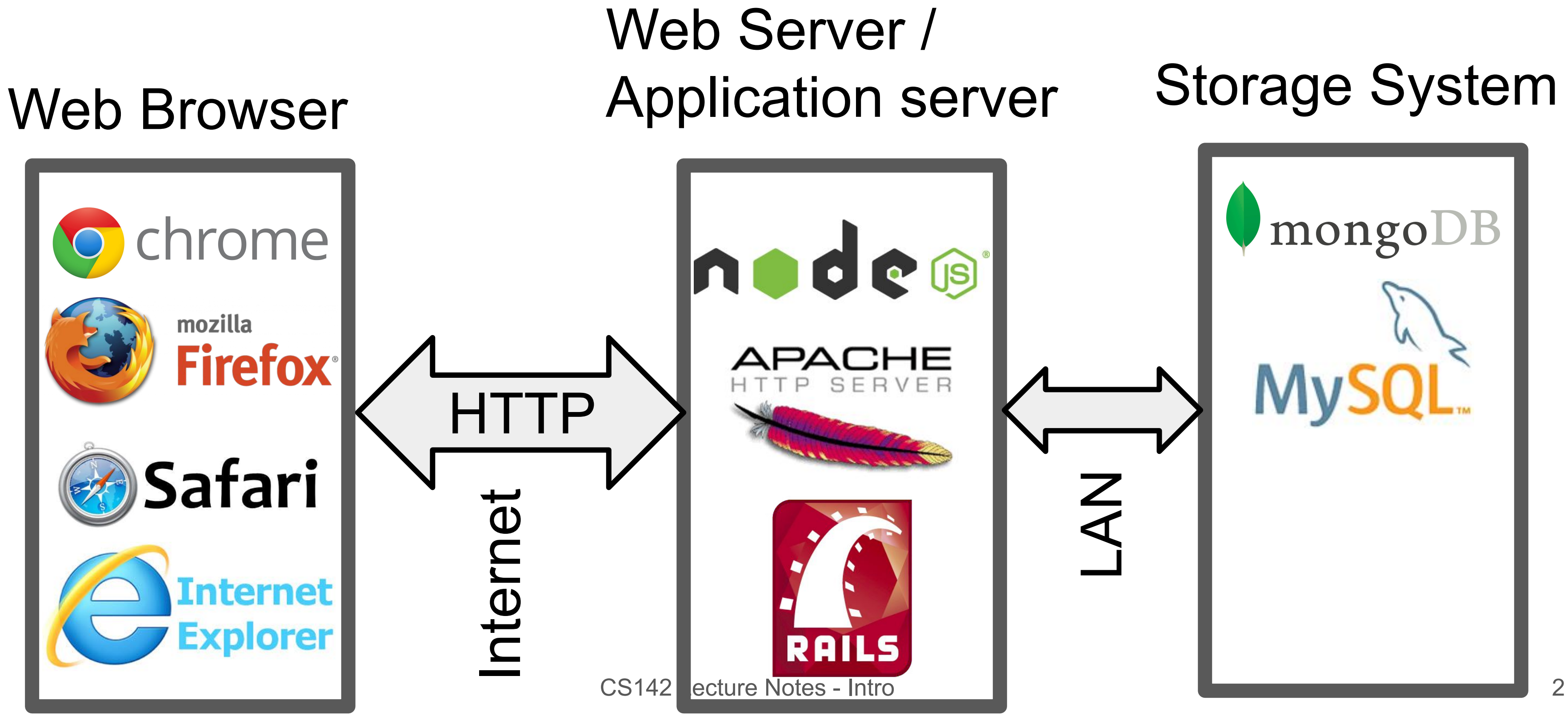
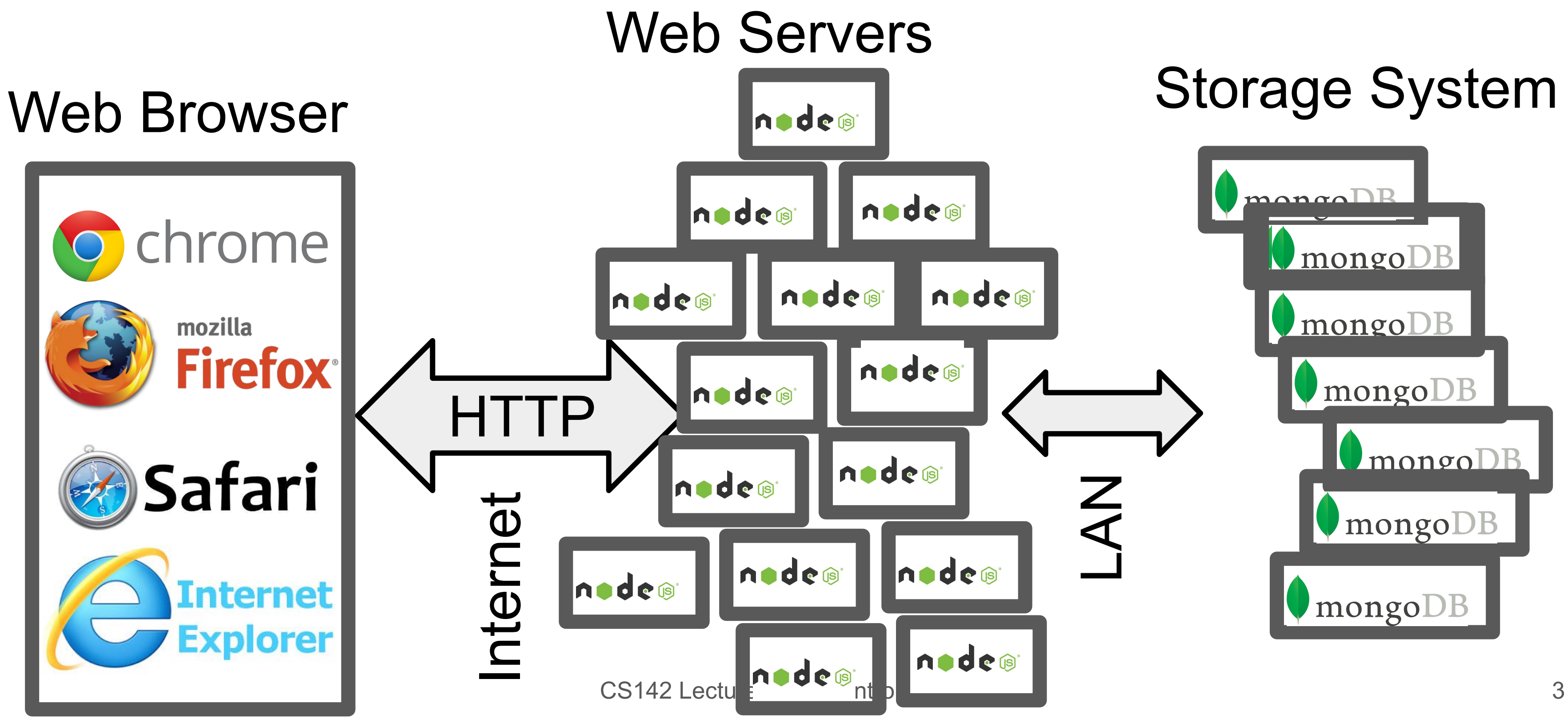
Web Application Architecture



Large-Scale: **Scale-Out Architecture**



Scale-out architecture

- Expand capacity by adding more instances
- Contrast: **Scale-up architecture** - Switch to a bigger instance
    - Quickly hit limits on how big of single instances you can build
- Benefits of scale-out
    - Can scale to fit needs: Just add or remove instances
    - Natural redundancy make tolerating failures easier: One instance dies others keep working
- Challenge: Need to manage multiple instances and distribute work to them

Scale out web servers: Which server do you use?

- Browsers want to speak HTTP to a web server - TCP/IP connect
- Use load balancing to distribute incoming HTTP requests across many front-end web servers
- HTTP redirection (e.g. HotMail):
  - Front-end machine accepts initial connections
  - Redirects them among an array of back-end machines
- DNS (Domain Name System) load balancing:
  - Specify multiple targets for a given name
  - Handles geographically distributed system
  - DNS servers rotate among those targets

Load-balancing switch ("Layer 4-7 Switch")

- Special load balancer network switch
  - Incoming packets pass through load balancer switch between Internet and web servers
  - Load balancer directs TCP connection request to one of the many web servers
  - Load balancer will send all packets for that connection to the same server.
- In some cases the switches are smart enough to inspect session cookies, so that the same session always goes to the same server.
- Stateless servers make load balancing easier (different requests from the same user can be handled by different servers).
- Can select web server based on random or on load estimates

`nginx` ("Engine X")

- Super efficient web server (i.e. speaks HTTP)
  - Handles 10s of thousands of HTTP connections
- Uses:
  - Load balancing - Forward requests to collection of front-end web servers
  - Handles front-end web servers coming and going (dynamic pools of server)
    - Fault tolerant - web server dies the load balance just quits using it
  - Handles some simple request - static files, etc.
  - DOS mitigation - request rate limits
- Popular approach to shielding Node.js web servers

Scale-out assumption: any web server will do

- Stateless servers make load balancing easier
  - Different requests from the same user can be handled by different servers
  - Requires database to be shared across web servers
- What about session state?
  - Accessed on every request so needs to be fast (memcache?)
- WebSockets bind browsers and web server
  - Can not load balance each request

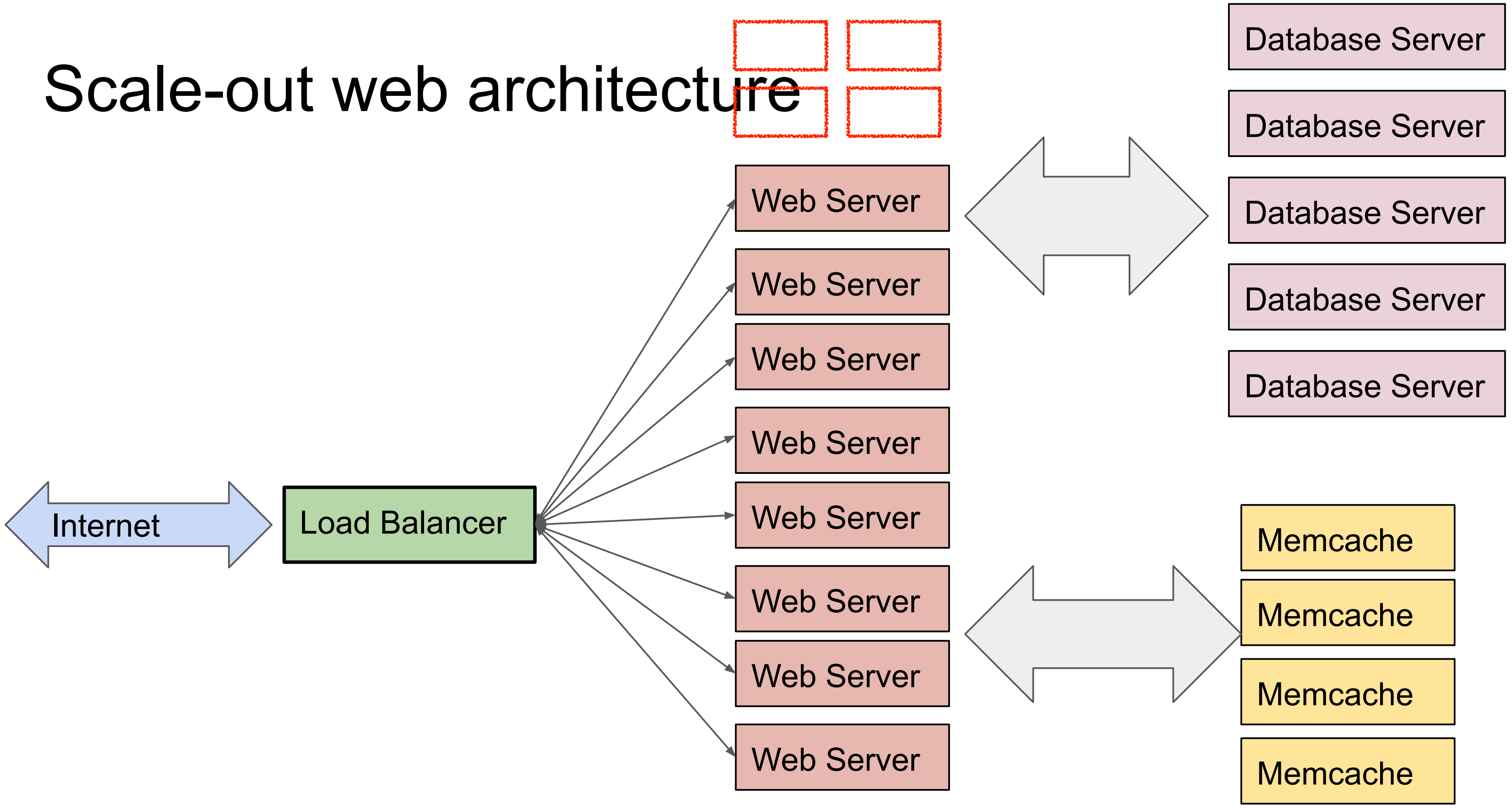
Scale-out storage system

- Traditionally Web applications have started off using relational databases
- A single database instance doesn't scale very far.
- **Data sharding** - Spread database over scale-out instances
  - Each piece is called **data shard**
  - Can tolerate failures by **replication -** place more than one copy of data (3 is common)
- Applications must partition data among multiple independent databases, which adds complexity.
  - Facebook initial model: One database instance per university
  - In 2009: Facebook had 4000 MySQL servers - Use hash function to select data shard

Memcache: main-memory caching system

- Key-value store (both keys and values are arbitrary blobs) very big string
- Used to cache results of recent database queries
- Much faster than databases:
  - 500-microsecond access time, vs. 10's of milliseconds
- Example: Facebook had 2000 memcache servers by 2009
  - Writes must still go to the DBMS, so no performance improvement for them
  - Cache misses still hurt performance
  - Must manage consistency in software (e.g., flush relevant memcache data when database gets modified)

Scale-out web architecture



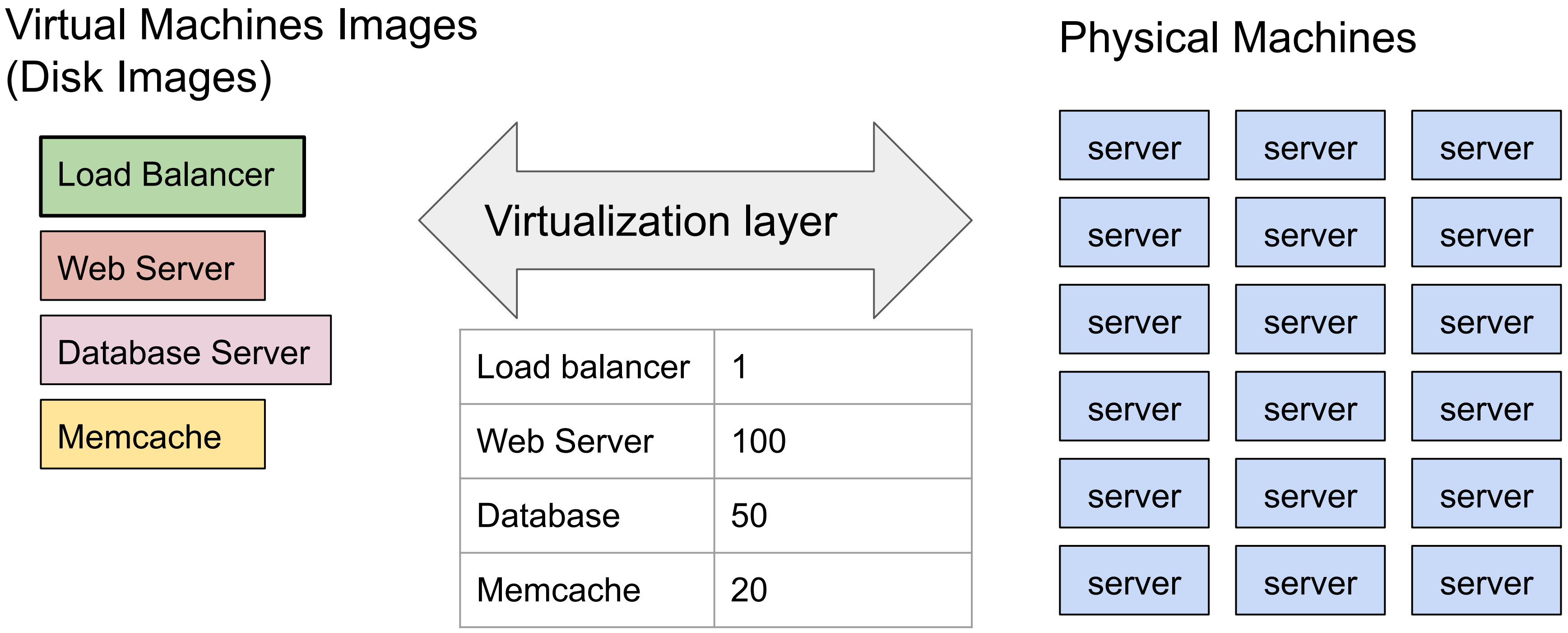
Building this architecture is hard

- Large capital and time cost in buying and installing equipment
- Must become expert in datacenter management
- Figuring out the right number of different components hard
  - Depends on load demand

Scaling issues were hard for early web app

- Startup: Initially, can't afford expensive systems for managing large scale.
- But, application can suddenly become very popular ("flash crowd"); can be disastrous if application can not scale quickly.
- Many of the early web apps either lived or died by the ability to scale
  - Friendster vs. Facebook

Virtualization - Virtual and Physical machines



Load balancer	1
Web Server	100
Database	50
Memcache	20

Cloud Computing

- Idea: Use servers housed and managed by someone else
  - Use Internet to access them
- Virtualization is a key enabler

  Specify your compute, storage, communication needs:
  Cloud provider does the rest

- Examples:

  Amazon EC2
  Microsoft Azure
  Google Cloud
  Many others

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Cloud Computing Advantages

- Key: Pay for the resources you use
  - No up front capital cost
  - Need 1000s machines right now? Possible
  - Perfect fit for startups:
    - 1998 software startup: First purchase: server machines
    - 2012 software startup: No server machines
- Typically billing is on resources:
  - CPU core time, memory bytes, storage bytes, network bytes
- Runs extremely efficiently
  - Buy equipment in large quantities, get volume discounts
  - Hirer a few experts to manage large numbers of machines
  - Place servers where space, electricity, and labor is cheap

Higher level interfaces to web app cloud services

- Managing a web app backend at the level of virtual machines requires system building skills
- If you don't need the full generality of virtual machines you can use some already scalable platform.
  - Don't need to manage OSes: **Container** systems like Docker
    - Specify programs and dependencies that run as a process
  - Don't need to manage storage - Cloud database storage
    - Let the cloud run the database
  - Don't need to manage instances/load balancing: Serverless
    - Let the cloud run the scale-out compute infrastructure

Cloud Database Storage

- Rather than running database instances - Use cloud run databases
  - Cloud provider has experts at running large scale systems
- Example: Google Spanner, Amazon DynamoDB
  - You: define schama, provide data, access using queries
  - Cloud provider: runs storage services
- Features:
  - High Available
  - High Performance
  - Global replication and region containment
  - Consistency
  - Security
  - Usage based pricing

Serverless approach: Amazon Lambda

- You provide pieces of code, URLs associated with each piece of code

- Amazon Lambda does the rest:
    - Allocate machines to run your code
    - Arrange for name mappings so that HTTP requests find their way to your code
    - Scale machine allocations up and down automatically as load changes
    - Lambda environment also includes a scalable storage system

- More constrained environment
    - Must use their infrastructure and supported environments: Python, JavaScript, Java, Go, ...

Serverless architecture - Cloud provider

- Hand over web-servers to cloud infrastructure
- Developer just specifies code to run on each URL & HTTP verb
  - Like Node/Express handlers
- Examples:
  - Amazon Lambda Functions
  - Microsoft Azure Functions
  - Google Cloud Functions
- Cloud provides services only (no servers)
  - Handles all scale-out, reliability, infrastructure security, monitoring, etc.
  - Pay by the request - Enable to pack function execution into available server resources
- Web App backend: Schema specification for cloud storage, handler functions

Content Distribution Network (CDN)

- Consider a read-only part of our web app (e.g. image, html template, etc.)
  - Browser needs to fetch but doesn't care where it comes from
- Content distribution network
  - Has many servers positions all over the world
  - You give them some content (e.g. image) and they give you an URL
  - You put that URL in your app (e.g. `<img src="...)`
  - When user's browsers access that URL they are sent to the closest server (DNS trick)
- Benefits:
  - Faster serving of app contents
  - Reduce load on web app backend
- Only works on content that doesn't need to change often

Cloud Computing and Web Apps

- The pay-for-resources-used model works well for many web app companies
  - At some point if you use many resources it makes sense to build own data centers
- Many useful infrastructure services available:
  - Auto scaling (spinning up and down instances on load changes)
  - Geographic distribution (can have parts of the backend in different parts of the world)
  - Monitoring and reporting (what parts of web app is being used, etc.)
  - Fault handling (monitoring and mapping out failed servers)
- Cloud Application Programming Interfaces (APIs):
  - Analytics
  - Machine learning - Prediction, recommendation, etc.
  - Translation, image recognition, maps, etc.