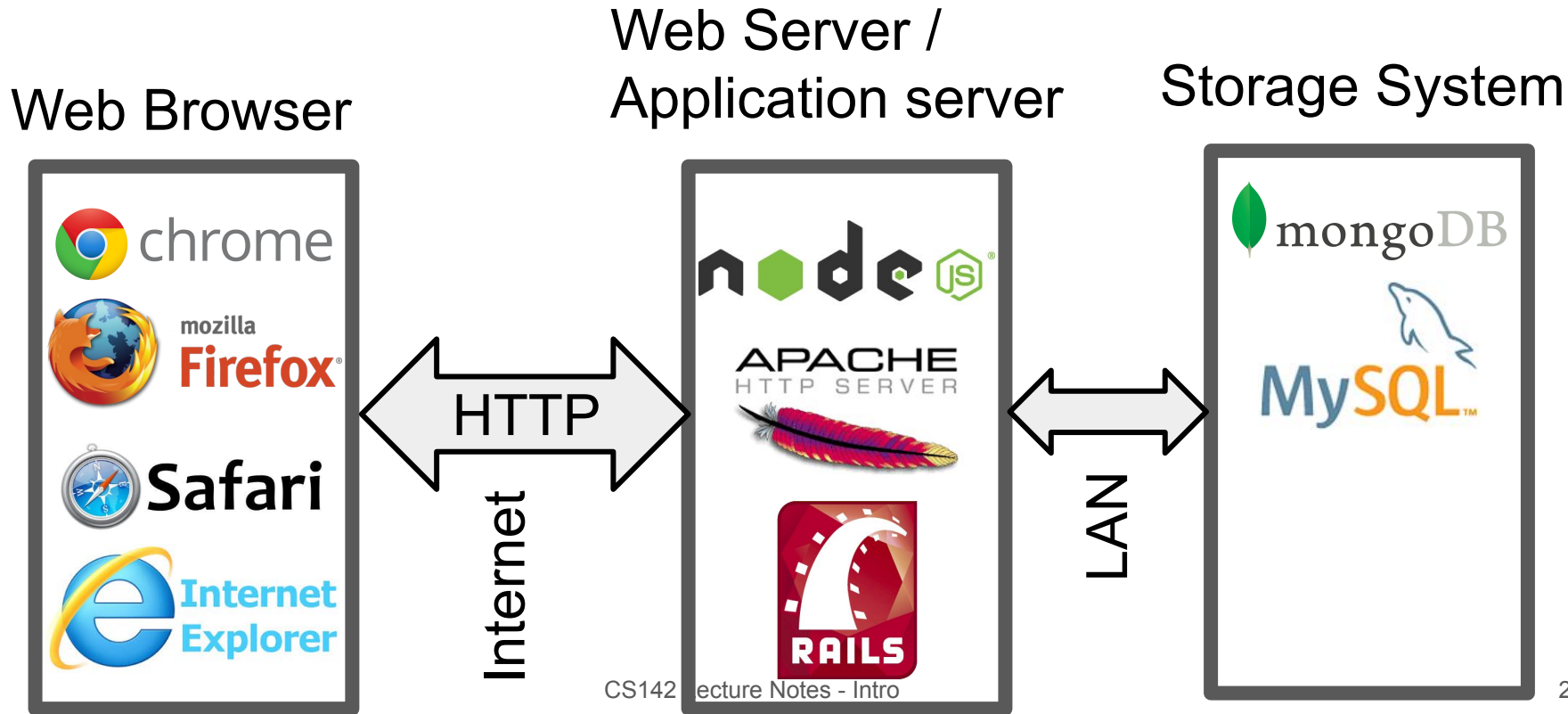


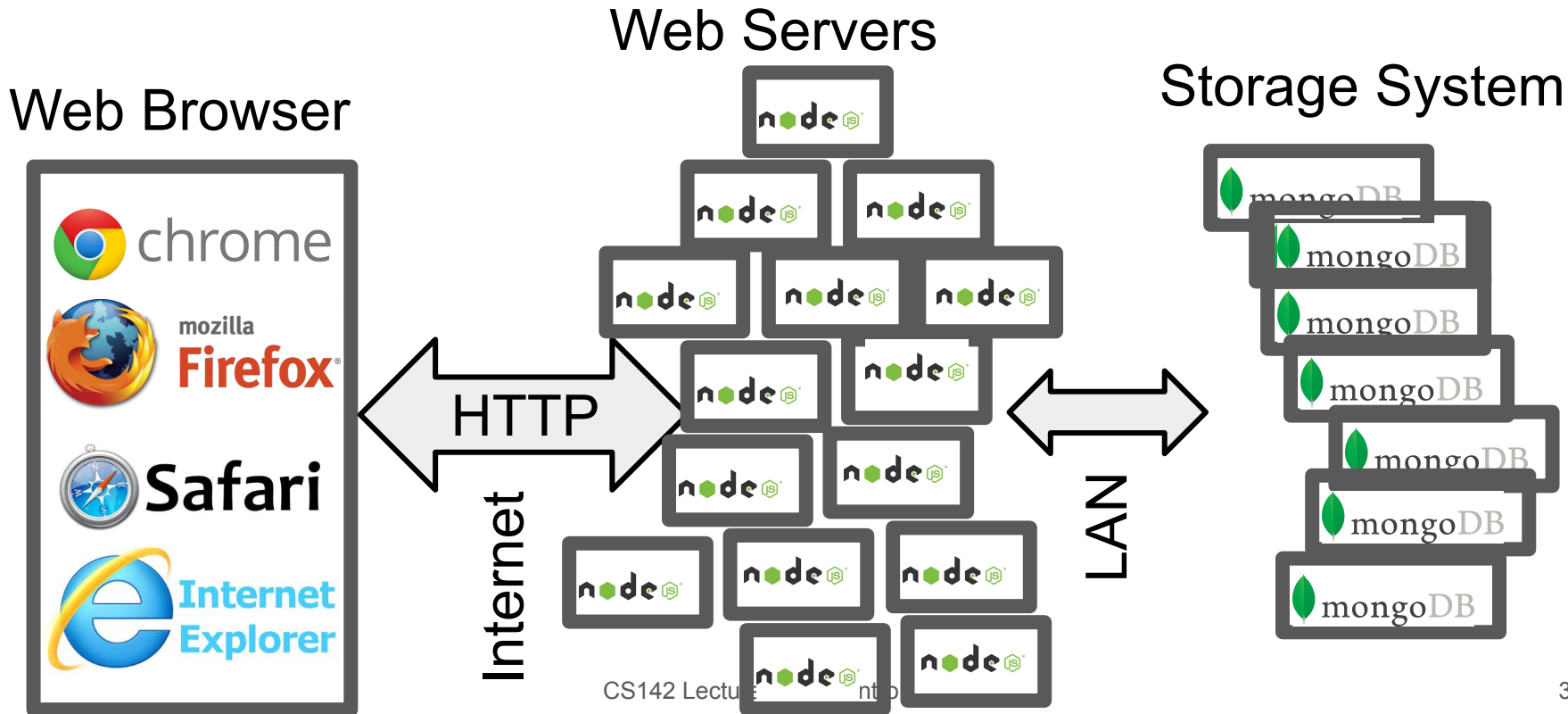
Large-Scale Web Applications

Mendel Rosenblum

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

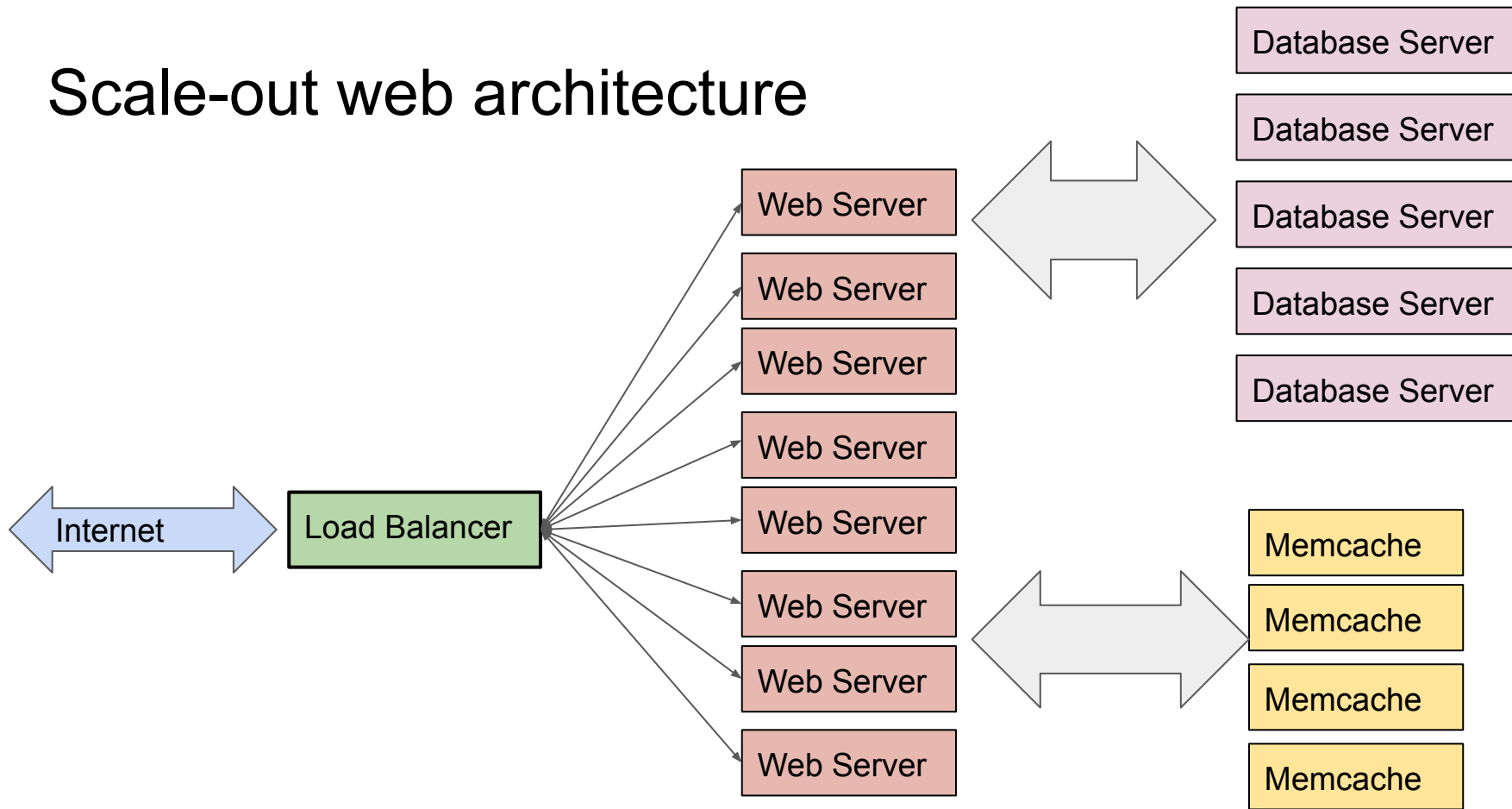
Scale-out storage system

- 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)
- 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

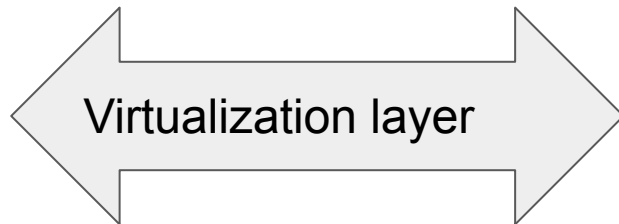
Virtual Machines Images (Disk Images)

Load Balancer

Web Server

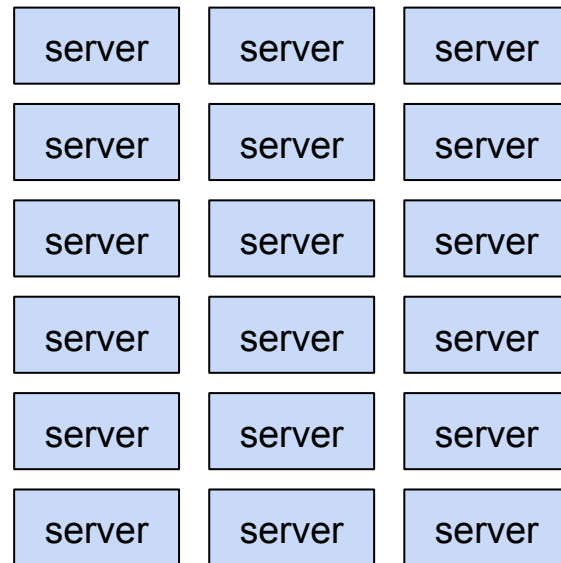
Database Server

Memcache



Load balancer	1
Web Server	100
Database	50
Memcache	20

Physical Machines



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

Load balancer	1
Web Server	100
Database	50
Memcache	20

Cloud Computing Advantages

- Key: Pay for the resources you use
 - No upfront 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 schema, 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.