# Distributed Data Infrastructures, Fall 2017, Chapter 2

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# Chapter Outline

- Warehouse-scale computing overview
- Workloads and software infrastructure
- Failures and repairs

- Note: Term “Warehouse-scale computing” originates from Google → Examples typically of Google’s services
- Trend towards WSC is more general

- This chapter based on book Barroso, Hölzle: “The Datacenter as a Computer” (see course website)

# What is Warehouse-Scale Computing (WSC)?

- Essentially: Modern Internet services

- Massive scale of…
  - Software infrastructure
  - Data repositories
  - Hardware platform

- Program is a service
- Consists of tens of interacting programs
  - Different teams, organizations, etc.

# WSC vs. Data Centers

- Both look very similar to the outside
  - “Lots of computers in one building”

- Key difference:
- Data centers host services for multiple providers
  - Little commonality between hardware and software
  - Third-party software solutions

- WSC run by a single organization
  - Homogeneous hardware and software and management
  - In-house middleware

# Cost Efficiency

- Cost efficiency extremely important

- Growth driven by 3 main factors:
  - Popularity increases load
  - Size of problem increases (e.g., indexing of Web)
  - Highly competitive market

- Need bigger and bigger systems → Cost efficiency!

# Future of Distributed Computing?

- WSC is not just a collection of servers
    - New and rapidly evolving workloads
    - Too big to simulate → New design techniques
    - Fault behavior
    - Energy efficiency
    - New programming paradigms

- Design spectrum:
    - One computer → Multiple computers → Data center
    - WSC = Multiple data centers operating together
    - Modern CDN: "Server" = WSC data center

# Relationship to Big Data?

- Distributed infrastructures needed for processing large data sets
- Need to understand the computing environment
- Many differences to working on a single computer
  - Or manually distributing tasks to a small number of computers

- Typically, WSCs have distributed data processing components
  - MapReduce, Dynamo, …

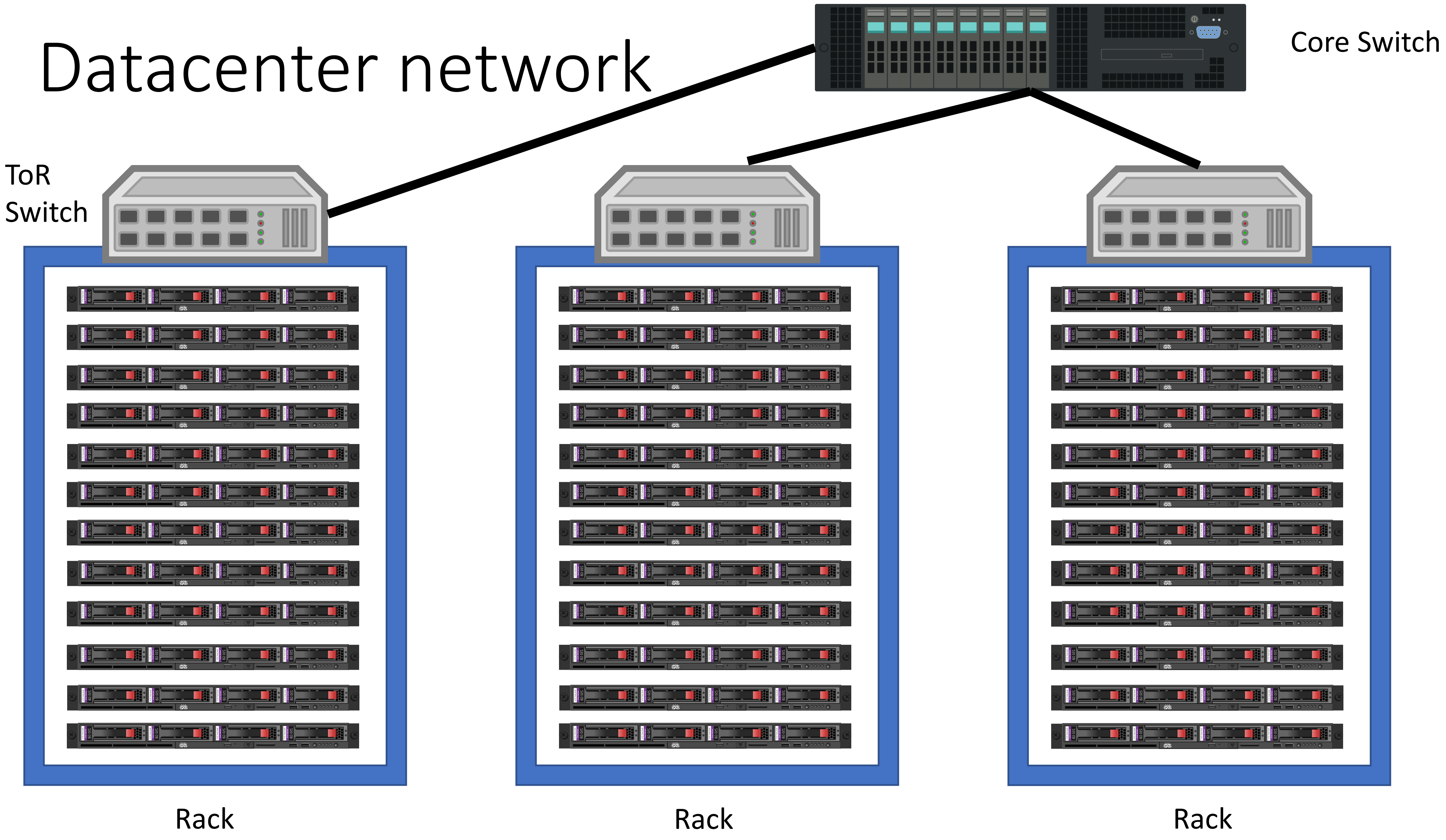
# Architectural Overview

- Networking
- Storage
- Storage hierarchy
- Latency, bandwidth, capacity
- Power usage
- Handling failures

# General architecture

- Servers, e.g., 1-U servers
- Racks
- Interconnected racks

# Datacenter network



# Datacenter network topologies

- Previous picture shows a very simplistic topology
- Real topologies have multiple links between switches
- Varying link bandwidths in different places in topology
- One factor: Cost of switches
- Bisection bandwidth
- Examples of real topologies:
    - FatTree: More bandwidth on higher levels of topology
    - DCell, BCube

# Network

- 48-port 1 Gbps Ethernet switches are “cheap”
- Good bandwidth within one rack
- Problem: Cluster-level bandwidth?
  - Bigger and faster switches prohibitively expensive?
- Hierarchical network organization:
  - Good bandwidth within rack
  - Less bandwidth within cluster
  - Programmer must keep this in mind! (transparency?)

# So, what does a real datacenter look like?

Video by Mikko Pervilä

# Storage

- Tradeoff: NAS vs. local disks as distributed filesystem?

- NAS:
  - Easier to deploy, puts responsibility on vendor

- Collection of disks:
  - Must implement own filesystem abstraction (e.g., GFS)
  - Lower hardware costs (desktop vs. enterprise disks)
  - Reliability issues and replication?
  - More network traffic due to writes

# Storage Hierarchy

- Server:
  - N processors, X cores/CPU, local cache, DRAM, disks
  - Fast, but limited capacity
- Rack:
  - Individual servers, combined view
  - A bit slower, but more capacity
- Cluster:
  - View over all racks
  - Slower, but more capacity

- Tradeoff: Bandwidth, latency, capacity

# Power Usage

- No single culprit on server level
  - CPU 33%
  - DRAM 30%
  - Disk 10%
  - Network 5%
  - Other 22%

- Further optimization targets on cluster/WSC level
  - Cooling of data center

# Handling Failures

- At this scale, things will break often
- Application must handle them
- More details later

# Workloads and Software Infrastructure

- Different levels of abstraction

- Platform-level software
  - Firmware, kernel, individual OS

- Cluster-level infrastructure software
  - Distributed software for managing resources and services
  - “OS for a datacenter”
  - Distributed FS, RPC, MapReduce, …

- Application-level software
  - Actual application, e.g., Gmail, Google Maps

# Datacenter vs. Desktop

- Differences in developing software

- Datacenter:
  - Parallelism (both data and requests)
  - Workload changes
  - Homogeneous platform
  - Hiding failures

# Basic Techniques

| Technique | Reliability | Availability |
| --- | --- | --- |
| Replication | Yes | Yes |
| Partitioning | Yes | Yes |
| Load balancing | Yes | |
| Timers | | Yes |
| Integrity checks | | Yes |
| App.-specific Compression | Yes | |
| Eventual consistency | Yes | Yes |

# Cluster-Level Infrastructure Software

- Resource management
  - Mapping of tasks to resources
- Hardware abstraction and basic services
  - Distributed storage, message passing, …
- Deployment and maintenance
  - Software distribution, configuration, …
- Programming frameworks
  - Hide some of the above from programmer
  - Examples: MapReduce, BigTable, Dynamo

# MapReduce

- Google’s framework for processing large data sets on clusters
- Name from map and reduce (functional programming)
  - Not really much in common with real “map” and “reduce”
- One master, multiple (levels) of slaves
- Map:
  - Master partitions input, distributed to slaves
  - Slaves may do the same
- Reduce:
  - Slave sends its result to its master
  - Eventually root-master will get result

# Application-Level Software

- What is the application?
  - First was search, then many other have appeared

- Datacenter must support general-purpose computing
  - Too expensive to tailor datacenters for applications
  - Changing workloads → Faster to adapt software

- Two application examples:
  - Search
  - Similar scientific articles (see book for description)

# Search

- Inverted index
  - Set of documents matching a keyword
- Size of index similar to original data
- Consider query "new york restaurant"
  - Must search each of three terms
  - Find documents matching every term
  - Sorting (PageRank + other criteria) → Result
- Latency must be low (user waiting)
- Throughput must be high (many users)
- Read-only index → Easily parallelizable

# Monitoring Infrastructure

- Service-level dashboards
  - Real-time monitoring of few key indicators (latency, t-put)
  - Can extend to some more indicators
- Performance debugging tools
  - Dashboards only show problem, but no answer to "why"
  - No need for real-time (compare CPU profilers)
  - Blackbox monitoring vs. instrumentation approach
- Platform-level monitoring
  - Everything above is needed, but not sufficient
  - Need a higher-level view (see book for details)

# Buy vs. Build?

- Buy:
  - Typical solution
- Build:
  - Google’s (and others’) approach
  - Original reason: No third-party solutions available
  - More software development and maintenance work
  - Improved flexibility
  - In-house software can take “shortcuts”
    - Not implement every feature

# Failures

- Traditional software not good with failures

- Result: Make hardware more reliable

- WSC is different because of scale
  - Imaginary 30 year MTBF = 10,000 days MTBF
  - WSC with 10,000 servers = 1 failure per day

- Software must handle failures
  - Application or middleware
  - Middleware makes applications simpler

# Positive Side Effect

- Failures are a fact of life
- Can buy cheaper hardware
- Upgrades are simpler
  - Upgrade, kill, reboot
  - Same for hardware upgrades
- “Failure is an option” ☺
  - Can allow servers to fail, makes life simpler

# Caveats

- Cannot ignore reliability completely
- Hardware must be able to detect errors and failures
  - No need to recover, but can include
- Not detecting hardware errors is risky
  - See book for example
  - Every piece of software would need to handle everything

# Categorizing Faults

- Corrupted
  - Data lost or corrupted
  - Can data be regenerated or not?
- Unreachable
  - Service unreachable by users
  - User network reliability?
- Degraded
  - Service available, but degraded
  - What can be still done?
- Masked
  - Fault occurs, but is masked

# Sources of Faults

- Hardware not the common culprit (~10%)

- Software and configurations are bigger problems
  - Exact numbers depend on study

- Hardware problem = single computer
- Software/configuration problem = many computers simultaneously

# Causes of Crashes

- Anecdotal evidence points to software
- Hardware: Memory or disk
- DRAM errors happen, but can be helped with ECC
  - Some errors still persist
- Real crash rate higher than studies predict
  - Again points to software
- Predicting problems in WSC not useful
  - Need to handle failures anyway
  - Could be useful in other systems

# Repairs

- When something breaks, it must be repaired
- Two important characteristics of WSC
- No need to repair immediately
  - Optimize time of repair technician
- Collect lot of health data from large number of servers
  - Use machine learning to optimize actions

# Summary: Key Challenges

- Rapidly changing workloads
- Building balanced systems from imbalanced components
- Energy use
- Amdahl's Law

# Chapter Summary

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