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Chapter 7: Distributed Systems: Warehouse-Scale Computing

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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

Architectural Overview

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

General architecture

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

Storage

- Tradeoff: NAS vs. local disks as distributed filesystem?
- Network Attached Storage (NAS):
  - Easier to deploy, responsibility lies with 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 (GFS)

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?)

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 (30% of total power use)
  - CPU 33%
  - DRAM 30%
  - Disk 10%
  - Network 5%
  - Other 22%

- Further optimization targets on cluster/WSC level
  - Cooling of data center (50%-)
  - UPS to handle power outages (7-12%, less significant)

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” / middleware
  - 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: rapid development cycles
  - Homogeneous platform
  - Hiding (masking) 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 others have appeared
- Datacenter must support general-purpose computing
  - Too expensive to tailor datacenters for applications
  - Changing workloads → Faster to adapt software
- Two application examples:
  - The standard keyword search
  - Find 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, thru’put)
  - Can extend to some more indicators
- Performance debugging tools
  - Dashboards only show the problem, we want the “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
  - Imagine 30 year MTBF = 10,000 hours 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
  - Not necessary to recover too, but can pay off to include it
- Not detecting hardware errors is risky
  - See book for nice 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 (e.g. slow)
  - What can be still done?
- Masked
  - Fault occurs, but is completely masked from user

Sources of Faults

- Hardware not the common culprit (~10%)

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

- Hardware problem = affects 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: new radical services
- Building balanced systems from imbalanced components
- Energy use
- Amdahl’s Law: performance gains come from more cores

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