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Chapter 7: Distributed Systems: Warehouse-Scale Computing

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Slides joint work with Jussi Kangasharju et al.



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

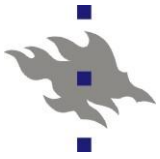
- Cost efficiency extremely important
- Growth driven by 3 main factors:
 - Popularity increases load
 - Size of problem increases (e.g., indexing of Web)
 - Highly competitive market
- Need bigger and bigger systems → Cost efficiency!



Future of Distributed Computing?

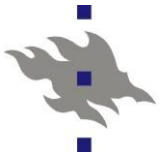
- WSC is not just a collection of servers
 - New and rapidly evolving workloads
 - Too big to simulate → New design techniques
 - Fault behavior
 - Energy efficiency
 - New programming paradigms

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



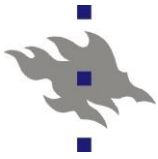
Architectural Overview

- 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



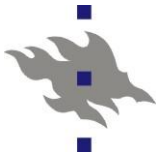
Workloads and Software Infrastructure

- 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



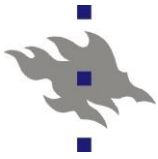
Datacenter vs. Desktop

- 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

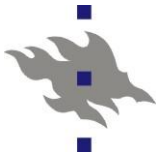


Failures

- Traditional software not good with failures
- Result: Make hardware more reliable

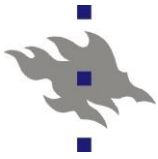
- WSC is different because of scale
 - Imagine 30 year MTBF = 10,000 hours MTBF
 - WSC with 10,000 servers = 1 failure per day

- 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



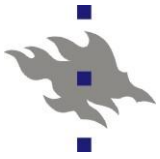
Repairs

- 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



Chapter Summary

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