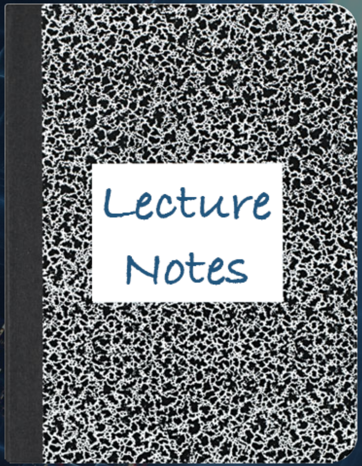
CS 417 – DISTRIBUTED SYSTEMS



Week 14: Infrastructure

[Original] Google Cluster Architecture

Paul Krzyzanowski

A note about relevancy

This describes the Google search cluster architecture in the mid 2000s. The search infrastructure was overhauled in 2010.

Nevertheless, the lessons are still valid, and this demonstrates how incredible scalability has been achieved using commodity computers by exploiting parallelism.

WEB SEARCH FOR A PLANET: THE GOOGLE CLUSTER ARCHITECTURE

AMENABLE TO EXTENSIVE PARALLELIZATION, GOOGLE'S WEB SEARCH APPLICATION LETS DIFFERENT QUERIES RUN ON DIFFERENT PROCESSORS AND, BY PARTITIONING THE OVERALL INDEX, ALSO LETS A SINGLE QUERY USE MULTIPLE PROCESSORS. TO HANDLE THIS WORKLOAD, GOOGLE'S ARCHITECTURE FEATURES CLUSTERS OF MORE THAN 15,000 COMMODITY-CLASS PCS WITH FAULT-TOLERANT SOFTWARE. THIS ARCHITECTURE ACHIEVES SUPERIOR PERFORMANCE AT A FRACTION OF THE COST OF A SYSTEM BUILT FROM FEWER, BUT MORE EXPENSIVE, HIGH-END SERVERS.

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•••••• Few Web services require as much computation per request as search engines. On average, a single query on Google reads hundreds of megabytes of data and consumes tens of billions of CPU cycles. Supporting a peak request stream of thousands of queries per second requires an infrastructure comparable in size to that of the largest supercomputer installations. Combining more than 15,000 commodity-class PCs with fault-tolerant software creates a solution that is more cost-effective than a comparable system built out of a smaller number of high-end servers.

Here we present the architecture of the Google cluster, and discuss the most important factors that influence its design: energy efficiency and price-performance ratio. Energy efficiency is key at our scale of operation, as power consumption and cooling issues become significant operational factors, taxing the limits of available data center power densities.

Our application affords easy parallelization: Different queries can run on different processors, and the overall index is partitioned so that a single query can use multiple processors. Consequently, peak processor performance is less important than its price/performance. As such, Google is an example of a throughput-oriented workload, and should benefit from processor architectures that offer more on-chip parallelism, such as simultaneous multithreading or on-chip multiprocessors.

Google architecture overview

Google's software architecture arises from two basic insights. First, we provide reliability in software rather than in server-class hardware, so we can use commodity PCs to build a high-end computing cluster at a low-end

22

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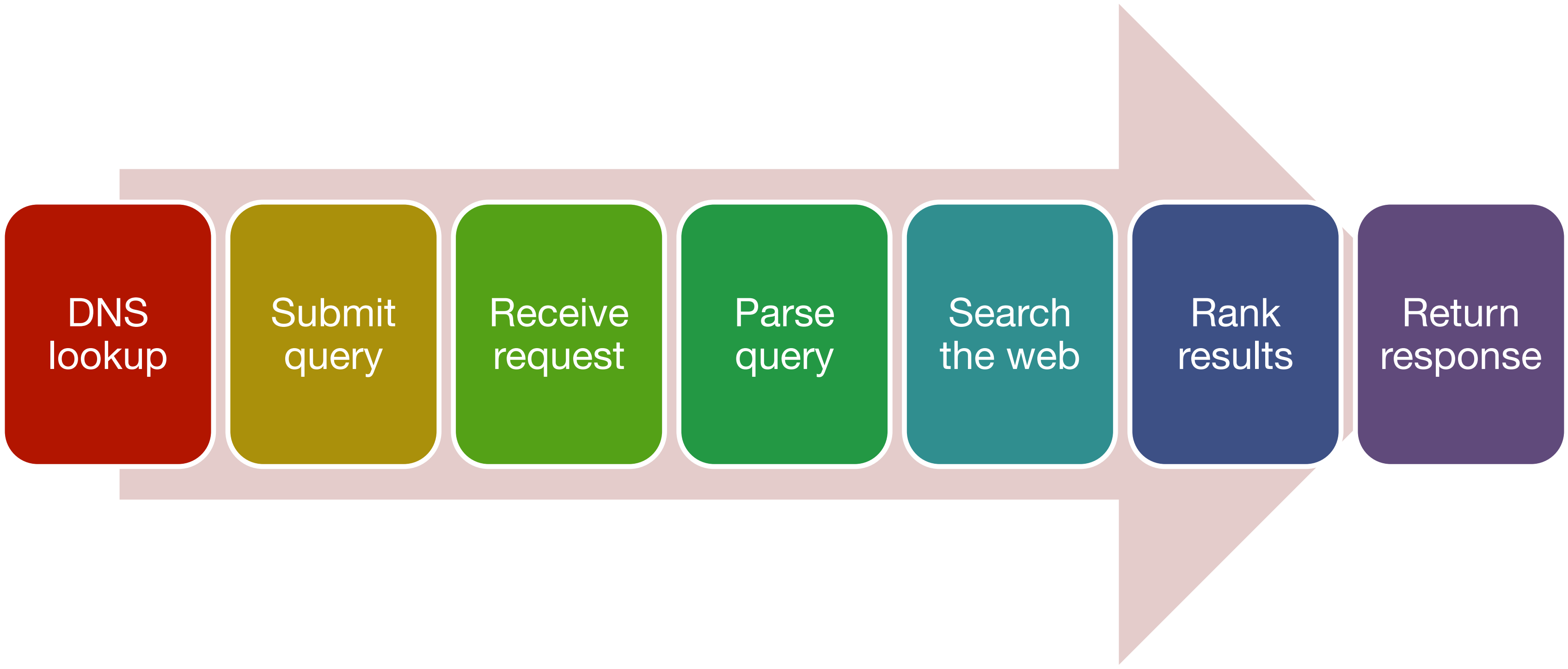
Search flow

What needs to happen when you do a search?



Some statistics

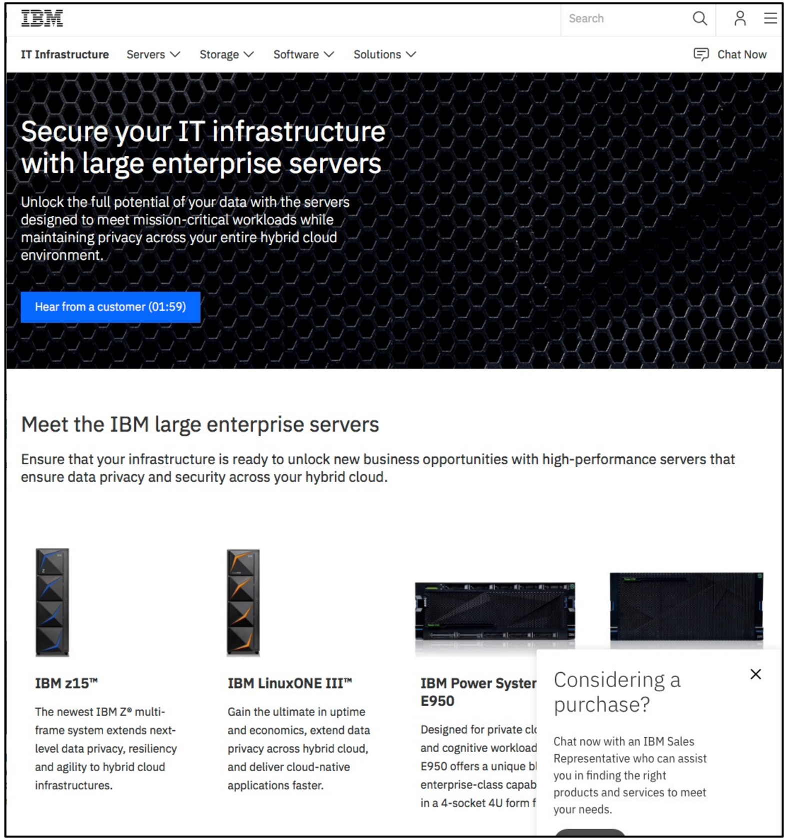
- 3.5 billion searches/day – trillions per year
- Volume grows ~10% per year – ability to scale is crucial
- 16-20% of searches have never been issued before
  - Caching won't help much
- Average user session < 1 minute
- Hundreds of billions of web pages indexed
  - Index > 100 million gigabytes (10^{17} bytes)
- 60% of searches are done via a mobile device

Query sizes

What is needed?

- A single Google search query
  - Reads 10s-100s of terabytes of data
  - Uses tens of billions of CPU cycles
- Environment needs to support tens of thousands of queries per second
- Environment must be
  - Fault tolerant
  - Economical (price-performance ratio matters)
  - Energy efficient (this affects price; watts per unit of performance matters)
- Parallelize the workload
  - CPU performance matters less than price/performance ratio

Best Practices?



"Enterprise-grade" components

Key design principles

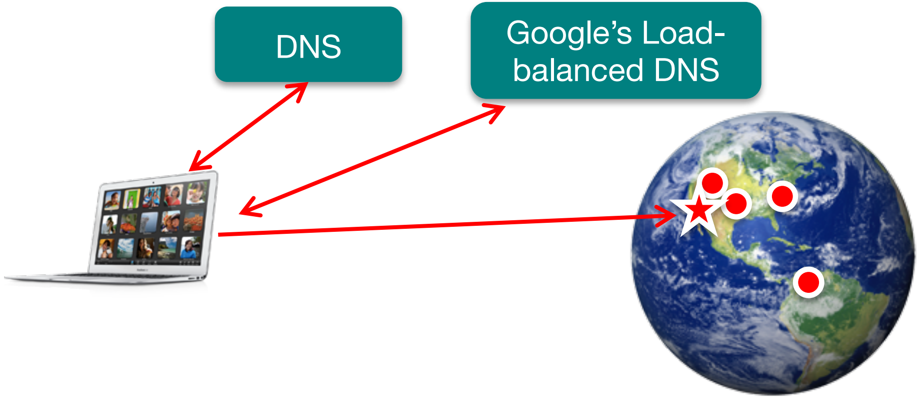
- Have reliability reside in software, not hardware
  - Use low-cost (unreliable) commodity PCs to build a high-end cluster
  - Replicate services across machines & detect failures

- Design for best total throughput, not peak server response time
  - Response time can be controlled by parallelizing requests
  - Rely on replication: this helps with availability too

- Price/performance ratio more important than peak performance

Life of a query – step 1: DNS

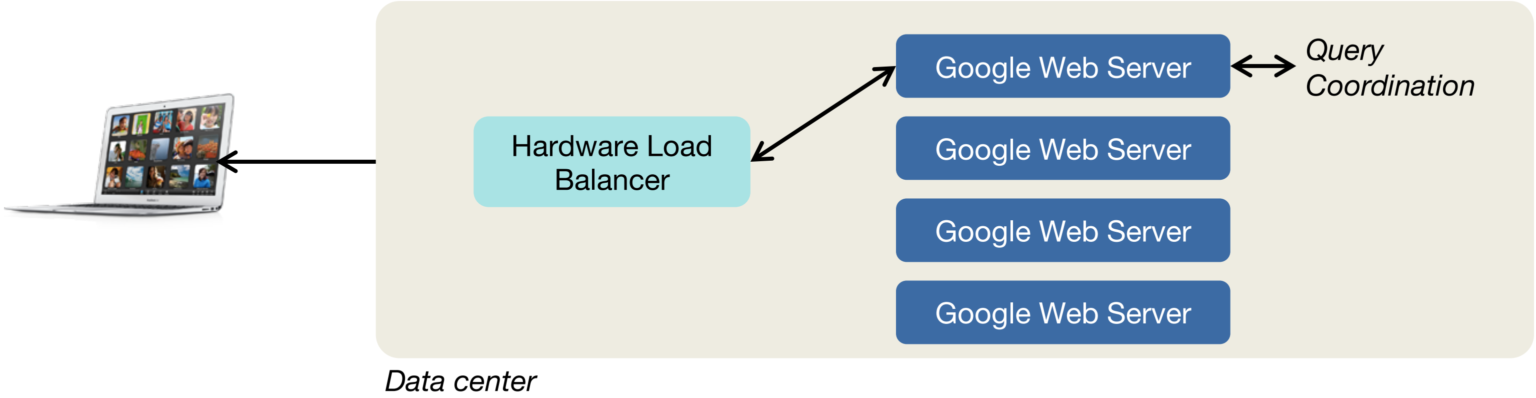
- User's browser must map *google.com* to an *IP address*
- "google.com" comprises multiple clusters distributed worldwide
  - Each cluster contains thousands of machines
- DNS-based load balancing
  - Select cluster by taking user's geographic & network proximity into account
  - Load balance across clusters



1. Contact DNS server(s) to find the DNS server responsible for google.com
2. Google's DNS server returns addresses based on location of request
3. Contact the appropriate cluster

Life of a query – step 2: Send HTTP request

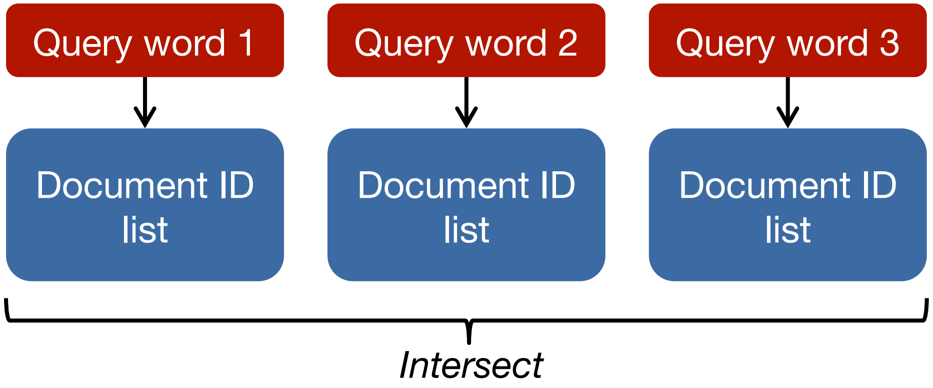
- IP address corresponds to a load balancer within a cluster
- Load balancer
  - Monitors the set of Google Web Servers (GWS)
  - Performs local load balancing of requests among available servers
- GWS machine receives the query
  - Coordinates the execution of the query
  - Formats results into an HTML response to the user



Step 3. Find documents via inverted index

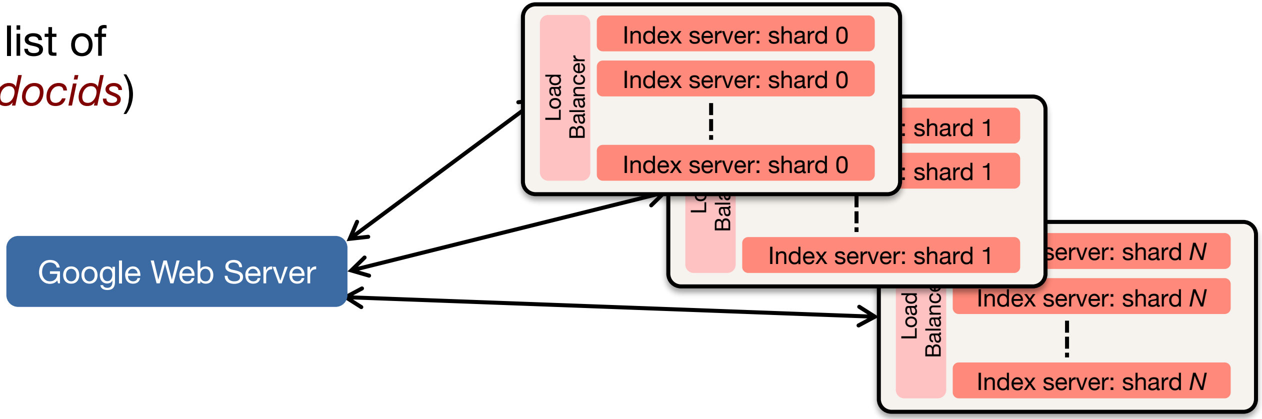
Index Servers

- Map each query word → {list of document IDs} *(this is the **hit list**)*
  - Inverted index generated from web crawlers → **MapReduce**
- Intersect the hit lists of each per-word query
  - Compute relevance score for each document
  - Determine set of documents
  - Sort by relevance score

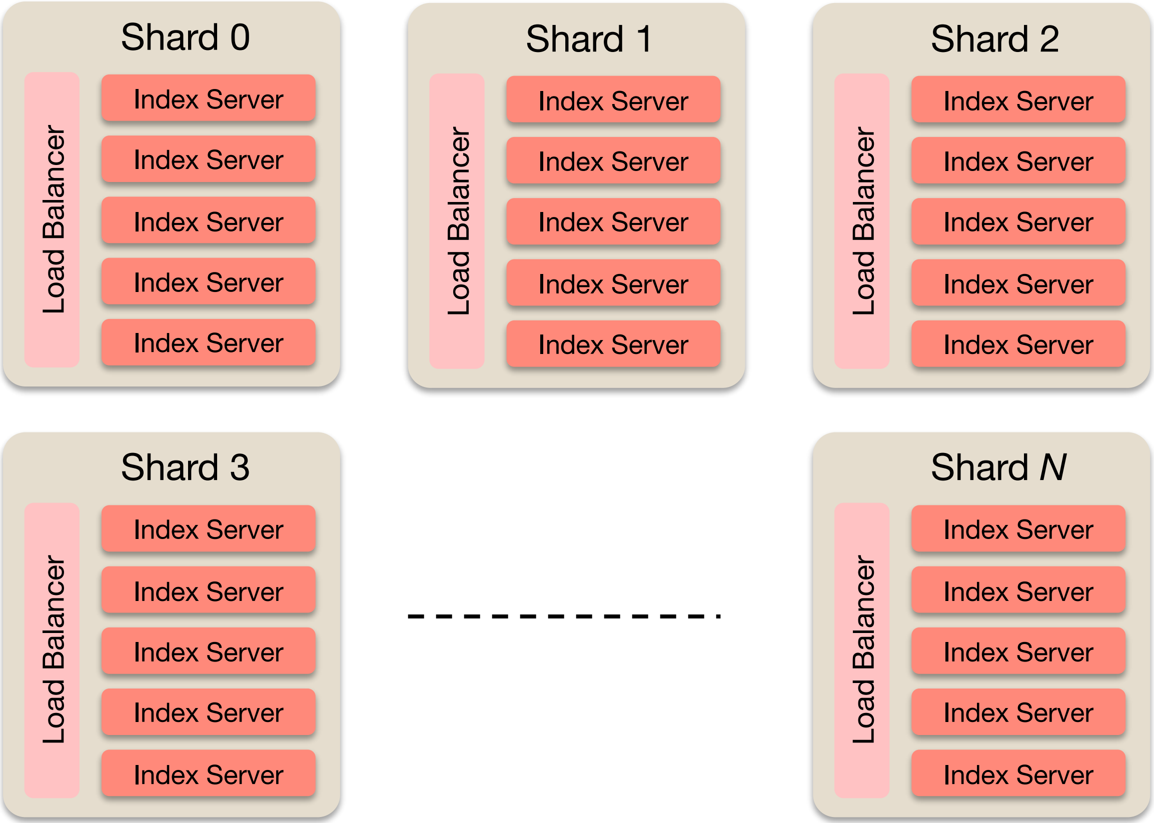


Parallel search through an inverted index

- Inverted index is 10s of terabytes
- Search is parallelized
  - Index is divided into *index shards*
    - Each index shard is built from a randomly chosen subset of documents
    - Pool of machines serves requests for each shard
    - Pools are load balanced
  - Query goes to one machine per pool responsible for a shard
- Final result is ordered list of document identifiers (*docids*)



Sharded & Replicated Index Servers



Step 4. Get title & URL for each docid

For each *docid*, the GWS looks up the *docid* to get

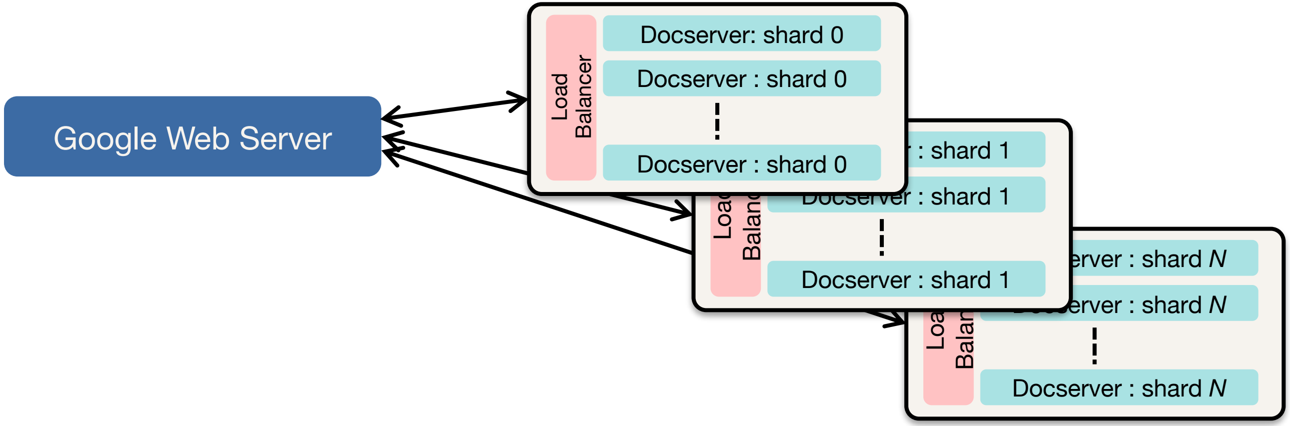
- Page title
- URL
- Relevant text: document summary specific to the query

This is handled by document servers (docservers)

Parallelizing document lookup

- Like index lookup, document lookup is partitioned & parallelized
- Documents distributed into smaller shards
  - Each shard = subset of documents
- Pool of load-balanced servers responsible for processing each shard

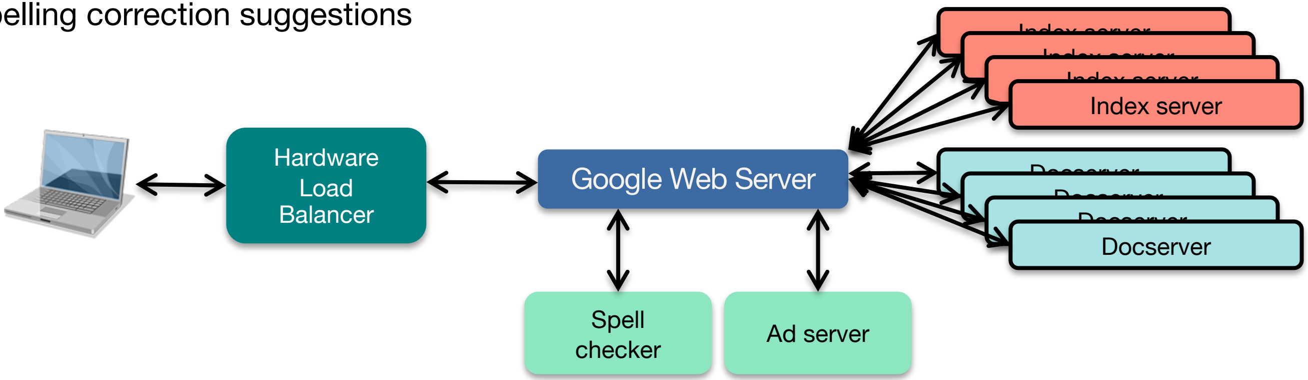
Together, document servers access a cached copy of the entire web!



Additional operations

- In parallel with search:
  - Send query to a spell-checking system
  - Send query to an ad-serving system to generate ads

- When all the results are in, GWS generates HTML output:
  - Sorted query results with
    - Page titles, summaries, and URLs
    - Ads
    - Spelling correction suggestions



Lesson: exploit parallelism

- Instead of looking up matching documents in a large index
  - Do many lookups for documents in smaller indices
  - Merge results together: merging is simple & inexpensive

- Divide the stream of incoming queries
  - Among geographically-distributed clusters
  - Load balance among query servers within a cluster

- Linear performance improvement with more machines
  - Shards don't need to communicate with each other
  - Increase # of shards across more machines to improve performance

Updating & scaling are easy

Updates

- Updates infrequent compared to reads
- Load balancers make updating easy
  - Take the system out of the load balancer during the update
  - No need to worry about data integrity and locks
- Shards don't need to communicate with each other

Scaling

- Add more shards as # of documents grows
- Add more replicas if throughput increase is needed

Summary

- Use software to achieve reliability
- Use replication for high throughput
- Price-performance is more important than peak CPU
- Use commodity hardware

The End

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