Outline & Objective

A talk about Google.

Google

1 ... as in "to Google"
2 ... as in "Google-scale"
3 ... as a mindset & engineering principle
4 ... as a paradise for computer scientists
5 ... as an economic force
6 ... as a research power house
7 ... for the Fine(r) Arts
Information for Billions

Google as in "to Google"

officially added to the Oxford English Dictionary on June 15, 2006
Google's Mission

To organize the world’s information and make it universally accessible and useful.

We actually mean it and act upon it!
The User Comes First

*Source: www.internetworldstats.com, Copyright 2011, Miniwatts Marketing Group

## WORLD INTERNET USAGE AND POPULATION STATISTICS

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Africa</td>
<td>1,037,524,058</td>
<td>4,514,400</td>
<td>118,609,620</td>
<td>11.4%</td>
<td>2,527.4 %</td>
<td>5.7 %</td>
</tr>
<tr>
<td>Asia</td>
<td>3,879,740,877</td>
<td>114,304,000</td>
<td>922,329,554</td>
<td>23.8%</td>
<td>706.9 %</td>
<td>44.0 %</td>
</tr>
<tr>
<td>Europe</td>
<td>816,426,346</td>
<td>105,096,093</td>
<td>476,213,935</td>
<td>58.3%</td>
<td>353.1 %</td>
<td>22.7 %</td>
</tr>
<tr>
<td>Middle East</td>
<td>216,258,843</td>
<td>3,284,800</td>
<td>68,553,666</td>
<td>31.7%</td>
<td>1,987.0 %</td>
<td>3.3 %</td>
</tr>
<tr>
<td>North America</td>
<td>347,394,870</td>
<td>108,096,800</td>
<td>272,066,600</td>
<td>78.3%</td>
<td>151.7 %</td>
<td>13.0 %</td>
</tr>
<tr>
<td>Latin America/Carib.</td>
<td>597,283,165</td>
<td>18,068,919</td>
<td>215,939,400</td>
<td>36.2%</td>
<td>1,037.4 %</td>
<td>10.3 %</td>
</tr>
<tr>
<td>Oceania / Australia</td>
<td>35,426,995</td>
<td>7,620,480</td>
<td>21,293,830</td>
<td>60.1%</td>
<td>179.4 %</td>
<td>1.0 %</td>
</tr>
<tr>
<td><strong>WORLD TOTAL</strong></td>
<td><strong>6,930,055,154</strong></td>
<td><strong>360,985,492</strong></td>
<td><strong>2,095,006,005</strong></td>
<td><strong>30.2%</strong></td>
<td><strong>480.4 %</strong></td>
<td><strong>100.0 %</strong></td>
</tr>
</tbody>
</table>

Internet Users in the World Distribution by World Regions - 2011

- **44.0%** Asia
- **22.7%** Europe
- **13.0%** North America
- **10.3%** Latin America/Carib.
- **5.7%** Africa
- **3.3%** Middle East
- **1.0%** Oceania / Australia

2 Billion internet users

[5+ Bs of mobile phone users]

*Source: www.internetworldstats.com, Copyright 2011, Miniwatts Marketing Group*
Empowering Users

Google products: Simple and intuitive!
Discovery via Search

70-80% of users use search engines to find Web sites

*Source: Forrester Research*
Search = Rocket Science
that doesn't look like it (on the surface)
10+ Years of Web Search Evolution

Today's Web
~Trillion URLs
~Billion searches /d
~Million spam pages /h

Key innovation #1:
PageRank algorithm
( = Markovian random walk over Web page graph )

Exploit link structure of Web to assess page authority
“[Google’s results] are unbiased and objective, and we do not accept payment for them or for inclusion or more frequent updating.” - Google Founders IPO Letter, 2004
Search cannot be performed linearly at run time. Solution: build special data structure (search index) offline

Inverted File Index
- for each term: store a sorted list of documents (ids) that contain it (+position, etc.)

Document Sharding
Go Fetch! 10000+ times per second

Divide & conquer & replicate

Index shard = set of web pages

Results are merged together at root

Replicas for traffic
[ typical: ~200ms response 1000+ computers ]

shards loaded into main memory
Google Suggest

Increase usage speed!

Query guessing w/ few keystrokes

$P(\text{query} | \text{prefix})$

Extremely fast response times

Mine query logs & filter "bad stuff"

Important for mobile!
Google Instant

Increase speed (even more)!

Trigger results as you type [no <ENTER>]

when sufficient confidence in $P(\text{query} | \text{prefix})$

- Increase in back-end serving capacity required
  - [Caching important]
Realtime Search

Google

Get live results

Real-time data feeds integrated into search results, e.g. sports, news

Requires non-trivial real-time indexing capabilities

Realtime results, June 5, 2011, 16:00 CET
Universal Search

Query all content sources, always

Complete redesign of backends:

Websearch query is send to all corpora in parallel

x10-1000 increase for news, books, images, etc.
Spam

Web search is an arms race

Huge economic incentives => smart spammers

Spam can render Web search ineffective

The secret ranking sauce.
idea → implement idea in sandbox
idea → implement idea in sandbox → generate a sample of before/after differences → send differences to external raters
idea → implement idea in sandbox → generate a sample of before/after differences

send differences to external raters

divert a tiny slice of live traffic to the sandbox

analysts prepare an independent report
1. idea
2. implement idea in sandbox
3. generate a sample of before/after differences
4. send differences to external raters
5. divert a tiny slice of live traffic to the sandbox
6. launch committee reviews report
7. analysts prepare an independent report
Experiment-driven Engineering

Improvements are refined and evaluated experimentally.

Many teams working in parallel on various improvements.

Statistics/Analyst team

Weekly launch cycle [not your traditional software release cycle]

2010 numbers

- Precision evaluations: 23,523
- Side by side experiments: 11,295
- Click evaluations: 2,668
- Final launches: 516
2

Global Scale Computing

Google as in "Google-scale"
Scale & Numbers

- Giga $10^9$, Tera $10^{12}$, Peta $10^{15}$, Exa $10^{18}$, Zetta $10^{21}$
- Publicized: Bigtable of 70 PB, 10M ops/sec
- Search Queries:
  - ~1B per day = ~10K/s @ latency <200ms
- Towards warehouse computing: ~10M nodes
- Trends:
  - Storage: $10^{18}$ -> $10^{20-21}$
  - Devices: $10^?$ -> $10^{12}$
  - Network: $10^{20}$, now, ->$10^{21}$/yr 32 KB/sec. for 1B people
The Starting Point

Stanford
"lego" design
anno 1998
Hardware philosophy

● optimize performance/$

● use commodity components: PC class motherboards + low end storage & networking

● LINUX-based systems

● workload easily parallelized

● failures, failures, failures! reliability re-gained at software level
Architecture

Servers
- CPUs
- DRAM
- Disks

Racks
- 40-80 servers
- Ethernet switch

Clusters
- O(100) racks
Storage Hierarchy

One server
- DRAM: 16GB, 100ns, 20GB/s
- Disk: 2TB, 10ms, 200MB/s

Local rack (80 servers)
- DRAM: 1TB, 300us, 100MB/s
- Disk: 160TB, 11ms, 100MB/s

Cluster (30 racks)
- DRAM: 30TB, 500us, 10MB/s
- Disk: 4.80PB, 12ms, 10MB/s
Data Centers

Many data centers around the world
- Multi B$ investment - 2008 alone: 2B+ US$
- Speed of light: 3000 km / 10ms
- Intra data center bandwidth >> inter data center bandwidth
- Move data/index towards where users are
- Energy consumption & efficiency a main factor
Energy Efficiency

- In standard data centers, cooling is 30-70% of overhead.
- Evaporative cooling enables 'free cooling' (no chiller usage).
- Use recycled water.
- 1J per search query (0.2g CO$_2$) = 2m car driving (~100g per km).
## Warehouse-scale Computer

<table>
<thead>
<tr>
<th>Data center</th>
<th>Warehouse-scale computer</th>
</tr>
</thead>
<tbody>
<tr>
<td>● Co-located machines that share security, environmental requirements</td>
<td>● Computing system designed to run massive Internet services</td>
</tr>
<tr>
<td>● Applications == a few binaries, running on a small number of machines</td>
<td>● Applications == tens of binaries running on hundreds-thousands of machines</td>
</tr>
<tr>
<td>● Heterogeneous hardware and system software</td>
<td>● Homogeneous hardware and system software</td>
</tr>
<tr>
<td>● Partitioned resources, managed and scheduled separately</td>
<td>● <strong>Common pool of resources managed centrally</strong></td>
</tr>
<tr>
<td>● Facility and computing equipment designed separately</td>
<td>● <strong>Integrated design of facility and computing machinery</strong></td>
</tr>
</tbody>
</table>
3
Systems Infrastructure

Google as a mindset & engineering principle
Google File System

How exactly do you store a file in here?

We need a file system.
Google File System

Requirements & Design Principles

**Reliability** – in the presence of failures caused by disks, memory, connectors, network, power supply, etc. as well as software bugs and human operator failures

**Big files** – organize large volume of data (e.g. web snapshot) in medium number of big files instead of many small ones

**Fast append** – mutation of files is often happens in append mode, no random access needed (e.g. logs)

**Weak consistency** – e.g. concurrent append without extra synchronization

**Bandwith** – needs to support high read/write speeds
Google File System

- Files broken into chunks (e.g. 64 MB) stored on servers
- Master manages metadata
- Data transfers directly between clients/chunkservers
Google File System

- 200+ GFS clusters
- Managed by an internal service team
- Largest clusters
  - 5000+ machines
  - 5+ PB of disk usage
  - 10000+ clients

Google Principal Engineer Sean Quinlan and consultant Kirk McKusick at the Googleplex.
Big Table

- 10k-ft view: Row & column abstraction for storing data
- Reality: Distributed, persistent, multi-level sorted map
- (row, col, timestamp) -> value
<table>
<thead>
<tr>
<th>language:</th>
<th>contents:</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;aaa.com&quot;</td>
<td></td>
</tr>
<tr>
<td>&quot;cnn.com&quot;</td>
<td></td>
</tr>
<tr>
<td>&quot;cnn.com/sports.html&quot;</td>
<td>&quot;&lt;html&gt;...&quot;</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tablets</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;website.com&quot;</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>&quot;yahoo.com/kids.html&quot;</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>&quot;yahoo.com/kids.html&quot;</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>&quot;zuppa.com/menu.html&quot;</td>
</tr>
</tbody>
</table>
Big Table - Features

- **Single-row transactions**: easy to do read/modify/write operations

- **Locality groups**: segregate columns into different files

- **In-memory columns**: random access to small items

- **Suite of compression techniques**: per-locality group

- **Bloom filters**: avoid seeks for non-existent data

- **Replication**: eventual-consistency replication across datacenters, between multiple BigTable serving setups (master/slave & multi-master)
Big Table - Usage

- 500+ BigTable cells
- Largest cells manage 6PB+ of data, 3000+ machines
- Busiest cells sustain >500,000+ ops/second 24 hours/day, and peak much higher
It's the Cheese Food Spirit

Google as a paradise for computer scientists
Google's Real Secret (Revealed)
Google's Real Secret (Revealed)
Innovation with 20% time
Team Empowerment
A as in Ads

C as in Commerce

Google as an economic force
The 20B+ US$ p.a. business idea

Running a second price auction for each search query

Largest machine learning system in the world: 1% of 20B $ = ?
Ad Sense - A Partner Business

- $5 Billion paid to partners annually
- Used by sites that collectively reach 76% of US Internet Users (73% Reach of Global Users)
- Access to hundreds of thousands of advertisers
Ad Sense - Ads on a Webpage

- Matching page content with ads
- 10+x load vs. search
Google as a Commerce Engine

- Over 1 million AdWords advertisers worldwide
- Over 1 million AdSense publishers worldwide

- Google Ad Network reach: over 80% of global internet users in 100 countries and 20 languages
- YouTube: monetizing over a billion video views per week globally

- In 2009, Google generated $54 billion of economic activity for American businesses, website publishers, and non-profits. Similar benefits elsewhere.
Local Shopping

Google product search = smart shopping

#1 price comparison site in US

Acquire in-store availability data (huge!)

Comparison between on-line and in-store
Google Shopper - Mobile Shopping

Scan the covers of books and media
Find a product by simply pointing your camera phone at the cover art of a book, CD, DVD, or video game.

Barcode scanning
Scan the barcode of almost any product to quickly learn more about it.

Search by voice
Say the name of a product and find it easily in Shopper.

Detailed product information
Find prices, reviews, specs, and more. Shopper is powered by Google Product Search.

Online prices
Shop at your favorite web site or find the best price online.

Local stores
Find nearby stores, then call them, get directions, and more.

Save your history and favorites
Shopper saves your history and lets you star your favorites for later.

Share your finds with friends
Find something you want to share? Click on the share link to post to Gmail, Facebook, Twitter, Instant Messaging, etc.
Disruptive Changes in Commerce
Let's talk about Research

Google as a research powerhouse
Machine Translation

Statistical Machine Translation
- Model translation process with a statistical model
- Learning from data: monolingual & bilingual
  - More data: better translation quality
- Computationally expensive approach
  - Models have many hundreds of Gigabyte of data
  - (Moore's law helps here)

Results:
- Much better translation quality
- Ongoing progress
  - More research groups, ...
- ∼60 languages and growing
  - recently: Haitian Creole, Urdu, Georgian, ..., Latin
October 12: CGT and FOR to call an indefinite strike at RATP

04.10.2010, 19:15 | Last updated: 11:08 p.m.

The Inter-national Committee met Monday at the headquarters of the CFE-CGC to take stock of the mobilization on Saturday against the proposed pension reform, the third in less than a month. The unions have confirmed they will organize a day of strikes and demonstrations Tuesday, October 12, calling on "workers, pensioners, unemployed people to participate forward.

The Inter and returns to the conventional action days during the parades."

On the eve of consideration of the text in the Senate, the CFDT, and Partners (FP alone did not initial) estimate that "the mobilization is a tremendous success over France. "The inter-emphasizes that it parades."

Chrome/Toolbar (websites). YouTube (CLIR, captions, snippets). Reader (feeds). GMail, Docs, Spreadsheets, and more
The Art Project
Art Project: 17 Museums + Google

**WHAT?**  A first ever collaborative effort by the world's premier museums to bring art online using Google APIs and 3rd party image capture.

**HOW?**  A combination of "museum view" imagery, high resolution art imagery, and a single feature painting per museum that will be enabled via a microsite enabled by Google APIs.

**WHO?**

MoMA, USA  
Uffizi, Italy  
Tate Britain, London UK  
Hermitage, Russia  
National Gallery, London UK  
Alte Nationalgalerie, Germany  
Gemäldegalerie, Germany  
Rijksmuseum, Netherlands  
Thyssen, Spain  
Reina Sofia, Spain  
The Metropolitan Museum of Art, USA  
Versailles, France  
The Frick Collection, USA  
The Freer Gallery, Wash USA  
Kampa, Czech Rep  
Tretyakov, Russia  
Van Gogh Museum, Netherlands
Museum view indoor navigation
17 Giga Pixel Images
1 Giga = 10 x 10 x 10M

The Ambassadors
1533
Hans Holbein the Younger
1 Giga = 10 x 10 x 10M

The Ambassadors
1533
Hans Holbein the Younger

Zoom level 1
1 Giga = 10 x 10 x 10M

The Ambassadors
1533
Hans Holbein the Younger

Zoom level 2
1 Giga = 10 x 10 x 10M

The Ambassadors
1533
Hans Holbein the Younger

Zoom level 3
Challenges with Indoor Photography

1. Exposure and dynamic range
2. Focus and parallax
3. Motion
4. Throughput
5. Lighting
6. No one room is the same
Art Project: Behind the Scenes
THANK YOU!

I will use Google before asking dumb questions. I will use Google before asking dumb questions. I will use Google before asking dumb questions. I will use Google before asking dumb questions. www.mrburns.nl before asking dumb questions. I will use Google before asking dumb questions. I will use Google before asking dumb questions. I will use Google before asking dumb questions. I will use Google before asking dumb questions. I will use Google before asking dumb questions. I will use Google before asking dumb questions. I will use Google before asking dumb questions. I will use Google before asking dumb questions. I will use Google before asking dumb questions. I will use Google before asking dumb questions. I will use Google before asking dumb questions. I will use Google before asking dumb questions. I will use Google before asking dumb questions.

THANK YOU!