DEPARTMENT OF
COMPUTER SCIENCE

THE NEW AGE OF DISCOVERY

What Is Computing Today? Deconstruction

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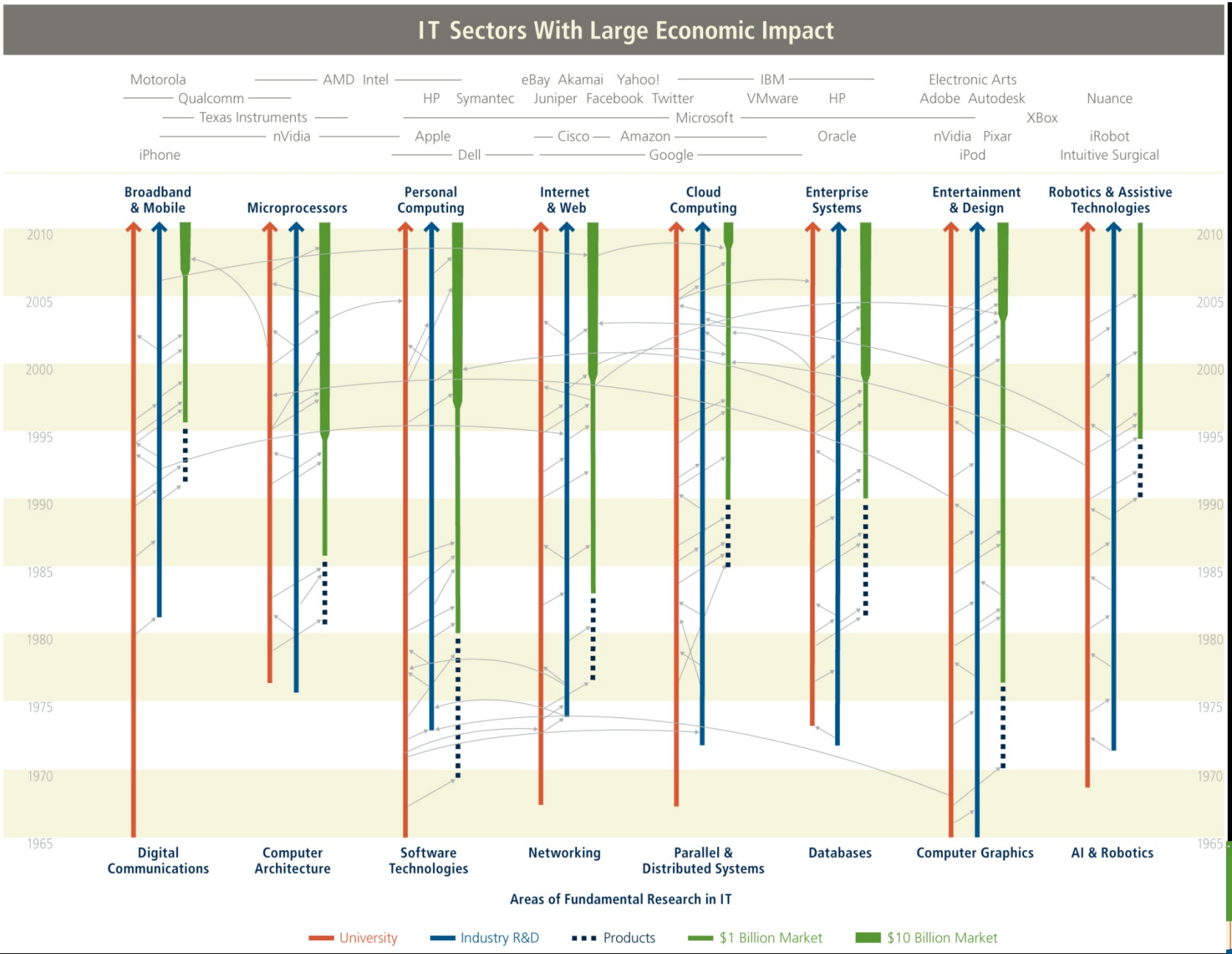
Questions

- How does “stuff work” and how did it come to be?
- What are the basic research areas of CS that impacted it?
- What are commercial needs drove it?
- How has that “stuff” changed with time?



2012 NITRD update by PCAST

Some Background Information

- IT is around 1T$* of US economy (itself 18T$ GDP)
  - **Apple Inc. (Nasdaq: AAPL), (560B/30B)**
  - Exxon Mobil Corporation (NYSE: XOM),
  - **Google Inc (Nasdaq: GOOG), (358B /12B)**
  - **Microsoft Corporation (Nasdaq: MSFT), (344B/20B)**
  - Berkshire Hathaway Inc. (NYSE: BRK.B),
  - Wal-Mart Stores, Inc. (NYSE: WMT),
  - Johnson & Johnson (NYSE: JNJ),
  - General Electric Company (NYSE: GE),
  - Chevron Corporation (NYSE: CVX)
  - Wells Fargo & Co (NYSE: WFC)

*Atkinson, R. D., & Stewart, L. A. (2013). Just the FACTS: The Economic Benefits of Information and Communications Technologies

Deconstructing a Search Query

Challenges in Building Large-Scale Information Retrieval Systems

Jeff Dean
Google Fellow
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Credits to material used from static.googleusercontent.com/media/research.google.com/en/us/people/jeff/WSDM09-keynote.pdf

The Origins of PageRank

- Stanford WebBase project (1996 - 1999)
  http://dbpubs.stanford.edu:8091/~testbed/doc2/WebBase/
  http://dbpubs.stanford.edu:8091/diglib/

- funded by NSF through DLI1
  http://www.dli2.nsf.gov/dlione/

"The Initiative's focus is to dramatically advance the means to collect, store, and organize information in digital forms, and make it available for searching, retrieval, and processing via communication networks -- all in user-friendly ways." quote from the DLI1 website

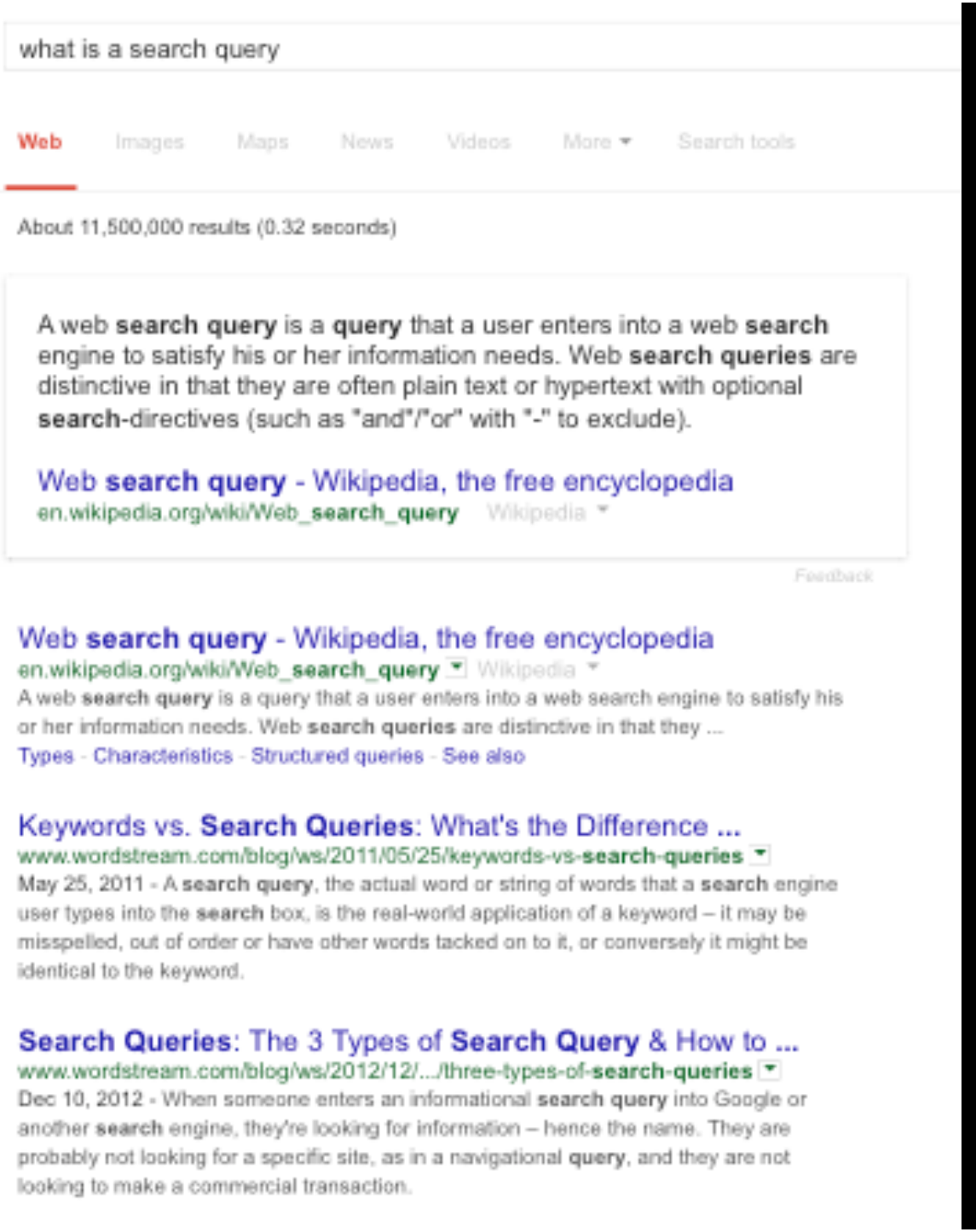
Page, Lawrence, Sergey Brin, Rajeev Motwani, and Terry Winograd. The PageRank citation ranking: Bringing order to the web. (1999).
Brin, Sergey, and Lawrence Page. The anatomy of a large-scale hypertextual Web search engine. *Computer networks and ISDN systems* 30, no. 1 (1998): 107-117.

Some Other Research Ideas

- Cache (M. Wilkes, 1965, Cambridge)
- The internet (Cerf, Kahn, 1969, ARPA)
- The Web and HTML (T. Berners-Lee, 1989, CERN)
- PageRank (Brin, Page, Motwani, Winograd, Stanford, 1997)
- SIFT Image Features (Lowe, UBC, 1999)
- Hadoop (Cutting, Cafarella, Yahoo/UW, 2005)
- Deep Learning (Hinton+others, Toronto+ others, ??)
  - GPUs ….

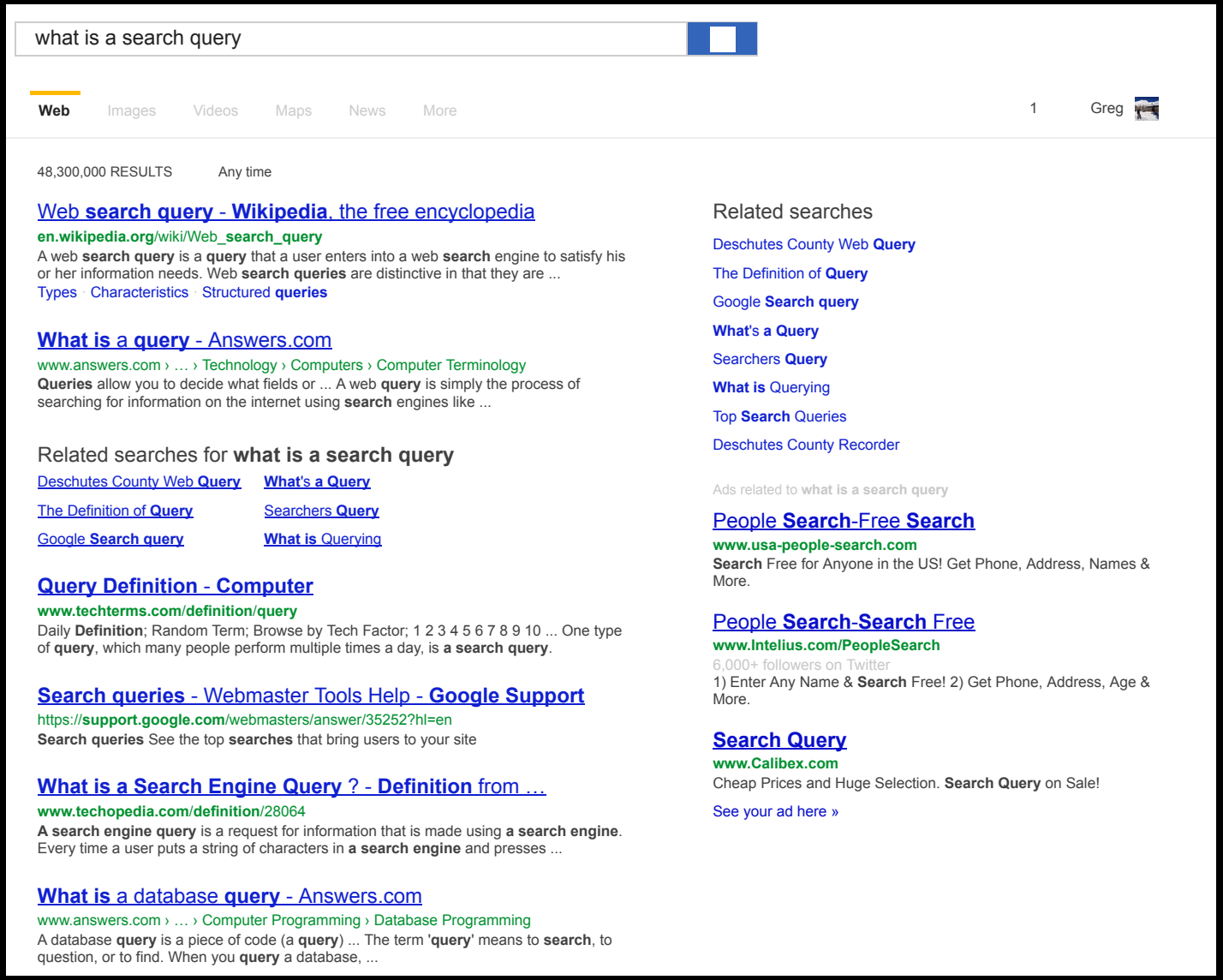
What Is a Search Query?

Google's answer



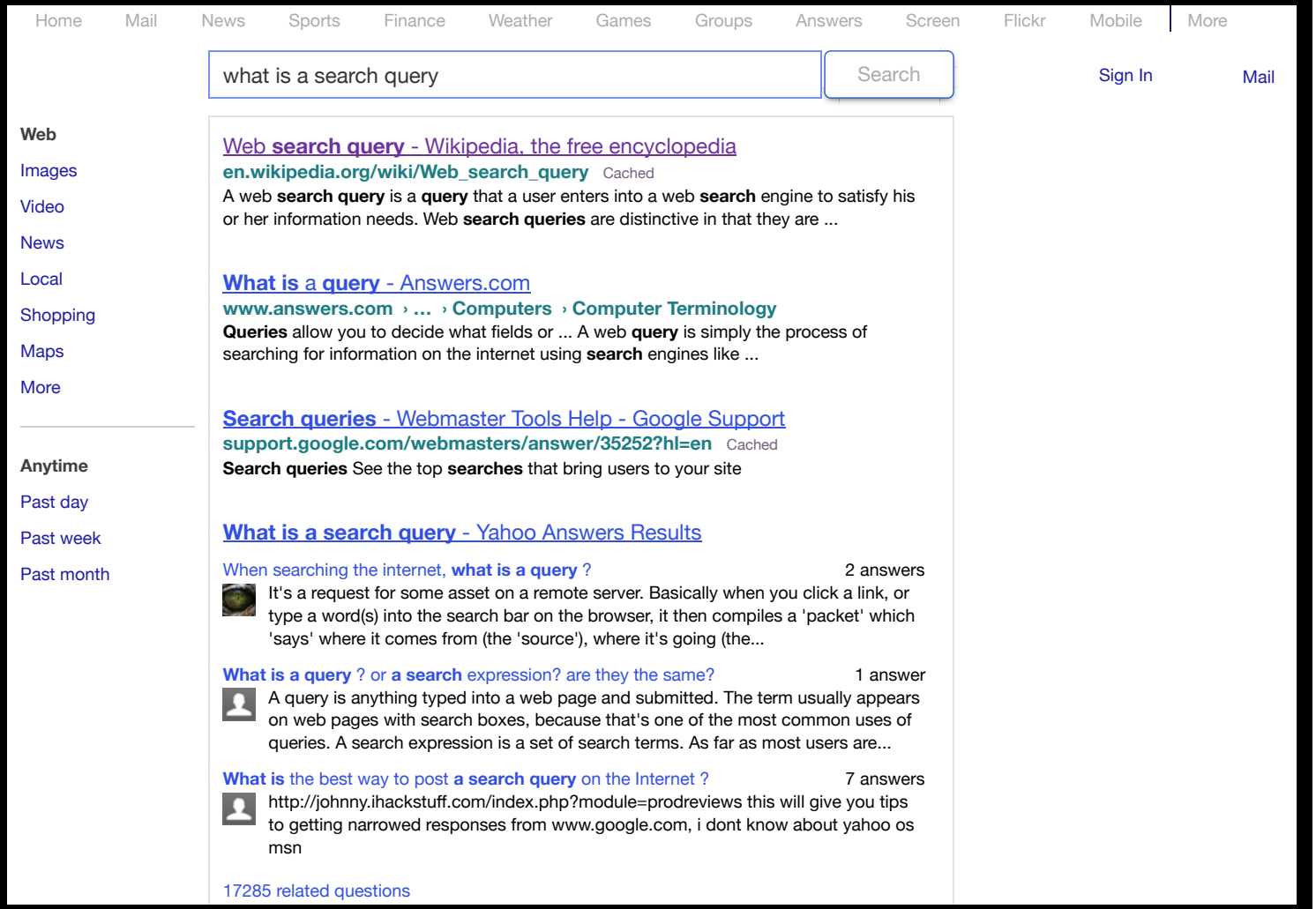
What Is a Search Query?

Bing's answer

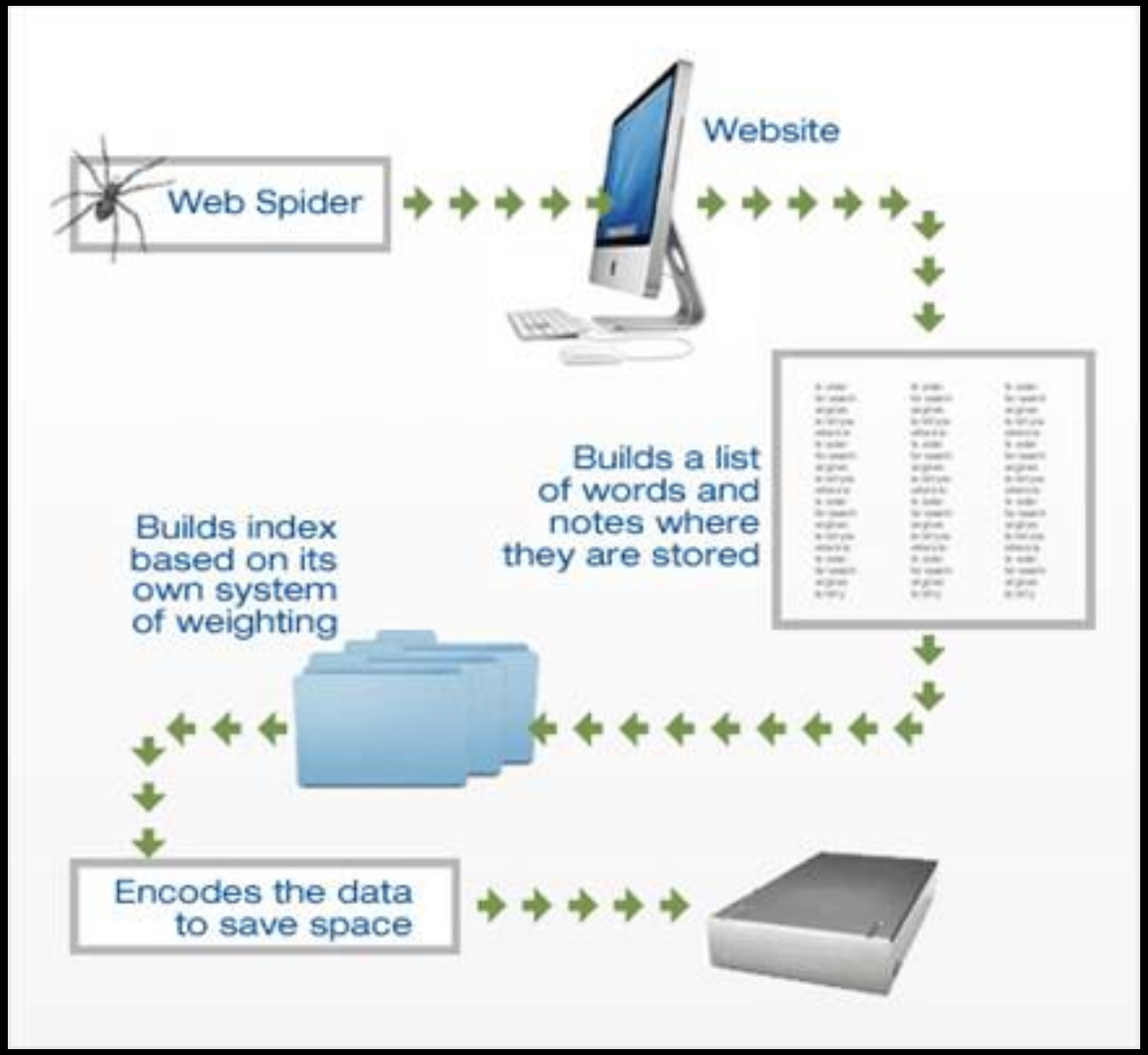


What Is a Search Query?

Yahoo's answer



It All Starts With a Spider



http://programming4.us/website/15366.aspx

Inverted Index

For example, let's say we have two documents, each with a `content` field containing:

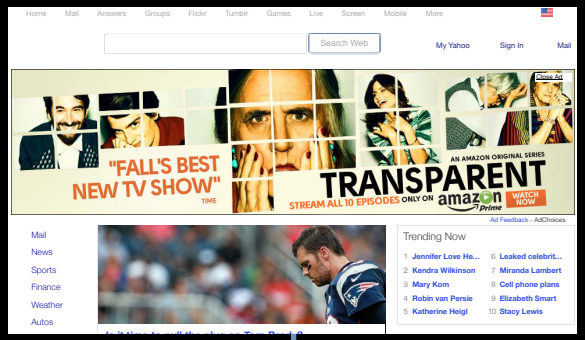
1. "The quick brown fox jumped over the lazy dog"
2. "Quick brown foxes leap over lazy dogs in summer"

To create an inverted index, we first split the `content` field of each document into separate words (which we call *terms* or *tokens*), create a sorted list of all the unique terms, then list in which document each term appears. The result looks something like this:

```
Term      Doc_1  Doc_2
-------------------------
Quick   |       |  X
The     |   X   |
brown   |   X   |  X
dog     |   X   |
dogs    |       |  X
fox     |   X   |
foxes   |       |  X
in      |       |  X
jumped  |   X   |
lazy    |   X   |  X
leap    |       |  X
over    |   X   |  X
quick   |   X   |
summer  |       |  X
the     |   X   |
------------------------
```


http://www.elasticsearch.org/guide/en/elasticsearch/guide/current/inverted-index.html

Browser to Computer to Internet to Search Engine to Cloud



Then We Need Horsepower …

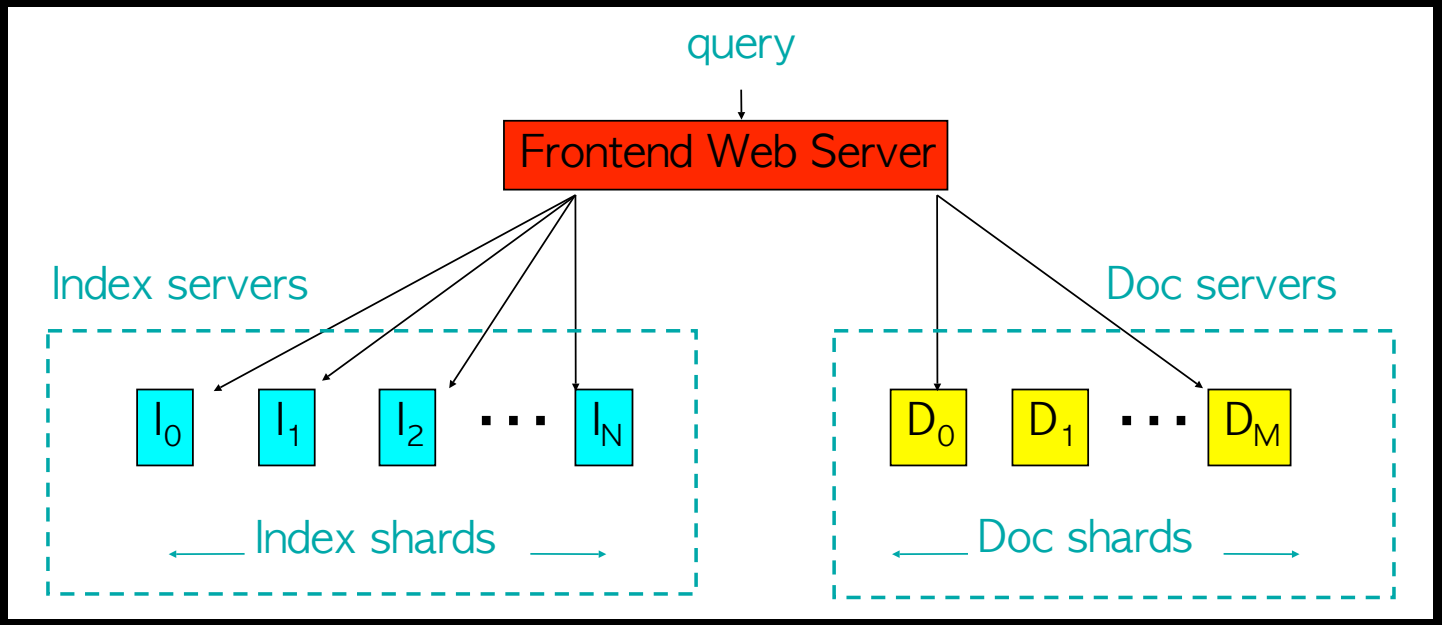


Image from Dean, Google 1997

- Given search terms e.g. dog, cat
- Return pair <docid, score>
- Score is the "secret sauce" for ranking docs
- Doc servers return pre-formatted snippets plus doc address

Some Questions

- Where are the bottlenecks?
- What is missing?

Adding Speed and Income

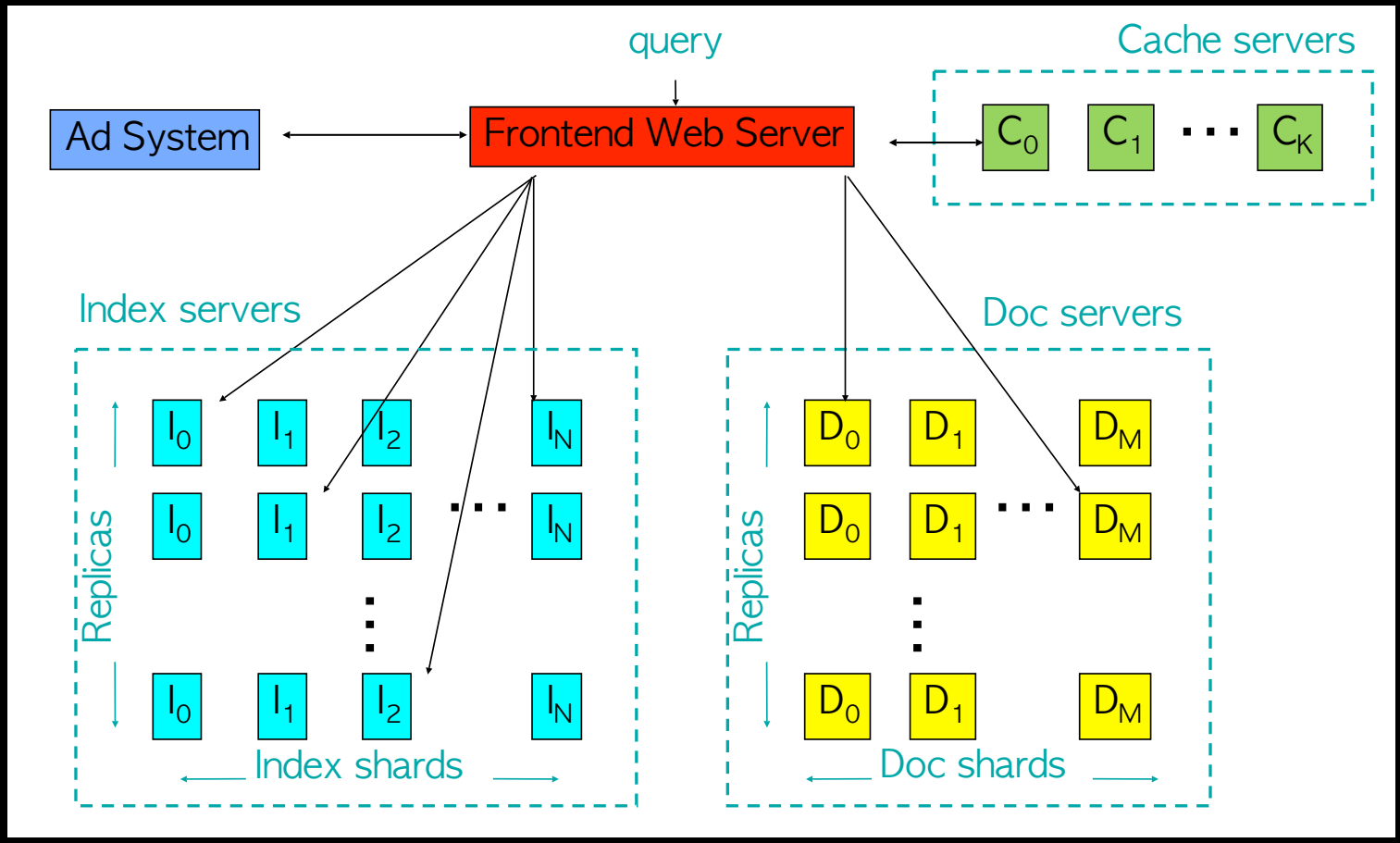


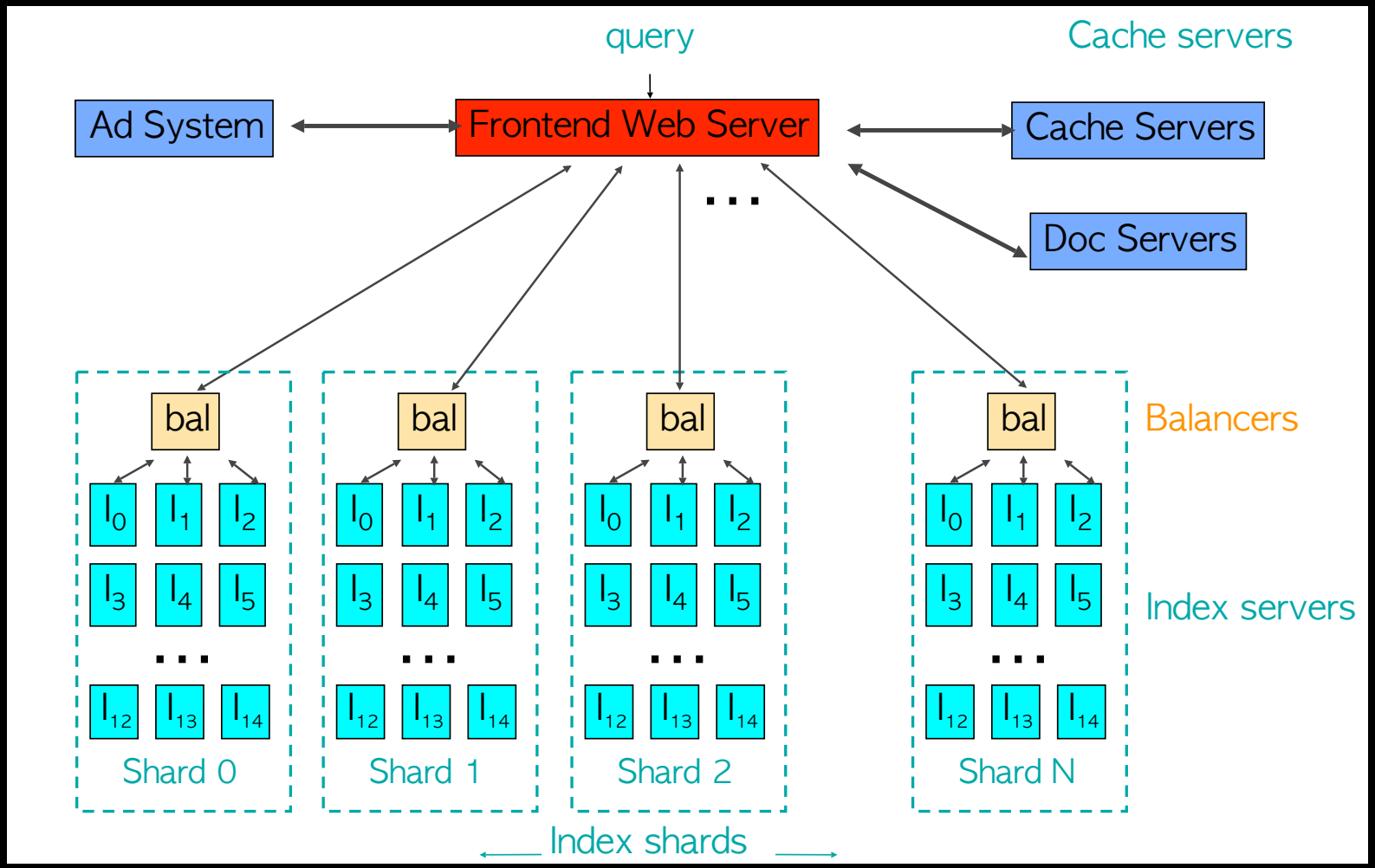
Image from Dean, Google 1999

What Makes an Effective …

- Search?

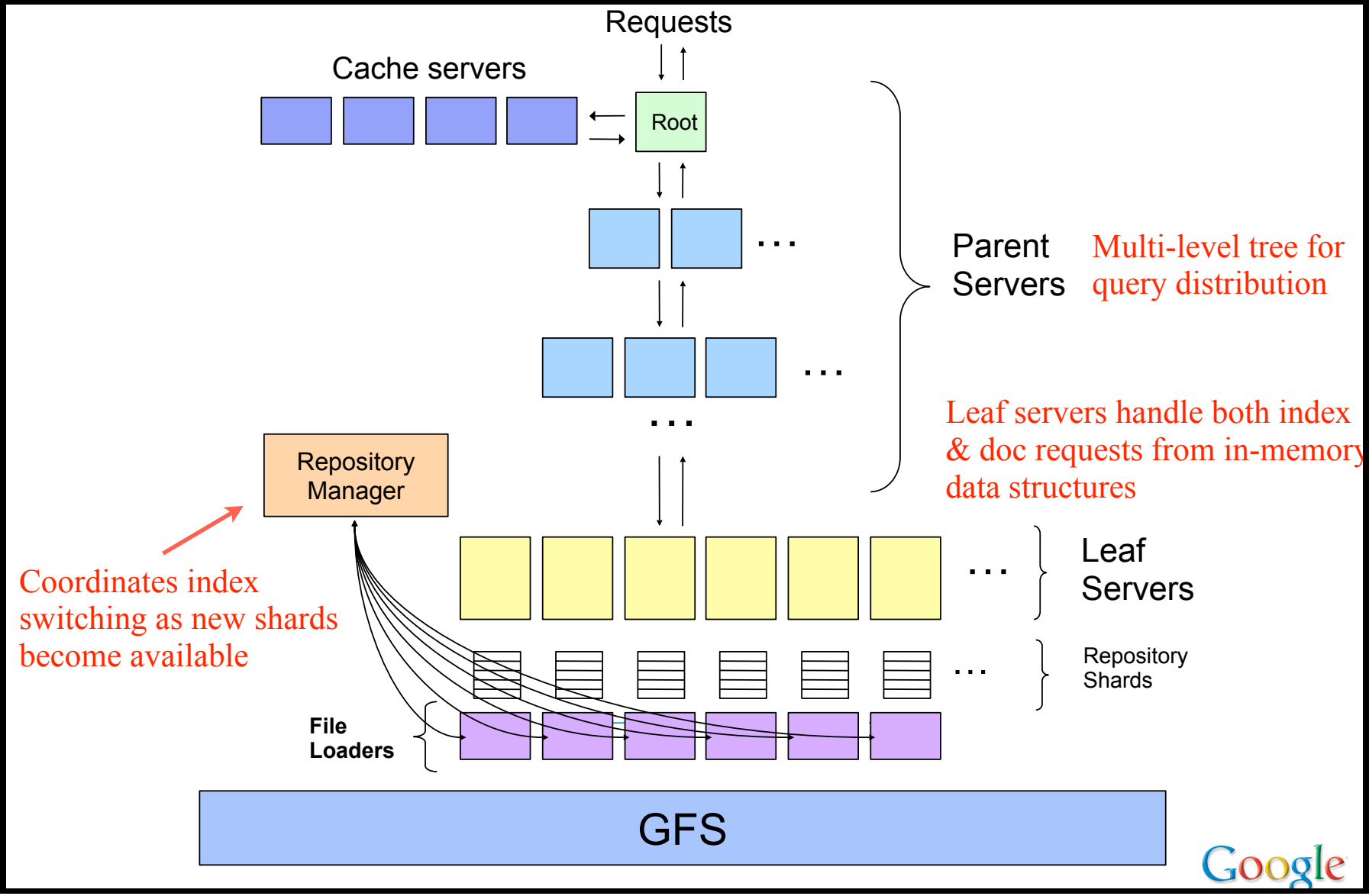
- Ad?

More Scale?



Dean, Google 2001

A More Complete Picture



Some Interesting Plusses and Minuses

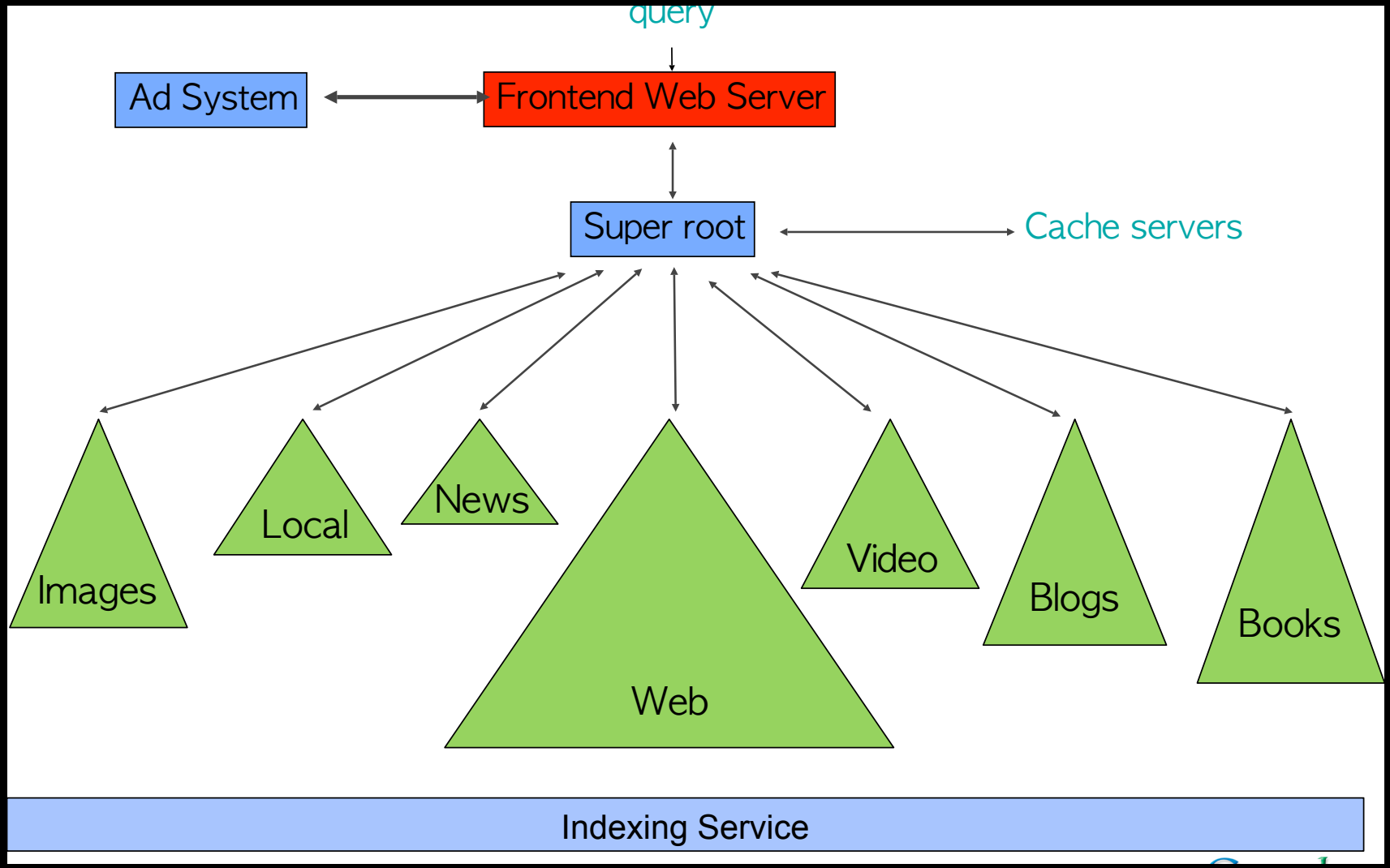
- Queries are now fast – particularly at tail
- Throughput is high

- Now depending on a very large # of machines – one key machine down and that query fails or takes a long time
- What if a query kills a machine – you can mow down the entire cluster

Canary Requests

- Send a request to one machine and see if it dies
- If not, go ahead
- If it does, try a couple more; if they die, give up

Google 2007 Architecture



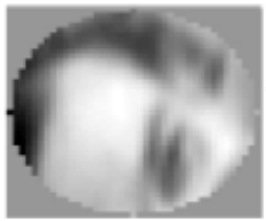
An Aside – Visual Search

- Key breakthrough due to Lowe (SIFT, 1999)
- Second key technology: use of weak labels from the Web
- Third key technology: learning technologies that can be applied at scale

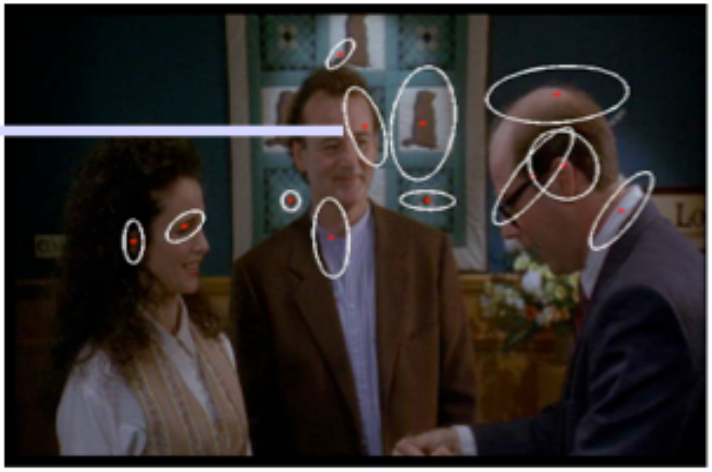
1.Feature detection and representation

Compute SIFT descriptor

[Lowe'99]



Normalize patch



Detect patches

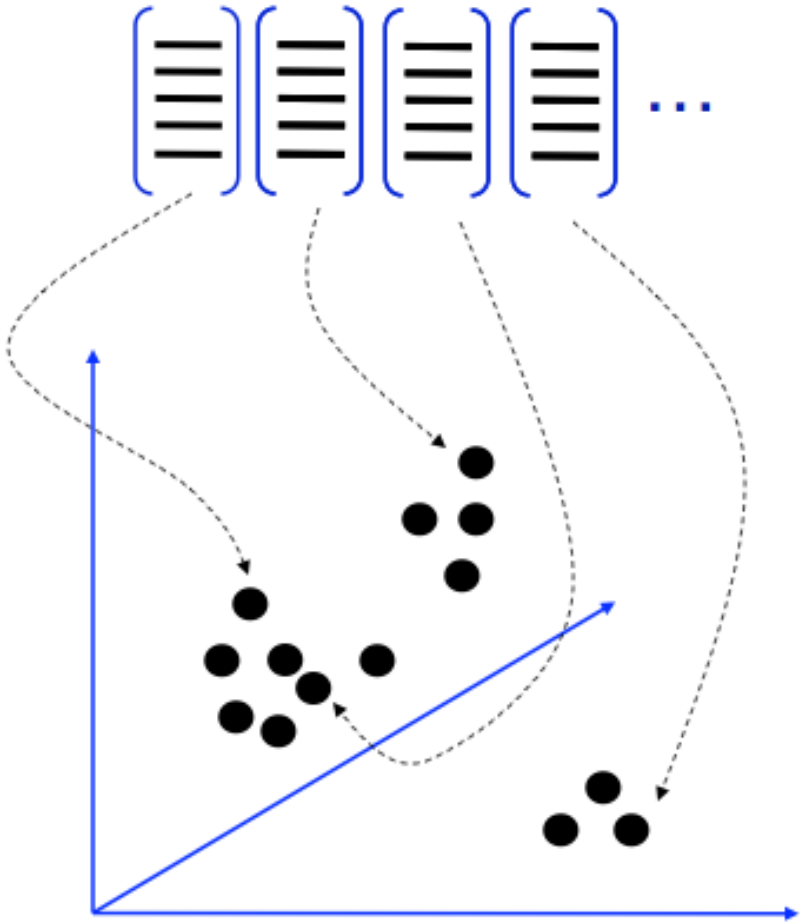
[Mikojaczyk and Schmid '02]

[Mata, Chum, Urban & Pajdla, '02]

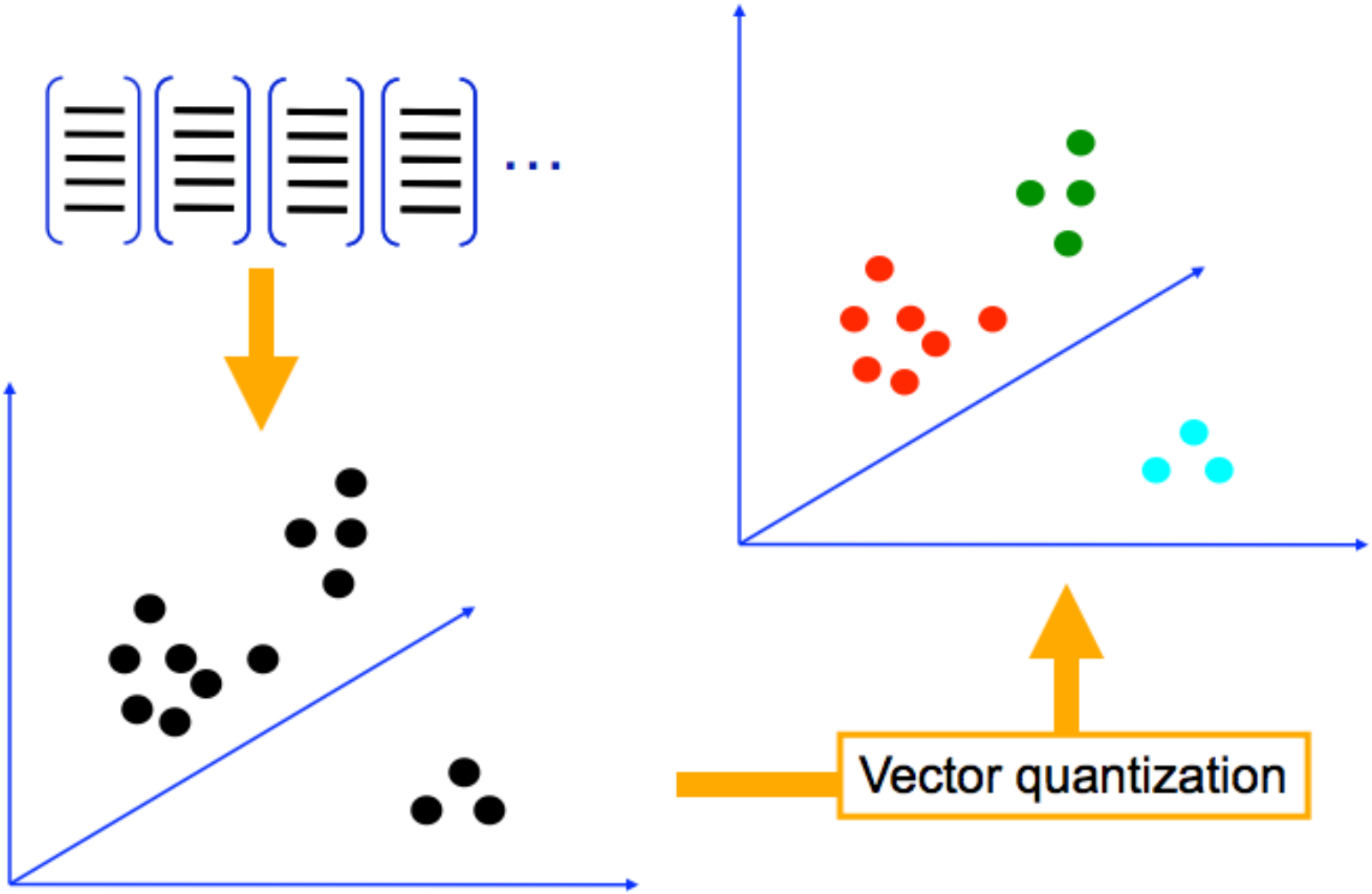
[Sivic & Zisserman, '03]

Slide credit: Josef Sivic

2. Codewords dictionary formation



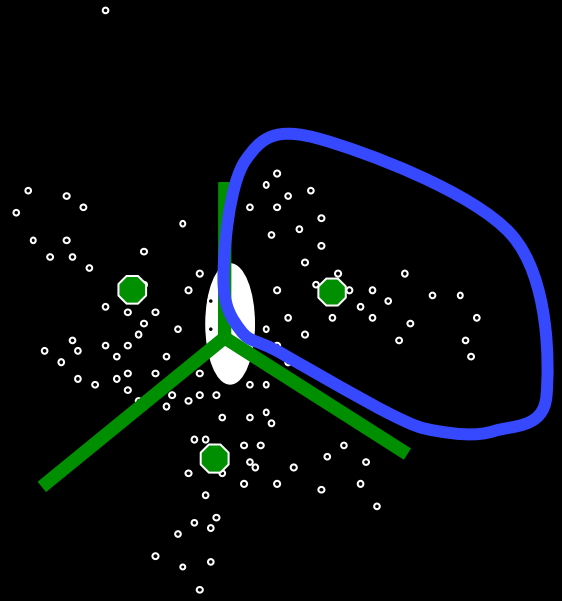
2. Codewords dictionary formation



Slide credit: Josef Sivic

Visual Words

- Example: each group of patches belongs to the same visual word



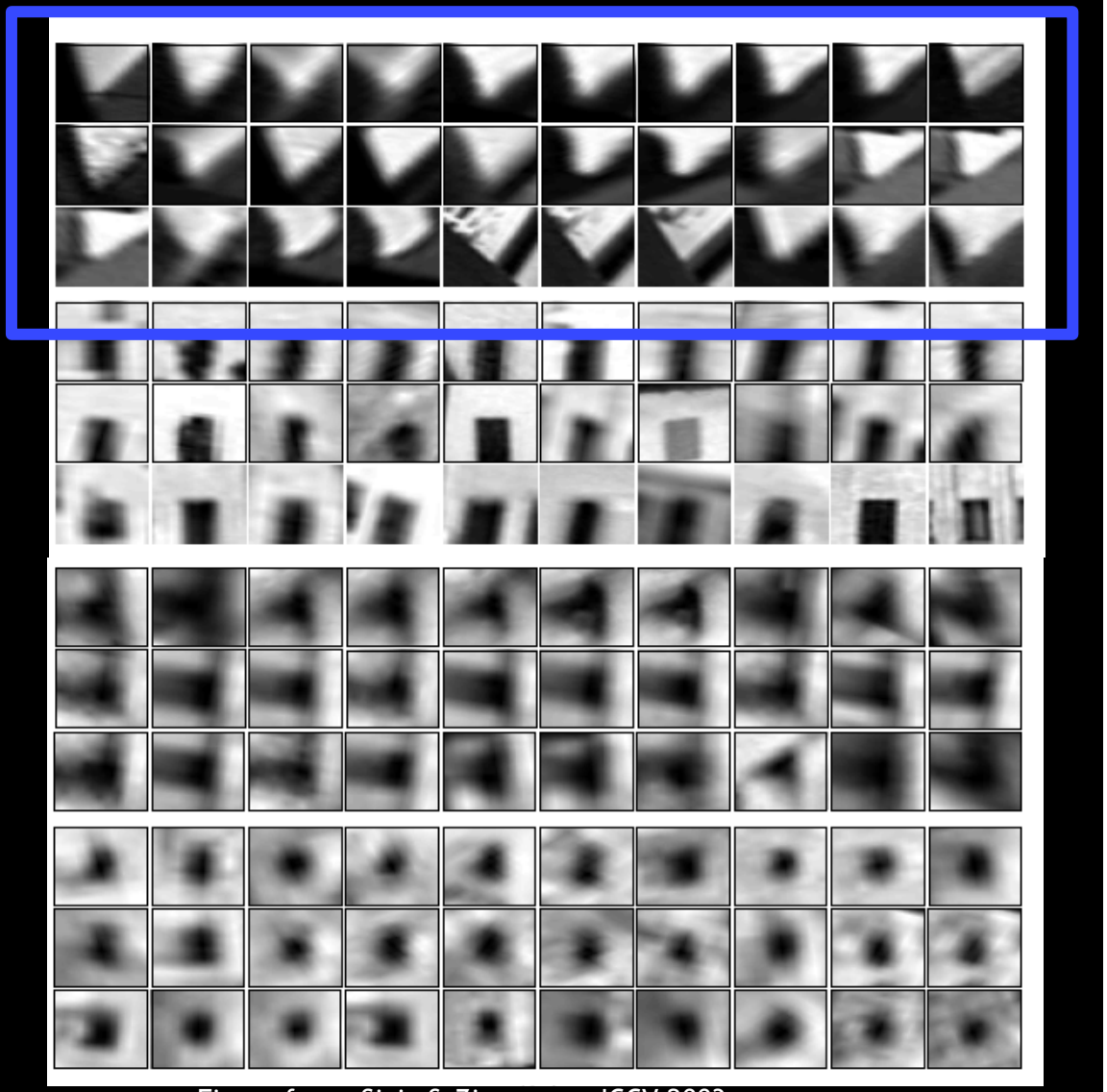
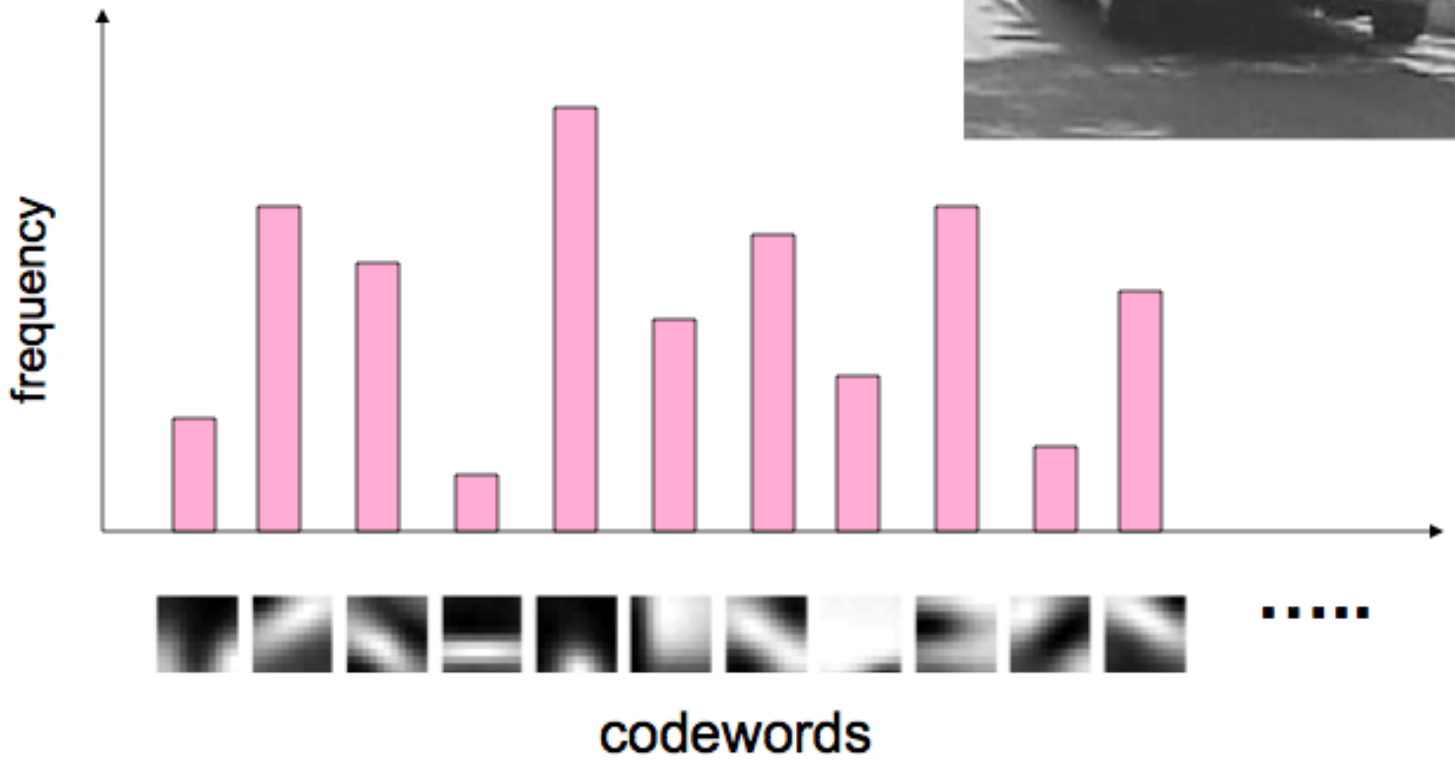


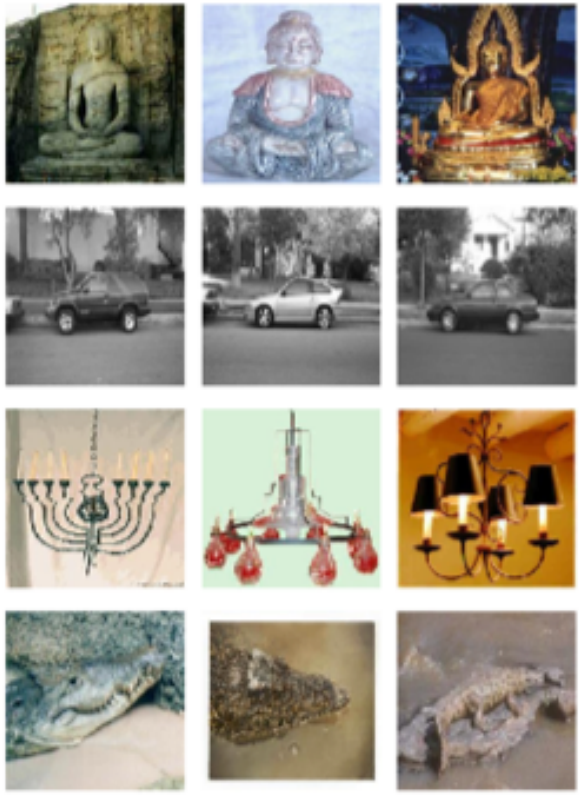
Figure from Sivic & Zisserman, ICCV 2003

3. Image representation



Object recognition results

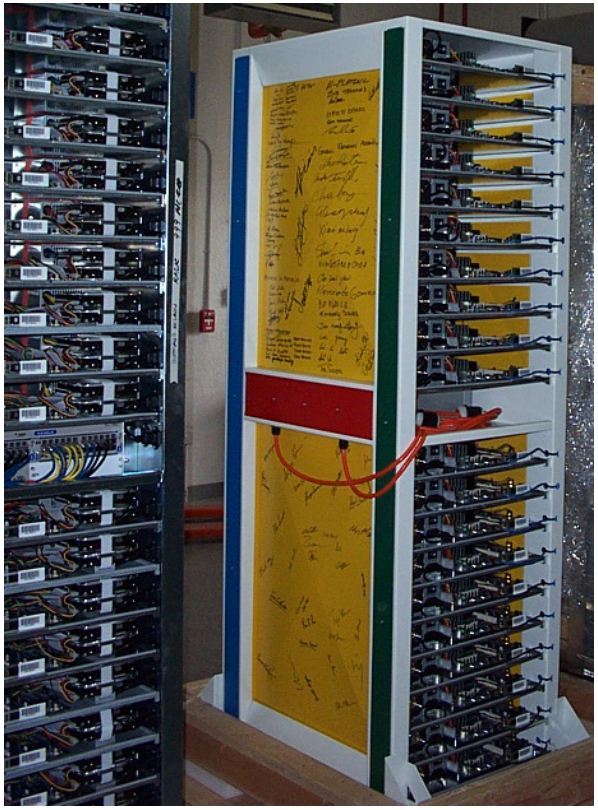
- Caltech objects database
  101 object classes
- Features:
  - SIFT detector
  - PCA-SIFT descriptor, *d*=10
- 30 training images / class
- 43% recognition rate
  (1% chance performance)
- 0.002 seconds per match



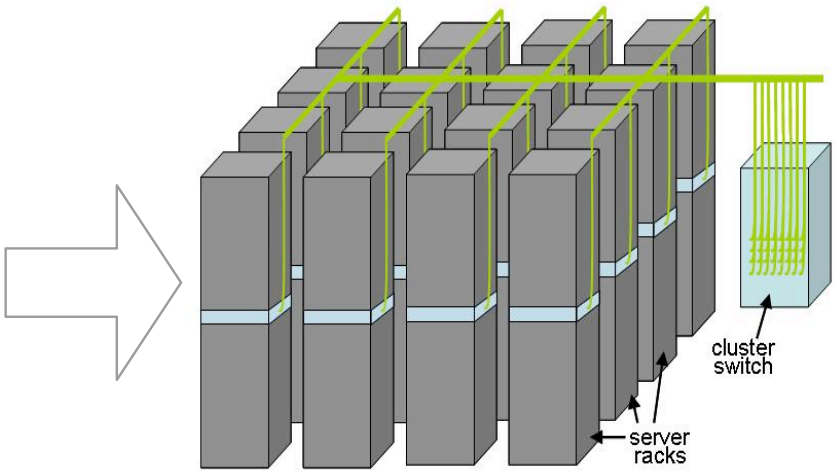
Slide credit: Kristen Grauman

Running in The Real World

Machines + Racks



Clusters



- In-house rack design
- PC-class motherboards
- Low-end storage & networking hardware
- Linux
- + in-house software

From Dean

Running in the Real World

Typical first year for a new cluster:

~1 network rewiring (rolling ~5% of machines down over 2-day span)

~20 rack failures (40-80 machines instantly disappear, 1-6 hours to get back)

~5 racks go wonky (40-80 machines see 50% packetloss)

~8 network maintenances (4 might cause ~30-minute random connectivity losses)

~12 router reloads (takes out DNS and external vips for a couple minutes)

~3 router failures (have to immediately pull traffic for an hour)

~dozens of minor 30-second blips for dns

~1000 individual machine failures

~thousands of hard drive failures

slow disks, bad memory, misconfigured machines, flaky machines, etc.

Dean

Time for a Reality Check

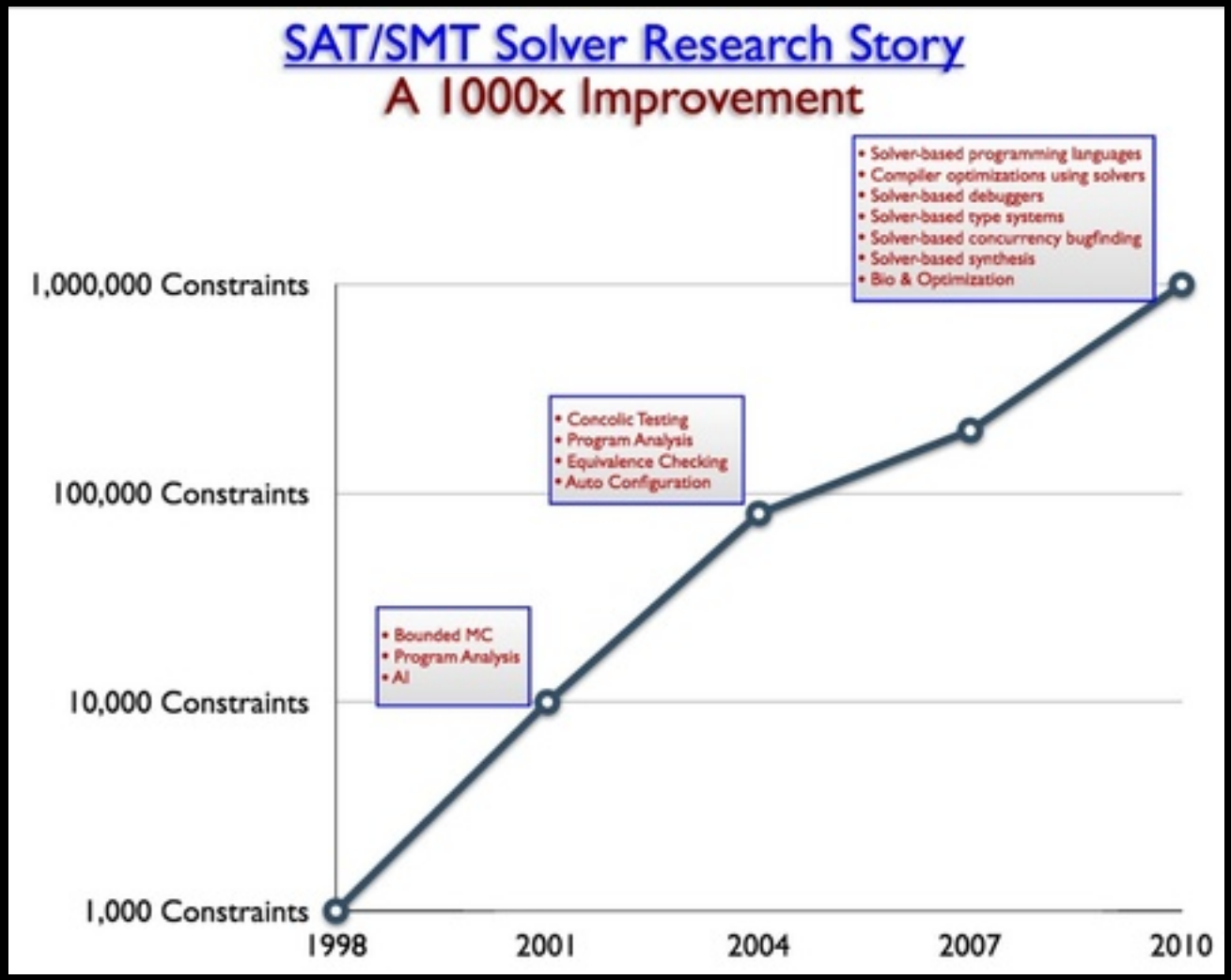
- Suppose you have a bug that is exercised once in a million queries
- How often will that bug be exercised in a day at Google?

3.5 billion queries/day -> 40k/second -> **every 25 seconds**,

A Slight Digression – SAT and Program Verification

- Simple problem: is a boolean formula satisfiable?
  - A & B === yes A=1, B=1
  - A & ~A === no!
- Original NP complete problem (Cook 1971)
- So What?

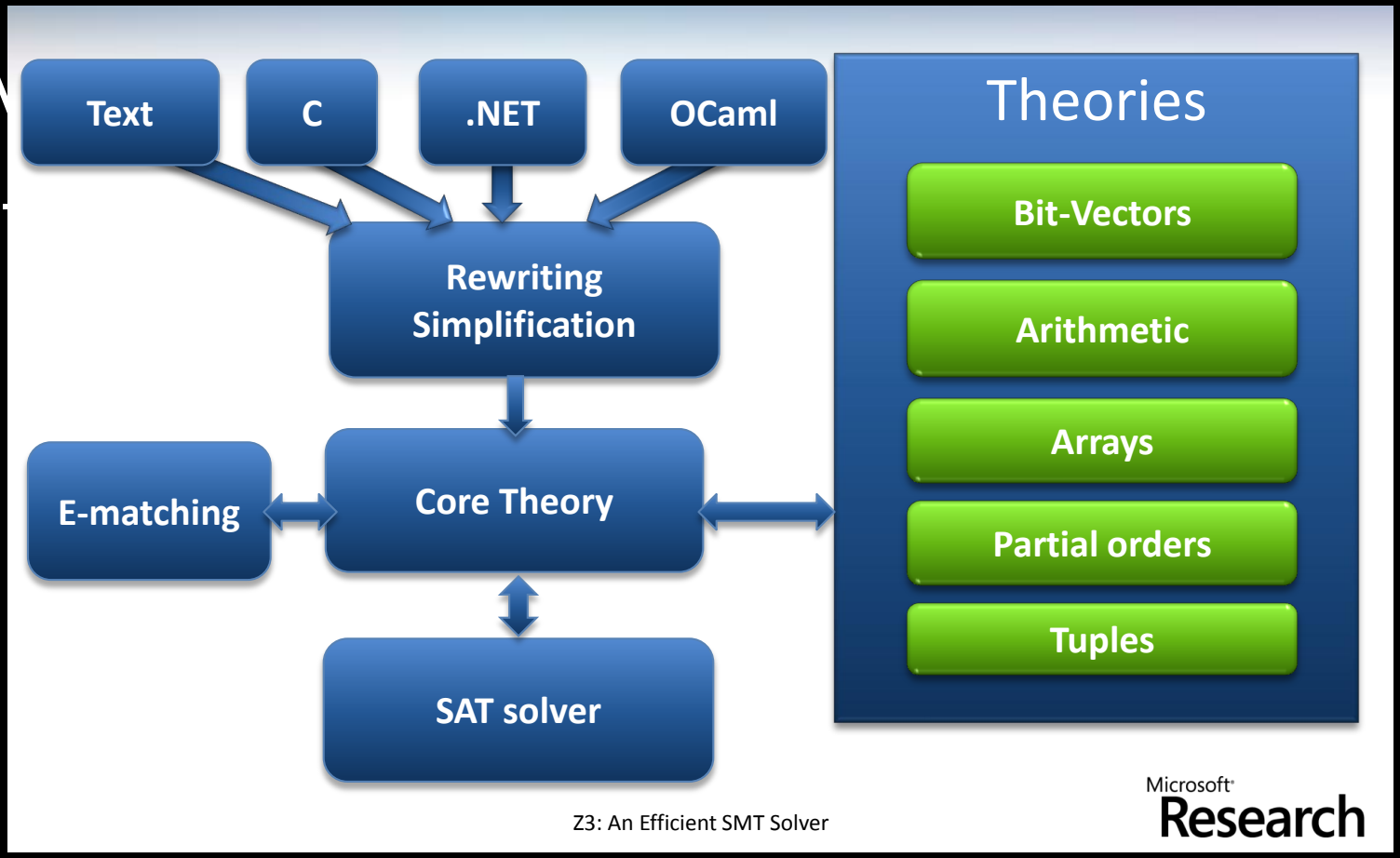
A Slight Digression -- SAT



Courtesy Vijay Ganesh

Add Some Horsepower

- N



A large fraction of windows bugs now found by program verifications

http://research.microsoft.com/en-us/um/redmond/projects/z3/Z3_System.pdf

Time for a Reality Check

- Suppose you have a bug that is exercised once in a million queries
- How often will that bug be exercised in a day at Google?

  3.5 billion queries/day -> 40k/second -> **every 25 seconds**,

- Even more complicated because queries are highly parallel!

A Paradigm Is Born

- Every problem has to deal with all of the possible hardware and software exceptions – lots of work!
- BUT, many of the underlying computations are "embarrassingly parallel"
  - Send a query to server (e.g. "do you have this term")
  - Aggregate the results
- The idea of **Map-Reduce**

Map Reduce

- User writes two main functions
  - Map -> the work each worker has to do – e.g. find docs for an index term
  - Reduce -> the work to combine the results – e.g. find the top n queries based on ranking
- System handles
  - Distribution, load balancing, communication, checkpointing …
- Apache Hadoop a common (open source) system for Map-Reduce

Computing at Scale

	Aug, '04	Mar, '06	Sep, '07	May, '10
Number of jobs	29K	171K	2,217K	4,474K
Average completion time (secs)	634	874	395	748
Machine years used	217	2,002	11,081	39,121
Input data read (TB)	3,288	52,254	403,152	946,460
Intermediate data (TB)	758	6,743	34,774	132,960
Output data written (TB)	193	2,970	14,018	45,720
Average worker machines	157	268	394	368

Dean: Map Reduce Statistics

Some Lessons

- Reality is a harsh taskmaster – many of the best ideas are forged from real problems
- It's usually not a single idea – borrow from the best!
- It's hard to trace the impact of ideas to fruition – at best we can do an anecdotal approximation; don't be fooled by an overly simplistic view!
- There are few truly failed ideas, just failed applications thereof – persevere!

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Where is Computing Going?

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What Do Computers Do Well

- Office work: accounting, wordprocessing

- Simulation: science, gaming

- Automation: manufacturing, embedded systems

What's Hard?

Driving

Automated Driving 1986

Navlab 1 (CMU)

- 5 racks of computing equipment
- Warp supercomputer
- Vision, laser scanner

By late 80's software systems could drive at 20 m.p.h.

Fig. 1. The Navlab.

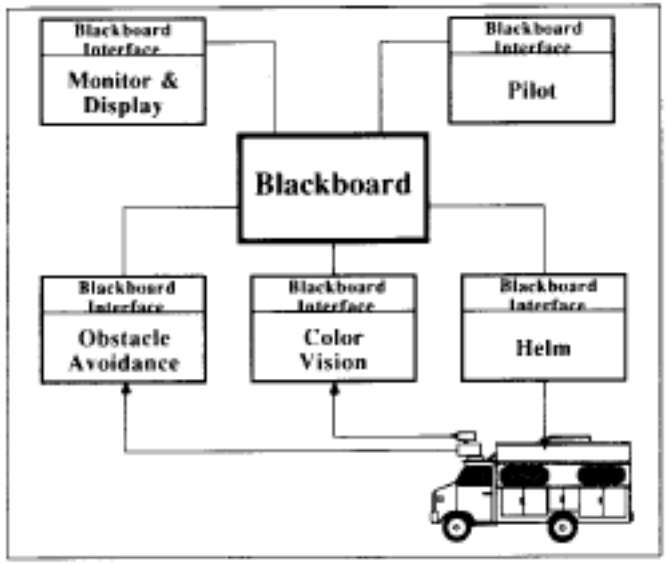


Fig. 20. Navlab software architecture.

1986: Dickmanns demonstrates 60 mph driving using simple vision-based control approach

Automated Driving 1996

Navlab 5: 1990 Pontiac Trans Sport
- Portable Advanced Navigation Support
- Sparc LX with a color video digitizer
- Differential GPS, fiber optic rate gyro
- Position estimation, vehicle control, and safety monitoring.
- Powered from cigarette lighter

(Pomerleau et al. CMU)

No Hands Across America

2797/2849 miles (98.2%)
automated driving

2004 DARPA Grand Challenge:

- 150 mile off-road robot race across the Mojave desert
- Natural and manmade hazards
- No driver, no remote control
- No dynamic passing
- Fastest vehicle wins the race (and 2 million dollar prize)

Courtesy Thrun

July 15: Driving the DGC 2004 Course

Straight Roads

Mountain Roads

Cattle Guards

Open Lake

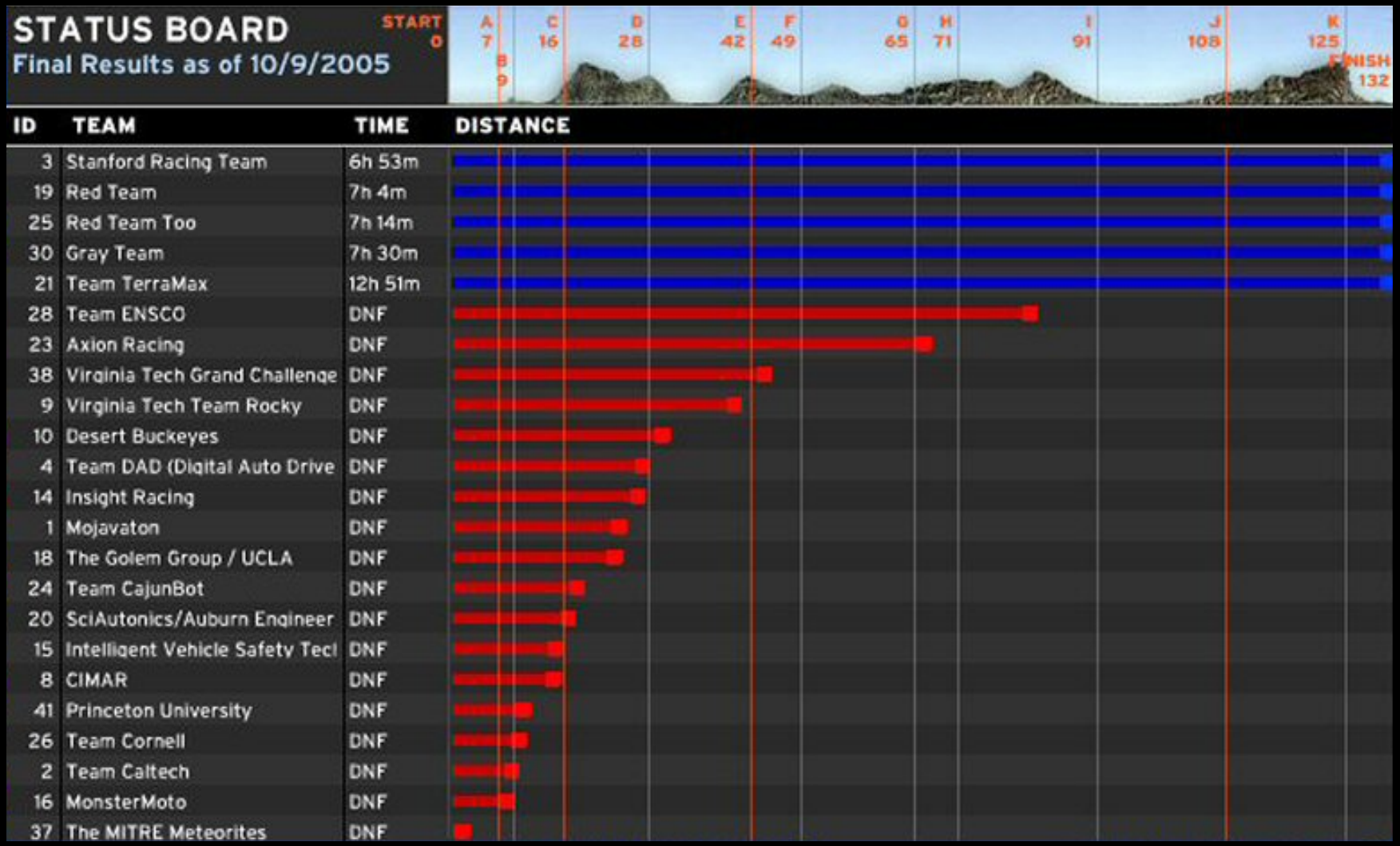
The 2004 DARPA Grand Challenge

- 150 mile course through Mojave Desert
- 15 entrants who made it to the final https://www.youtube.com/watch?v=FaBJ5sPPmcI
- After a few hours, all failed
- Sandstorm (CMU) made it 7.4 miles

Grand Challenge 2005: 195 Teams

Courtesy Thrun

Final Result: Five Robots finished!



The Winners

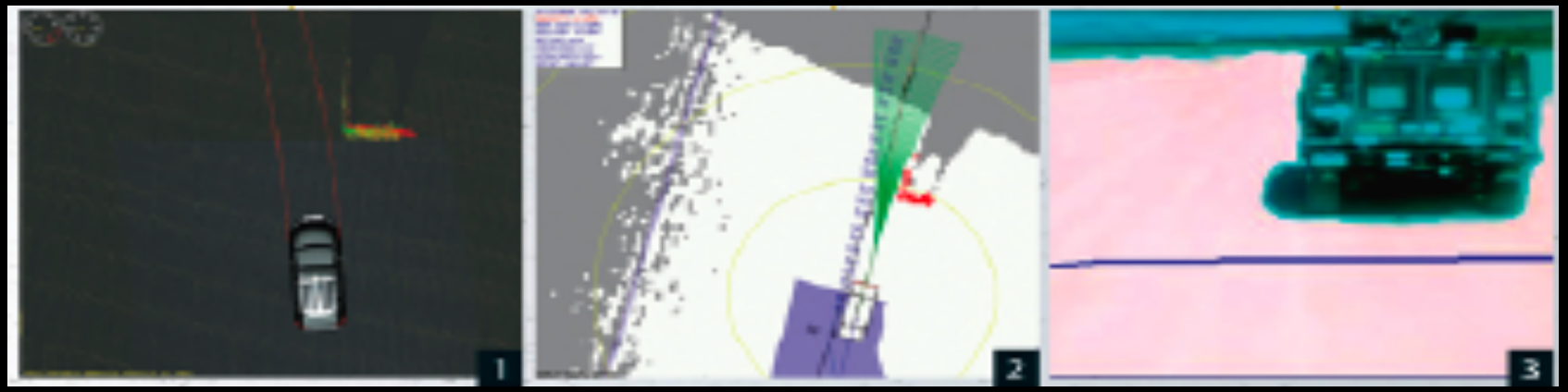
- Stanley (Stanford)
  6:54

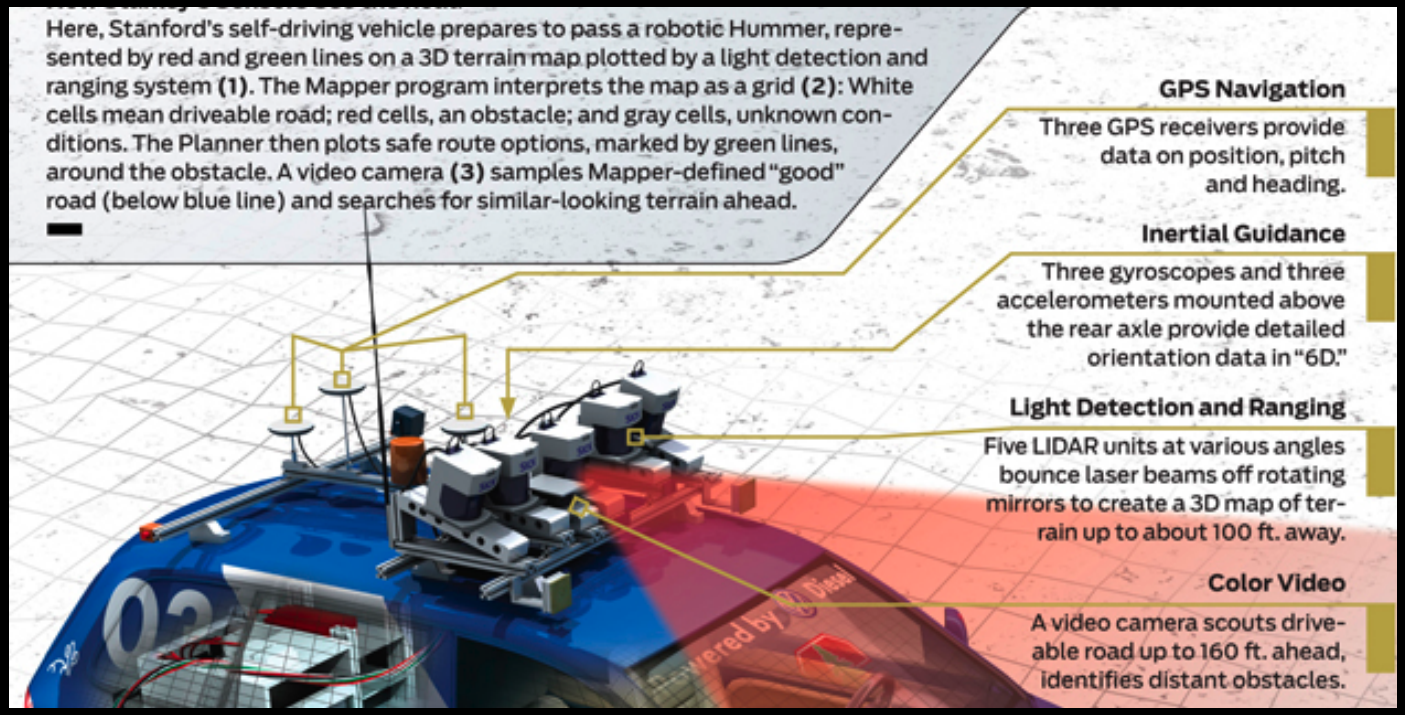
- Sandstorm (CMU)
  7:05

- H1ghlander (CMU)
  7:14

The Grand Challenge Race

Automated Driving 2006





Stanford DARPA Grand Challenge Vehicle (Thrun)

(Popular Mechanics Jan '06)

Stanley Software Architecture

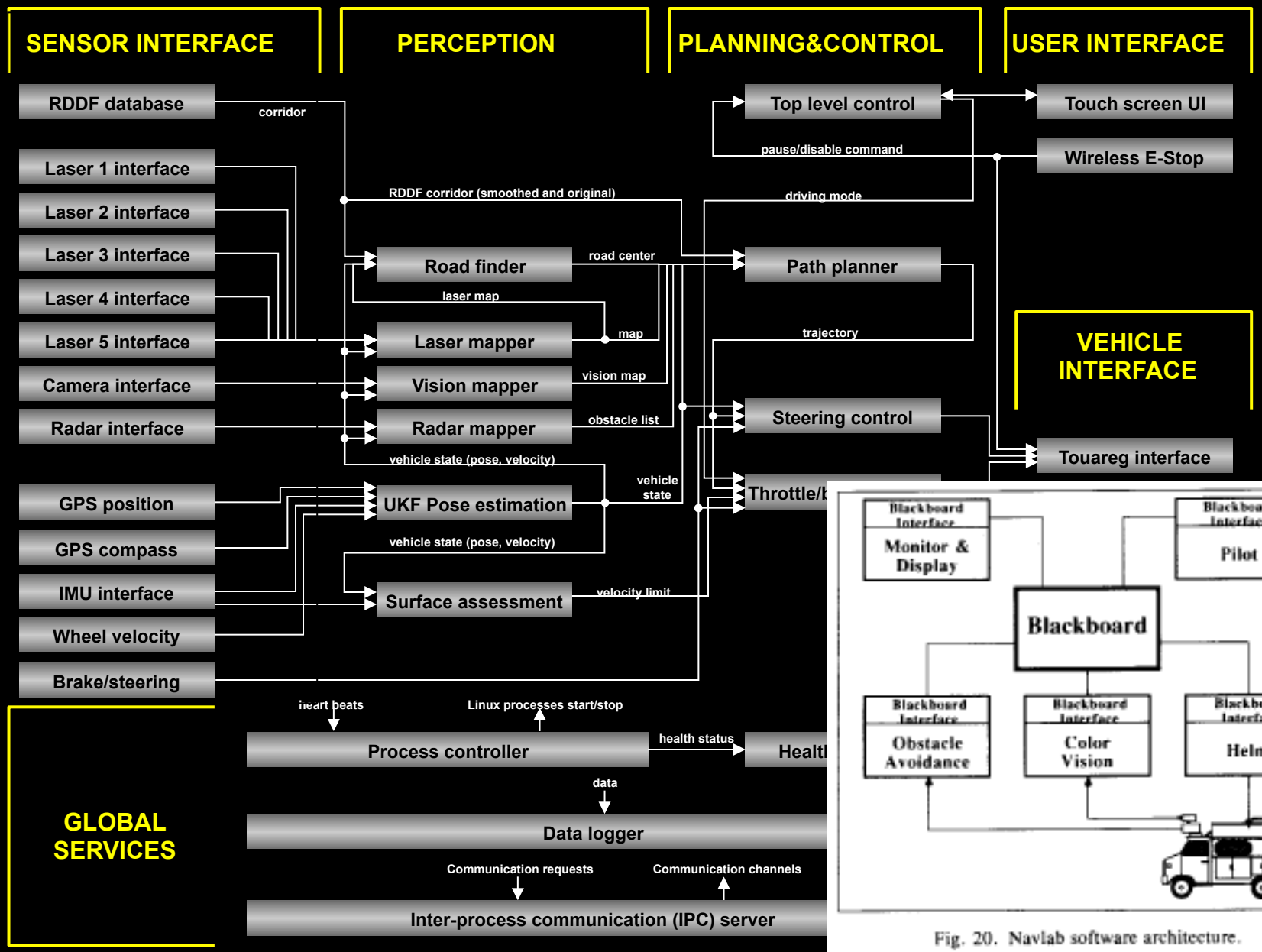
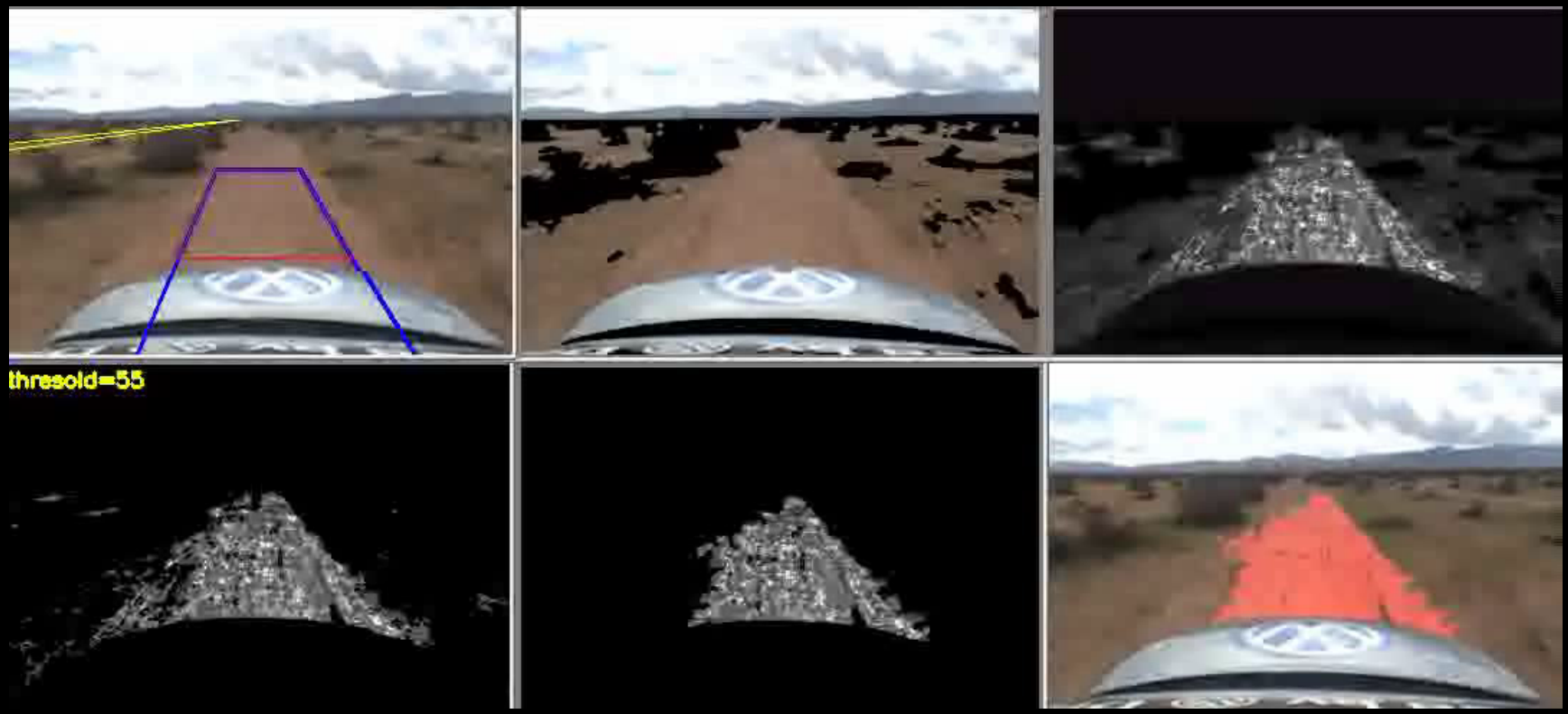


Fig. 20. Navlab software architecture.

A Look Under the Hood



Courtesy David Stavens, Sebastian Thrun

Adaptive Vision in Mojave Desert

The Next Challenges

- Darpa Urban Challenge: https://www.youtube.com/watch?v=0wJAANgG-Vg
- Google Car: https://www.youtube.com/watch?v=TsaES--OTzM

DARPA Robotics Challenge

- 1. Drive a utility vehicle at the site.
- 2. Travel dismounted across rubble.
- 3. Remove debris blocking an entryway.
- 4. Open a door and enter a building.
- 5. Climb an industrial ladder and traverse an industrial walkway.
- 6. Use a tool to break through a concrete panel.
- 7. Locate and close a valve near a leaking pipe.
- 8. Connect a fire hose to a standpipe and turn on a valve.

DARPA Robotics Challenge

What Computers Can’t Do (Yet?)

The Popular View of Computers

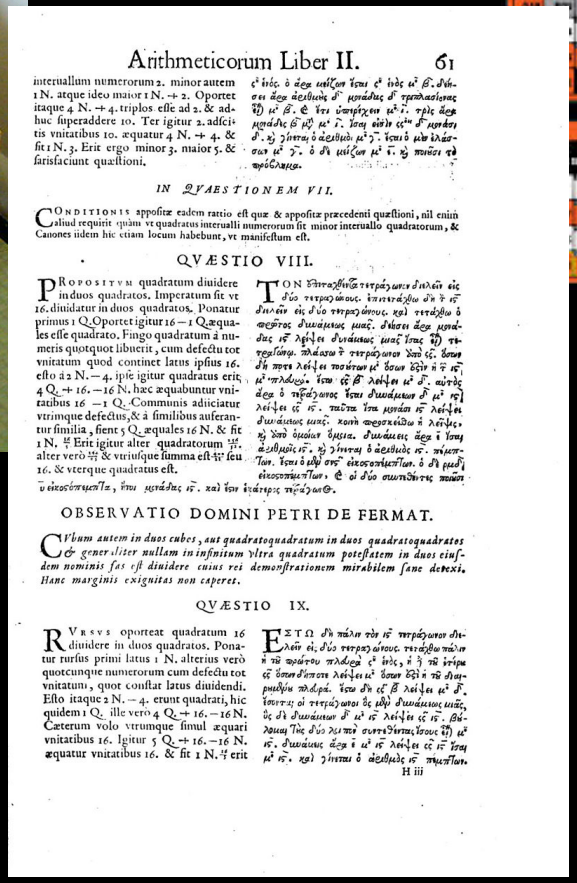
Simon 1957

- Predicted that by 1967:
  - A computer would be world champion in chess
  - A computer would discover and prove an important new mathematical theorem
  - Most theories in psychology will take the form of computer programs.

And so far …

- A computer would be world champion in chess
  - On May 11, 1997, the machine won the second six-game match against world champion Garry Kasparov, two to one, with three draws.
- A computer would discover and prove an important new mathematical theorem
  - The four color theorem was proven in 1976 by Kenneth Appel and Wolfgang Haken. It was the first major theorem to be proved using a computer.
- Most theories in psychology will take the form of computer programs.
  - Hmmm, still waiting …

Some Seemingly Simple Problems



Arithmeticorum Liber II. 61

interuallum numerorum 2. minor autem 1 N. atque ideo maior 1 N. + 2. Oportet itaque 4 N. + 4. triplos esse ad 2. & adhuc superaddere 10. Ter igitur 2. adscitis vnitatibus 10. æquatur 4 N. + 4. & fit 1 N. 3. Erit ergo minor 3. maior 5. & satisfaciunt quæstioni.

IN QVAESTIONEM VII.

CONDITIONIS appositæ eadem ratio est quæ & appositæ præcedenti quæstioni, nil enim aliud requirit quàm vt quadratus interualli numerorum sit minor interuallo quadratorum, & Canones idem hic etiam locum habebunt, vt manifestum est.

QVÆSTIO VIII.

PROPOSITVM quadratum diuidere in duos quadratos. Imperatum sit vt 16. diuidatur in duos quadratos. Ponatur primus 1 Q. Oportet igitur 16 — 1 Q. æquales esse quadrato. Fingo quadratum à numeris quotquot libuerit, cum defectu tot vnitatum quod continet latus ipsius 16. esto 2 N. — 4. ipse igitur quadratus erit 4 Q. + 16. — 16 N. hæc æquabuntur vnitatibus 16 — 1 Q. Communis adiiciatur vtrimque defectus, & à similibus auferantur similia, fient 5 Q. æquales 16 N. & fit 1 N. $\frac{16}{5}$. Erit igitur alter quadratorum $\frac{256}{25}$. alter verò $\frac{144}{25}$. & vtriusque summa est $\frac{400}{25}$. seu 16. & vterque quadratus est.

OBSERVATIO DOMINI PETRI DE FERMAT.

CVbum autem in duos cubos, aut quadratoquadratum in duos quadratoquadratos & generaliter nullam in infinitum vltra quadratum potestatem in duos eiusdem nominis fas est diuidere cuius rei demonstrationem mirabilem sane detexi. Hanc marginis exignitas non caperet.

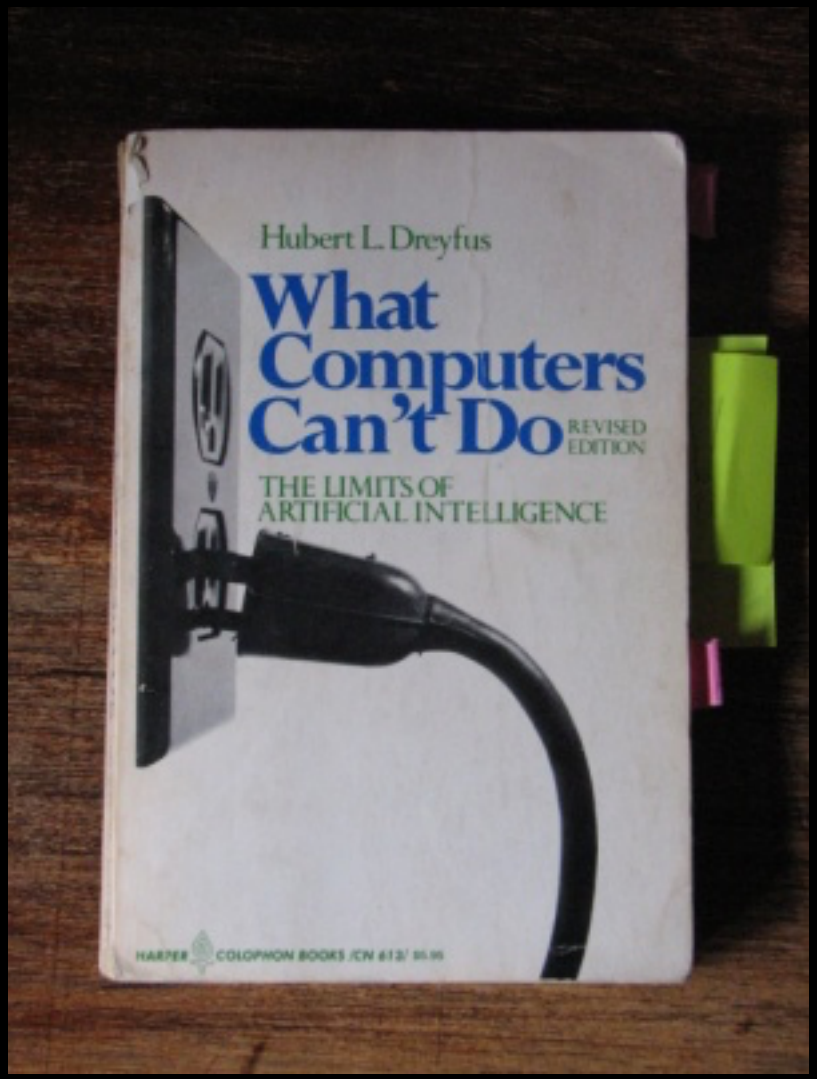
QVÆSTIO IX.

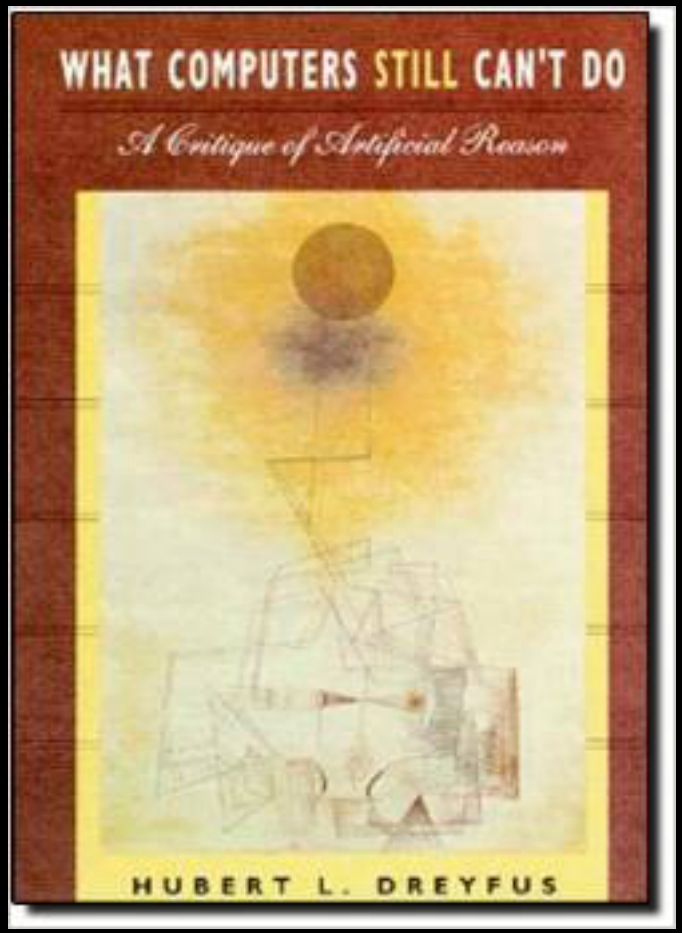
RVRSVS oporteat quadratum 16 diuidere in duos quadratos. Ponatur rursus primi latus 1 N. alterius verò quotcunque numerorum cum defectu tot vnitatum, quot constat latus diuidendi. Esto itaque 2 N. — 4. erunt quadrati, hic quidem 1 Q. ille verò 4 Q. + 16. — 16 N. Cæterum volo vtrumque simul æquari vnitatibus 16. Igitur 5 Q. + 16. — 16 N. æquatur vnitatibus 16. & fit 1 N. $\frac{32}{5}$ erit

H iii

$A^n+B^n = C^n$ for Integers A, B, C and n>2?

Dreyfus 1972, 1992





AI Will Fail Because ….

- **The biological assumption**
  - *The brain processes information in discrete operations by way of some biological equivalent of on/off switches.*
- **The psychological assumption**
  - *The mind can be viewed as a device operating on bits of information according to formal rules.*
- **The epistemological assumption**
  - *All knowledge can be formalized.*
- **The ontological assumption**
  - *The world consists of independent facts that can be represented by independent symbols*

And Now??

- Can a computer create music?
  - https://www.youtube.com/watch?v=PzrcoqpnZqA

And Now??

- Can a computer create music?
  - https://www.youtube.com/watch?v=PzrcoqpnZqA

Some Questions

- Can a computer create music?
  - https://www.youtube.com/watch?v=PzrcoqpnZqA
- Can a computer write an article?

This is the article generated by the LA Times algorithm: A shallow magnitude 4.7 earthquake was reported Monday morning five miles from Westwood, California, according to the U.S. Geological Survey. The temblor occurred at 6:25 a.m. Pacific time at a depth of 5.0 miles.
According to the USGS, the epicenter was six miles from Beverly Hills, California, seven miles from Universal City, California, seven miles from Santa Monica, California and 348 miles from Sacramento, California. In the past ten days, there have been no earthquakes magnitude 3.0 and greater centered nearby.
This information comes from the USGS Earthquake Notification Service and this post was created by an algorithm written by the author.

Some Questions

- Can a computer create music?
  - https://www.youtube.com/watch?v=PzrcoqpnZqA
- Can a computer write an article?

Friona fell 10-8 to Boys Ranch in five innings on Monday at Friona despite racking up seven hits and eight runs. Friona was led by a flawless day at the dish by Hunter Sundre, who went 2-2 against Boys Ranch pitching. Sundre singled in the third inning and tripled in the fourth inning … Friona piled up the steals, swiping eight bags in all …

http://www.narrativescience.com

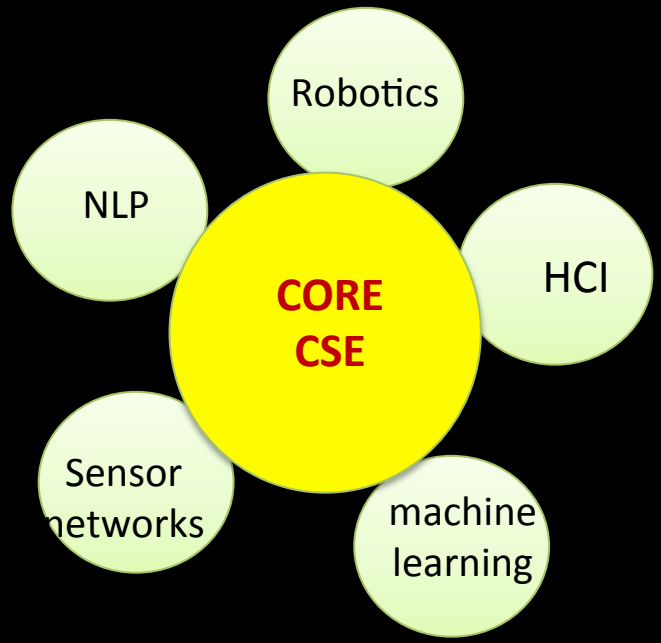
Some Questions

- Can a computer create music?
  - https://www.youtube.com/watch?v=PzrcoqpnZqA
- Can a computer write an article?
- Can a computer paint?

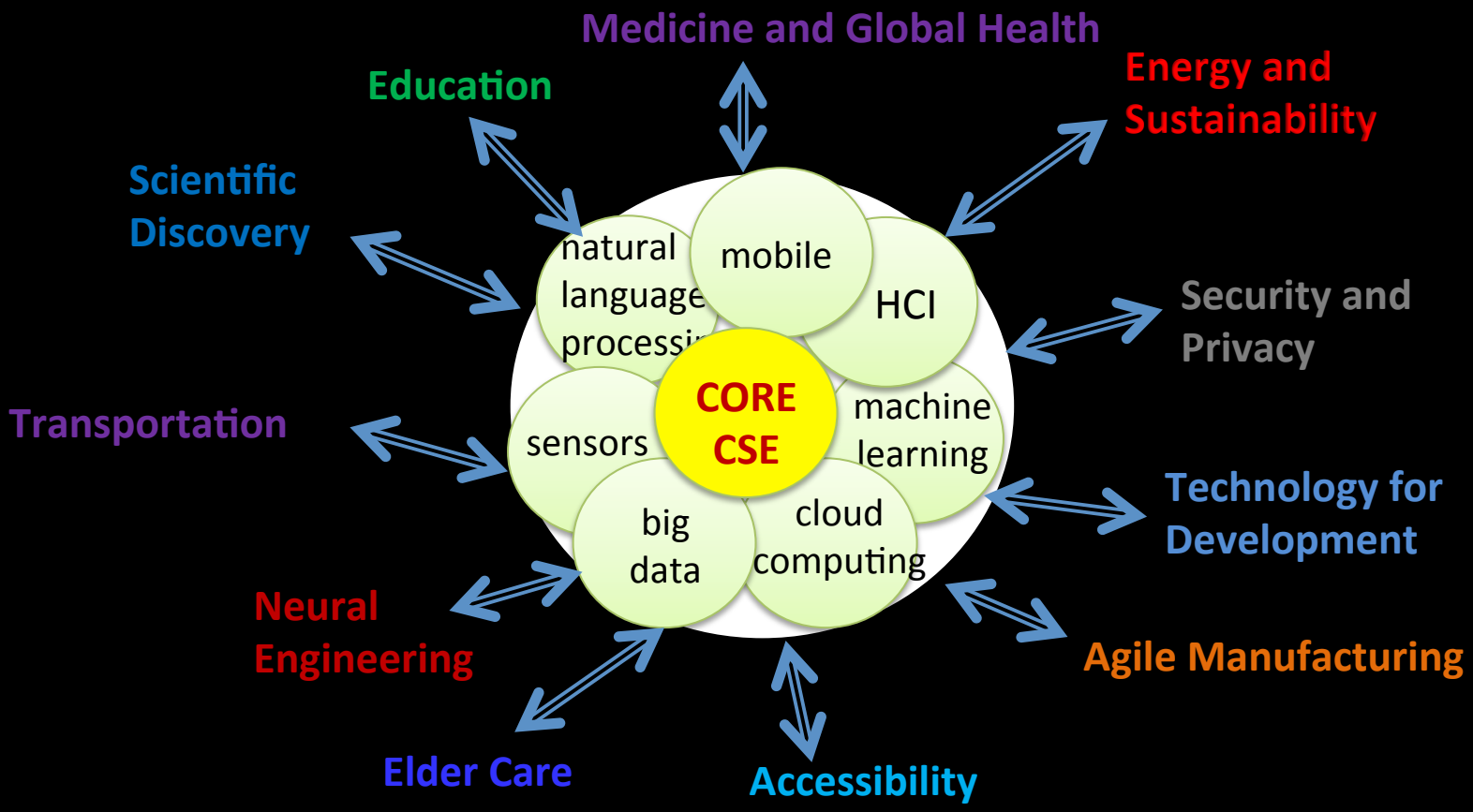
http://www.thepaintingfool.com

What Would Intelligence Mean?

Computing as it is Today



Where Computing is Going



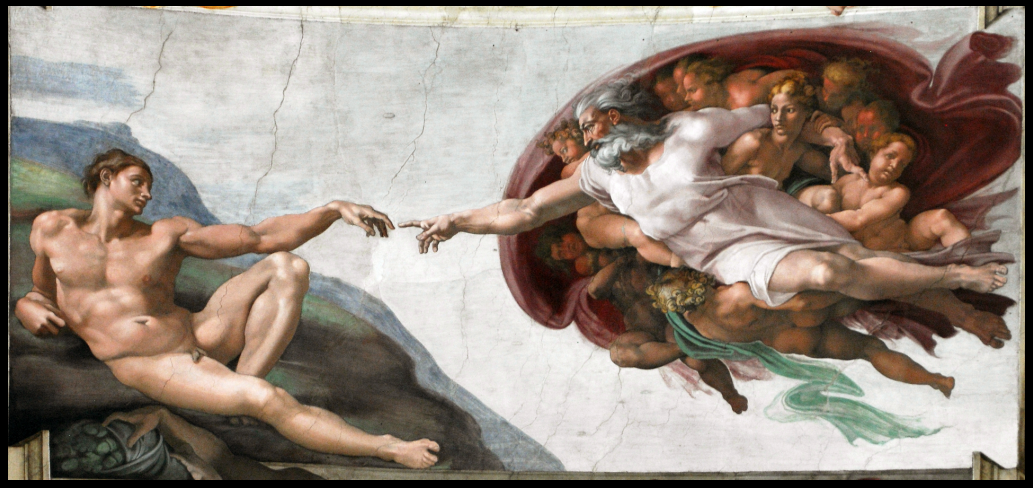
Drivers: Industry, Society, Government, Science

Modified from Lazowska

What Is Our Future?
How Will We Shape It?

Is Computing the future of thought and discourse?

Is it the beginning of the end of Computing as we know it?



Is Computing creating a new ways to combine and create?