Lecture 15:

Scale, scale, scale

(Counting)

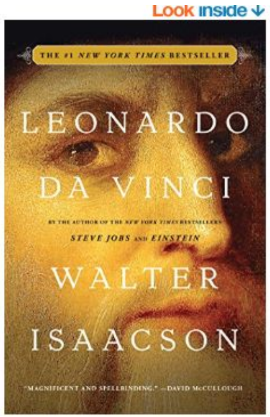
Announcements

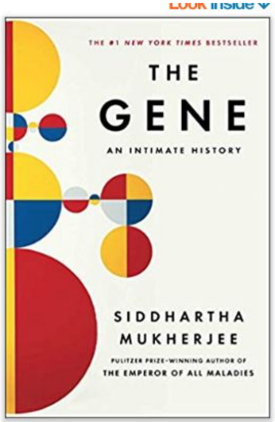
Guest speaker

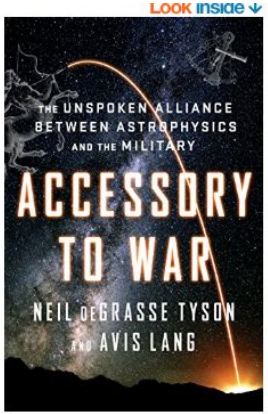
Theo Vassilakis, CTO of Grab today

Open questions on role of tech in … (DJ's talk)

- war and peace?
- human medicine? (Asilomar gathering)
- mismatches in 'US' values, diverse groups? <pick-your-fav-country> values?


Look inside
THE #1 NEW YORK TIMES BESTSELLER
LEONARDO DA VINCI
BY THE AUTHOR OF THE NEW YORK TIMES BESTSELLERS STEVE JOBS AND EINSTEIN
WALTER ISAACSON
"MAGNIFICENT AND SPELLBINDING." —DAVID McCULLOUGH


Look inside
THE #1 NEW YORK TIMES BESTSELLER
THE GENE
AN INTIMATE HISTORY
SIDDHARTHA MUKHERJEE
PULITZER PRIZE-WINNING AUTHOR OF THE EMPEROR OF ALL MALADIES


Look inside
THE UNSPOKEN ALLIANCE BETWEEN ASTROPHYSICS AND THE MILITARY
ACCESSORY TO WAR
NEIL DEGRASSE TYSON AND AVIS LANG

This week

Scale, Scale, Scale

How to read/write indices?

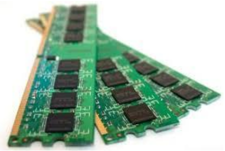
Sorting, Counting, Hashing

(for RAM, Disk, Clusters)

Big Scaling (with Indexes)

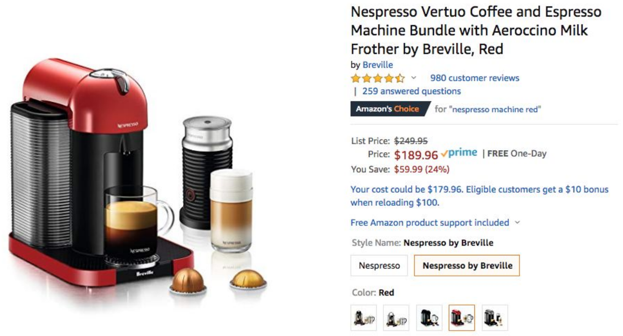
Roadmap

Primary data structures/algorithms

	Hashing	Sorting	Counting
	HashTables (hash$_i$(x))	BucketSort, QuickSort MergeSort	HashTable + Counter (hash$_i$(key) --> <count>)
	Hashes for disk location (hash$_i$(x))	MergeSortedFiles SortFiles	?????
	Hashes for machines, shards (hash$_i$(x))	MergeSortedFiles SortFiles	

Counting?

Counting product views for billion products



Nespresso Vertuo Coffee and Espresso Machine Bundle with Aeroccino Milk Frother by Breville, Red

by Breville

980 customer reviews

| 259 answered questions

Amazon's Choice for "nespresso machine red"

List Price: ~~$249.95~~

Price: $189.96 ✓prime | FREE One-Day

You Save: $59.99 (24%)

Your cost could be $179.96. Eligible customers get a $10 bonus when reloading $100.

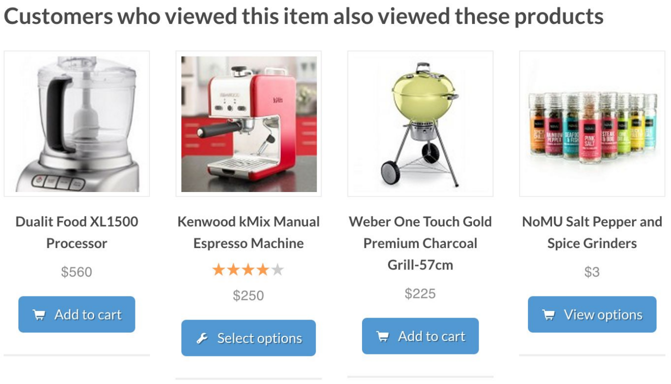
Free Amazon product support included

Style Name: Nespresso by Breville

Nespresso | Nespresso by Breville

Color: Red

Counting popular product-pairs

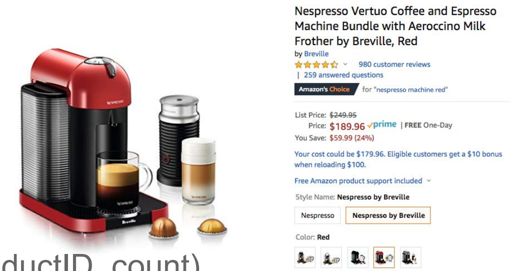


Customers who viewed this item also viewed these products

Dualit Food XL1500 Processor	Kenwood kMix Manual Espresso Machine	Weber One Touch Gold Premium Charcoal Grill-57cm	NoMU Salt Pepper and Spice Grinders
	★★★★☆		
$560	$250	$225	$3
Add to cart	Select options	Add to cart	View options

Counting in RAM

Counting product views for billion products



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Nespresso | Nespresso by Breville

Color: Red

UserViews(UserId, ProductID)

	Nespresso Coffee
	Bread maker
	Kenwood Espresso
	…

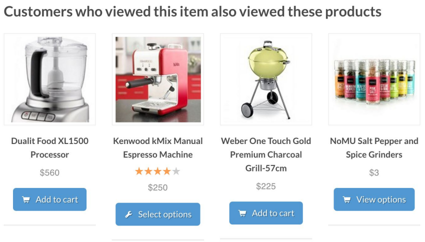
ProductViews(ProductID, count)

Nespresso Coffee	5003
Bread maker	20,007
Kenwood Espresso	45
	…

```
Algorithm: For each user, product $p_i$
        $Counter[p_i] += 1$
        // [ .. ] is python ‘dict’ notation
        // e.g., $h_1(p_i)$ denotes location
```

…	Nespresso coffee: 5003	…

Counting in RAM



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NoMU Salt Pepper and Spice Grinders
$3
View options

Counting product views for billion product PAIRs

UserViews(UserId, ProductID)

	Nespresso Coffee
	Bread maker
	Kenwood Espresso
	...

ProductViews(ProductID, ProductID, count)

Nespresso Coffee	Bread Maker	301
Bread maker	Kenwood Espresso	24597
Kenwood Espresso	Bike	22
		...

Algorithm: For each user, product p_i p_j
Counter[$p_{i,}$ p_j] += 1

...	Nespresso Coffee, Bread Maker: 245	...

Sizing up problem

Input data

Number of products	P	~1 Billion
Number of users	u	~1 Billion
Products viewed in user/session (avg)	q	~10

Output data

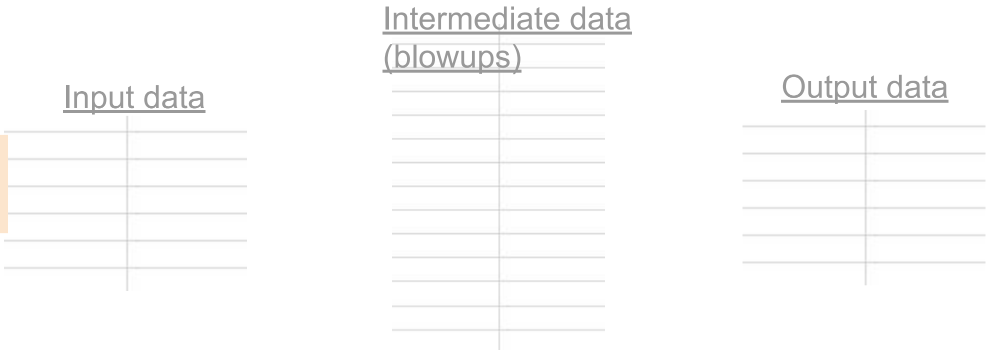
Number of product-pairs	P^2	~1B* 1B = 10^18
Number of product-pairs with count > 1	k*P^2	k*10^18

Size data

Bytes per productID (2^32 ~=4 Billion)	4
Bytes per userID	4
Bytes per tuple (2 productIDs + count)	12

Machine(s)

RAM, Page/disk block size	64 GB, 64KB
Disk seek, Disk IO	10 msec, 100 MB/sec



Input data

Intermediate data (blowups)

Output data

Look for data blowups. . .

Performance Analysis

(Engg approximations)

Counting product views

Input size (4 bytes for user, 4 bytes for productid)	~1Bil * [4 + 4] = 8 GB
Output size (4 bytes for productid, 4 bytes for count)	~1Bil * [4 + 4] = 8 GB

Trivial

Counting product pair views

Output/Intermediate data size - worst case (8 bytes for productid pair, 4 bytes for count)	~1Bil * 1Bil * 4 = 4 Million TBs

'Trivial?'
(if you have ~25 Billion$, at 100$/16GB RAM)

Design 1: P * P matrix for counters in RAM

- RAM size = 4 Million TBs

Design 2: Array for products + per-product linked list for <other product, counter>

- Worst case: u * q^2 * [8 bytes + 8 bytes for pointer] = 1.6 TB

Design 1 & 2 (on disk): Let OS page into memory as needed

- Worst case #1 = 300 million years
- Worst case #2: O(u * q^2) seeks = 100 Billion seeks = 31 years

Idea #1: smarter disk strategy

With Sorting

UserViews(UserId, ProductID)

	Nespresso Coffee
	Bread maker
	Kenwood Espresso
	...

Design 3

```
Algorithm: For each user, product $p_i$ $p_j$
        Append < $p_i$ $p_j$> to file-to-sort
    External Sort, then Count
```

Design 3: Output u * q^2 tuples to a file

- Data size: u * q^2 * [8 bytes] = 800 GB
- Time to write (@100 MB/sec) = 8000 secs (~2.5 hours)

Recall Sorting

$$\sim 2N\left(\left\lceil \log_B \frac{N}{2(B+1)} \right\rceil + 1\right)$$

Side math

B = 64GB/64KB = 1 million pages

N = 800 GB/64 KB = 12.5 million pages

$\text{Log}_{1000000}$ 12.5Million/(2 * 1Million) = 0.13

⇒ for B ~= N, IO Sorting cost ~= 2 N pages

Sort file

- Data size: u * q^2 * [8 bytes] = 800 GB
- Time to read-write (@100 MB/sec) = 16000 secs (~5 hours)

⇒ Compute time ~= 7.5 hrs !!

Idea #2: partition
Output smarter

With Sorting (hashing + parallelism)

UserViews(UserId, ProductID)

	Nespresso Coffee
	Bread maker
	Kenwood Espresso
	…

Design 4

```
Algorithm: For each user, product $p_i$ $p_j$
        x = hash($p_i$ $p_j$) % numFiles // bucket
        Append < $p_i$ $p_j$> to file $f_x$
        External Sort each $f_x$, as you go
```

Design 4: Output u * q^2 tuples to a file

- Cutting out 1 extra r/w
- Time to write (@100 MB/sec) = 8000 secs (~2.5 hours)

With parallel disks,

- Time to write (10 @100 MB/sec) = 800 secs (~15 mins)

Idea#3: Simplify the problem, Approximate the problem

Popular product pairs

UserViews(UserId, ProductID)

	Nespresso Coffee
	Bread maker
	Kenwood Espresso
	...

Design 5:

```
Algorithm: For each user, product $p_i$ $p_j$
        x = hash($p_i$ $p_j$) % numFiles // bucket
        With probability p', append < $p_i$ $p_j$> to file $f_x$
        External Sort each $f_x$, Count as you go
```

Design 5: Cut down I/O time with sampling, probabilistic hashing (e.g., p' = 1%)

- Time to write ~ minutes

Summary

Scale, Scale, Scale

Sorting, hashing,counting toolkit

- E.g, Smarter disk strategy (sorting)
- Smarter partition (hashing, parallelism)
- Simplify, Approximate the problem

⇒ With the right scaling techniques, we went from
~25B$ or 300 million years ⇒ minutes/hours and < 10k$

General note on query optimization (more in next lecture)

- Data systems use such techniques to optimize queries
- For super-expensive queries, developers reframe and hand optimize query plans